Health Effects of Low-Level Radiation in Shipyard Workers

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1 Introduction
1.1 Overview

An individual may receive ionizing radiation from multiple sources in his daily living including natural background radiation, medical uses, energy sources and occupational exposures. An individual's exposures vary widely. The average annual effective dose equivalent exposure per capita in the U.S. is 3.6 millisieverts (mSv)/year or 360 mrem/year. Eighty-two percent of this exposure arises from national sources and two-thirds of this radiation is due to radon. (BEIR V, 1990). Those individuals employed in industries where there is a potential exposure to radiation generally receive an average annual dose equivalent about equal to that of the current estimated exposures of the general population. However, only half of the workers in these industries have measurable exposure levels. Therefore, for this small group among the general U.S. population, the average annual dose equivalent is three times that of the average individual whereas for all monitored workers in industries with potential occupational exposures, their dose represents only a doubling of that of the U.S. average dose equivalent. Therefore, among occupational groups who generally have low radiation dose equivalents (DEs) on the job under current radiation control measures, other sources of radiation represent an important part of the total radiation exposure incurred. However, studying health effects of radiation exposure in an occupational group which has a carefully measured radiation DE and for whom an appropriate control group can be identified for comparison could add important information on the health effects of continuous exposure to low levels of radiation. The shipyard workers involved in overhaul of nuclear propulsion plants appear to be such a population.

Workers in U.S. shipyards involved in the overhaul of nuclear-powered

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vessels may receive exposure to ionizing radiation in addition to exposure to other potentially hazardous agents associated with their trades. Several years ago, concern was raised about the risk to these workers from radiation exposure in a limited study of deaths among the Portsmouth, New Hampshire shipyard workers (Najarian, 1978). At about the same time, Caldwell reported an apparent excess of leukemia among U.S. military veterans who had been involved in nuclear weapon testing (Caldwell, 1980). Both the shipyard workers and the veterans had had exposure to very low radiation doses. Since that time, a continued follow-up of the original veteran population plus similar cohort studies of all of the 50,000 veterans who had participated in atmospheric tests of nuclear weapons in the 1950s have indicated that only the group of veterans at the Smoky test site who were identified originally as having a risk of leukemia have continued to show an excess of leukemia deaths. These results led a review panel to conclude that, for all nuclear weapons test participants, there is no indication of an increased risk of leukemia from exposure to radiation at the levels recorded in these tests (Robinette, 1985). A subsequent cohort study of all shipyard workers at Portsmouth did not confirm the original observation that leukemia was associated with higher exposures to radiation (Rinsky, 1981). However, the concern of scientists as well as the public in trying to better define the upper and lower bounds of risk associated with radiation exposure remains. In an effort to address these concerns, this study of nuclear shipyard workers was carried out.

The method of exposure of the majority of the shipyard population is somewhat different from that of other occupational groups. Shipyard work does not necessarily require routine occupational exposure to ionizing radiation as part of the job as is the case for many of the occupational radiation worker cohorts. In the shipyard setting, a worker qualified to receive occupational radiation exposure carries out his usual trade with all its concomitant non-radiological exposures and occasionally is assigned to work where radiation exposure can take place. The worker is exposed to potential radiation from corrosion products of the reactor plant with the primary constituent being cobalt-60. Thus, these shipyard workers are exposed to the usual substances associated with trades in the construction or manufacturing industry while also receiving intermittent occupational exposure to low-level gamma radiation. The shipyard workers not qualified for radiation work receive the same non-radiological exposures without the radiation exposure and thus comprise a "control population" against which risks of radiation exposure may be assessed. In other populations, exposure to radiation may be closely tied to the other work-related exposures so that risks associated with radiation may not be evaluated independently of risks associated with other work materials such as chemicals.

The Nuclear Shipyard Workers Study (NSWS) was designed to determine whether there is an excess risk of leukemia or other cancers associated with exposure to low levels of gamma radiation. The study compares the mortality experience of shipyard workers who qualified to work in radiation areas to the mortality of similar workers who hold the same types of jobs but who are not authorized to work in radiation areas. The population consists of workers from six government and two private shipyards:

- Charleston Naval Shipyard, Charleston, South Carolina;
- General Dynamics Corporation, Electric Boat Division, Groton, Connecticut;

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- Mare Island Naval Shipyard, Vallejo, California;
- Newport News Shipbuilding and Drydock Company, Newport News, Virginia;
- Norfolk Naval Shipyard, Norfolk, Virginia;
- Pearl Harbor Naval Shipyard, Pearl Harbor, Hawaii;
- Portsmouth Naval Shipyard, Portsmouth, New Hampshire;
- Puget Sound Naval Shipyard, Bremerton, Washington

Data were gathered from personnel and radiation dosimetry records as well as from various sources of industrial hygiene information. The mortality of workers was ascertained from the beginning of overhaul of nuclear powered ships in each yard (1957-1967) through December 31, 1981.

The study of workers at these shipyards has a unique characteristic compared to many large occupational studies with combined industrial settings because relatively standardized procedures for monitoring the exposure of interest have been used across all eight shipyards. In fact, the Naval Nuclear Propulsion Program (NNPP) was charged with oversight of the radiation programs in all yards. The NNPP established, approved and inspected the shipyards to ensure that uniform standards for radiation protection were met at all facilities. The six Navy yards had very similar procedures for monitoring and recording radiation exposures. The two private yards had developed somewhat different procedures for collecting and recording radiation data, but the differences were identified and resolved so that the data from each yard could be combined into a single database for analysis. The non-exposed population was over three times larger than the exposed group so there were adequate numbers among the non-exposed groups for internal comparisons of the effect of radiation. Thus, in terms of standardized collection of radiation exposure data and size of the population, this group of workers is an important resource for the study of low dose radiation effects.

The original population of shipyard workers was identified by filming and abstracting every record from each shipyard's personnel files. Other records were filmed and abstracted to assure the completeness of the database. The total number of personnel represented by these records is almost 700,000 as shown in Table 1.1.A; however, many of the non-nuclear workers in the population did not work during the period when nuclear overhauls were done. These "workers" were not considered to be comparable to nuclear workers and were excluded from the database. Other exclusions from the original database included females, males who worked less than a year, contractors who did not have a personnel record, military and individuals who did not have sufficient identifying data in their record to allow matching to the national automated death record systems. Individuals who were in the original radiation computer files received from the yards, but who had no microfilmed personnel file records because of transcription errors in identification numbers, missed records, or other reasons, were excluded from the current analysis. Many of these individuals were probably contractors or military. However, these workers have been followed on an individual basis for vital status so that they may be included in any future analyses.

Initially, the study was to include all nuclear and non-nuclear workers employed at any time in each yard during the period of overhaul. The start period of the study differed for each yard because the beginning of overhaul varied by yard from 1957 to 1967. In order to make the most efficient use of

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1.1 Overview (cont'd)

money and time, the study design was subsequently modified to include all workers with a working lifetime cumulated DE of 0.5 rem or more by January 1, 1982, a 25 percent sample of nuclear workers who had less than 0.5 rem cumulated DE by January 1, 1982, and a planned sample of non-nuclear workers such that the ratio of non-nuclear to $\geq$ 0.5 rem nuclear workers was to be approximately 3:2. The three sample groups are denoted by $NW_{\geq 0.5}$, $NW_{<0.5}$, and NNW, respectively. The last two samples were selected to be comparable to the total population of $\geq$0.5 rem nuclear workers in regard to the following variables: shipyard, birth year, hire year, job hazard index, and interval from start of employment to start of nuclear work or a pseudo interval used for non-nuclear workers. The workers whose DE was less than 0.5 rem and the non-nuclear workers were selected to be comparable to the $NW_{\geq 0.5}$ group, but the samples were not individually matched on the five stratification variables. The sampling closely achieved the proposed goal, with the exception of only a few strata which were difficult to fill. Hence, the exact planned sampling ratio (3:2) was not achieved.

The personnel files did not identify the race of workers. Therefore, race could not be taken into account when sampling the populations. However, the nuclear workers and the personnel from many of the shipyards were predominantly white. For all current analysis the population was treated as if they were white males. This assumption would result in incorrect estimates of risk when the mortality from specific diseases differed by race and when an external population was used as a comparison. Internal comparisons would have errors if nuclear and non-nuclear workers in the sample were not balanced in racial distribution. However, comparisons between exposure groups should present no problem because the racial balance must be equal since the nuclear workers represent a single population.

The power of the current study sample with radiation DEs cumulated through 1981 and follow-up through December 31, 1981 is limited, if the risk as estimated in the BEIR III report is correct. The power calculations used an extension of the Mantel-Haenszel Chi-square (X^2) test to detect a dose-related trend in death rates using internal comparisons. The procedures used were those suggested by Gilbert (Gilbert, 1983). Twelve DE groups were used and the DE was lagged by two years for leukemia and lymphoma and five years for lung cancer. The risk of death during follow-up was compared to 1970 U.S. white male lifetable probabilities.

Power calculations showed that this study sample of almost 30,000 nuclear workers with DEs of 0.5 rem or more and over 350,000 person-years follow-up through 1981 could be expected to have a 78 percent chance of finding a risk of leukemia from radiation, if the risks were as large as five times the linear model estimates in BEIR III (see Section 4.3).

Since this population included workers employed in both Navy and private shipyards, follow-up for vital status required searches through multiple record systems. The sources included the Social Security Administration, the Civil Service Retired and Active, Health Care Financing Administration, National Death Index, Veterans Administration, and shipyard personnel records.

Information on incremental annual DEs and on cumulated DEs of individuals was provided on computer tape for all but one yard. The shipyard study personnel constructed annual DEs for each worker from original records for that yard so that all yards would have similar radiation information

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1.1 Overview (cont'd)

available for all workers.

During the study, information was collected regarding the procedures used to determine an individual's radiation exposure and the methods and accuracy of record-keeping. It was essential that the investigators not only were certain about the high quality of the information on DEs but also understood the potential impact of measurement errors. To that end, extensive data on radiation DEs and quality tests have been gathered.

Data from the Portsmouth Naval Shipyard report (Murray, 1982; Murray, 1983), as well as discussions with the Navy, and other data (Naval Sea Systems Command Reports) indicated that these DEs are primarily from the decay of cobalt-60, which emits two gamma rays of 1.17 and 1.33 MeV which are adequately measured by film badge or thermoluminescent dosimeter (TLD). Since the quality factor (QF) for radiation of this type and of this energy is one, the dose in rads and the DE in rem are numerically equal, i.e. DE(rem) = Dose(rads) x QF. Before 1973, the film badges were used as a direct measure of exposure and an estimate of the DE. From 1973 to 1976, the yards converted to use of TLD. By 1976, all yards were using TLD. Measurements were recorded monthly in all yards when film badges were used; when TLDs were used, daily measurements were recorded for workers in the Naval shipyards, and weekly measurements in one and monthly measurements in the other of the two private yards.

Several steps were undertaken to check the quality of the radiation data. Annual DEs were added sequentially and matched against the reported cumulated DE for each year. The yards were notified about discrepancies, and the records were returned to them for corrections or explanations regarding

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1.1 **Overview** (cont'd)

the differences. The discrepancies often resulted from DEs incorrectly assigned to an individual by incorrectly matched identification numbers or were the result of temporarily assigned DEs which were later corrected. The shipyards have adopted the policy of assigning a maximum allowable DE to anyone who received radiation at another site during any period in which the exact dose is not known. For this reason, all suspiciously high annual and cumulative DEs were reviewed to determine what proportion of these values represented assigned amounts.

The second method of checking the accuracy of the DE was to abstract the quarterly DEs recorded for stratified samples of workers' medical records from two of the yards. The radiation DEs as recorded on the radiation file were found to be virtually identical to those recorded in medical records. Similar accuracy of record-keeping for radiation doses was reported by Rinsky, et al regarding the data from the Portsmouth Navy yard (Rinsky, 1981).

The evaluation of whether there is complete identification of the radiation exposed workers included on the shipyard radiation tapes has been accomplished in several ways. First, the shipyards have provided new radiation tapes with cumulative DEs for each worker for each successive year from 1980 through 1986. Tapes for 1979 were provided by some yards. Each tape provided for 1979 through 1982 has been checked to be sure that no deletions of radiation workers have occurred. Virtually all eligible workers who were on the original 1979 radiation tape have remained on all subsequent tapes. This suggests that the first 1979 tape was probably also complete if the record-keeping in the past was as good as in the current period.

Secondly, information from the 5 Rem Study being conducted by Oak Ridge

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Associated Universities was shared with Nuclear Shipyard Workers Study. The Oak Ridge study team, using other resources than the radiation tapes, had identified 1,043 shipyard workers who had received 5 rem or more in a single year in the seven yards for which the study team had gathered complete radiation data at the time of the analysis. The data for this study derives from the years before 1967 where exposures in excess of 5 rem in a year were permitted up to 12 rem subject to an accumulated 5(N-18)rem, where N is a person's age. In 1967, the Navy reduced the annual limit to 5 rem. The radiation file records received by NSWS staff were checked to confirm identification of individuals and verification of their annual DEs. This procedure could uncover incorrect yearly DEs. The discrepancies indicated that some measured exposure may have been missed in 1.6 percent of NSWS population. However, only two (0.2%) workers would have been missed.

The final source of identification was a questionnaire which was sent to recent workers at two yards. In the first yard, six percent of the workers said they wore a badge when the radiation file contained no record of the individual. The accuracy of the answers of these workers was verified by telephone interview. Surprisingly, two percent of the workers listed as nuclear workers on the radiation tapes claimed that they had not worn a film badge or TLD. The initial responses were confirmed by a second telephone call. The investigation of the reasons for the incorrect classification of nuclear workers is not complete for both yards at this time. Most of the discrepancies (52%) arise because the workers were qualified for nuclear work after the closing date for the study's cumulative radiation records. Some individuals may actually have worn a badge in another shipyard or in the military. Of the 50 records which were reviewed for individuals claiming they were nuclear workers even though their names were not on the radiation tapes, only 3 workers had received a badge usually on a temporary assignment while at the shipyard. If these findings hold for all workers reporting, then only 0.1 percent of workers potentially exposed to radiation could have been missed and two-thirds of those omitted were only badged temporarily for a special assignment (Section 2.7).

The nuclear workers in this population were exposed to low DEs of radiation. Concern was expressed by members of the study's Technical Advisory Panel that especially individuals with DEs of less than 0.5 rem, and possibly even those with higher DEs, may have accumulated their cumulated DE through a series of non-existent radiation exposures, because of the possible procedure of assigning a minimum level at the threshold of the badge detection out of concern for the safety of the workers. The Radiation Dosimetry Advisory Committee (RDAC) suggested that one could propose the opposite argument, that repeated low DEs could be missed in the measured dose because of confusion with background radiation. Thus, individuals may be read as having no exposure when they were exposed. The problem of the error in DEs which may result from repeated exposures within the lowest range of sensitivity of the instrument is an issue for low dose exposure to any agent. The distribution of these very low measurements in individuals in this population will be discussed further in Section 2.7.

In summary, this report describes the establishment of a population of shipyard workers who have been exposed to low levels of gamma radiation as an incidental exposure while engaged in the overhaul of nuclear propulsion

1 Introduction
1.1 **Overview** (cont'd)

systems in Navy ships. Similar control populations have been selected with the objective of comparing the mortality experience of these nuclear and non-nuclear workers. During the period of this study, an extensive review of the accuracy and completeness of the radiation files has been undertaken. Limited data have been collected regarding potential confounding variables in the population. Methods of evaluating other industrial exposures have been developed. These steps will be described in the following sections. The initial analysis of the mortality of nuclear and non-nuclear workers will be presented.

1 Introduction

1.1 **Overview** (cont'd)

Table 1.1.A Derivation of and Notation for Study Sampling Frame and Samples for the Three Major Comparison Groups:

(1) Nuclear Program Shipyard Workers with ≥0.5 rem Cumulative Exposure as of 1-1-82 ($NW_{\geq 0.5}$)
(2) Nuclear Program Shipyard Workers with <0.5 rem Cumulative Exposure as of 1-1-82 ($NW_{<0.5}$)
(3) Non-Nuclear Shipyard Workers (NNW)

	Nuclear Program Workers						Non-Nuclear Workers	
	Total Nuclear Workers		Cumulative Exposure (1-1-82)					
			≥0.5 rem		<0.5 rem			
	No.	%	No.	%	No.	%	No.	%
Total in Database	106,851	100%	35,079	100%	71,772	100%	692,612[1]	100%
Exclusions	29,342	27%	7,019	20%	22,323	31%	574,894[2]	83%
Sampling Frame (8 yards)	77,509	73%	28,060	80%	49,449	69%	117,718	17%
Sample Size (notation)	38,522 (NW)	50%	28,060 ($NW_{\geq 0.5}$)	100%	10,462 ($NW_{<0.5}$)	21%	33,353 (NNW)	28%

[1] The beginning total in the database used to define non-nuclear includes the entire shipyard population at the time of microfilming -- both nuclear program workers and non-nuclear program workers.

[2] Of the 574,894 records excluded, 404,700 (70%) were for workers that did not work during the nuclear overhaul time period or worked less than a year.

1 Introduction
1.2 Pilot Study

A pilot study entitled "Study of Feasibility of Detecting Effects of Low-Dose Radiation in Shipyard Workers" (DOE Report No. DOE/AV/04992, Contract No. DE-AC02-78EV04992) was completed in August, 1978, prior to initiation of the full scale Nuclear Shipyard Workers Study.

At the time the pilot study was conducted, little information was available on the chronic health effects from repeated exposures to low levels of radiation. The pilot study examined the adequacy of documentation and the probable accuracy of radiation DEs in shipyard workers, the control procedures used in the radiation control programs, and the feasibility of establishing an appropriate population of nuclear and non-nuclear shipyard workers for long-term studies of low level radiation.

The availability of records and information systems for population identification and the adequacy of radiation dose were evaluated during initial visits to the yards. Personnel, industrial hygiene, radiation and medical records were examined for study suitability, completeness and accuracy. It was necessary to assure that no significant errors or omissions in personnel and radiation records existed in order for the final data to have validity. All of this review indicated a very well managed record-keeping system. The radiation control program provided careful monitoring of potential individual exposures to radiation. There is also a careful program of radiation monitoring using surveys and area monitoring equipment. Therefore a study of these populations was considered to have a high probability of yielding important and accurate information on the long-term effects of low dose radiation.

Preliminary investigations of the methods of follow-up in the Portsmouth population and the time required for each procedure were also completed under the feasibility study in order to have a better estimate of the total cost for a long-term study. A copy of the final report for the pilot study may be found in Appendix 4 of this report.

2 Methods

2.1 Sources of Data

The primary task in the study was to derive from the total database which includes personnel records, radiation records, and other records, a suitable population for study and then to select appropriate groups for comparison. The objective was to treat each worker in the database as similarly as possible despite differing sources of information for some groups and to limit the workers in the study population to those of interest (male, civilian workers employed at least one year during overhaul in the shipyards). Before populations and samples could be defined and collected, appropriate computerized databases had to be constructed from available records.

A personnel database (Per DB) was constructed by microfilming employment records in each of the eight shipyards. These microfilmed records were the primary source of information on the total set of workers at any given yard. A total of 728 reels (2,000 frames per reel) of microfilmed records on 692,612 workers have been collected, cataloged and processed into the Per DB.

Table 2.1.A shows the number of workers whose records were microfilmed and the time periods of employment which were covered. The table shows that personnel records from periods prior to nuclear overhaul were microfilmed. Physical arrangement of the paper based personnel files made it impossible to reliably restrict microfilming to the subset of workers employed since overhaul began in a yard.

A database, representing a total of 107,976 records of presumed nuclear workers from all eight shipyards, (Nuc DB) was also constructed (see Table 2.1.A). (The initial database included duplicate radiation records on the same individual within the same yard which were immediately corrected.) Construction of this database started with the computerized files of nuclear workers that were made available by the six Navy Yards. At the time that nuclear overhauls began in each of the Navy Yards, they had a requirement

2 Methods
2.1 Sources of Data (cont'd)

to report to the Bureau of Medicine and Surgery the radiation exposure of any personnel occupationally exposed to ionizing radiation at least annually. When an individual that had been occupationally exposed during a calendar year left the Shipyard, this information was reported at the end of the month in which they left. These were called "situational reports." Additionally, all personnel still employed on December 31 that had received occupational exposure to ionizing radiation were reported in January of the following year with their radiation exposure information. These were called "annual reports". Each Shipyard retained copies of their situational reports (12 for each year) and their annual reports. In 1979 the Shipyards' standard computerized exposure information program was changed to include a historical file which created a computer record for any individual that was ever occupationally exposed at that facility with personal identifying information and appropriate exposure information for each year in which they were monitored for radiation exposure. When this program became available, each Shipyard manually input the information from the beginning of their nuclear work using the situational and annual reports as source document. Since this initial "batch" update of the file, the historical file had been automatically updated by the computerized exposure records system used by all Navy Shipyards. This historical file has been reproduced onto magnetic tape and provided to [Johns Hopkins], with annual updates. This is referred to by the study group as the "Shipyard Radiation Tapes".

The private Groton Yard provided a computerized file, but in a different format from those provided by the Navy yards. Appropriate software was developed to make these data consistent with the Navy format. The private Newport News Shipbuilding and Drydock Company did not have complete historical computerized records of all nuclear workers who had radiation exposure at any time during the overhaul period. All paper-based records related to nuclear workers at the shipyard were microfilmed, and a nuclear

2 Methods

2.1 Sources of Data (cont'd)

workers' database for that yard was constructed by the study team.

Construction of these two databases and determination of the vital status of the workers required acquisition, decoding, and processing of numerous computer files from many different sources. A major problem due to the inclusion of data from so many sources was development of methods for correctly linking records and for identifying and eliminating duplicate records. Often information from different sources about a given worker was inconsistent. In these cases, extensive investigations were required to resolve the discrepancies.

These two databases, Per DB and Nuc DB, were the primary data sources for the study and represented the starting point for study population definition and the sampling procedures described in Sections 2.2 and 2.3.

2 Methods

2.1 Sources of Data (cont'd)

Table 2.1.A Number of Workers in the Personnel (Per DB) and Nuclear Workers (Nuc DB) Databases by Time Periods Covered

Shipyard	Total Workers in Per DB	Total Nuclear Workers in Nuc DB	Time period of Microfilmed Personnel Records	Year Nuclear Overhaul Began
Charleston	86,150	6,551	1946 - 1979	1963
Groton	93,986	25,777	1955 - 1979	1957
Mare Island	66,734	12,768	1958 - 1979	1962
Newport News	205,516	26,219	1920 - 1980	1964
Norfolk	122,657	7,901	1936 - 1978	1965
Pearl Harbor	26,081	6,419	1950 - 1980	1962
Portsmouth	40,533	11,138	1954 - 1977	1959
Puget Sound	50,955	11,203	1953 - 1979	1967
Total	692,612	107,976		

2 Methods
2.2 Definition of Sampling Frames

The study population for evaluation of radiation effects had to be selected from the total database of computerized personnel, radiation and other records. As indicated in Section 1.1, several revisions to the study design occurred as the project progressed throughout which the scientific integrity of the study was maintained. The final design, arrived at in consultation with the Technical Advisory Panel in July, 1983, set a general policy of limiting data collection and analysis to the following groups of workers in the eight nuclear shipyards:

- NNW - A stratified sample of non-nuclear (as of 12/31/1981) shipyard workers about equal in size to the $NW_{\geq 0.5}$ sample (a selection ratio of 3:2 was chosen in order to arrive at the final sample);
- $NW_{<0.5}$ - A 25 percent stratified sample of nuclear workers with a cumulative DE $\geq$0.5 rem as of 12/31/1981;
- $NW_{\geq 0.5}$ - All nuclear workers with a cumulative DE $\geq$0.5 as of 12/31/1981.

(The final sample as shown in Table 1.1.A is close to the ratios defined in the design. Some strata were limited in size.)

The stratification made the three sample groups, NNW, $NW_{<0.5}$, and $NW_{\geq 0.5}$, comparable with respect to five factors:

- Shipyard of employment;
- Age;
- Year of entry into shipyard work;
- Pre-nuclear lag (i.e., duration of shipyard work prior to beginning nuclear work) for the $NW_{\geq 0.5}$ and $NW_{<0.5}$ groups or a

corresponding pseudo duration of pre-nuclear work for the NNW group; and

- An overall job hazard index (see Section 2.8) based on a worker's most recent job title.

Selection of these stratified samples required definition of appropriate sampling frames from which to sample. In general this involved defining subsets of individuals with accurate information on DE from the nuclear worker database (Nuc DB) and accurate information on the stratification variables from the personnel database (Per DB) for each shipyard. To be included in the frame a record also had to have appropriate identifying information about the individual so that a computerized vital status search could be completed through outside agencies.

On-going editing and updating of the population information sometimes changed the sampling frame in which an individual would be included. The general philosophy adopted to deal with this problem was as follows:

- If revised data reclassified a worker into or out of either the $NW_{<0.5}$ or NNW frame, the worker was deleted from the $NW_{<0.5}$ or NNW frame (and hence from the sample selected from that frame);
- If revised data reclassified a worker into the $NW_{\geq 0.5}$ frame, the worker was added to the $NW_{\geq 0.5}$ frame, (and hence included in the $NW_{\geq 0.5}$ sample) provided that an appropriate vital status search could be completed.

The proposed sample sizes were increased in anticipation of potential deletions from the $NW_{<0.5}$ or NNW frames subsequent to their initial definition in July, 1983. The three sampling frames were constructed from the Nuc DB and

Per DB and 11 major exclusion criteria were applied subsequently to the databases. To the extent possible, the criteria were applied uniformly and in the same sequence to each of the three groups as shown in Table 2.2.A.

The details of the definition of the sampling frames for the study are given in the remainder of this section. The methods used for selection of the stratified samples are described in Section 2.3.

Definition of the Nuclear Worker Sampling Frames: $NW_{<0.5}$ and $NW_{\geq 0.5}$

The first step in the construction of these sampling frames was to establish accurate data on recorded radiation DE in order to classify each worker's status as of 12/31/1981 as non-nuclear (NNW), cumulative DE <0.5 rem ($NW_{<0.5}$), or cumulative DE $\geq$0.5 rem ($NW_{\geq 0.5}$). Computerized records of lifetime DEs of all workers were available from seven of the eight shipyards. The methods used to establish their accuracy is described in Section 2.7. The radiation records from the Newport News Yard did not provide annual rates on all workers or information on terminated workers in computerized form, and a database had to be constructed, primarily from paper records.

The radiation records for the nuclear workers were combined across yards to create a unified radiation record so that all workers with $\geq$0.5 rem lifetime DE could be included in the $NW_{\geq 0.5}$ frame. The correct lifetime DE should have appeared in the last shipyard in which an employee worked. In addition, any worker who had a lifetime recorded DE of $\geq$0.5 rem was included in the $NW_{\geq 0.5}$ frame for each yard in which the worker was exposed.

Although the number was small (a total of 482 $NW_{\geq 0.5}$ workers (2%) performed nuclear work in more than one yard), it was difficult to determine what decision should be made regarding workers who received radiation exposure at multiple shipyards. Samples were selected by yard and yet the total population was analyzed as a group. In addition, each yard was analyzed individually to assess the degree of variation. A worker was not counted twice in the total analyses.

A problem exists, however, of including an individual in a higher DE category in the first yards in which he worked just because there is knowledge of his receiving radiation due to subsequent employment in another shipyard. If his second employment was in a nuclear facility other than one of the eight shipyards included in the study, then there would be no knowledge of the added exposure to radiation in the later employment. It seemed appropriate to include this small number of individuals at their known lifetime DE when selecting each shipyard's sample and to consider them once for total population analysis. All exposure data for nuclear workers who worked in multiple shipyards are available so that any future analysis by yard can consider these individuals as if they had achieved only the dose which was cumulated to the point of severance from that yard as well as total dose to the end of the study. For the analysis of the combined yards, an individual was included in the first yard in which he was a nuclear worker at his known lifetime DE. It was recognized that these decisions may have created a positive bias but the numbers were small, so the analyses were probably not substantially influenced by the presence of these workers.

The cases can be examined to see if they represent workers with multiple yard exposures. In addition, future analyses will consider handling the data from these few workers in different ways such as counting a worker's exposure only as it relates to his first place of employment and then following him for survival to see if these changes alter any of the conclusions reached with the current data set. For the current analyses, the individual's DE was his total cumulative recorded DE for all shipyards as of December 31, 1981. This cumulative DE as of December 31, 1981 was used to classify nuclear workers into those with a DE of <0.5 rem, the $NW_{<0.5}$ group and those with a DE of $\geq$0.5 rem, the $NW_{\geq 0.5}$ group.

Workers were eligible to be part of the sampling frame if they worked for at least one year during the period of nuclear overhaul in one of the eight yards. This means that the population for follow-up started at a different calendar time in each yard (the start date of nuclear overhaul). This decision was necessary since workers who had recorded doses prior to the period of overhaul of nuclear propulsion vessels would not have exposures equivalent to those of more recent nuclear workers. Workers during overhaul had exposures mainly to gamma rays from cobalt-60. Before the overhaul period, workers monitored for radiation were likely to be medical technicians, radiographers, instrument repairmen or other occupational groups exposed to a variety of sources of radiation.

The radiation file and personnel file were matched using social security number. Some nuclear workers did not match to the personnel record file either because they did not have a social security number or because there was no microfilmed personnel record for them. Some of these workers were not civilian shipyard employees; for example, some were Navy personnel or outside contractors. Other workers who failed to match to the personnel file were recent employees who started work after the date of microfilming. Whatever the reason for the discrepancy, a nuclear worker without a social security number or a microfilmed personnel record was not searched for vital status. This group was included in the nuclear worker population and their vital status was ascertained by procedures discussed below, but they were not included in the original sampling frame for selection of controls.

As may be seen from Table 2.2.A, among the total population in the Nuc DB, 27 percent were excluded from the sampling frame. A large proportion of these were omitted because they were recent hires who did not have a personnel record at the time of microfilming or they were missing a social security number on the personnel file.

Definition of the Non-Nuclear Worker Sampling Frame: NNW

The non-nuclear workers who were eligible for the sampling frame included only males who had worked one year or more in the yard during the period of nuclear overhaul, who had had a vital status search, and who had information in their record related to the stratification variables for the sample.

Table 2.2.A shows that a large proportion (70%) of the non-nuclear workers in the Per DB were excluded primarily because they had no social security number or they worked in periods prior to nuclear overhaul. There were 117,718 non-nuclear workers eligible for the sampling frame.

2 Methods
2.2 Definition of Sampling Frames (cont'd)

Race

The personnel files did not contain information on race, even though the radiation tapes from some yards did contain that data. Therefore, the selection of an NNW sample stratified on this variable was impossible.

For some yards this was not a problem because the geographic location of the yard was in a predominantly white population. From the data available for other yards, the known racial distribution of nuclear workers appeared to represent the racial composition of the area. Therefore, it seemed reasonable that the non-nuclear workers were also similar to the general population in racial distribution and that stratifying on birth year and year of hire should produce subsamples which were similar by race. This means internal comparisons should have been racially comparable. However, no analysis by race was possible. There are some methods by which race could be classified for some workers in the future.

Certainly, the comparison of the <0.5 rem NW and the ≥ 0.5 rem NW should present no problem. The workers in these two groups were all selected to be in the nuclear program. Then the categories were balanced by yard, age, hire date and job grouping. Comparisons using these internal groups which are all in the nuclear program and balanced by other major characteristics should represent similar race distributions as well. Comparisons by dose in the group of ≥ 0.5 rem NW should have racial balance since all workers in this group start in the lowest category and simply move to other dose groups. Methods of determining race for these populations has been identified and will be used in future analyses.

Rationale and Specifications for Exclusion Criteria

The list of exclusion criteria developed to define the study sampling frames from the available databases is summarized in Table 2.2.A. Essentially two sources of data were used to define the members of the study population.

- The computerized file of all personnel records microfilmed at each yard; and
- Shipyard radiation data files obtained from the Navy or the private yards.

Both data files included records for individuals who did not fit the study population definition. For example, military workers, workers with exposure only in the pre-overhaul time period, contractors, and short term workers were not considered to be part of the study. Other major exclusions limited the study to male shipyard workers employed at least one year during the nuclear overhaul period. The time period of nuclear overhaul varied from yard to yard, the earliest beginning in 1957. The other major exclusions as noted in the table represented sources of incomplete information on individuals which would limit the inclusion of their data in the analysis. In no case were the exclusions based on measured dose data or any health effects variables.

The personnel microfilm file as described earlier included all workers' records available at the time of microfilming. The dates of filming varied by shipyard. This file was the primary source of demographic and job history data for both nuclear and non-nuclear workers. According to information from the Naval Nuclear Propulsion Program, the radiation files included any person who was required to wear a personal dosimeter because they entered a radiation area regardless of whether they were a shipyard worker, contractor or military personnel. These two files (personnel and radiation) were merged to define the sampling frames. Both files had to undergo considerable processing before they could be combined. In most cases, social security numbers were used to link records, but these were not always available on both files. A well defined hierarchical list of exclusion criteria or "filters" for determining whether a worker was eligible for a particular study group had to be developed. A worker had to pass through all "filters" before being eligible for a particular sampling frame.

The "filters" were applied on a yard by yard basis since data on yards were prepared one yard at a time. Thus, if a worker was employed in more than one shipyard, he had to be excluded from all shipyards in which he worked in order for him to be excluded from the sampling frame. Also, he was only included in the individual shipyard sampling frames in which he was eligible. This could lead to duplicates, so a mechanism was developed to ensure that workers eligible in one or more yards were included only once for analysis purposes.

Both the content and order of exclusion "filters" was important. The final ordering was somewhat arbitrary but was arrived at after considering:

- Similar treatment of nuclear and non-nuclear workers despite the differing sources of data for the two groups;
- Overall logical order from the standpoint of study definition; and
- Placement of "filters" that excluded the most workers near the top to minimize the size of files to be processed on subsequent steps.

Preparation of Files for Sampling Frame Definition

A first task was to eliminate duplicates and combine data for a given worker across yards to create unified radiation and personnel files. For the radiation data file, one record per worker was created using social security number to link workers' records from each shipyard worked. Then, the combined data (annual cumulative DEs, yards worked, radiation program entry and withdrawal dates, employee identification numbers) were ordered chronologically. Lifetime measured DE was calculated as the maximum cumulative DE obtained from a worker's complete radiation history.

This collation of radiation data was required because radiation dosimetry files kept by the Navy are maintained on a yard by yard basis. Inconsistencies on personal characteristics as well as other items were identified in this process. A system for appropriately editing the data was resolved with the Navy.

For the personnel file, one record per worker was created using social security number to link workers' records. Since filming of records was done on a yard by yard basis and since social security numbers were not always available, a simple identification system for workers was developed based on serial number of a worker's record on a roll of microfilm. This allowed unique identification of records on a yard by yard basis. Methods of identifying duplicate records on individuals within and among yards were developed. Once identified, a "key" ID number was assigned to duplicate records. This was arbitrarily defined as the serial ID number associated with the yard with the lowest code number. Then, data were collated to order the employment data (yards worked, dates of entry and withdrawal, shipyard census numbers) chronologically.

Though the consolidation of the multiple records for each worker was complicated and involved, at times, individualized decisions to handle discrepant data, the number of such cases were relatively few. Of the 102,176 nuclear workers with valid social security numbers (Tables 2.2.A after sequence 3), only 1,112 (1%) workers performed radiation work in two shipyards, and 27 (<1%) were nuclear workers in three shipyards. Of the 467,633 non-nuclear workers on the microfilmed personnel file, 23,918 (5%) worked in more than one shipyard.

Definition of the Nuclear Worker ($NW_{\geq 0.5}$ and $NW_{<0.5}$) Sampling Frames

This section gives the specifications for exclusion criteria used to identify the two populations of nuclear workers: $NW_{\geq 0.5}$ (workers with lifetime DE greater than or equal to 0.5 rem as of 12/31/1981) and $NW_{<0.5}$ (workers with lifetime DE less than 0.5 rem as of 12/31/1981).

The steps given below were applied sequentially in the order listed. Apart from step 2 which split the Nuc DB into the two parts based on cumulative DE, all steps were applied to both groups in the same way and in the same order. The specific numbers of workers excluded by each filter are given in Table 2.2.A (Note: the steps listed below do *not* correspond to the numbers in the table since some are simply definition statements).

Step 1: The nuclear worker database was established by the presence of a record on the 1981 radiation files.

Step 2: The nuclear worker database was divided into workers with ≥0.5

rem or <0.5 rem cumulative DE. The cumulative DE was calculated from a worker's entire exposure history by collating the radiation record files received from all shipyards and summing each individual's DE.

Step 3: Nuclear workers not active in the radiation program during the period of nuclear propulsion plant overhauls for each of the study yards were excluded. The time period of nuclear overhaul varied by shipyard as may be seen from the following list of years in which the first nuclear overhaul was carried out:

Charleston Naval Shipyard	1963
General Dynamics Corporation, Electric Boat Division	1957
Mare Island Naval Shipyard	1962
Newport News Shipbuilding and Drydock Company	1964
Norfolk Naval Shipyard	1965
Pearl Harbor Naval Shipyard	1962
Portsmouth Naval Shipyard	1959
Puget Sound Naval Shipyard	1967

Workers who had only a DE recorded for the period prior to work at the yard were excluded from the sampling frame in this step. In some yards, a worker with all blank exposures was one who had qualified for the radiation program but had never performed any radiation work. These workers are different from those with recorded DEs of zero who worked in radiation areas but never received any radiation dose above a film badge or TLD's detectable level. Very few workers were excluded by this criterion, and in each case, the yard was queried about the worker's status before the decision to exclude was made.

2 Methods
2.2 Definition of Sampling Frames (cont'd)

Step 4: Workers without a valid social security number present on the radiation file were excluded. An invalid social security number was defined as either non-numeric or a pseudo social security number (those with all 9's or those beginning with three zeroes) The rationale for this step was that social security number was found to be the most reliable method of linking a worker's records from the various sources. More importantly, vital status ascertainment from the combination of national computerized sources is readily feasible only for workers with a social security number.

Very few nuclear workers lacked a social security number (191 in the $\geq$0.5 group (1%) and 1,659 in the <0.5 group (2%)). However, workers in the three study groups without social security numbers would have been difficult to trace in a population of this size. Further work has been done in later stages of the study to try to characterize the group excluded on this basis and to follow them for vital status.

Step 5: Nuclear workers who could not be matched to a microfilmed personnel record were excluded. The personnel record was used to obtain dates of employment in the yard, sex, birthyear, and job history. These data were considered to be the minimum information required for analysis and for stratification in sample selection. Since the data used for stratification for both the nuclear and non-nuclear samples have the same source (the personnel record), the nuclear workers have comparable

2 Methods

2.2 Definition of Sampling Frames (cont'd)

information from the same sources as that of the non-nuclear group.

The only practical way to screen out non-shipyard workers with radiation records on file such as visitors, contractors, and military personnel was to match the radiation records with the personnel records. Nuclear workers with records on the 1981 radiation file but whose employment began after the date of microfilming of the personnel records in the yard were also excluded by the matching in this step. The dates of microfilming by shipyard were as follows:

Charleston Naval Shipyard	1979
General Dynamics Corporation, Electric Boat Division	1979
Mare Island Naval Shipyard	1979
Newport News Shipbuilding and Drydock Company	1980
Norfolk Naval Shipyard	1978
Pearl Harbor Naval Shipyard	1980
Portsmouth Naval Shipyard	1977
Puget Sound Naval Shipyard	1979

Any workers with errors in their social security number as recorded on either the radiation file or personnel file were excluded by this step. All complete vital status searches were based on the social security number from personnel records. Even though some radiation workers could be matched to the personnel file on the basis of information other than social security number, the workers were excluded since they would not have an adequate vital status search through record linkage.

2 Methods
2.2 Definition of Sampling Frames (cont'd)

Step 6: Workers who did not work a year or more in at least one shipyard according to the length of employment as recorded on personnel record were excluded. If there were multiple personnel records for a given shipyard, the worker was arbitrarily considered to have worked at least a year.

Some inconsistencies in the employment data on the personnel file and the radiation file were discovered although the number was very small. For example, of the 803 Groton or Navy workers excluded from the ≥0.5 rem group as working less than a year based on personnel record employment dates, approximately 500 of these would have been classified as working more than a year based on the radiation file data. This amounts to variations in employment records in about 1.8 percent of the ≥0.5 rem group. Examination of these discrepancies revealed transcription and reporting errors on both personnel and radiation files. The major problem arose from the less precise determination of length of employment on the radiation files as provided by the Navy and private yards due to failure to record the cumulated data on months of entry or withdrawal from the radiation program based on days worked.

Step 7: Female workers were excluded. The worker's gender was taken from the microfilmed personnel file. Once again, some discrepancies existed between the radiation file and the personnel file. Only 82 of the 124 women excluded from the nuclear workers with ≥0.5 rem cumulative DE were reported as female on both the radiation and personnel files. Examination of the 42 workers with discrepant gender codes indicated recording errors on both files. Again, this error rate is only 0.1 percent.

Step 8: Workers who did not have a complete vital status search were excluded. In principle, no worker should be excluded by this step and few actually were. However, editing of the personnel files was an ongoing process. Certain records discovered as missing in quality assurance checking were added to the personnel database after it was transmitted to the Social Security Administration and other agencies for vital status searches. Nuclear workers matched to such personnel records would not be comparable regarding vital status ascertainment and were excluded.

Step 9: Any worker who had incomplete or invalid data for the stratification variables used in the sampling scheme was excluded. These variables included birthyear, year of hire, and time from hire to the start of nuclear program work. The stratification variable, job hazard index, could be missing and no worker was excluded from the sample on this basis. The workers with $\geq$0.5 rem cumulative DE with missing data have had their records edited and have been characterized by other demographic variables and vital status.

Both birthyear and year of hire were taken from the microfilmed personnel record. Birthyear was considered invalid if the information was missing or if a worker was born before 1876 (worker would be older than 100 years at time of microfilming) or after 1962 (worker would be less than 18 years at time of microfilming). The year of hire was considered invalid if it was recorded as missing or unknown on the personnel record, or if there was no personnel record for the worker in a shipyard in which the same worker had a radiation record.

The interval from time of hire in a study shipyard to start of nuclear work in that shipyard was added to each worker's record. This variable, pre-nuclear lag, was developed to control for the bias which resulted because a nuclear worker had to survive long enough to qualify for work in the nuclear program after he was hired. During that interval the employee would have worked for several years in non-nuclear jobs before entering the nuclear program. The variable was calculated as follows:

Pre-nuclear lag = year of first radiation record minus year of hire for the first yard worked in the nuclear program,

Pre-nuclear lag = 0 for any additional yards in which radiation work was done.

This variable could not be calculated if either the year of hire or year of entry into the radiation program was invalid, or if there was no matching personnel record for the first yard in which nuclear work occurred. Pre-nuclear lag would be negative if the nuclear program entry year was reported as earlier than the year of hire on the microfilmed personnel record for a given shipyard. It was decided to equate pre-nuclear lag to zero in these cases. A total of 669 workers in the ≥0.5 rem group had negative values for this variable. These workers' records were listed and edited.

A score derived from the code for each worker's last shipyard job was also appended to each worker's record (see Section 2.8). First, the 49 original job categories used to characterize a job title were recoded to a nine point score (0 to 8) indicating a measure of overall "risk" from all agents associated with the job. Seven industrial hygienists independently rated all job titles. The first available job title code was used in the case of duplicate records for a given personnel identification number.

Only 2 percent of the ≥0.5 group's and 3 percent of the <0.5 group's total yard records did not match to the job file at the time of frame definition. For purposes of the stratification variables, the job variable for these mismatches was considered missing.

A worker was excluded from the sampling frame if either birthyear was invalid, or year of hire or pre-nuclear lag were invalid in all yards in which nuclear work was performed. Also, on a yard by yard basis, a worker was eligible for a given yard in which he worked in the nuclear program only if valid data for that yard existed on all three of these variables.

The results of application of the steps listed above are summarized in

Table 2.2.A. This table shows that the number derived for the $NW_{\geq 0.5}$ sampling frame is 28,060 and the number derived for the $NW_{<0.5}$ sampling frame is 49,449. These were derived from an original database of 106,851 nuclear workers on the 1981 radiation files yielding an eligibility rate for the current analysis of 73 percent.

Definition of the Non-Nuclear Worker Sampling Frame

The derivation of a suitable comparison group of shipyard workers at each yard who never worked in the nuclear program corresponded closely to the derivation of the $NW_{\geq 0.5}$ and $NW_{<0.5}$ sampling frames. Due to imperfections in the available record sources, a practical selection algorithm had to be developed. This algorithm was similar both in content and order of execution to the steps used to select the nuclear workers' sampling frame. These steps are listed below in the order in which they were carried out. The specific numbers of workers excluded by each filter are given in Table 2.2.A. The starting database for the derivation process was the microfilmed personnel file consisting of 692,612 records. (Note: the steps listed below do not correspond to the numbers in the table since some are definition statements).

Step 1: A worker had to be present in the microfilm personnel file and have been a civilian shipyard worker. Non-civilian shipyard workers' records and those workers with only charge out cards indicating assignment to another post were excluded.

Step 2: Workers with invalid or missing social security number on the personnel file were excluded. There were 207,160 workers (31%) without a valid social security number on this file. However, among male workers working at least one year during the nuclear overhaul period (that is, the population defined as eligible for study), the number of invalid social security numbers was reduced to approximately 24,000 (4%).

Step 3: Duplicate personnel records were excluded. In general, this was a complicated and difficult process since reliable unique identifying information was often unavailable. For workers with social security numbers, the process was more straightforward. The general approach taken was to collect records with the same social security number and to consolidate multiple records. A single unified record for each worker was created. Some workers had as many as six personnel records when data from all yards were collated. As described earlier, employment history data and yard identifiers were collated chronologically by yard in which work occurred and stored in a single record.

Step 4: Workers who did not work at any study yard at any time during the period of nuclear overhaul were excluded. As a corollary, a worker was eligible for the sampling frame of a given yard only if he worked during the nuclear overhaul period in that yard.

Step 5: Workers who did not work a year or more in at least one study shipyard were excluded. The criterion of duration worked was applied on a yard by yard basis. Employment data from duplicate records within a yard were not added together. A worker was eligible for a given shipyard's non-nuclear population if he worked at least one year in that yard as indicated on any one

2 Methods
2.2 Definition of Sampling Frames (cont'd)

personnel record or if there were multiple personnel records for a given shipyard.

Step 6: Female workers were excluded.

Step 7: Workers who were ever nuclear workers in any study shipyard were excluded from the non-nuclear worker sample in all yards. This step was accomplished by matching the 1981 Nuc DB to the remaining personnel file on the basis of social security number. A comparison with steps 1-8 of the nuclear worker population derivation would lead one to think that exactly the total nuclear workers remaining after step 8 should be the number excluded in step 9. However, the set of workers excluded due to radiation status includes 612 nuclear workers (486 from Newport News) which are different from the 78,666 nuclear workers in both nuclear populations. These are nuclear workers who were screened out by the nuclear worker selection criteria, but not by the corresponding non-nuclear criteria or vice-versa. For example, a worker may have worked in a shipyard during the overhaul period even if all nuclear work was done prior to overhaul. Or, conversely, the personnel file indicated that the nuclear worker was not a shipyard worker or only had a "charge out" card in the system.

Step 8: Workers who did not have a complete vital status search were excluded. As indicated for the nuclear sampling frame, this number should be nil but, due to ongoing completeness checks, records were added after the major vital status computerized searches were initiated. So, the non-nuclear workers who remained eligible in the sampling frame up to this step were matched to files of records actually sent out for vital status searches. Workers whose records were not sent had to be excluded.

Step 9: Workers with missing or invalid data for the stratification variables (birthyear, year of hire, and duration worked) were excluded. No workers were excluded for missing data on the job title risk score as was described previously for the nuclear workers.

A time variable had to be created for non-nuclear workers which was comparable to the pre-nuclear lag variable for the nuclear workers. The best solution that could be found for defining a variable comparable to the interval from hire to the start of nuclear work was simply to calculate duration worked. Then, for example, nuclear workers who had a five year lag between first hire at a shipyard and the start of nuclear work would be considered in the same strata as non-nuclear workers with at least five years of shipyard work. The use of this variable is discussed in depth in Section 2.3. It is calculated as follows:

Duration worked = withdrawal year minus entry year for noncurrent workers

Duration worked = 1981 minus entry year for current workers.

Though the employment months were available from the personnel records, only years were used since the full dates from the corresponding radiation files were not available.

On this basis, a worker was excluded from the sampling frame for non-nuclear workers if either birthyear was invalid, or year of hire or duration worked were invalid in all yards worked. A worker was eligible for a given yard in which he worked non-nuclear only if valid data for that yard existed on all three variables.

The results of application of the steps listed are summarized in Table 2.2.A. The number derived for the NNW sampling frame is 117,718 workers from a starting database of 692,612 records.

2 Methods
2.2 Definition of Sampling Frames (cont'd)

Table 2.2.A Application of Exclusion Criteria to the Personnel and Nuclear Workers Databases to Define the $NW_{\geq 0.5}$, $NW_{<0.5}$, and NNW Sampling Frames

	Sampling Frames					
	$NW_{\geq 0.5}$		$NW_{<0.5}$		NNW	
Exclusion Criteria (Applied Separately to Each Shipyard)	No.	%	No.	%	No.	%
Workers in Initial Database[1]						
Total	106,851		106,851		692,612	100%
Split <0.5 vs. ≥0.5 rem (Cum. DE, 12/31/81)	35,079	100%	71,772	100%		
Sequence of Exclusion Steps[2]						
1 No Nuclear Work After Overhauls Began						
Excluded	454	1%	2,371	3%	--	
Still Remaining	34,625	99%	69,401	97%		
2 Non-Civilian						
Excluded	--		--		17,819	3%
Still Remaining					674,793	97%
3 No Social Security No.						
Excluded	191	1%	1,659	2%	207,160	31%
Still Remaining	34,434	98%	67,742	94%	467,633	68%
4 No Record in Per DB						
Excluded	4,985	14%	12,350	18%	--	
Still Remaining	29,449	84%	55,392	77%		
5 Duplicate Record in Per DB						
Excluded	--		--		22,733	5%
Still Remaining					444,900	64%
6 No Employment After Overhauls Began						
Excluded	--		--		135,765	31%
Still Remaining					309,135	45%
7 Employment <1 Year						
Excluded	944	3%	4,619	8%	86,814	28%
Still Remaining	28,505	81%	50,773	71%	222,321	32%

(cont'd)

2 Methods
2.2 Definition of Sampling Frames (cont'd)

Table 2.2.A Application of Exclusion Criteria to the Personnel and Nuclear Workers Databases to Define the $NW_{\geq 0.5}$, $NW_{<0.5}$, and NNW Sampling Frames (cont'd)

	Sampling Frames					
	$NW_{\geq 0.5}$		$NW_{<0.5}$		NNW	
Exclusion Criteria (Applied Separately to Each Shipyard)	No.	%	No.	%	No.	%
8 Female						
Excluded	124	<1%	488	1%	24,222	11%
Still Remaining	28,381	81%	50,285	70%	198,099	29%
9 Nuclear Worker (in Nuc DB)						
Excluded	--		--		78,114	39%
Still Remaining					119,985	17%
10 Incomplete Vital Status Ascertainment						
Excluded	32	<1%	61	<1%	174	<1%
Still Remaining	28,349	81%	50,224	70%	119,811	17%
11 Missing Data For Stratification (Birthyear, hire year, pre-nuclear lag or duration worked)						
Excluded	289	1%	775	2%	2,093	2%
Still Remaining	28,060	80%	49,449	69%	117,718	17%
Final number excluded	7,019	20%	22,323	31%	574,894	83%
Final Sampling Frame	28,060	80%	49,449	69%	117,718	17%

[1] Starting points were the Nuclear Worker Database (Nuc DB) for the $NW_{\geq 0.5}$ and $NW_{<0.5}$ groups, and the Personnel Database (Per DB) for the NNW group.

[2] Denominators for percents are total entering step for "Excluded" and total indicated in initial database for "Still Remaining". A -- indicates that the exclusion step did not apply.

2 Methods

2.3 Selection of Stratified Samples

The initial study design called for the study of all workers in the nuclear program regardless of DE and all non-nuclear workers employed during the period of nuclear overhaul. The design ultimately specified a 100 percent sample of the $NW_{\geq 0.5}$ frame (approximately 30,000 workers) and stratified samples of approximately 11,000 workers (25%) from the $NW_{<0.5}$ frame and 44,000 workers (37%) from the NNW frame. This allowed for roughly 10 percent more non-nuclear workers than nuclear workers in the overall sample. The 10 percent oversampling was done since it was expected that there might be accessions into the nuclear sample due to ongoing edits of the radiation data. Every available $NW_{\geq 0.5}$ nuclear worker with acceptable data was included. The design also specified stratification based on age (birthyear), starting year of employment, job hazard index (categorized by last job held), and duration of employment prior to the start of nuclear work (or a corresponding pseudo duration for the NNW group).

As described earlier, a total of 28,060 nuclear workers have been currently identified in the $NW_{\geq 0.5}$ sampling frame of which 482 workers worked in more than one shipyard. All of these $NW_{\geq 0.5}$ workers were followed and analyzed.

Stratification Variables

The stratified sampling schemes for the $NW_{<0.5}$ and NNW groups were based on shipyard plus four additional stratification variables:

- Birthyear (5 groups);
- Year of hire (4 groups);
- Overall job hazard index (4 groups); and

2 Methods
2.3 Selection of Stratified Samples (cont'd)

- Interval from time of hire to start of nuclear work (pre-nuclear lag) or a corresponding pseudo interval for the NNW workers (4 time groups for $NW_{<0.5}$ and single years for NNW).

After examination of yard by yard and overall frequency distributions, groupings for these variables were defined to reduce the number of strata for sampling purposes to a large but manageable number. Combination of the grouped variables led to 320 possible strata. Birthyear was grouped into five classes: <1920, 1920-1929, 1930-1939, 1940-1949, 1950+. Four groups were defined for year of hire: <1950, 1950-1959, 1960-1969, 1970+. A single digit job score reflecting the overall job risk (see section 2.8) was recoded to three job risk exposure groups: low, medium, high. A missing job score was coded as a separate class for a total of four groups. The missing scores are generally associated with job codes which denote administrative/supervisory level positions which were not related to any hazard score. A separate categorization was considered preferable to simply excluding workers with missing information on job title.

The fourth stratification variable is less straightforward than the first three. Its determination differed depending on nuclear worker status. Nuclear workers, by definition, must survive from their hire date to the start of radiation work and their consequent appearance on the radiation files. There is no corresponding guaranteed survival interval for non-nuclear workers during which deaths cannot occur. If this interval for the nuclear workers is large as it might be especially at the beginning of the program, an artifactually increased survival in the nuclear group would result when compared with non-nuclear workers. Consequently, for sampling purposes, nuclear workers were stratified by number of years worked in the first

2 Methods

2.3 Selection of Stratified Samples (cont'd)

shipyard before the start of radiation work (pre-nuclear lag). This interval equaled zero in any subsequent yards in which nuclear work was done after the first yard. Strata for non-nuclear workers were defined on the basis of total duration worked (i.e., the length of time from the year of hire to either the year of withdrawal from the shipyard or 12/31/81 for current workers) as long or longer than the corresponding pre-nuclear lag for nuclear workers. As an example, a sample of non-nuclear workers corresponding to nuclear workers with four years of employment before the start of nuclear work would be drawn from non-nuclear workers with at least four years employment. While this approach at least partially corrected for the artifact mentioned, the sampling process was complicated by the fact that some non-nuclear workers were eligible as controls for more than one strata --a non-nuclear worker with 20 years of employment would be eligible for selection in 20 strata.

Except for the large number of strata involved, the use of the pre-nuclear lag variable posed no problems in selecting the $NW_{<0.5}$ stratified sample. The pre-nuclear lag variable was grouped into four classes: 0-1 year, 2-4 years, 5-9 years, and 10+ years. Within each shipyard, a simple stratified sampling scheme with a maximum of 320 strata was used, where approximately one $NW_{<0.5}$ nuclear worker was chosen for every three $NW_{\geq 0.5}$ nuclear workers.

As noted, the duration worked variable complicated the non-nuclear (NNW) sample selection. One still stratified on the first three variables (birthyear, year of hire and job). However, a modification was made to the sampling scheme so that the non-nuclear worker controls were eligible to be chosen from as many strata as were relevant whereas each nuclear worker was in only one unique stratum. For example, the control for a nuclear worker with a given birthyear, year of hire, and job who was employed two years before becoming a nuclear worker was chosen from non-nuclear workers who had the same birthyear, year of hire, and job but were employed two or more years.

The distributions of the stratification variables along with duration worked for the total sampling frame for each group ($NW_{\geq 0.5}$, $NW_{<0.5}$, and NNW) and for the corresponding samples that were selected are presented in Tables 2.3.A and 2.3.B and in Figures 2.3.A to 2.3.E. They show marked differences among the sampling frames with respect to each of these variables, but very good balance after sample selection.

The distributions of the stratification variables for individual shipyards are not presented. There were yard to yard differences in the distributions of the four stratification variables. For example, the Groton shipyard workers in all three groups tended to be more recently hired workers with fewer years of employment. The nuclear workers from Groton tended to qualify for nuclear work after only a few years of employment, and the Groton non-nuclear workers tended to be younger than those in other shipyards. On the other hand, Norfolk $NW_{\geq 0.5}$ workers tended to work many years before becoming nuclear workers. The Portsmouth workers in all three groups tended to be older. The Puget Sound nuclear workers tended to be more recent hires and those in the $NW_{<0.5}$ group tended to be younger than workers in the other shipyards.

The samples selected, however, were well balanced from yard to yard as reflected in the Tables and Figures for all yards combined.

Specifications for the Sampling Plan

Both the $NW_{<0.5}$ and the NNW samples were drawn on a yard by yard basis as

2 Methods

2.3 Selection of Stratified Samples (cont'd)

the necessary data became available. Since the samples were selected on a yard by yard basis, a worker who worked in multiple shipyards was eligible for sample selection in each yard in which he worked. Multiple records were eliminated at the analysis step, so that any one worker was included only once.

There was a maximum of 320 possible strata within a shipyard from which to draw the $NW_{<0.5}$ sample. Some strata did not exist due to unlikely combinations (e.g., a young worker newly hired working 10 or more years), along with diminished total numbers once the $NW_{<0.5}$ group was broken down by individual shipyard.

Though overall numbers were quite adequate in both the $NW_{<0.5}$ and the NNW sampling frames from which to draw the specified sample size, at times individual strata were not large enough to select the numbers required. When this occurred, workers were selected ("borrowed") from the next closest stratum or strata with adequate numbers. This was expected to give the prespecified sample size and produce distributions of characteristics for the sample close to those in the $NW_{\geq 0.5}$ sample. In the $NW_{<0.5}$ samples selected, this "borrowing" happened infrequently, and in cases where it did occur, generally only the pre-nuclear lag variable was affected. "Borrowing" occurred for approximately 10 percent of the NNW controls. Control on birthyear was always maintained, and control on year of hire was maintained for the $NW_{<0.5}$ sample.

2 Methods
2.3 Selection of Stratified Samples (cont'd)

Selection of the $NW_{<0.5}$ Sample

Implementation of the sampling scheme for the $NW_{<0.5}$ sample at a given shipyard involved the following steps:

Step 1. The sampling frames for a specified shipyard were determined by selecting all eligible nuclear workers in the $NW_{<0.5}$ or $NW_{\geq 0.5}$ frames for that shipyard. Separate computerized frame files were established for $NW_{\geq 0.5}$ and $NW_{<0.5}$ for each shipyard. The frame file included the workers' identifiers and employment data, cumulative DE, and grouped and ungrouped stratification variables. Multiple records for a given worker in a specified shipyard were consolidated. The earliest year of hire and length of employment before nuclear work in that shipyard, and most current non-missing job hazard index were recorded. The files were sorted by the grouped stratification variables in order by birthyear, year of hire, job hazard index, and pre-nuclear lag and a random number. The latter was done so that individuals within any stratum were filed in random order.

Step 2. Joint stratum distributions for each yard were computed and stored in a separate file. A listing of the number of workers in each stratum by nuclear group was visually examined to assure adequate numbers for selection.

Step 3. Allocation numbers, n_i, were computed for each stratum, i, using a proportional allocation method modified by "borrowing" from nearby strata. Ideally the proportion selected from each stratum would be:

$$p = (\text{number in } NW_{<0.5})/(\text{number in } NW_{\geq 0.5})$$
$$= 11{,}000/30{,}000$$
$$= 0.37$$

This would result in a total of 11,000 nuclear controls combining the samples from all shipyards. The sample size for a given shipyard, s, is:

$$N_s = 0.37M_s$$

where N_s = number in the $NW_{<0.5}$ sample for shipyard s, and M_s = number of $NW_{\geq 0.5}$ workers in shipyard s.

Step 4. Using the stratum allocation numbers previously computed, the first n_i workers were drawn from each stratum. Since the frame file of $NW_{<0.5}$ workers was sorted randomly, this constituted a stratified random sample.

A total of 10,462 $NW_{<0.5}$ workers were selected from the sampling frame of 49,635 workers (see Table 2.3.B).

Selection of the NNW Sample

Implementation of the sampling scheme for the non-nuclear (NNW) sample is summarized in the following steps:

Step 1. The NNW sampling frame for a specified shipyard was determined by selecting all non-nuclear workers eligible for the sample in that shipyard. The individual shipyard's frame file included the workers' identifiers and employment data, and grouped and ungrouped stratification variables. Multiple records for a given worker for the specified shipyard were consolidated. The earliest year of hire and most current non-missing job code

2 Methods
2.3 Selection of Stratified Samples (cont'd)

were recorded. Time from hire to withdrawal or the study endpoint was calculated to reflect the worker's total duration worked in a given shipyard. The file was sorted by the grouped stratification variables, duration worked in single years, and a random number. The reference frame of $NW_{\geq 0.5}$ had already been established.

Step 2. The nominal stratum counts for the NNW sample were calculated as follows. The projected number of non-nuclear controls was 44,000, so the ratio of non-nuclear controls selected to the number in the $NW_{\geq 0.5}$ population was:

$$p = \frac{44,000}{30,000} = 1.47.$$

This ratio worked well in the four shipyards for which the total number of NNW workers was at least three times the resulting sample size. In the four yards in which satisfactory balance was not achieved and excessive borrowing occurred, the ratio was defined as:

$$p = \frac{(\text{\# of NNW/3})}{(\text{\# of } NW_{\geq 0.5})}.$$

The proportional allocation method was used to calculate the nominal number of workers to be selected for the sample by stratum using this ratio (p) of non-nuclear to nuclear workers. The nominal stratum counts for the NNW sample and the numbers available for the sample in the non-nuclear population were listed and reviewed.

Step 3. To select the actual sample, a modified stratified sampling scheme was used. The modification arose in requiring the non-nuclear controls for a given stratum to work at least as long as the comparable $NW_{\geq 0.5}$ workers' pre-nuclear lag times, since non-nuclear workers have no comparable time period during which they cannot die.

The workers in each sampling frame ($NW_{\geq 0.5}$ and NNW) were first stratified on birthyear, year of hire and job hazard index, which will be called a block. Within the block, the $NW_{\geq 0.5}$ workers were randomly ordered to avoid any systematic bias that could have been introduced by ordering on the pre-nuclear lag variable. The nominal number of workers for each stratum, as previously noted, was p ($\leq$1.47) times the number of $NW_{\geq 0.5}$ workers. The strategy was to select the non-nuclear controls for the nuclear workers within each block, beginning with the group reflecting the earliest birthyear, earliest year of hire and lowest job hazard index, and then for each succeeding block in order.

Non-nuclear controls were randomly selected from all NNW workers in the block with a total duration greater than or equal to the $NW_{\geq 0.5}$ worker's pre-nuclear lag. For example, if the $NW_{\geq 0.5}$ worker in a given block worked four years before entering nuclear work, then a non-nuclear control was randomly selected from all NNW workers in the block with a total duration of four or more years. This pseudo pre- nuclear lag of four years was stored in each non-nuclear control's record. After the non-nuclear controls were selected for the first

2 Methods

2.3 Selection of Stratified Samples (cont'd)

block, then the entire process was repeated for the next birthyear, year of hire and job hazard index grouping.

A problem arose in those strata where the number of non-nuclear workers was inadequate to meet the nominal sample size. In these cases, the remaining non-nuclear worker controls were then selected from the next succeeding stratum or strata according to the pre-nuclear lag value if possible until adequate numbers were achieved. Controls were selected within a block first.

A total of 33,353 NNW workers were selected from the sampling frame of 117,718 workers. This is less than the projected number of 44,000 workers due to the change in p used in some yards; however, there are still more non-nuclear controls than $NW_{\geq 0.5}$ workers.

2 Methods
2.3 Selection of Stratified Samples (cont'd)

Table 2.3.A Population Distributions of Birthyear, Year of Hire, Job Hazard Index, Duration of Pre-Nuclear Work, and Total Duration Worked

Variable	NW≥0.5 * (N=28,542) No.	%	NW<0.5 * (N=49,635) No.	%	NNW * (N=119,179) No.	%
Birthyear						
<1920	5240	18%	11967	24%	26984	23%
1920-1929	6298	22%	9702	20%	16658	14%
1930-1939	6486	23%	9959	20%	15979	13%
1940-1949	8345	29%	13994	28%	30958	26%
1950+	2173	8%	4013	8%	28600	24%
Year of Hire						
<1950	5435	19%	11185	23%	21627	18%
1950-1959	5977	21%	9771	20%	11294	10%
1960-1969	12048	42%	20078	41%	36079	30%
1970+	5082	18%	8601	17%	50179	42%
Job Hazard Index						
Missing	1440	5%	2152	4%	3940	3%
Low	5038	18%	13601	27%	26238	22%
Medium	13047	46%	23585	48%	59452	50%
High	9017	32%	10297	21%	29549	25%
Duration of Pre-Nuclear Work						
0- years	10685	37%	16413	33%	N/A	N/A
2- years	6326	22%	10447	21%	N/A	N/A
5- years	4348	15%	7293	15%	N/A	N/A
10- years	4272	15%	6763	14%	N/A	N/A
20+ years	2911	10%	8719	18%	N/A	N/A
Total Duration Worked						
1- years	870	3%	2709	5%	13531	11%
2- years	2822	10%	8923	18%	38350	32%
5- years	5554	19%	10318	21%	26367	22%
10- years	8716	31%	11454	23%	15572	13%
20+ years	10580	37%	16231	33%	25359	21%

* Note: The numbers in the group do not correspond to Table 2.2.A because editing of the database continued even after sampling was completed.

2 Methods
2.3 Selection of Stratified Samples (cont'd)

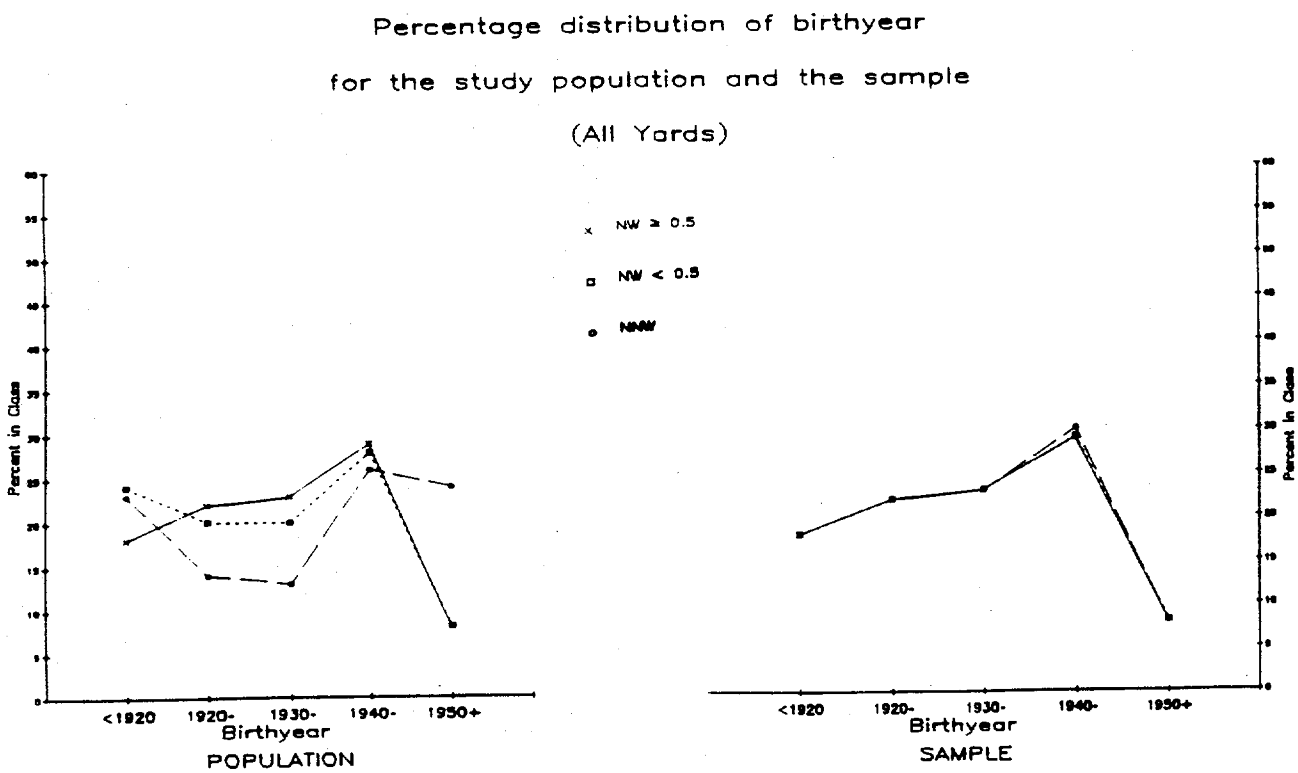
Table 2.3.B Sample Distributions of Birthyear, Year of Hire, Job Hazard Index, Duration of Pre-Nuclear Work, and Total Duration Worked

Variable	$NW_{\geq 0.5}$ (N=28,542) No.	%	$NW_{<0.5}$ (N=10,462) No.	%	NNW (N=33,353) No.	%
Birthyear						
<1920	5240	18%	1920	18%	5861	18%
1920-1929	6298	22%	2307	22%	7195	22%
1930-1939	6486	23%	2382	23%	7802	23%
1940-1949	8345	29%	3059	29%	9932	30%
1950+	2173	8%	794	8%	2563	8%
Year of Hire						
<1950	5435	19%	1976	19%	5860	18%
1950-1959	5977	21%	2152	21%	6221	19%
1960-1969	12048	42%	4462	43%	15035	45%
1970+	5082	18%	1872	18%	6237	19%
Job Hazard Index						
Missing	1440	5%	547	5%	1727	5%
Low	5038	18%	1929	18%	7534	23%
Medium	13047	46%	4783	46%	14918	45%
High	9017	32%	3203	31%	9174	28%
Duration of Pre-Nuclear Work[1]						
0- years	10685	37%	3874	37%	12871	37%
2- years	6326	22%	2308	22%	7313	22%
5- years	4348	15%	1565	15%	5003	15%
10- years	4272	15%	1238	12%	4633	14%
20+ years	2911	10%	1477	14%	3533	11%
Total Duration Worked						
1- years	870	3%	537	4%	2145	6%
2- years	2822	10%	1991	19%	7561	23%
5- years	5554	19%	2089	20%	7702	23%
10- years	8716	31%	2650	26%	7428	22%
20+ years	10580	37%	3195	31%	8517	26%

[1]Pseudo pre-nuclear lag given for NNW

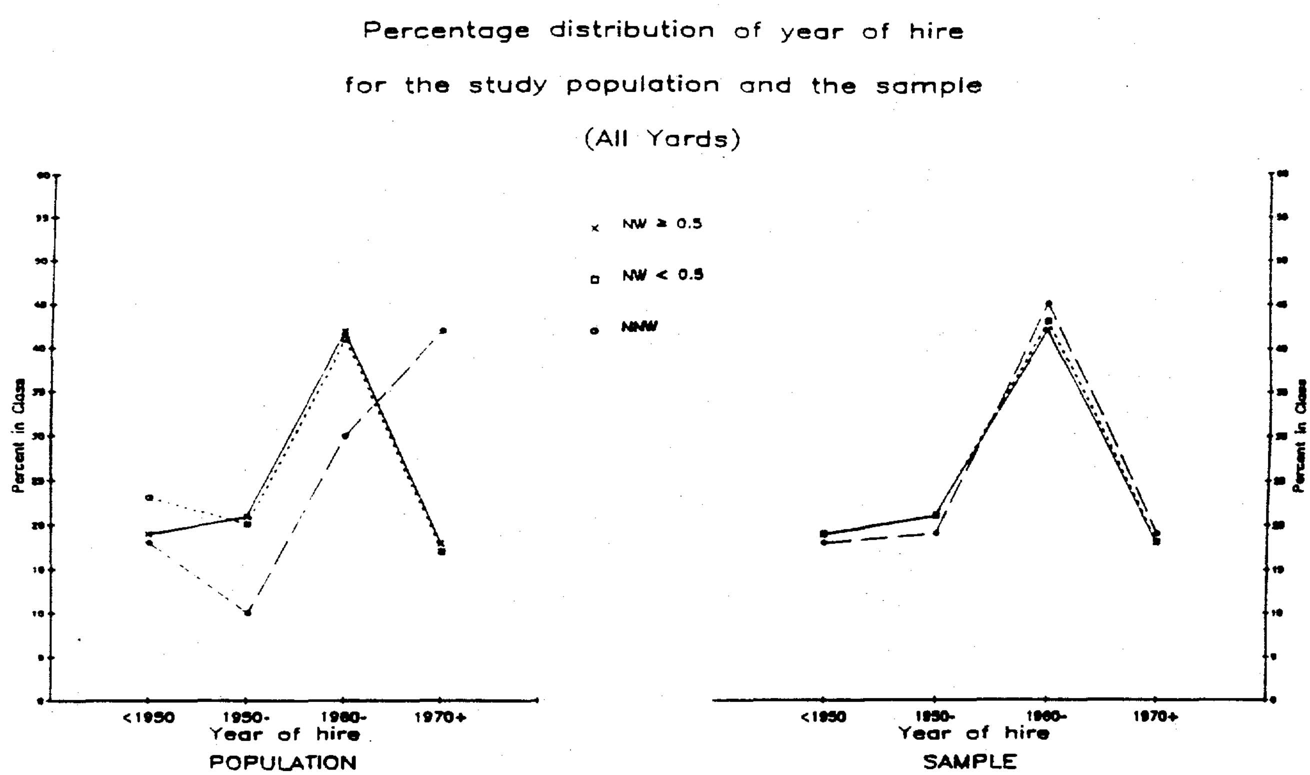
2 Methods
2.3 Selection of Stratified Samples (cont'd)

Figure 2.3.A Distribution of Birthyear: Populations vs. Stratified Samples



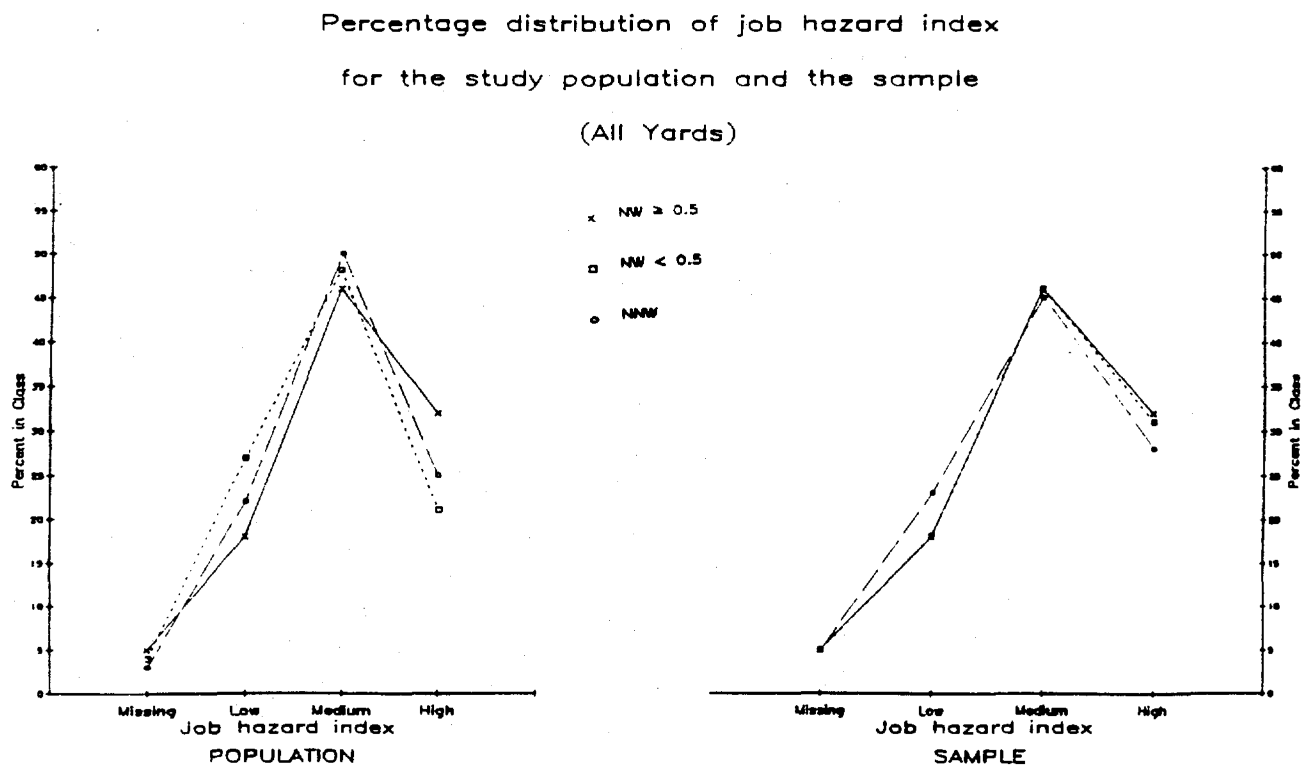
2 Methods
2.3 Selection of Stratified Samples (cont'd)

Figure 2.3.B Distribution of Year of Hire: Populations vs. Stratified Samples



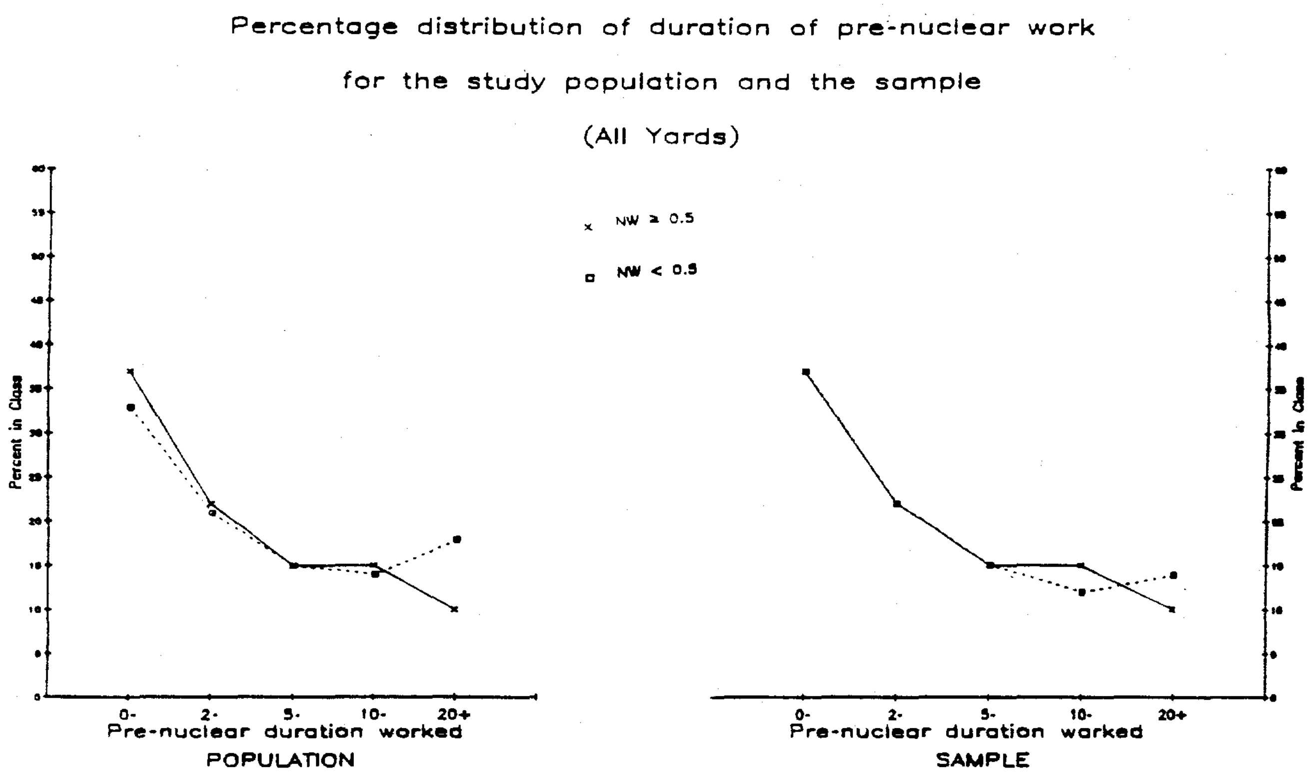
2 Methods
   2.3 Selection of Stratified Samples (cont'd)

Figure 2.3.C Distribution of Job Hazard Index: Populations vs. Stratified Samples



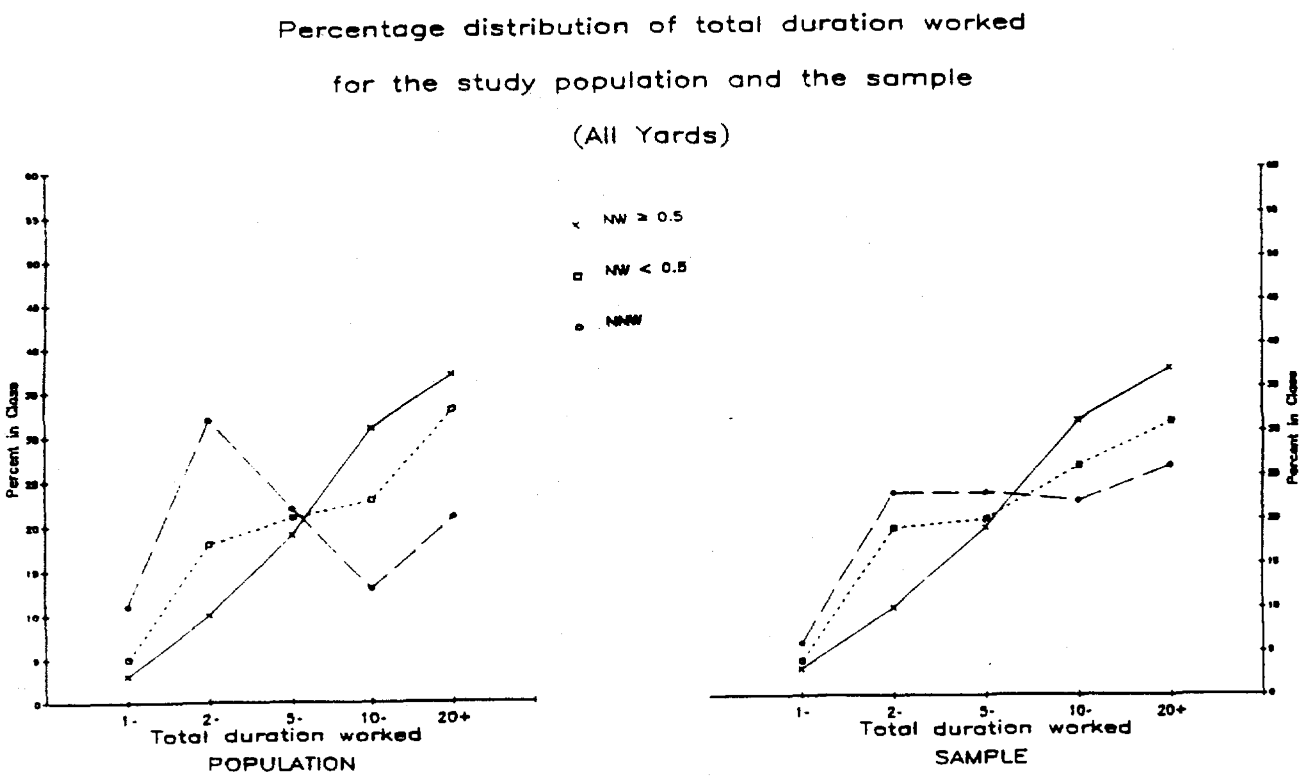
2 Methods
 2.3 Selection of Stratified Samples (cont'd)

Figure 2.3.D Distribution of Duration of Pre-Nuclear Work: Populations vs. Stratified Samples



2 Methods
2.3 Selection of Stratified Samples (cont'd)

Figure 2.3.E Distribution of Total Duration Worked: Populations vs. Stratified Samples



2 Methods

2.4 Data Management and Quality Control

The database management tasks for the Nuclear Shipyard Workers Study are, in principle, quite straightforward. They are implied by the key steps of the study:

- Establish a population base by microfilming all available personnel records at each of the eight shipyards. These records were filmed in succession in each yard, but it required 18 months to complete all eight yards.
- Film other pertinent documents such as industrial hygiene reports, selected medical records, lists of workers prepared for special purposes, job descriptions, etc., during the period of on-site filming of personnel records. These records provide information on work exposures other than radiation and also provide a check on the completeness of the population established via the personnel records.
- Obtain data on recorded radiation exposures for nuclear workers. The Navy's computerized data system for the Nuclear Propulsion Program provides exposure data for workers at the six Navy yards. The Groton yard, which is a private yard, utilizes a computerized system similar but not identical to the Navy's system while Newport News, also a private yard, utilizes a system which has some paper-based components and some computerized components.
- Determine the vital status (death or confirmed alive) of all persons identified in the study sample. The searches must minimize the number with vital status unknown.

2 Methods
2.4 Data Management and Quality Control (cont'd)

- Obtain death certificates for all identified deaths from the states or foreign countries in which the deaths occurred.
- Administer a questionnaire to workers in two yards to obtain information on potentially confounding variables.
- Maintain a file of new workers -- i.e., accessions into the shipyard population of workers first employed after the microfilming. The maintenance of files has included the keeping of records of accessions into the nuclear worker system.
- Develop procedures to assess and, if possible, assure quality and consistency of all data collected and processed.
- Define appropriate subgroups of the microfilmed population base for analysis.
- Produce appropriate comparisons and analyses by combining data from the personnel records, vital status sources, death certificates, and other sources, and exposure records.

The data management system developed for carrying out the steps described above is complex and involves both manual and computerized procedures.

Data Collection Procedures

A description of the methods used to collect the source data for establishing the population census and job histories from the shipyards and the assembly of these data at the Shipyard Study office follows. Source data included the collection of all available personnel records (SF-7 cards for Naval shipyards) and any other sources of records which could be used to validate the completeness of the personnel records.

To initiate data collection at the shipyards, a visit by the senior project staff was scheduled with the shipyard staff who were responsible for the records of interest. At this initial visit, the information sources which would be needed were examined to determine the organization and location of the records to be filmed and to assess the availability of the facilities which would be needed by the microfilming team. The team then made a detailed inventory of all records to be filmed. This inventory was used by the microfilming team as a guide to the order in which the records were to be filmed as well as a checklist to assure that no records were missed or overlooked. At the time of the initial visit, arrangements were made with the shipyard's print and publication shop to develop our microfilm. This allowed on-site verification that the filming had been done correctly and completely. Development of the film at the shipyard helped to protect the confidentiality of the data.

Microfilming

During the initial visit, calculations were made to determine the total number of records to be filmed so that the microfilming trip could be planned in detail. Portable Recordak microfilm units provided by the Shipyard Study microfilming team were used. The team was responsible for the pulling, filming and refiling of all records. Care was taken to assure that all records were logged in the inventory and that all records were returned to their storage areas in proper order.

The number of machines and number of filmers required for data collection at a yard depended on the estimates of the total number of records, the system of filing, the amount of preparation the records required before filming, and the space available at the shipyards. Conservative estimates indicated that we could film 1,000 records per reel of film and that one microfilming unit could produce 1.5 to two reels per day. Two persons were required per microfilming unit. In almost all of the yards, we were able to send four machines, eight filmers, and one supervisor. The total amount of time necessary to accomplish the filming at individual shipyards ranged between two and six weeks, with the average being about three weeks.

Upon return, the filmed data were prepared for coding in the Shipyard Study office. This operation involved assigning a serial number to each reel of film, preparing a library index card for the reel, and creating a circulating library log. These index cards were used for charging out reels to coders so that at any time a reel's location and stage of processing could be verified. After cataloging of the microfilm was complete, data extraction could begin. Data extraction involved four passes through each reel of film.

Data Extraction

First, each reel of film was censused by coding identification information for each worker included on the reel of film. The items coded on the first pass of the microfilm included a yard identifier (ID), a reel ID, the record type, the name of the worker, his social security number, his date of birth, and the total number of frames pertaining to that individual. This was done for 100 percent of the workers identified on the film. These items represented the minimal data required to initiate vital status searches. For some yards these searches were begun after the census data were collected.

The second pass through the film involved an abbreviated coding of the reel (every tenth record was coded in its entirety and the intervening nine records were coded by sequence number and the worker's initials only). This coding provided a validation check against the census file to assure that an accurate and complete record of the population of individuals contained on the microfilm reels had been made.

The coded records were prepared for keypunching by being grouped by reel, batch, and lot. Four keypunching firms were utilized to handle the volume of data. The steps involved in processing the data tapes returned after keypunching are described in a later section.

The next pass of the microfilm involved coding baseline data. A baseline coding form was generated for each worker in the study population from the computerized census file. Forms were generated by yard and by reel of microfilm with identifying information from the census record printed on the code sheet to facilitate the matching of the specific worker on the reel to his baseline data form. The baseline data include demographics such as race and sex, birthplace, veteran's status, dates of shipyard employment, and the status of the employee as indicated by the last entry on the job card.

The fourth and final pass through the microfilm was for coding information on last job title. Data abstracted in this step included a code for the last job title and shop, the date the last job was entered, and the associated wage grade.

It was recognized at the start of the study that a large number of staff would be handling the data at each step. These procedures divided the extensive microfilm extraction efforts for personnel records into two or more passes through the film as described above. Although this approach was somewhat inefficient, there was an advantage in that the abstractor was able to concentrate on relatively few items, making data extraction simpler and more reliable. Multiple passes through the films using computerized listings of previously recorded data resulted in the discovery of many errors of omission.

Computerized Data Files

The Shipyard Study utilized several computer centers located within the Johns Hopkins Medical Institutions. Hundreds of computerized data files were created during the course of this study; only the main data files and programming systems are discussed in this section. Most of these files are retained in the Information Systems Division (ISD) located in the Johns Hopkins Hospital. This installation is centered around an IBM 3081 mainframe with an MVS operating system. Shipyard Study staff used TSO, JCL, PL/1, SAS, SYNCSORT and assorted utility programs in applications for the study.

In the ten years of the study, more than 2,000 computer programs involving over 250,000 lines of source statements were produced in the study's developmental and production program libraries. There are over 1,500 magnetic tape files for the study in the ISD tape library. This figure does not include the backups for many of these files which were maintained and stored outside of the computer center. This complexity resulted from the large number of data sources and the need to integrate them. Each data file, whether internally generated by the Shipyard Study staff or obtained from an external agency or institution, had its own set of peculiarities to resolve. Furthermore, the large size of many of the individual data files was a complicating factor.

Two types of computerized data files occurred in this study:

- Internal files: Data collected and computerized by the NSWS from a source document, usually some sort of collection of paper records; and
- External files: Data produced by a group outside of the NSWS, usually received in the form of one or more magnetic tapes.

See Table 2.4.A for a listing of the major internal and external files for this study and the number of records in each.

These two types of data files presented different sorts of problems. Ultimately, both types of data files had to be linked and integrated. The status of any particular data file varied as the study progressed. It could have been in any one of the following states:

- Active: New data expected; editing is ongoing;
- Editing: No new data expected; editing continues;
- Closing: File is nearly complete; final edits and documentation are underway; and
- Final: No more changes to data file.

Internal Files

Typically, the source of internally generated files was either microfilmed records or, less frequently, some set of paper documents such as questionnaires. A large clerical staff extracted, coded, and recorded the data onto data forms designed for each particular application. Each application had one or more data forms, and a detailed set of instructions were prepared for each form.

Coded data forms were divided into batches and lots for data entry purposes. The batch size was determined by the number of forms that fit easily into a large envelope. Lots were collections of batches, the size of which varied depending on the capacity of the particular keypunching firm or data entry unit being used.

The batch oriented approach was chosen over more direct methods of data entry for three reasons:

- Flexibility: Many different commercial data entry firms supplemented a small core, "in-house" data entry capability making it easy to deal with ebbs and flows in demands for rapid entry;
- Cost: The computing equipment for a direct data entry system for 50-60 clerks was very costly at the time the study started;
- Convenience: The mechanics of reading microfilm and keying the data directly are difficult. A clerical recording step works well with microfilm reading; and
- Training: Relatively large numbers of clerical staff could be recruited and supervised more easily than workers with both clerical and direct data entry skills.

All data entry providers were required to key and verify data. The media on which the providers returned the keyed data included punched cards, data diskettes of various formats, and magnetic tapes in a variety of formats.

Due to the large number of data entry providers, every data lot was listed in a standard format and sight checked by a clerk against the forms. Entry errors and especially missing data could be detected this way. An occasional batch of 100 or more forms was skipped by the data entry provider. Early discovery of such problems more than justified the clerical review effort.

Once the data were entered on a computerized file and the sight checks were completed, there was an immediate need to be able to make changes (additions, corrections, and deletions) to the file. These updates were performed by senior clerical staff.

At the time the study began, there did not seem to be a unified database system available that could accommodate all of the features mentioned above. Disk space was very expensive for files of the size needed for this study. Accordingly, the general purpose ARCHIVE-ASSEMBLY system was developed to carry out database construction and management for internally generated data files.

The major features of this system were as follows:

- Main database transactions were stored on one magnetic tape at a density of 6250 characters per inch; this tape was called the ARCHIVE tape;
- A 100% audit trail of all transactions (including deletions) to the database was maintained on tape; this tape was called the LINK tape;

2 Methods
2.4 Data Management and Quality Control (cont'd)

- The system was able to display the history of any record from its initial entry to current status. This was termed an audit of the record;
- All transactions were added to the end of the ARCHIVE tape using the backwards read feature of the available highspeed tape drives. This lead to tremendous processing efficiencies;
- The system was able to handle data organized in lots and batches from many different magnetic (or other) media;
- The system was able to maintain several types of records on the same ARCHIVE file;
- The ARCHIVE file was periodically assembled into an ASSEMBLE file; all data updates entered on the file were applied in this step. Most performance reports and analyses utilized the ASSEMBLE file;
- Ease of use was required to accommodate entry of thousands of batches; the system also had to function over a period of years with data entry occurring throughout the period;
- The system had the capacity to manage up to 3.6 million transactions of all types in any one file; and
- Each record on the ARCHIVE file had a unique identification number; all corrections made to the record were referenced to this number.

The ARCHIVE-ASSEMBLE system outlined above could thus carry out all database maintenance activities for an internally generated data file using just four magnetic tapes:

- ARCHIVE;
- LINK (links corrections to their target records);
- ASSEMBLE; and
- BACKUP (kept off-site).

External Files

The external files varied widely as to their source and characteristics. Produced by different agencies and institutions, using their own computers, operating systems, and software, these files were usually received in the form of magnetic tape files. These tapes had to be processed expeditiously so that problems were discovered and dealt with while the agency contact person and the programmer who prepared the tape were still at the source data site.

Several software tools were developed to process these external files so that they could be integrated with the NSWS system. The general steps were:

- Copy the file into the Shipyard Study tape library; this step quickly identified any technical problems regarding tape recording characteristics;
- Validate the documentation by comparing the record layouts and other documents provided with the file to listings and cross-tabulations;
- Archive the original tape as a hedge against accidental destruction of the copy used for processing; if the source data site requested return of the tape, a copy was made and stored at the Shipyard Study office; and

- Prepare and run application programs; these varied depending on the nature of the files and their intended use.

In many cases, the application programs involved integrating the external file with existing internal files. This process often revealed unanticipated problems which were not identified by earlier processing steps. The resolution of these problems sometimes resulted in the creation of formal edit programs whose results were sent back to the supplier of the original external data. When the revisions were received, either in paper form or on magnetic tape, the original file was updated or replaced. The cycle described above was then repeated.

Magnetic Tape Library

As indicated earlier, the primary data files for the Shipyard Study resided on magnetic tape, and nearly all database management activities were carried out using magnetic tape based systems.

The ISD computer facility maintains a tape library in excess of 40,000 reels for administrative and research users. The physical security of the tape library is excellent from the point of view of access limitation, coverage by a full time tape librarian, and protection from hazards such as fire or water damage. The management of the library pool of tapes is assisted by the widely used software product, Tape Management System (TMS). Signing out new tapes from the pool is automated, requiring only a statement or two in the computer "job" creating the tape. Multi-file reels or multi-volume files are supported by TMS. Release of tapes back into the pool is done by means of expiration dates. Once the expiration date has passed (for all files on a tape reel), the tape is automatically returned to the pool. However, revising an expiration date requires a clerical procedure that is somewhat cumbersome.

Essentially, three types of expiration dates were used by the Shipyard Study depending on the nature of the data file.

- Transient files: expiration dates of 24 hours; used for intermediate files too large for temporary disk space and for "check point" restarting of large production jobs;
- Intermediate files: expiration dates of 30 days or, occasionally, 90 days; these were primarily data entry files which were kept until there was no reasonable doubt that they have been successfully integrated into the system; and
- Permanent files: final expiration date (12/31/89); to the extent possible, permanent files (once closed) were combined on tape reels.

2 Methods
2.4 **Data Management and Quality Control** (cont'd)

Table 2.4.A Major Computerized Data Files by Source of Data Generation (Internal or External)

	Data File	Source	Number of Records on File[1]
1.	Microfilm Personnel Record Census	INTERNAL	1,555,374 (691,862)
2.	Last Job Classification	INTERNAL	278,940 (278,398)
3.	Measured Radiation DE (Navy Yards)	EXTERNAL	304,994 (55,684)
4.	Measured Radiation DE (Groton Yard)	EXTERNAL	107,755 (25,760)
5.	Measured Radiation DE (Newport News)	INTERNAL	115,946 (25,889)
6.	Currently Employed Shipyard Workers Yearly Files (Navy yards only)	EXTERNAL	533,979 (61,135)
7.	Master Death Index (All deaths)	INTERNAL	92,050
8.	Master Living Index	INTERNAL	393,980
9.	Unknown vital status	INTERNAL	3,023
10.	Coded Death Certificate File	INTERNAL	36,568
11.	Norfolk Yard Health History Questionnaire Short Form (95% Sample)	INTERNAL	11,355
12.	Norfolk Yard Health History Long Form (5% Sample)	INTERNAL	539
13.	Charleston Health History Questionnaire Short Form (100% Sample)	INTERNAL	6,950
14.	Sample Frame	INTERNAL	(72,357)

(cont'd)

2 Methods
2.4 Data Management and Quality Control (cont'd)

Table 2.4.A Major Computerized Data Files by Source of Data Generation (Internal or External) (cont'd)

	Data File	Source	Number of Records on File[1]
15.	Cause of Death Validation	INTERNAL	468 (460)
16.	Social Security Administration Search 1 Results	EXTERNAL	37,272
17.	Social Security Administration Search 2 Results	EXTERNAL	188,065
18.	Social Security Administration Search 3 Results	EXTERNAL	96,173
19.	Civil Service (OPM) Active Workers Search 1 Results	EXTERNAL	26,159
20.	Civil Service (OPM) Active Workers Search 2 Results	EXTERNAL	49,363
21.	Civil Service (OPM) Retired Workers Search 1 Results	EXTERNAL	13,620
22.	Civil Service (OPM) Retired Workers Search 2 Results	EXTERNAL	50,655
23.	National Death Index Search Results	EXTERNAL	27,310
24.	California State Death Clearance (CAMLIS) Results	EXTERNAL	6,479
25.	Virginia State Death Clearance Results	EXTERNAL	12,192
26.	Virginia Department of Motor Vehicles File	EXTERNAL	133,752
27.	Analysis file	INTERNAL	(70,730)

[1]For internally generated files, this count represents the number of transactions to the file: additions, changes, deletions. The number in parentheses represents the total individuals.

2 Methods
2.5 Vital Status

The vital status ascertainment included in the current analysis of the Shipyard Study population has relied almost exclusively on automated data systems which yield information about the current vital status of individual workers. Several federal and local resources have been utilized. Federal resources include the Social Security Administration (SSA), the Civil Service Active Record System (CSA), the Civil Service Beneficiary Record System (CSR), the Health Care Financing Administration (HCFA), the Veterans Administration (VA) and the National Death Index (NDI). Local resources include the shipyard personnel records, direct review of death certificates in New Hampshire and Maine, and the health history questionnaire. Initial submissions to these agencies established vital status through different points in calendar time. Additional searches were submitted to the SSA, CSA, CSR, and VA in order to complete follow-up through December 31, 1981.

Ascertainment of vital status of the shipyard workers in this study represents a unique situation. The Navy shipyards are covered by the Civil Service retirement system while the private yards are covered by the Social Security retirement system. These two retirement systems do not have coordinated record keeping nor are their records mutually exclusive; thus, it is imperative to search both systems for all deaths. In addition, the shipyards tend to have a rapid turnover of workers which makes record keeping difficult. The problem is compounded by the fact that many individuals have a trade such as carpentry which may be pursued outside of the usual structured working environment. Thus, individuals who are no longer actively employed in the shipyards may be working in the "underground economy" and not be paying into any retirement system. Therefore, there is a particular need to verify the vital status of individuals who were not identified by any of the automated systems through direct follow-up.

The results of searches through these various systems were combined to establish an individual worker's vital status. The vital status for the study sample is: 83 percent alive, 12 percent dead and 5 percent status unknown.

Selection of the particular records to be submitted to an agency for vital status ascertainment depended on several considerations:

- The constraints on search population size imposed by the agency;
- The timing of the search with respect to the study sample selection; and
- The timing of the search with respect to the extent of known vital status in the candidate records.

Shipyard Study staff recognized that the large number of deaths expected in the Shipyard Study population necessitated early initiation of vital status ascertainment and retrieval of death certificates. Vital status ascertainment had to begin before the study sample had been selected and even before the census population was fully established. As time went on, the study sample became more completely identified, and the proportion of workers being searched who were not in the sample became smaller. The numbers in the individual searches described below reflect the changes in the search population over time. Shipyard Study staff also realized that simultaneous searching by several sources was necessary since a resource could take as long as eight months to complete its search. Processing of the results at the Shipyard Study office could take an additional two months because of the large population in each search.

Social Security Administration (SSA)

A contract was executed between the Johns Hopkins University and the Office of Enumeration and Earnings Records (OEER) of the Social Security Administration (SSA). SSA reports each individual as deceased, assumed alive, or status unknown. A worker was classified as deceased by SSA if death benefits were being paid on the worker's account, if a funeral director's notice of the death had been received, or if a death notice had been received from the state of last residence. A worker was classified as assumed alive if earnings had been posted in at least one quarter on the worker's account in the Summary Earnings Record (SER). Individuals could be classified as status unknown for two reasons: if status could not be checked because the specified social security number was invalid or incompatible with the name on the OEER record, or if there was no OEER death report and Social Security taxes had not been paid during at least one quarter of the year.

Matching submitted records to the OEER records proceeded in two steps. Submitted records were first matched against the records of individuals currently paying into the system. Non-matches were then searched for current payment of benefits or for a record of death. Matching was done on both social security number and last name.

In November of 1980, a tape of 66,978 workers from the Norfolk and Charleston shipyards was submitted to SSA for matching against the SSA earnings records through 1978. Results were received in March, 1981 for 66,856 workers as the input tape contained 122 duplicate records on workers. Death indications were recorded for 6,242 individuals (9.3%). Among the remaining individuals, 29,584 (44.3%) had paid on earnings or received benefits in 1978. Thus, there was a group of size 31,030 (46.4%) for whom no vital status information was available from SSA.

In September of 1981, a second tape was submitted to SSA. This tape contained a total of 447,158 workers with social security numbers and last names from the remaining yards and all individuals in the first search who had not been identified as deceased. This tape was matched against SSA earnings records through 1979. Results were received in April, 1982 for 447,100 workers as SSA identified 58 duplicate records on workers on the input tape. Death indications were found for 60,229 workers (13.5%), 259,035 (57.9%) were found to have paid on earnings or received benefits, and 127,836 (28.6%) were classified as status unknown or unmatched.

In September of 1985, a third tape was submitted to SSA. This tape contained records for 173,672 workers divided among 2 groups:

- Shipyard workers in the sample with social security numbers, last names, and unknown vital status; and
- Radiation workers without a personnel employment record and with known social security number and last name.

Results were received in March, 1986 for 173,672 workers. Death indications were recorded for 14,497 individuals (8.3%). Among the remaining workers, 129,238 (74.4%) had paid on earnings or received benefits in 1982. Thus, vital status information was unavailable for 29,937 workers (17.2%).

In December, 1986, the names of 849 hard to trace workers in the study sample were submitted to the SSA Program Service Centers for vital status ascertainment. The workers had known social security number and last name, had been identified as deceased by some source, and had insufficient information to obtain death certificates. As a result of this search, 287 workers (33.8%) were identified as alive and 105 workers (12.4%) were identified as deceased.

As a result of the initial matches to the SSA files and conversations with other utilizers, a problem was identified with Social Security death search for the years 1977-1979. In November of 1977, the posting of deaths to the SER file had been discontinued. The posting of deaths to the SER was reinstated in November, 1982, but at least two years (1978 and 1979) were permanently lost. Lump sum payments for deaths of non-beneficiaries (that is, actively employed workers) were posted to this file prior to November, 1977 making it a very complete source of death ascertainment. It is likely that deaths from 1977 on for non-retired, non-disabled shipyard workers in the Social Security beneficiary system are under reported. This discovery is another reason for supplementing the SSA search with other methods of verification of vital status.

Civil Service Active Record System (CSA)

Contact with the Office of Personnel Management (OPM) Active Records Division was initiated in the Spring of 1980. The Active Records Division has a large computer file of all individuals currently employed by the federal government, as well as those who have terminated employment within the past 18 months. This division is also responsible for the hard copy files of all individuals who have ever worked in the Civil Service system. This system requires manual searching of records without social security numbers and allows computerized searching of records with social security numbers. Death information is not available from this source, but confirmed living status as indicated by current employment status is available.

In November of 1980, a tape was sent to OPM Active Records Division containing the same group of 66,978 Norfolk and Charleston workers as was sent to SSA. The results of this match were received in February, 1981. Of the 66,978 records from the Norfolk and Charleston yards, 26,159 (39.1%) matched to OPM records, indicating that these workers were actively working Civil Service employees. In December, 1981, a second tape was sent to OPM Active Records Division containing the same group of 447,158 shipyard workers submitted to SSA in September, 1981. A total of 49,363 workers (11.0%) were considered alive since they were actively working as Civil Service employees. The state of residence for each active worker was provided.

In December, 1986, a tape was sent to OPM Active Records Division containing the names of 3,553 workers. 2,953 of these workers had unknown vital status; the names of 300 workers known to be alive and 300 workers known to be dead were also submitted as a test of the system. CSA was able to identify 1,618 workers (44.6% of those with unknown vital status) as alive as of September, 1986. All 300 workers known to be alive were confirmed as alive by CSA and none of the known deaths matched to the CSA files.

Civil Service Beneficiary Record System (CSR)

The third major system to be searched was the OPM Civil Service Beneficiary Record System (CSR). This system identifies all individuals who have retired from federal service and who are claiming retirement benefits.

Beneficiaries of deceased civil servants are also in this system, but are identified separately as survivors. Thus, this system allows identification of individuals who are deceased as well as alive. Search of this system requires two matches: a match against the CSR current files (files containing information on annuitants who are currently in pay status or who were in pay status at some time in the last three years) and a match against a special file of annuitants who died between May, 1973 and May, 1976. The search is based on social security number. The tape of the 66,978 Norfolk/Charleston workers was sent to CSR in December, 1980, and results were received in May, 1981. This match identified 13,620 shipyard workers as civil service annuitants; 10,682 (78.4%) of these annuitants were alive, 2,930 (21.5%) were deceased, and 8 had unknown vital status. Neither geographic location nor date of death was provided for these matches. The same tape of 447,158 workers submitted to SSA and CSA was also submitted to CSR in September, 1981 and resulted in 50,655 matches; 40,844 (80.6%) of these annuitants were alive, 9,755 (19.3%) were deceased, and 56 had unknown vital status. State of residence was provided for each worker identified as deceased in this match, but date of death was not given.

The same tape of 2,953 workers with vital status unknown and 600 test workers which was submitted to CSA in December, 1986 was submitted to CSR for vital status ascertainment. CSR identified 40 of the previously known alive workers as alive and 83 known deads as deceased; 201 of the status unknowns were found to be alive and 29 of the status unknowns were found to have died. Three of the workers known to be alive were identified as deceased by CSR; however, the date of death post dated the last known date alive. Thus, the combined Civil Service searches identified 1,318 active employees and 201 living annuitants among the 2,953 workers (51.4%) whose vital status was unknown following SSA searches. An additional 29 were identified as deceased so that a total of 1,548 workers (52.4%) who had unknown vital status after other searches were now verified.

Veterans Administration (VA)

The Veterans Administration (VA) files (BIRL System) can be used to identify the vital status of only those veterans who have applied for VA benefits or whose next-of-kin have received death benefits. This system can identify individuals either by name and social security number or by name and birthdate. The number of records which may be searched at one time through this system is small because of the VA's formatting requirements. Copies of death certificates for all deceased individuals in the BIRLS file are retained by the VA and may be requested if a certificate cannot be obtained directly from the state vital records office. The VA provides date of death and the location of the regional office responsible for processing the veteran's claim. Three files of shipyard workers were submitted to the VA between April, 1981 and October, 1982, resulting in identification of 3,892 workers as deceased and 39,783 workers as alive.

The VA's search in December, 1986, of the 2,953 status unknown workers and 600 test workers also submitted to CSA and CSR resulted in identification of 673 status unknowns (22.8%) as alive and 92 status unknowns (31.0%) as deceased. One hundred workers previously known to be alive were confirmed as alive; 107 previously known deaths were confirmed and 4 previously known alives were identified as deceased, with a date of death subsequent to the last date known alive.

Health Care Financing Administration (HCFA)

The Health Care Financing Administration (HCFA) maintains extensive records on individuals who have been part of the Social Security Medicare System and is able to provide information on vital status and current address, as well as to assist in the identification of social security numbers for those study subjects whose numbers are unknown, but who have known dates of birth.

Two tapes were submitted to HCFA in February, 1981. The first tape contained 94,478 records of workers aged 65 or older who had social security numbers. This file resulted in identification of 3,759 deceased workers and 47,495 living workers. The second tape consisted of 108,844 records of workers aged 65 or older without social security numbers, but with known dates of birth. This file was first matched against HCFA files for ascertainment of social security number and then matched against HCFA files for address and vital status data. This second match identified 1,753 workers as deceased and 18,603 workers as alive. Date of death and last known address were provided for the workers identified as deceased, and present address was provided for the workers identified as alive.

Microfilm Personnel Records

The personnel records microfilmed by the Shipyard Study staff at the start of the study also contained death information. A file of 18,466 deaths derived from these records was constructed in the course of baseline coding.

2 Methods
2.5 Vital Status (cont'd)

Date and place of death were generally available.

National Death Index (NDI)

The National Death Index (NDI) was utilized in 1982 as a source of vital status ascertainment. This source matches a user's data against a file of all deaths in the United States. At the time of the search for the Shipyard Study, death data for the years 1979, 1980, and 1981 were on file at NDI.

Matches are based on first and last name and month and year of birth, or first and last name and social security number. Name matches can be exact or Soundex matches. (Soundex is a letter and number probability translation of a name.) Date of death, state of death, and certificate number are provided by NDI. One difference between NDI and other sources of vital status ascertainment is that NDI may provide multiple matches for a particular user record. The user must review all matches and decide which, if any, is correct.

Three files were submitted to the NDI in May, 1983. The first file contained the records for 182,078 workers who were male shipyard workers with at least one full year of employment after 1955, and who had not been identified as deceased by SSA or were known to have worked in 1982. The other two files were "test" files for determining the sensitivity and specificity of the NDI search. One test file contained the records for 8,947 workers identified as deceased by SSA in 1979, 1980 or 1981. The other test file contained 7,456 records of workers known to have been alive at some time in 1982. A total of 27,310 matches to NDI records resulted. On the basis of the assessment of the false-positive matches as indicated by the matches to the "known alive" test file, a decision was made to retain data from the following three types of matches:

- Exact matches of all submitted data (last name, first name, middle initial, race, sex, month and year of birth, social security number);
- Exact social security number matches regardless of mismatch of other data; and
- Exact (not Soundex) first name, last name, month and year of birth matches and no mismatch on social security number.

Of the 27,310 NDI matches, data from 13,119 matches were retained; these matches involved 12,693 unique Shipyard Study workers (7.0%). Of these matches, 10,936 were to a single NDI record.

Oak Ridge Associated Universities Vital Records Office (ORAU)

An exchange of vital status information for workers in both the Oak Ridge Associated Universities (ORAU) 5 Rem Study and the Shipyard Study resulted in the identification of 65 deaths common to both studies and receipt of the death certificates from the ORAU death certificate retrieval office.

National Institute of Occupational Safety and Health (NIOSH)

A printout of the deaths identified in the Portsmouth Naval Shipyard Study conducted by the National Institute of Occupational Safety and Health (NIOSH) was received and keypunched to tape. This source resulted in identification of 4,933 deaths among workers from the Portsmouth Shipyard that were common to the Shipyard Study.

2 Methods
2.5 Vital Status (cont'd)

Pilot Study for Identification of Portsmouth Naval Shipyard Deaths

As part of the pilot study (see Appendix 4) to determine whether information collected by Najarian and Colton (Najarian, 1978) could be duplicated, death certificates on file in the states of New Hampshire and Maine were reviewed by Shipyard Study staff and selected on the basis of the shipyard related occupations or industries listed on the death certificates. This cross-sectional review resulted in the identification of 2,036 deaths of which 1,514 were for workers in the Shipyard Study.

Health History Questionnaire

Between January, 1981 and June, 1982, Shipyard Study staff sent out three mailings of the Health History Questionnaire to 14,395 current (1980) workers in the Norfolk shipyard. Telephone follow-up of nonrespondents was carried out between June, 1982 and September, 1982. This survey resulted in identification of 8,816 census population members as alive in 1982 and 63 census population members as deceased. A second survey was initiated in current (1985) workers at the Charleston Naval Shipyard, and this survey identified one death in the census population.

Shipyard Address Tapes

An important source of confirmation of living status are the tapes of addresses used for W2 mailings to current workers by the shipyards. These tapes have been received on a yearly basis since 1979 from all six Navy shipyards. Any worker present on the address tape for a given year is assumed to have been alive at some point during that year. Processing to date of 25 address tapes received for the years 1979-1983 has resulted in identification of 55,408 workers in the study population as alive in the period from 1979 through 1983.

State of Virginia Death Tapes

Because over 47 percent of the study population was derived from two shipyards in Virginia, special arrangements were sought with the State of Virginia Health Department Vital Records Unit for vital status ascertainment and certificate retrieval. An agreement was set up to permit searches of their computer files of historical death data.

Implementation of the Virginia searches required a great deal of effort. Twelve trips were made to the Virginia Health Department Vital Records Unit. Preparation for the searches involved identification of the computer files containing historical death data, examination of the record layouts and coding instructions for these files, selection of useable matching factors, and identification of the years for which the matching factors were available. Software to standardize and compress the Virginia death records to allow efficient processing and sorting had to be developed. Names had to be Soundexed and each year had to be sorted on Soundex code and first initial. Tabulations of each matching variable had to be produced and reviewed so that binit (Newcombe, et al., 1959) weights could be calculated and so that the standardization program could be checked. A sample had to be matched by hand or by a unique identifier such as social security number so that disagreement rates in true matches could be assessed. Scores and software for each year could then be developed. Next, a representative year had to be matched to get the distribution of matching scores and to establish cut points for the "true" matches, non-matches, and equivocal matches. At this point, each year could be matched against the shipyard records, retaining "true" matches and equivocal matches. Revision of cut points for true matches was necessary in some cases. Accepted matches could then be sorted on certificate number and screened for duplicates. Lists of certificate numbers sorted by calendar year and certificate number were produced and submitted to the Virginia Health Department staff for retrieval and copying of certificates.

Programs and procedures for matching shipyard files against Virginia deaths for the years 1955-1981 have been completed. All years of Virginia deaths have been matched and retrieved.

Results of Vital Status Ascertainment

Tables 2.5.A and 2.5.B indicate the results of vital status ascertainment in the study sample groups and in the group of radiation workers without a personnel employment record, respectively. Overall vital status ascertainment for the three study groups combined is 12 percent deceased (death confirmed by receipt of death certificate), 83 percent confirmed alive, 1 percent possibly deceased (at least one source indicates deceased but no death certificate has been received) and 5 percent status unknown. The percent deceased is highest in the NNW group compared to the other two categories. Only four to six percent of the populations had unknown vital status which represents a small difference between the three groups.

Vital status ascertainment in the total group of radiation workers without a personnel employment record is 9 percent deceased (death confirmed by receipt of a death certificate), 53 percent confirmed alive, 1 percent possibly deceased (at least one source indicates deceased but no death certificate has been received) and 37 percent status unknown. The percentages for each category of vital status are essentially the same for workers with ≥0.5 rem exposure as for workers with <0.5 rem exposure. Among this group of workers without personnel records, where information has been obtained on vital status, 724 workers are deceased and 4,413 are living. This represents 14.1 percent of the population who are deceased compared to 10.7 percent in the population with records. This probably represents a slightly older age and earlier time of employment for those workers with missing records.

Certification of Deaths

Vital status searches for more than 500,000 individuals in the Shipyard Study population have resulted in the identification of 92,050 deaths from one or more sources. The next step is to certify the fact of death by comparison of a copy of an individual's death certificate with study records on the individual. Once a death certificate is confirmed as matching to a worker, selected information on the certificate, including causes of death, was coded and added to the database. Section 2.6 discusses details in coding causes of death and in validating the listed causes using other sources such as hospital records and tumor registries.

Because of the size of the study population, the staggered return of results from the different vital status searches, and the delay in establishing the study population and sample from the total database, it was not feasible to wait for the study population to be finalized before initiating death certificate acquisition just as it was not practical to wait for completion of sample selection prior to vital status searching. Furthermore, the delays inherent in state search and retrieval processes indicated that early initiation of death certificate requests would result in more complete and efficient certificate acquisition. As the study population has evolved, the intent and action has been to focus retrieval efforts on workers known to be in or likely to be in the final study population.

Therefore, early in 1982, with the return of the results of the first SSA search, death certificate retrieval was initiated. Certificates were sought for all 6,242 workers identified as deceased in this search. With receipt of the results of the second SSA search, the second wave of requests was initiated. At this time, certificate requests were limited to a group defined as male shipyard workers with at least one year of shipyard employment after January 1, 1955. This date was chosen because it is inclusive of the earliest start date of nuclear overhaul and thus no members of the final study population should be excluded. Certificates were sought for the 21,268 members of this group. With the processing of the results of the second SSA search, the deaths in the study population covered all 50 states, many foreign countries, and various U.S. possessions. Years of death covered a thirty year period.

The Epidemiology Department of the Johns Hopkins University maintains a vital records unit which coordinates the procurement of certificates from the various state vital records offices. All Shipyard Study certificate requests were processed by this office. To facilitate their work, a computer-printed card system was developed specifically for this project. Three cards were printed for each death record. One was sent to the state to request the certificate, one was kept at the university's vital records unit, and one was kept at the Shipyard Study office. All details of the request, including the date of request, the state contacted, and the results of the request, were recorded on these cards.

Requests were sent in batches as large as the state would allow. For the states with large numbers of certificates for retrieval, it proved advantageous to make special arrangements to facilitate death certificate returns.

Much of the retrieval time was spent in identifying the certificate number of the desired death certificate. Once the number was known, retrieval was a matter of copying the certificate and forwarding the copy to the Shipyard Study office. Consequently, methods of automating identification of certificate numbers became a high priority for states with large numbers of deaths. For the states of Virginia and California, special arrangements were made to match the deaths identified in those states against computer files to obtain certificate numbers.

Since both the Norfolk and Newport News shipyards are in the state of Virginia and account for 47 percent of the Shipyard Study population, the Health Department in Virginia was approached to determine methods by which certificate numbers could be identified and additional deaths might be identified. As described earlier in this section, after extensive discussions with personnel in the Health Department, agreements were reached giving the Shipyard Study permission to reformat the state's death files so that the shipyard files could be matched against them in order to identify the certificate numbers of workers known to be deceased.

The California Automated Mortality Linkage Information System (CAMLIS) permits matching of a user population to the California mortality files for the purpose of identification of death certificate numbers. Arrangements were made to match the Shipyard Study California deaths to the CAMLIS files and to hire two persons to work in the California vital records office exclusively on retrieval of death certificates for the Shipyard Study deaths.

The state of New Hampshire does not have an automated system for identifying certificate numbers. Extensive negotiations resulted in the hiring of an individual to work in their vital records office exclusively on retrieval of Shipyard Study certificates. A two step process was implemented, with manual identification of the certificate numbers first from yearly indices of deaths and then retrieval of the certificates. Similar procedures were instituted in the State of Connecticut.

Limited use was made of the Oak Ridge Associated Universities (ORAU) Death Certificate Retrieval Office. In January, 1984, ORAU agreed to carry out a pilot death certificate search for a group of 199 records for which an initial response of "no record found" had been received from the presumed state of death, as identified by Social Security. Their searches retrieved 88 percent of the certificates requested.

A total of 36,568 death certificates were retrieved for the Shipyard Study. Not all of the certificates are for members of the study population or sample since certificate retrieval was initiated in 1981 and definition of the study population and sample selection were not completed until June, 1987. As described earlier, the intent and action in death certificate retrieval efforts were to focus on workers known to be in or likely to be in the final study population. This group of workers included males with at least one year of shipyard employment during the period of nuclear overhaul. As indicated by Table 2.5.C, for the three sample groups, certificate retrieval and coding are complete for 94 percent of the total deaths included in the present analysis tape.

Table 2.5.D indicates the status of certificate retrieval for the radiation workers without a personnel employment record. Certificates have been received for 87 percent of all deaths in this group. Since retrieval of certificates for those without records is a more recent effort, this percentage would probably increase with further efforts.

The clerks responsible for the procurement of the death certificates and the coders who processed the received certificates had no knowledge of the radiation status of the deceased workers. Certificates were usually requested in batch format on a state-specific basis and were returned in state-specific batches.

Once a certificate was received, the staff compared the certificate data to identifying data for the worker in order to make a preliminary assessment of whether the received certificate actually related to the Shipyard Study worker for whom it was obtained. If a match was determined to be "good", the worker's study identification number was recorded on the certificate, International Classification of Disease, Ninth Revision (ICD-9) codes were assigned to the underlying and contributory causes of death. These and other items on the certificate were abstracted. These abstracted data included demographics, decedent's occupation and industry, veteran's status, the relationship of the informant to the deceased, an indication whether an autopsy was performed, the underlying cause of death, and up to three contributory causes of death selected in the order in which they were listed on the certificate. The abstracted data were then added to the death certificate ARCHIVE file. Updates to the data management file for death certificate requests were also made.

A more complete, objective assessment of match quality was conducted after the certificate data were computerized. Worksheets were produced comparing the abstracted data to the microfilm census data, and an automated evaluation of the match quality of each of the following items was done: surname, Soundexed surname, first name and first initial, middle name and initial, first and middle name cross (reversal), birthdate, birthday (month and day), age at death, death date, social security number, race, and sex. Match scores were assigned to each of these items. The scores were summed to give an overall match pattern which correlates with the quality of the match. Discrepancies between the subjective and objective assessments of match quality were flagged and reviewed for final resolution of the status of the death certificate match.

Data Management for Vital Status

Two data systems were set up to manage the vital status ascertainment procedures described in earlier sections. The Master Death Index (MDI) system was used to manage the death information received about a worker and the history of requests needed to obtain the worker's death certificate. The

Master Living Index (MLI) system was used to manage the information received about workers who had been confirmed to be alive by one or more sources. The MLI was modelled on the MDI and served as its complement in the assessment of vital status.

Master Death Index (MDI)

The Master Death Index (MDI) computer record was comprised of three subsections. The first subsection contained basic identification data: yard-reel-sequence number, census record number (on which the file was sorted), last name, first name, middle name, date of birth, social security number, race, and sex. All of these data were copied from the main census file, not from the source file or death certificate. These data were updated periodically, after corrections were made to the census file.

The second subsection of an MDI record contained the source information. The data recorded consisted of number of sources, source code, date of death, city of death, vital records office covering that city, certificate number (when provided by the source), and match quality. Space was allocated for recording data from up to nine sources. Data were recorded sequentially in fixed fields. It should be noted that no attempt was made to record only new information; i.e., if two different sources indicated the same place and date of death, both sources were recorded.

The third subsection was the worker's death certificate request history. Death certificate requests were initiated only for workers with MDI records, i.e., workers who had been identified as deceased by some source and processed to the MDI. The data recorded consisted of month and year the vital records office was contacted, month and year the request was returned, results of the request, and the number of the returned certificate. Data for up to five requests could be recorded. The results of a request were classified as good match, weak match, wrong match, or no record found. An initiated but unreturned request (i.e., a pending request), was marked with an asterisk.

Most of the vital status search resources returned their search results on magnetic tape. If the source did not provide a tape, arrangements were made to have the returned data keypunched to tape. Generally, the records for deceased workers and living workers were returned on the same tape. The census record number might or might not have been preserved. Thus, the first processing step consisted of eliminating the records for living workers, screening for duplicates, re-establishment of the census record number if necessary, and concatenation of the source data to the worker's census record. The second step consisted of reformatting the source data to conform to MDI standards. Geographic data were recoded using a set of standard geographic abbreviations, and the data related to dates were put in standard format. When standardization of the data was completed, the source data were ready for combination with the MDI.

When a source tape was combined with the current version of the MDI, three outcomes were possible. The source tape could provide more data on a previously known death; the new data were then recorded in the next available source field. The source tape could provide the first indication of a death; a new MDI record was then created. Finally, the source tape might provide no further data on a previously known death; the original MDI record was then transmitted to the updated version of the MDI unchanged. All of the resulting records (changed, new, and unchanged) were recorded on the new version of the MDI.

Initiating a death certificate request was generally an automated process and involved marking the MDI record to reflect the existence of the request. Except for the matches in Virginia, California, New Hampshire and Oak Ridge Associated Universities, initiation of death certificate requests included printing of request cards. Three cards were printed: one for Shipyard Study use, one for use by the Department of Epidemiology vital records unit, and one to be sent to the state vital records office with a cover letter. All information about a request recorded on the MDI was duplicated on the Shipyard Study card.

Manual initiation of a death certificate request was handled by completion of a special form, since a certificate request did not print data from a specific source, but data derived from examining all sources of information. The form was completed after a review of all information, and the data were keypunched into the ARCHIVE system. The ASSEMBLE file was combined with the current version of the MDI. The pertinent data were recorded in fields set aside for history of requests, and the certificate request cards were then printed.

Mass death certificate requests were accomplished with generation of books of worksheets containing the numbers of the certificates to be retrieved. Certificate numbers were available from the NDI, the Virginia match, and the CAMLIS match.

Edits to the MDI occurred due to incorrect formatting, incorrect standardization of source data, or from updates to death certificate requests such as the return of a request. When a request was returned, the date of return and the results of the request were entered into the MDI record. Form MDI.1 was used to correct source data, and Form MDI.2 was used to correct or update request fields. These forms were completed in the Shipyard Study office, keypunched to tape, and processed to their ARCHIVE file. A computer program was then run which combined the current ARCHIVE file with the current version of the MDI. After this program was run, the MDI records contained the updates implemented by the MDI.1 and MDI.2 forms. (See Section 2.4 for a description of the ARCHIVE-ASSEMBLE data management system.)

A program was written which permits examination of user specified MDI records in an efficient and useful way.

Master Living Index (MLI)

Each Shipyard Study worker who was identified as alive by at least one source was entered on the Master Living Index (MLI) and had exactly one record on the MLI. If information was received from more than one source, the information from the additional sources was appended to the existing record. The information recorded consisted of source of data, last year known to be alive according to the source, and residence and shipyard worked as of that time. Space was allocated for data from up to 14 sources. Data were recorded sequentially in fixed fields. A standard set of codes was used to record the geographic data. Unknown dates were left blank. It should be noted that no attempt was made to record only new information; i.e., even if two different sources indicated the same year and place, both sources were recorded.

Most of the sources returned their search results on magnetic tape. If the source did not provide a tape, Shipyard Study staff arranged to have the data keypunched to tape. Generally, the records for deceased workers and living workers were returned on the same tape. The census record number might or might not have been left intact. The first processing step thus consisted of eliminating the records of deceased workers, screening for duplicates, re-establishment of the census record number if necessary, and concatenation of the source data to the worker's census record. The second step consisted of reformatting the source data to conform with MLI standards. Geographic data were recoded using a set of standard geographic abbreviations, and the data regarding dates of events were put in standard format. When standardization of the data was completed, the source data were ready for combination with the MLI.

When a source tape was combined with the current version of the MLI, three outcomes were possible. The source tape could provide more data on a worker previously known to be alive; the new data were then recorded in the next available source field. The source tape could provide the first indication of living status; a new MLI record was then created. Finally, the source tape might provide no further data on a previously known living worker; the original MLI record was then transmitted to the updated version of the MLI unchanged. All of the resulting records (changed, new, and unchanged) were recorded on the new version of the MLI.

Table 2.5.A Vital Status Ascertainment in the Study Sample Groups ($NW_{\geq 0.5}$, $NW_{<0.5}$, NNW)

Vital status classification (10/13/87)	Study Sample Groups					
	$NW_{\geq 0.5}$		$NW_{<0.5}$		NNW	
	No.	Percent	No.	Percent	No.	Percent
Deceased[1]	2797	10%	1168	11%	4453	13%
Alive[2]	24356	85%	8619	82%	27061	81%
Possible deaths[3]	189	1%	71	1%	349	1%
Status unknown	1200	4%	604	6%	1489	4%
Total	28542	100%	10462	100%	33352	100%

1 Death certificate in file (N = 8414) or death confirmed but certificate unobtainable (N = 4).

2 Sources include SSA, SSA-PSC, Civil Service Active and Retired Workers files, HCFA, current worker tape rosters, direct follow-up.

3 At least one source (SSA, SSA-PSC, Civil Service Retired Workers file, HCFA, Veteran's Administration, National Death Index, personnel records, Health History Questionnaire, NIOSH, or State Vital Records) has indicated the worker is deceased; however, searches to date have not yielded a death certificate.

2 Methods
2.5 Vital Status (cont'd)

Table 2.5.B Vital Status Ascertainment for Radiation Workers Without a Personnel Employment Record

Vital status classification (10/13/87)	Cumulative Radiation Dose Equivalent (DE) (rem) ≥0.5		<0.5	
	No.	Percent	No.	Percent
Deceased[1]	219	9%	505	9%
Alive[2]	1374	53%	3039	53%
Possible deaths[3]	29	1%	76	1%
Status unknown[4]	947	37%	2090	37%
Total	2569	100%	5710	100%

[1] Death certificate on file; only source is SSA.

[2] Sources include SSA and direct follow-up.

[3] At least one source has indicated the worker is deceased; however, searches to date have not yielded a death certificate.

[4] Workers ≥0.5 rem have been sent to Civil Service Active and Retired Records files, and the Veterans Administration. Direct follow-up is limited due to lack of additional information on these workers such as full-name and addresses.

2 Methods
2.5 Vital Status (cont'd)

Table 2.5.C Status of Death Certificate Retrieval for the Study Sample Groups

Status of death certificate retrieval (10/13/87)	Study Sample					
	$NW_{\geq 0.5}$		$NW_{<0.5}$		NNW	
	No.	Percent	No.	Percent	No.	Percent
Retrieved	2796	94%	1167	94%	4451	93%
Pending requests	189	6%	71	6%	349	7%
Certificate unobtainable[1]	1	<1%	1	<1%	2	<1%
Total possible deaths	2986	100%	1239	100%	4802	100%

[1]Vietnam war death

2 Methods
2.5 Vital Status (cont'd)

Table 2.5.D Status of Death Certificate Retrieval for Radiation Workers Without a Personnel Employment Record

Status of death certificate retrieval (10/13/87)	Radiation Dose Equivalent (DE) (rem) ≥0.5		<0.5	
	No.	Percent	No.	Percent
Retrieved	219	88%	505	87%
Pending requests	29	12%	76	13%
Total possible deaths	248	100%	581	100%

2 Methods

2.6 Causes of Death

For workers identified as deceased as a result of the vital status ascertainment procedures described in Section 2.5, the causes of death listed on the death certificate were reviewed and coded using methods described below. Also described are the checks conducted on the validity of the cause of death information provided on the certificates and the methods used to determine subclassifications of certain tumors; leukemia, lymphoma, mesothelioma, and lung cancer were emphasized in the validation.

Cause of Death Coding

Causes of death were coded according to the 9th revision of the International Classification of Disease (ICD). The National Center for Health Statistics (NCHS) provided a special training course on 9th revision ICD coding to members of the Shipyard Staff so that death coding for this project would be consistent with NCHS coding. All coding was checked by two senior coders. Any problems were referred to the senior staff nosologist.

To assure the validity of the coding, two quality control samples were selected for complete recode by the experienced staff nosologist who is standardized for death coding with State and Federal nosologists. The first sample selected for recoding was a 100 percent sample of all certificates with malignant neoplasms of the lymphatic and haematopoietic tissue (ICD-9 200-208). The second sample was a 20 percent random sample of all other certificates. The recoded certificates were compared with the original coding of the Shipyard Staff, and the level of agreement was assessed. Disagreements in codes were resolved by a review panel consisting of the principal investigator and a co-investigator, who are both physicians, the project coordinator, the senior nosologist, and one of the two senior death certificate coders for the study.

Verification of Death Certificate Reports of Neoplasms

Objectives

The objectives of this component of the project were:

- To verify the diagnosis of neoplasm on a sample of death certificate reports listing specific neoplasms as primary or secondary causes of death, with year of death between 1960-1981, and received by the project through 1986. The set of death certificate reports selected for verification consisted of: (1) all reports of leukemia (ICD codes 204.0-208.9, 9th revision), lymphoma (ICD codes 200.0-203.8, 9th revision), and mesothelioma (ICD codes 158.0-158.9 and 163.0-163.9, 9th revision) from the study samples, and (2) a 10 percent sample of reports of lung cancer (ICD codes 162.0-162.9, 9th revision) from the sampling frame; and
- To characterize the neoplasms morphologically.

Sources of data

We attempted to verify diagnoses of neoplasms reported on the death certificates with relevant medical information. Medical information was sought from two general sources: hospital medical records and state tumor registry records.

Each death certificate report, regardless of whether the death was part of the sample, was reviewed to determine place of death. Reports identifying a hospital as th place of death were selected for medical record data retrieval. Tumor registries and medical records departments of hospitals listed on the death certificates were asked to complete medical record abstract forms verifying the diagnosis of the neoplasm and date of diagnosis, and indicating method(s) of diagnosis, and cell type information. A copy of the abstract form is in Appendix 10. A second follow-up mailing of abstract forms was sent to the respective hospitals when completed forms were not returned within two months of the first mailing date. A third mailing was sent if the second mailing failed to yield any results. Abstract forms and accompanying materials returned from the hospitals were reviewed for completion and consistency. Whenever a returned abstract was found to have incomplete or inconsistent information, a follow-up telephone call was made to the hospital tumor registrar or medical records librarian to obtain the correct information. Data asbtracted from medical records were coded and entered onto magnetic media for storage and analysis.

Death certificate reports indicating California, Connecticut, Hawaii, Washington or Virginia as state of death were selected for matching with Surveillance, Epidemiology and End Results (SEER) or state tumor registries. For each of these states a file of death certificate reports was prepared, written onto magnetic tape, and the tape was submitted to the appropriate tumor registry for matching. If a death certificate report matched a tumor registry record, information on date of diagnosis of neoplasms and morphology was retrieved from the registry. For matching records diagnostic and morphology data derived from turmor registry files were used to supplement information obtained from hospital medical records.

Verification and Morphology of Cancers

By the end of 1986 the number of death certificate reports of neoplasms with a year of death between 1960-1981 received by the project included: 65 reports of leukemia, 103 reports of lymphoma, and 32 reports of mesothelioma in the study samples. Five hundred and seventy-five reports of lung cancer were selected at random from the sampling frame and included in the set of reports for verification and morphological characterization. Of the 775 death certificate reports of neoplasms in the set for verification, about 88 percent identified a hospital as the place of death; the remainder identified the usual place of residence (home or nursing home) as the place of death (Table 2.6.A1). A total of 420 hospitals of death were identified. These hospitals were distributed over 41 states; however, most of them (83%) were located in states with study shipyards.

The distribution of death certificate reports by type of neoplasm and availability of medical record is shown on Table 2.6.A. Medical record information was obtained on 60 percent (460/775) of the death certificate reports selected for verification. The yield was better for lymphomas and leukemias (66-71%) than for lung cancer and mesothelioma (57-59%). Reasons for incomplete retrieval of medical record information included no identifiable hospital of death (92), and, among records with an identifiable hospital of death (223), hospital unwilling to collaborate with the study, medical record unavailable, lack of hospital resources to abstract the requested information, or diagnostic information unavailable.

To ascertain whether the death certificate reports with available medical records differed from those without such records, death certificates reports with and without medical records were compared on gender, race, age at death, state of death (shipyard vs. non-shipyard), and neoplasm type. Death certificate reports with and without medical record information were similar on these characteristics (Table 2.6.B).

For death certificates reports with available medical record information the level of agreement between the death certificate diagnosis and the medical record diagnosis is shown on Table 2.6.C. Death certificate reports of leukemia, lymphoma and lung cancer with available medical record information could be verified as having an accurate diagnosis 93-95 percent of the time; for death certificate reports of mesothelioma the corresponding figure was 75 percent. False positive reports were primarily due to lymphomas in the case of leukemia reports, leukemia and lung cancer in the case of lymphoma reports, mesothelioma and other tumors in the case of lung cancer reports, and lung cancer in the case of mesothelioma reports. Data in Table 2.6.C include eight reports containing more than one primary neoplasm.

Abstracted medical record information was also used to characterize the morphology of the validated neoplasms. Among the leukemias (Table 2.6.D), about half were acute (poorly or non-differentiated) and half were chronic. Of the leukemias with morphology data (33), 61 percent were myelogenous (acute and chronic), 24 percent were chronic lymphocytic, 15 percent were acute lymphocytic, and 3 percent were undifferentiated.

Among the 69 reports of lymphoma with medical record information, 83.6 percent were non-Hodgkins and 16.4 percent were Hodgkins (Table 2.6.E). Within the non-Hodgkins group the most frequent types included multiple myeloma (34%), reticulum cell sarcoma (20%), and malignant lymphoma (18%).

2 Methods

2.6 Causes of Death (cont'd)

Since histopathology information for the mesothelioma reports was limited, characterization of mesothelioma was based on site alone (Table 2.6.E1). The pleural to peritoneal mesothelioma ratio was 9:10, smaller than the 2-9:1 ratio reported in other studies.

Within the 320 lung cancer reports with medical record data (Table 2.6.F), the most frequent types included squamous (33%), undifferentiated (19%), adenocarcinoma (17%), and small cell (14%). Of these, squamous and adenocarcinoma neoplasms seemed to involve the right lung more frequently than the left (right:left = 1.5-2.5:1).

The review of medical diagnoses in shipyard workers indicated that except for mesothelioma, the death certificate diagnoses for this group of cancers represents the true cause of death as confirmed by hospital records. Thus, death certificate information should be reliable.

2 Methods
2.6 Causes of Death (cont'd)

Table 2.6.A Death Certificate Reports of Neoplasia by Medical Record availability and Type of Neoplasm

Medical Record Available	Tumor Type: Leukemia N %	Lymphoma N %	Mesothelioma N %	Lung N %	Total N %
Yes	46 (70.8)	68 (66.0)	19 (59.4)	327 (56.9)	460 (59.4)
No	19 (29.2)	35 (34.0)	13 (40.6)	248 (43.1)	315 (40.6)
Total	65 (100.0)	103 (100.0)	32 (100.0)	575 (100.0)	775 (100.0)

2 Methods
2.6 Causes of Death (cont'd)

Table 2.6.A1 Death Certificate Reports of Neoplasia by Type of Neoplasm and Place of Death

Place of Death	Leukemia N %	Lymphoma N %	Mesothelioma N %	Lung N %	Total N %
	Tumor Type				
Hospital	62 (95.4)	95 (92.2)	31 (96.9)	492 (85.6)	680 (87.7)
Nursing home	1 (1.5)	0 (0.0)	0 (0.0)	16 (2.8)	17 (2.2)
Other[1]	2 (3.1)	8 (7.8)	1 (3.1)	67 (11.2)	78 (10.1)
Total	65 (100.0)	103 (100.0)	32 (100.0)	575 (100.0)	775 (100.0)

[1] Other includes reports of individuals who died at home

2 Methods

2.6 Causes of Death (cont'd)

Table 2.6.B Death Certificate Reports of Neoplasia by Medical Record availability, Demographic Characteristics and Type of Neoplasm

Demographic characteristic and type of neoplasm	Availability of Medical Record Yes N %	No N %	Total N %
Sex			
Male	460 (100.0)	315 (100.0)	775 (100.0)
Race			
White	393 (85.4)	257 (81.6)	650 (83.9)
Black	46 (10.0)	37 (11.7)	83 (10.7)
Other	21 (4.6)	21 (6.7)	42 (5.4)
Age at Death			
20 - 29	4 (0.9)	2 (0.6)	6 (0.9)
30 - 39	15 (3.3)	9 (2.9)	24 (3.1)
40 - 49	56 (12.2)	30 (9.5)	86 (11.1)
50 - 59	157 (34.1)	115 (36.5)	272 (35.1)
60 - 69	169 (36.7)	109 (34.6)	278 (35.9)
70 - 79	54 (11.7)	50 (15.9)	104 (13.4)
80 - 89	5 (1.1)	0 (0.0)	5 (0.6)
Place of Death			
Shipyard state	367 (79.8)	266 (84.4)	633 (81.7)
Non-Shipyard state	93 (20.2)	49 (15.6)	142 (18.3)
Type of Neoplasm			
Leukemia	46 (10.0)	19 (6.0)	65 (8.4)
Lymphoma	68 (14.8)	35 (11.1)	103 (13.3)
Mesothelioma	19 (4.1)	13 (4.1)	32 (4.1)
Lung Cancer	327 (71.1)	248 (78.7)	575 (74.2)
Total	460 (100.0)	315 (100.0)	775 (100.0)

2 Methods
2.6 Causes of Death (cont'd)

Table 2.6.C Agreement Between Death Certificate and Medical Record Diagnoses

Medical Record Diagnosis	Death Certificate Diagnosis[1] Leukemia N %	Lymphoma N %	Mesothelioma N %	Lung Cancer N %	Total[2] N %
Leukemia	44 (93.6)	2 (2.9)	0 (0.0)	2 (0.6)	48 (10.3)
Lymphoma	3 (6.4)	65 (92.9)	0 (0.0)	1 (0.3)	69 (14.7)
Mesothelioma	0 (0.0)	0 (0.0)	15 (75.0)	6 (1.8)	21 (4.5)
Lung Cancer	0 (0.0)	2 (2.9)	4 (20.0)	314 (94.9)	320 (68.4)
Other	0 (0.0)	1 (1.4)	1 (5.0)	8 (2.4)	10 (2.1)
Total	47 (100.0)	70 (100.0)	20 (100.0)	331 (100.0)	468 (100.0)

1 As underlying or contributing cause of death
2 Total includes eight reports with more than one primary neoplasm

Table 2.6.D Leukemia Reports by Type and Morphology

	Leukemia Type		
Morphology	Acute/PD[1] N %	Chronic N %	Total N %
Myelogenous	15 (55.6)	5 (23.8)	20 (41.7)
Lymphocytic	5 (18.5)	8 (38.1)	13 (27.1)
Undifferentiated	0 (0.0)	1 (4.8)	1 (2.1)
No data	7 (25.9)	7 (33.3)	14 (29.2)
Total	27 (100.0)	21 (100.0)	48 (100.0)

[1] PD = Poorly differentiated

Table 2.6.E Lymphoma Reports by Type and Histopathology

Histopathology	Lymphoma type Hodgkins	Non Hodgkins	No data	Total
Lymphocytic predominance (paragranuloma)	1	0	0	1
Malignant lymphoma (lymphosarcoma)	0	10	0	10
Poorly differentiated lymphocytic lymphoma	0	5	0	5
"Mixed" lymphoma (lymphocytic-histiocytic)	0	4	0	4
"Histiocytic" lymphoma (reticulum cell sarcoma)	0	11	0	11
Undifferentiated lymphoma	0	2	0	2
Multiple myeloma	0	19	0	19
Other	5	5	0	10
No data	5	0	2	7
Total	11	56	2	69

2 Methods
2.6 Causes of Death (cont'd)

Table 2.6.E1 Mesothelioma Reports by Site

Site	Number	%
Pleural	9	42.9
Peritoneal	10	47.6
Other[1]	2	9.5
Total	21	100.0

[1]Other includes testicular and unspecified

2 Methods
2.6 Causes of Death (cont'd)

Table 2.6.F Lung Cancer Reports by Side and Morphology

Morphology	Side: Right	Side: Left	Side: Both	No Data	Total
Squamous	58	38	3	7	106
Adenocarcinoma	38	15	3	0	56
Mixed	2	3	1	0	6
Small Cell	23	18	0	4	45
Large Cell	6	16	2	1	25
Undifferentiated	27	23	1	10	61
No Data	9	8	0	4	21
Total	163	121	10	26	320

2 Methods

2.7 Radiation Exposures

The following section reviews the methods of establishing radiation dose equivalents (DEs) for nuclear shipyard workers. The purpose of the review is to assess the adequacy of individual recorded dose equivalents (DEs) for this study. The initial assessment of the population risk will be based on recorded DE levels as documented by the Navy and the cooperating private yards. After the initial evaluation of potential risks based on recorded data, any further examination of potential biases or errors related to these recorded DEs could be the subject of future specific reviews of limited numbers of cases and controls.

Sources of Radiation Exposure

The study focused on the group of civilian workers in the shipyards who were involved in the overhaul of nuclear powered vessels. This group of shipyard workers had a common, incidental, external exposure to radiation primarily from the neutron-activated corrosion products in the primary coolant system of the nuclear reactor. In the majority of instances, these exposures occurred from work done in the reactor compartment after reactor shutdown and in shops where radioactive components from ships were repaired and/or modified. Thus, as the radiation workers carried out their daily activities at their usual jobs in the vicinity of these radioactive sources, they were exposed to varying levels of radiation from activated materials.

The first exposures of relatively large numbers of workers occurred in the overhaul of a submarine in 1957 at the Groton, Connecticut yard. Over the subsequent ten years, the other study yards began nuclear-powered vessel overhauls until, by 1967, all eight shipyards were involved in this work.

Thus, the personnel dosimetry program which was critical to accomplishment of this study was initiated at different times in each of the eight yards and has continued through the present time.

The descriptions of radiation exposure from Naval nuclear propulsion plants have been derived from several sources. These include two reports related to the Portsmouth Navy Shipyard (Murray, 1982; Murray, 1983); two series of annual reports published by the Navy, the "Occupational Radiation Exposure Reports from U.S. Naval Nuclear Propulsion Plants and their Support Facilities", and the "Environmental Monitoring and Disposal of Radioactive Wastes from U.S. Naval Nuclear-Powered Ships and Their Support Facilities"; the Congressional Hearing regarding the Naval Nuclear Propulsion Program-1979; a Navy report reviewing the United States Naval Nuclear Propulsion Program-June 1982; and extensive discussions with Navy personnel, as well as on-site review by the Shipyard Study Staff. These data and other information and personal observation were used to develop the description of the control programs.

Naval nuclear powered ships use pressurized light water reactors. The water circulates through a closed primary piping system to transfer heat from a reactor core to a secondary heat exchange system which is isolated from the primary cooling water. Steam generated in the secondary system is then used as the power source for the propulsion plant.

Trace amounts of corrosion and wear products from the interior surface in the primary system are carried by the coolant into the reactor and are activated in the reactor core through neutron absorption. These products are then carried throughout the primary cooling system. In-line purification systems do not completely remove these activation products from the water. Since shipyard workers do not work in the reactor compartment until the reactor is shutdown, it is from the activation products deposited in the piping system and associated equipment and not from the operating reactor that radiation exposure primarily takes place.

Accidental exposure to uranium and/or its fission products due to loss of fuel element integrity has not been reported. The designs for naval reactors are more rigid than for commercial plants because they must withstand shock. Therefore, even fission gases are retained within the fuel elements. Uranium is also retained within the fuel elements so exposure does not occur. According to the earliest information available to the investigators, the Naval Nuclear Propulsion Program has reported no "abnormal occurrences" or incidents of external radiation exposure over 25 rem in a single episode (Congressional Report, 1979).

Table 2.7.A summarizes the sources of potential radiation exposure for workers involved in the overhaul, repair, and refueling of the nuclear powered ships. The primary coolant water contains several short-lived radionuclides. These include nitrogen-16, nitrogen-13, fluorine-18, argon-41, and manganese-56. All of these materials have short half-lives ranging from 7 seconds (nitrogen-16) to 2.5 hours (manganese-56). Procedures used in the shipyards delay exposure to these materials and greatly reduce any potential exposure incurred from their radioactivity. The other radionuclides are long-lived with half-lives ranging from 1 day to 92 years. They include tungsten-187, chromium-51, hafnium-181, iron-59, zirconium-95, cobalt-58, tantalum-182, manganese-54, iron-55, cobalt-60, and nickel-63 (Murray and Terpilak, 1983).

Of these materials, cobalt-60, with a half-life of 5.3 years, comprises the most significant source of external exposure. Radiation from cobalt-60 consists of one low-energy beta and two high-energy gamma rays (1.17 and 1.33 MeV) leading to exposures which should be accurately measured by film badge or thermoluminescent dosimeter (TLD).

Personnel are not permitted in the reactor compartment when the reactor is operating. Therefore, neutrons produced during fission of reactor fuel would not be present under the usual conditions of maintenance when the reactor is shut down. However, workers sometimes have short temporary assignments in the machinery spaces outside the reactor compartment when the reactor is operating. Neutron exposure has historically been measured at below minimum detectable levels of neutron sensitive film since there is both primary and secondary shielding of the reactor core. Only isolated workers who have been involved in radiation instrument calibration or in reactor plant instrumentation testing with neutron test sources have had low levels of neutron exposure as measured by film badge or lithium fluoride TLDs. These doses are reported in the annual and cumulated DE records. Beta radiation is present from the radioactive corrosion products in the reactor coolant at the time the systems are opened. However, the anticontamination clothing or plastic containments used protect the worker from beta exposure. Consequently, monitoring for beta radiation is usually not done (Occupational Report, 1979).

In regard to internal radiation exposure, it is unlikely that fission products could escape unless the fuel element had ruptured or, in some other way, lost its integrity. However, trace amounts of uranium, naturally occurring as an impurity in structural materials, undergo fission in the vicinity of the core, and very small quantities of fission products will be present in the reactor coolant.

Small amounts of tritium are formed in the reactor coolant systems due to neutron interaction with naturally occurring deuterium in water; however, the levels are less than in typical reactors because soluble boron is not used in the reactor coolant for reactivity control. Carbon 14 is also formed in small quantities from exposure of nitrogen and oxygen products to neutrons. However, the small amount of low energy beta radiation associated with carbon-14 is not an important radiation source (Occupational Report, 1979; Environmental Report, 1979). Exposure to cobalt-60 is the primary concern due to its major concentration, long life, and high-energy gammas.

Definition of Nuclear Workers

Any worker whose name appeared on the radiation tape or in the radiation dosimetry records of any shipyard was included in the study initially. Although the major proportion of these workers are exposed through overhaul and maintenance of the nuclear propulsion plant, there are records of other individuals who had radiation exposures and were monitored. These include medical personnel and radiographers. The latter group which is involved in non-destructive testing may be exposed externally to x-rays or gamma rays from cobalt-60 or iridium-192. Internal exposure from these radionuclides is extremely unlikely since radiography and instrument calibration use sealed gamma ray sources which are routinely tested for leakage. Thus, this group is similar to the nuclear propulsion plant workers in that their primary source of exposure is external radiation. Medical personnel are exposed primarily to machine produced x-ray sources. All these occupational groups are monitored under the radiation control program and their records are included in the database with the workers exposed to radiation during maintenance and overhaul of nuclear propulsion plants. However, only the latter group represent the focus of the study. Job histories will distinguish between the three groups.

Anyone who enters a radiation area or works with radioactive material must be monitored for exposure and the recorded dose will appear in the radiation record. A radiation area is defined as any area in which a worker may receive one to 100 millirem per hour to a major portion of his whole body. If the area is one in which the DE could exceed 100 millirem per hour, this is designated as a high radiation area and additional special precautions (locking and guarding) are taken for these areas (Occupational Report, 1979). Anyone entering either type of area or any individual who works with radioactive material must receive special training and must receive authorization to be classified as a nuclear worker.

All individuals receive radiation medical exams prior to assignment as nuclear workers. Prior to 1982, any worker who has had 0.5 rem in any year has a follow-up routine examination at least every three years. After 1982, all workers received physicals every three years with the exception of Groton, which was on a five year cycle until 1987. At any time that a worker is suspected to have ingested or inhaled significant quantities of radioactive materials, he will receive a special examination. A final physical examination is also given to all nuclear workers at the time of termination of employment or termination in the nuclear program if they had 0.5 rem or more in any year. The level of 0.5 rem was selected as the target for examination because that is the annual dose permitted for the general public (Occupational Report, 1979).

Individuals with malignancies, a prior history of radiation therapy, or a significant family history of cancer on medical examination may be disqualified from either initial entry into the radiation program or may be removed from the program at any time. Reinstatement in the program requires a special review. Thus, all nuclear workers receive frequent physical examinations throughout their shipyard tenure.

Dosimetry

From its inception, the radiation program in the shipyards was supervised from a central source. The dosimetry practices were well developed, under central oversight and standardized by virtue of common manuals (i.e., NAVMED P-5005, "Photodosimetry Manual", 1957, and NAVMED P-5055, "Radiation Health Protection Manual", 1965). Initially, in 1957 the radiation monitoring program of the Naval Shipyards was under the management and technical control of the U.S. Navy Bureau of Ships (later Naval Sea Systems Command) and the U.S. Navy Bureau of Medicine and Surgery. At that time film badges were worn to measure radiation exposure. The film badge holders had both an open and a closed window. Penetrating radiation (gamma) was read under the closed window portion of the badge, while high energy beta and "soft" x-rays were read under the open window. Skin exposures were estimated from the density of exposed film under the "open" window, while whole body penetrating dose was estimated from the film density under the metal shielded portion of the film. In general, Dupont type 552 film was used that had a nominal minimum detectability of about 50 mrem. However, as is evident by review of records, values as low as 15 mrem or so were often recorded. This film was used from about October 1957 to November 1961.

As noted by personnel from the shipyards, not all yards used the same film or the same badges. About half the yards used the same type of film and film badge holders. The films H and D curves (that is, the curves which relate film density to exposure) were usually calibrated with exposures to cobalt-60 or cesium-137 as the standard but this procedure also varied by yard. Some gamma ray standard sources were routinely calibrated at the National Bureau of Standards (NBS). In other cases, secondary gamma ray standards were used which were traceable to NBS sources.

From 1961 to 1968 other types of Dupont film were used; for example, Portsmouth used type SX 233 and Charleston used type 556. By 1968, most of the shipyards had shifted to Kodak type 3 which had a minimum detectable dose of approximately 10 mrem. Exact records of the type of film and badges used in each of the shipyards are probably available if these details related to radiation measurements prove necessary for subsequent review of individual dosimetry information.

The position for wearing the film badge was on the front of the trunk, outside of the clothing and at the waist or chest. Film badges were sometimes worn at other locations (e.g. head) depending on the location of highest exposure. In selected situations, additional dosimeters might be worn on the extremities. If an individual entered a high radiation area or a reactor compartment, he wore not only a film badge or TLD but a pocket ionization chamber as well (Occupational Report, 1979).

There was no DE assigned to an individual whose film badge could not be read because of the minimal detectable level of radiation characteristic of the film. Thus, any DE corresponding to 0.01 or 0.02 density units on the densitometer was called zero on Dupont film and any DE corresponding to 0.03 density units or above was read as such. Kodak type 3 film had a standardized recording level of 0.03 density units since the late 1960's, but its sensitivity corresponded to 10 mrem. The calibration H and D curves used for standardizing the badge measurements were produced at the individual shipyards. In reading films, a control film was used to subtract background level.

Film badges were processed every two weeks prior to 1960 and monthly thereafter. If the ionization chamber pocket dosimeter reading exceeded certain pre-set alert levels, the film badge was processed and read immediately to determine DE. Individual DEs were entered into the employee's medical record or into an exposure record at private shipyards as the official record. This is the information source which was available for use in confirming the radiation data on the individual DEs provided by the Navy on computer tape.

By 1973 and 1974 almost all shipyards converted to TLDs. Newport News shipyard did not convert to TLD until 1976. All of the yards use TLDs containing two chips of calcium fluoride with added manganese except Newport News which uses three chips of lithium fluoride. TLDs are read on a daily basis, with the exceptions of Groton which reads TLDs on a weekly basis and

Newport News which reads TLDs on a monthly basis.

Within the exceptions noted previously, the current TLD program is well-standardized in the shipyards. Due to the recent implementation of the TLD measurements, records are more readily accessible which makes it easier to document procedures for the TLD than for the older film badge program.

All individuals who are to work in radiation areas present their authorization cards to the TLD distribution office, at which point their eligibility is checked on a list indicating their current allowable DE level. An individual cannot enter a radiation area unless authorized to do so. If the individual expects to enter a high radiation area or reactor compartment, he will also receive both a pocket dosimeter and TLD, and his card will indicate work in that area. TLD readings were recorded on cards and manually input into a computer. Today, all input is automatic. The DD-1141 form for Navy yards and an equivalent form for private shipyards is then computer generated and entered into the employee's record.

Internal Dosimetry

Internal deposition of radioactive material or the potential of such radioactive deposition by ingestion, inhalation or skin absorption has been monitored and recorded. Of the contaminants normally present, cobalt-60 is the radionuclide of primary concern because it contributes the largest fraction of the radioactivity and has the lowest maximum permissible concentration. It is the focus of the internal monitoring program.

The shipyards prevent inhalation and ingestion of radioactive material by a rigorous program of contamination controls including frequent use of contamination containment, monitoring of personnel and areas, filtered ventilation, and use of protective clothing. In most cases, attempts are made to engineer a job so that the radioactivity is contained rather than send workers into a contaminated area with protective gear.

The airborne activity limit is set at 1×10^{-9} microcuries per milliliter of air based on the equivalent cobalt activity. At this level, workers must exit the area or wear masks or air fed hoods. If the airborne radioactivity reaches 10^{-6} microcuries per milliliter, no access is permitted. It is a general principle in the Naval Nuclear Propulsion Program not to allow workers to continue to work in airborne radioactivity even if masks are being worn. Usually the job is stopped so that control measures can be established to prevent airborne radioactivity from recurring. If work might produce airborne contamination, containment tents enclose the area which is then ventilated through high efficiency filters to remove even small particulates. The occupied areas near the tents are also ventilated. There is constant monitoring in areas where this contamination could occur such as during work in the reactor compartment. Moreover, the limits set by the Navy are conservative so that if an individual were to work 40 hours a week throughout the year at the 1×10^{-9} microcuries per milliliter level, the person would still only receive one-tenth of the Federal standard of 15 rem per year to organs such as the lungs (Occupational Report, 1979).

In the early 1960's, urine bioassays were routinely done at some shipyards as a check for the presence of internal exposures. Given the Navy's control of airborne radioactivity, it was felt that review of these results would not be useful at this time.

The external measurements of radioactivity in the lung used in the early 1960's, while adequate for that period, are considered by today's standards to be relatively insensitive. When the procedure used an end window Geiger-Mueller counter survey meter and a scaler, as well as a suitably long period of counting, the minimum detectable activity was about 75 nanocuries of cobalt-60. The minimum detectable activity was only one microcurie when a rate meter alone was used as in the early years. In 1962, some shipyards performed chest counts on their populations with a Geiger-Mueller counter and a scaler. This procedure was used at various times in the yards through about 1967. Gamma sensitive sodium iodide scintillation detectors, which can identify levels as low as about 2 nanocuries of cobalt-60, were used starting after 1967.

Before about 1971, internal monitoring was only performed following an event involving potential intake. After that date, routine monitoring was initiated at the time of physical examinations and after a potential intake. For example, approximately 7,000 individuals were monitored in 1971 and only four had between 10 and 20 nanocuries with the others being below 10 nanocuries. In the recent periods, for example in 1982 out of the more than 10,000 individuals who were monitored, only one individual was reported to have greater than 10 nanocuries, which is the reporting level used by the Navy (NT-83-2, 1983). The maximum exposure was 32 millirem. Ten nanocuries deposited in the lung would result in a dose to the lung of less than 10 millirem. Therefore, internal exposure in the study group was negligible; it was not included in the radiation DE used for mortality analyses in those few instances where it appeared on a record.

Skin Contamination

Any worker with radioactivity on the skin was required to cleanse the area until there was no further detectable radioactivity on the skin. Workers with open wounds or skin conditions that might make it difficult to decontaminate the area in the event of skin contamination were not allowed to work in contaminated areas. Records of skin contamination were documented in the worker's history. The Navy indicates the occurrence of these events on the radiation records, but since in most cases the episodes have resulted in no added dose for the individuals, the negative results were not routinely abstracted in preparing the radiation tapes for this study. Navy procedure also requires documentation of all radiation contaminated wounds. However, no incidents have occurred in recent years.

Assigned DE

Any worker who stated they received occupational exposure to radiation prior to employment at the shipyard, but whose DE could not be verified was administratively assigned the maximum allowable DE for that period. If subsequent information became available, the corrected DE was entered into the radiation record. In the early years of the program, workers also may have received assigned doses when they had worked on ships exposed to fallout from radioactive weapons testing. These are relatively uncommon events.

Prior to 1957, the annual limit was 15 rem per year. About the time of start of overhauls in 1959, the Atomic Energy Commission (AEC) and its licensees adopted a limit of 1.25 rem per quarter applicable to persons with no prior dose history available. These would have been the standards under which the shipyards administratively assigned doses.

Estimated DEs

When a worker's dose is unavailable as when he lost a film badge or TLD while working in the shipyard, the DE can be estimated from pocket dosimeter totals, the DEs of other workers performing similar work or exposure rates and time spent in the area.

Another procedure used by the Navy to assure the safety of individuals working in high radiation areas was the provision of both a pocket dosimeter and a TLD or film badge. If there was a difference of 25 percent or more between DEs as derived from the two types of instruments, an investigation was conducted to determine the cause of the discrepancy. The worker himself was interviewed, and other workers within the same general area were identified for comparison of DEs. Radiation survey records for the area were reviewed, and calibration of the TLD and pocket dosimeter was checked, if appropriate. Depending on the results of the investigation, the TLD reading or the pocket dosimeter reading might be accepted as the appropriate individual measurement. Alternatively, a DE based on the radiation level and exposure time or a DE comparable to DEs of other workers doing similar work might be used for estimation.

A similar procedure was used when dosimetry devices were lost or damaged. In such cases, the worker's dose was estimated either by considering the dose of other workers in the same area or the worker's time in the area and the measured radiation level of the area. Each of these assessments was documented in the individual's record.

Validity and Completeness of Radiation Records

In any epidemiological study it is extremely important to try to classify individuals correctly both in regard to their disease outcome and their exposure. Even random misclassification will tend to dilute any existing association between disease and exposure to radiation. This is of particular importance when calculating a dose response curve. It was important, therefore, that several areas of potential misclassification and variation in procedures by yard be investigated as a first step in checking the reliability of record-keeping systems.

The information on individual doses was furnished by the shipyards. All of the Navy shipyards and one of the private yards abstracted from the radiation records and compiled into a computer tape the radiation data by annual as well as cumulative DE for each individual who had ever been employed. One yard supplied the hard copy records of each individual's annual radiation DEs and a computer tape of radiation records which represented only current workers' cumulative DEs. Therefore, a computer tape was developed for each shipyard which was compatible with the general format and information provided on most Naval shipyard tapes. In assembling the tapes, the Naval Shipyards included various other additional information regarding potential sources of radiation such as exposure in prior employment, status of worker such as retirement or transfer, medical problems and special exposures such as skin contamination events.

Not all shipyards compiled these items on computer tape nor was the method of compilation standardized as it was for radiation dose and identifiers. Thus, for every worker the annual DEs plus the cumulative DE to date have been compiled for exposure within the shipyard. Previous exposures were included in each computer record. Unusual sources of exposure such as possible internal contamination and skin contamination exposures were compiled from some yards. The shipyards have provided the Shipyard Study staff with new radiation tapes at each year's end from the beginning of the study. The tapes were matched across all yards in order to record the total DE for an individual who might have worked in several yards. These tapes were also matched across years to identify potential editing errors. In order to combine data across shipyards for analysis, the first task required that all methods of recording information be standardized for the Navy and private yards.

The records from some yards included individuals who had not actually worked in that yard but had received radiation exposure in another shipyard whose records had been combined with those of the shipyard of primary interest. These other workers usually had received radiation as part of the medical or non-destructive testing departments. This presented a problem in population definition. It was necessary to remove these workers from the roster of nuclear workers since they were not part of the monitored work force in the shipyard of interest.

Newport News reported their workers' radiation DEs by individual annual DEs. The shipyard did not prepare a computerized cumulative DE with sequential annual DEs recorded by calendar year in each worker's record as was prepared by the other yards. The formation of a record system similar to that of the Navy yards was accomplished through the abstracting of Newport News information by the Shipyard Study staff. The initial set of microfilmed

2 Methods
2.7 Radiation Exposures (cont'd)

Newport News records did not contain all the available information, and additional records were requested and received from the yard to complete the data for each worker. Given the difficulty in reconstructing the database from several sources of data, the process was very time-consuming and the records still contain some discrepancies for individual records. Therefore, some nuclear workers from that yard have not been included in the current analysis.

Examination of the special codes used on the radiation history files revealed that the codes were not used consistently across the Navy yards in preparing computer tapes for the study. For example, Portsmouth used no special codes for exposures at other yards or medical exposure, while on average one to six percent of the annual records in the other shipyards contained such codes. In addition, there were marked differences by yard in reported assigned DEs which indicated that this identification code was not used in the same way in all yards. The frequency of any of these doses in the records was low.

The discrepancies noted above are unlikely to make a significant difference in terms of the worker's radiation history for a given shipyard, but the inconsistencies caused some problems in combining experiences across yards. Some assumptions were made in order to combine the radiation histories. In most cases, the records were manually edited and, if possible, the medical record was reviewed. Since only one percent of the study population worked in the radiation program in more than one shipyard, this was not considered to be a problem.

Completeness of the Exposed Population

A most crucial question is whether the total population of exposed nuclear workers has been completely identified and the risk of disease noted. Three methods have been used to attempt to confirm the completeness of the population.

The first procedure matched all workers listed on the radiation file with personnel files from each individual shipyard. In theory, all true shipyard workers listed on the radiation file should have had a personnel file record. There were 17,335 workers (16%) on the radiation file that did not match to a personnel record. Of these, 8,909 workers were from the Newport News yard, whose radiation database had to be constructed by study staff from the yard's microfilm exposure records. Some individual records had uncorrected problems at the time of this analysis. It is possible that non-matching has occurred because these workers were employed by a contractor and not by the shipyards directly or that the records represented visitors or active duty military personnel in the yards. Some of the nonmatches were due to errors in transcribing social security numbers (the matching criterion) on either the personnel or radiation files. It is also possible, however, that the personnel files of these individuals were not available at the time of the filming of the records. Such a situation might exist, for example, if a file was under investigation and therefore had been pulled out of the normal file location. Although attempts were made to avoid any such omissions, it was often difficult to be sure that every single personnel file had been located at the time of filming. Therefore, every individual with at least 0.5 rem cumulative exposure who had a record on the radiation file and for whom we had

2 Methods
2.7 Radiation Exposures (cont'd)

additional identifying information was carefully investigated.

Of the total 17,335 records, 4,985 were for workers with a cumulative DE ≥0.5 rem, of which 2,366 workers were from the Newport News shipyard. The files were submitted to the Social Security Administration and to other sources that provide information on vital status in order to determine the vital status of these individuals. The returns from the Social Security Administration and these other sources of death information indicated that the death rate of these individuals was 10 percent overall. This identification may not be complete since not all records had the information needed to provide matches with the vital status sources. Many of the discrepancies in the matches were resolved, and this population of workers with at least 0.5 rem or more was followed along with the radiation sample study group. Figure 2.7.A depicts the current status of the follow-up of these radiation workers excluding Newport News. The current analysis does not include these individuals since the death certificates were not available for all deceased. The subdivision of the 2,366 Newport News radiation workers without personnel records into dose categories and the ascertainment of the vital status of the groups was not complete when the tope was prepared for analysis.

It should be noted that the radiation computer files represented a unique situation for checking on the completeness of the population of exposed. In most working populations, the only source of identification is the personnel record, and there is no second source for validation. Therefore, in this case, unlike the usual situation in occupational studies, there is a source to check on the completeness of the population. The first source was the radiation exposure tapes and the second source was the personnel file.

The third source of information to confirm the completeness of the exposed population was that of individuals receiving a recorded DE of 5 rem or more exposure in a single year who had been reported to the Department of Energy (DOE) facility at Oak Ridge. This population was identified by the Shipyards and not necessarily from the information gathered for the Shipyard Study and includes workers from shipyards as well as DOE facilities who have a recorded annual DE of 5 rem or more regardless of the accepted annual occupational limit at the time of exposure. This population has been followed by Oak Ridge independently of the Shipyard Study even though 930 of the workers in their study received their exposure in one of seven of the shipyards. Some of these individuals were missing from our records, and others had not received 5 rem in any one year according to our data. These discrepancies are shown in Table 2.7.B for the seven yards for which radiation history data were available at the time of the comparison. As noted in the table, there were only 15 individuals on the Oak Ridge list with 5 rem or more in a single year who were not identified with that exposure level on the shipyard's radiation history file.

In addition, there were two individuals who were not identified at all by the shipyard's radiation history file. This means they were not included in the sample population of those with 0.5 rem or more exposure. However, they may be in the group who have extended follow-up (Figure 2.7.A). These missing workers would represent less than 0.2 percent of the Oak Ridge population which was missed in the shipyard study sample.

We have identified 113 individuals with 5 rem or more in a year who were not in the Oak Ridge study population. Not all the reasons for these discrepancies have been resolved. However, reasons for the discrepancies have been identified for the eight workers at Portsmouth. Six of the eight workers were radiographers, a group which was being followed in the Shipyard Study but which was not included in the Oak Ridge study. The seventh individual was recorded as having 5 rem in a year but he actually received that DE over two years at an installation other than Portsmouth. This DE appeared as a single reading of 5 rem when the individual returned to the shipyard. One eligible candidate was not identified by the Oak Ridge study. These two separate efforts provide reassurance that identification of the defined eligible workers is essentially complete. The validation check has also identified the ways in which eligible study individuals could be missed.

The fourth method of assessing the completeness of the population base was to query recent workers at both Norfolk and Charleston about whether they had worked in radiation areas and then to check their answers against our radiation files. The question on the survey read, "Did you wear a film badge, dosimeter, or TLD while in the shipyard?" Apparently some people misunderstood the question initially and so there was a relatively high percentage who indicated that they had worn a badge but for whom there was no record of their being a nuclear worker. About twice as many of the Norfolk respondents indicated that they had worn a film badge or TLD and were not on the radiation history file (16%) as those who indicated they had not worn a film badge but whose name appeared on the radiation history file (9%). Further calls to these individuals corrected the misconception about the meaning of the question relating to wearing a film badge. Many combined the film badge with an identification badge issued for security purposes. However, even after clarification of this error, there were still some individuals who reaffirmed on interview that they had worn a radiation monitoring device although we had no record of their exposure.

These discrepancies have been investigated further with the personnel and medical departments at Norfolk, and the summation of the results is seen in Table 2.7.C. Among recent workers at Norfolk, about 99 out of the approximately 14,000 contacted reported wearing radiation monitoring devices despite the fact that their names did not appear on a current radiation file. Fifty of the 99 still had a record available at Norfolk about three years later (the other 49 records had apparently been sent to the Federal Records Center), and their exposure history could be investigated. Of the 50 investigated, 26 (52%) had reported wearing a film badge or TLD, but at the time of the radiation file preparation they had not yet been called for active radiation work. Therefore, individuals were answering the question correctly and there was not actual discrepancy with the radiation file.

As can be seen from Table 2.7.C, 15 of the group, or 30 percent, reported working at the Newport News Shipyard and may have received exposure there although there was no record of it at Norfolk. There is no confirmation of this fact. An additional three workers had served in the military, and there was no information regarding whether unreported exposure could have occurred there. Three others had qualified for nuclear work in the distant past, but they had never worked in a radiation area. There were three who had a radiation record in their medical chart, but their names were not on the radiation history file. Two of these were positive responses to the question because they were badged when they were sent on a special assignment in which the individual might have been exposed at a site away from the shipyard, and there was one missed record.

Most of the discrepancies noted above resulted from differences between the study definition of included workers versus total radiation workers in the yard. Few eligible workers were missed. From these data, one out of 50 who would have been eligible for the sample might have been missed. Almost all of the 14,000 workers contacted were correctly classified as to their radiation history.

The data from the health history survey in Charleston have not yet been reviewed for completeness of identification of radiation workers. Problems should be less frequent than in Norfolk where confusion arose in responses due to the presence of two shipyards in close proximity (Norfolk and Newport News) both of which were hiring radiation workers.

Preliminary analysis of the data from the mailed survey of recent Charleston workers completed in 1987 indicated that about 12 percent of the population reported that they wore a film badge or TLD but their names did not appear on the 1985 Charleston radiation file. In addition, six percent of workers whose names appeared on the radiation file claimed that they were not nuclear workers. The results from both shipyards indicated that questioning individuals about radiation exposure status may yield results differing from documented records. It also indicates that the careful record-keeping systems have managed to reduce the number of missed radiation workers to a negligible percent, if Norfolk is any example for the other yards which seems likely.

Classification of Workers as Exposed versus Non-exposed

In any epidemiologic study, the complete ascertainment of the study population is essential in order to be sure that no selection bias has been introduced into the study group. This question was addressed by several comparisons between the radiation workers and personnel files. The complete ascertainment of the population of nuclear workers was paramount to avoid selection bias. Thus, this group was compared by annual records to be sure that no individual was deleted as described below. They were compared to data from the Oak Ridge 5 Rem Study to see if any workers had been missed through two identification systems. Those with ≥0.5 rem cumulative DE were followed separately if they did not have a personnel record until the reasons for the missing record could be determined and their study eligibility decided. The latter two methods were described above. It is not enough in this study to simply divide the population into exposed and non-exposed because accurate dose data were needed to calculate dose-response curves and hopefully in the end to determine whether the risk by dose would be compatible with previous estimates.

In reviewing the radiation information, it is important to recognize that the maintenance of radiation records and the total radiation control program is focused on the safety of the worker. Therefore, the shipyard personnel try to maintain exposures well below the limits set for occupational radiation. However, accumulating measurements over long periods using different techniques for the purpose of epidemiologic studies raises a different set of issues. Every reported reading actually represents a range of possible readings because of the limits of accuracy of the measuring device. As multiple readings are added together, we would hope that these positive and negative variations would cancel themselves out producing an accurate dose over time. However, when the readings are in the low dose ranges there may be limits on the system and the range of any reading may not be equally distributed on the positive and negative sides. Technicians may also have tended to read film badges conservatively in order to protect the health of workers. These factors could introduce bias into readings especially when accumulated over many days, months and years. The following portion of this reports examines the methods of determining exposure in order to identify any potential limitations in the use of these radiation data for epidemiologic purposes rather than for health and safety purposes.

In selecting the population for study, the workers were divided into three groups: the group qualified to do nuclear work with cumulated DEs of 0.5 rem or more by January 1, 1982, the group also qualified to work nuclear with cumulated DEs below that level and, as a final group, those workers who never appeared on the 1981 radiation file which represented a cumulative listing of all workers who had ever been classified as radiation exposed. The latter two control groups were regarded as low or zero exposed groups. The so-called "exposed" group had cumulative DEs which varied from 500 millirem to 30 rem or more.

In the simplest form of analysis, looking at the classification of nuclear workers versus non-nuclear workers, the reviews indicated that the major separation was extremely reliable based on shipyard records. We will discuss further the exact dose data below. The dose becomes important because in the analysis of the exposed group by dose, it is necessary to determine the relative accuracy of dosimetry in the upper versus lower dose levels and the accuracy depending on the size and rate of accumulation of daily doses.

Dosimetry on Individuals

A review of all procedures for collecting and recording exposure information was conducted to determine the reliability of the dose information. The sources of collecting and recording of the specific radiation readings from film badges and TLDs were reviewed and discussed in a previous section. Methods of checking the reliability of the dose data will be described in detail below.

Potential sources of internal exposures and the program for internal monitoring were also described above. This information was examined to determine whether there were any sources of exposure which might have been omitted from the dosimetry. Any radiation exposures of workers other than gamma rays were also noted in the radiation record. We have no indication that any of this information on internal exposures was in any way incomplete. There were very few internal radiation exposures recorded in recent years. In the past there has been much public attention to potential exposures in "accidental" situations which are not reported. No incidents have been found in the medical histories which were reviewed at two yards. Any incidents would have been noted in these records. Also, Navy procedures require the immediate reporting of any incident in which the exposure to any individual exceeded 25 rem or more. No such incidents are reported. Thus it would not be necessary or practical to try to review all medical records to prove that no "accidents" occurred.

2 Methods
2.7 Radiation Exposures (cont'd)

It is obvious that the recorded information on radiation doses represents exposure data which are usually not available for similar types of exposure to agents in the workplace. But it is also important to remember that if we are trying to establish risk estimates, the accuracy of this information is crucial. It is even more important that there is no bias in the data which are collected for high versus low DEs exposures within the group. To establish dose-response relationships and the risk per incremental dose, it is important to have accurate measurements. The radiation field is far advanced in the use of measured exposures and need not rely simply on relative rankings as in other occupational exposures.

Occupational exposures to radiation are characterized by repeated exposures over a period of time rather than the reception of a single dose or a few doses in a short interval which is typical of medical exposure used in the treatment of patients or in single environmental or accident exposure such as the testing of nuclear weapons or bombings. Therefore it was important in this study to try to characterize the way in which the individual workers have been receiving their DEs, since the errors in any single reading (which may in itself be small) are now compounded over repeated measurements for long periods of time.

The data have been validated by several means. One was an internal comparison in which all data from the individual radiation file records by years have been compared to determine, first, whether any records have disappeared from the tapes of individual yards, and second, whether the total cumulative DEs of individuals recorded by yard matched the sum of the annual DEs. Additionally, exposure information reported in quarterly or monthly intervals was abstracted from samples of the workers' medical records in two shipyards to validate the annual and cumulative DEs recorded on the computerized radiation history files and to examine the pattern of exposure by which workers received their lifetime DE. The medical record is considered to be the valid source of all information on radiation exposure. This complete validation of individual records was done for Pearl Harbor and Portsmouth.

The first check on the correctness of DE as well as the completeness of the population was done by evaluating the radiation computer files which have been received at the Shipyard Study office annually from the yards for the past eight years. Edit checks were performed to ensure that the annual DEs summed to the lifetime DE on the record. The shipyards were queried about any DE discrepancies, and the corrections were made to the file.

These records were also checked sequentially for deletions of either doses or workers from the database. As seen in Table 2.7.D, only 0.3 percent of workers and only 0.2 percent of the annual records were deleted from one year to the next. These deletions were not characteristic of any specific DE group. Investigations revealed adequate explanations for all but five of the 585 deletions (0.9%). For example, military personnel, visitors or contractors were removed because they were not considered to be part of the shipyard nuclear worker population. Assigned DEs may have been replaced by real doses gathered from outside sources following investigations and updates. Also, changes in a worker's radiation program identifier were the cause of many of the apparent deletions in Mare Island.

The description of the Pearl Harbor radiation exposure data validation is presented in Table 2.7.E. The 826 annual radiation exposure entries from the Pearl Harbor medical records of 84 workers who were found out of a sample of 100 represented the exposures of a sample consisting of all individuals at high DE and successively smaller fractions of the total population of workers at lower DEs. The retrieval was incomplete because some records were not received from the Federal Records Center. Comparison of the cumulative DE as calculated from their official medical records and from the computerized records (Figure 2.7.B) indicated that there were only two lifetime DE discrepancies in the records of all 84 workers (2.4%), creating an average difference of 0.635 rem in the cumulative DEs of the two workers. The correlation coefficient for the lifetime doses recorded in the two systems, medical charts and computer radiation history file, was 0.9996.

In general, if there were missing entries in one of the two systems, it was generally when there was a zero or blank dose in either the medical or the radiation record. Thus, of the 16 entries which were not present on total of 836 records in both systems (1.9%), 15 of the 16 entries fell in these categories (94%) and so would not alter the DE. For the additional nine annual entries in which the recorded DEs were not the same in the two systems for seven workers, the imprecision of zero versus blank recording of DE accounted for seven of the nine differences (78%). This indicates the high accuracy of the data reflected in the computerized radiation tape.

These dose data from Pearl Harbor have also been examined to see if the method of cumulating small doses could have caused an over- or under-estimation of dose based on measurement error. One must consider the pattern by which individual workers received their doses. In nuclear vessel overhauls, unlike other occupational exposures, the individual often has occasion to enter a radiation area and receive a DE and then not receive exposure for extended periods thereafter. In other populations, workers may receive very low DEs on a daily basis. For Pearl Harbor, the data could only be examined for quarterly intervals. For Portsmouth, the data were reported for increments of one month or less.

The data as indicated on Tables 2.7.E1, 2.7.F and Figures 2.7.C, 2.7.D suggest that the individuals who had higher annual DEs actually had on the average a few readings at the high DEs, and many readings which were zero. For example, individuals with an annual DE of 2.0 to 2.5 rem had 17 percent of their quarterly DEs at levels of 100 to 499 millirem, 43 percent at 500 to 999 millirem, 29 percent at 1.0 to 2.0 rem, and 10 percent at 2.0+ rem. Thus for individuals with annual DEs of 2.0 rem, about 40 percent must have accumulated all or at least half of this DE in a single quarter. The remaining population accrued the total annual DE by adding quarterly DEs of 0.5 to 1.0 rem.

However, as shown in the proportional distribution of DEs, individuals who had less than 0.5 rem and 1 to 2 rem annual DEs tended to have a high proportion of quarterly DEs which were below 0.5 rem. This was obviously a higher proportion for the lowest annual DE groups. Also apparent, quarterly DEs in this range became a higher proportion of the total annual DE for individuals who had the lowest annual DEs. Note that those individuals with annual DEs of 0 to 0.5 rem and 0.5 to 1.0 rem still had about the same proportion of their DE represented by quarterly measures of 0.1 to 0.5 rem (55 to 65 percent respectively). In summary, the data do suggest that 20 to 40 percent of the workers received the bulk of their annual DE in a single quarter regardless of cumulative DE.

Similar data were collected from Portsmouth. Of the total of 5,578 workers who were qualified to work in the radiation areas and who received radiation, 10 percent samples were taken of each of the groups who had been exposed to a cumulative DE of less than 0.5 rem, a DE between 0.5 and 0.9 rem, and a DE between 1 to 5 rem. One hundred percent of the records were taken of all those individuals with cumulative DEs of 5 rem or greater, unless all of that DE was received after 1974. The total sample represented 1,500 individuals and is described in Tables 2.7.G, 2.7.G1 and 2.7.G2.

The DEs after 1974 were omitted because the exposures of the workers were recorded in the medical records as a computerized output of the annual cumulative DEs for each year as reported from the radiation computer tape. In the review of Pearl Harbor records, the medical record and radiation tape did not show any differences in DEs after introduction of this computer output. Therefore, there may have been less opportunity for transcription errors in the latter period.

In Portsmouth, however, an independent set of records was available which permitted complete ascertainment of monthly rather than quarterly exposure data. These records consisted of film badge reports from August, 1959 through October, 1973. These badge records were microfilmed and ordered by shop number, employee identification number, month, and year. In addition, there were daily radiation DE reports on TLD readings at Portsmouth from 1974 until the recent year. Each microfilm reel was ordered by month, year, shop, and alphabetically by employee name. Approximately 24 reels of microfilm represented one year of records. Any individual worker may have from one to about 250 frames of microfilm representing daily work cards in a year.

Although it would be possible to reconstruct a person's daily TLD record from these detailed data, to actually search for individual workers' DEs in this way would be extremely difficult and would lead to very high error rates in recreating the DEs. Thus, because of the difficulties and the apparent acceptance of the validity of the daily TLD DEs by the review groups, no further attempts were made to reconstruct the dosimetry based on such extensive data. Thus, all of the following discussion relates to film badge readings only.

Table 2.7.G3 and Figure 2.7.E present the results for the Portsmouth radiation exposure data validation. The validation and analyses of the data for patterns of increments of exposure were performed on a sample of 269 workers from the sample of 1,500 workers for which the microfilmed records were coded and extensively edited. This sample included all 59 workers with 30 rem or greater lifetime exposure and a stratified random sample of the 1,441 individuals with less than 30 rem lifetime exposure.

As noted in Table 2.7.G2, only the workers in the highest DE category (5^+ rem) had exposures recorded for almost every month throughout the year as judged by a median of 10 reported exposure months annually. Other workers had only 2-3 exposure months per year regardless of final cumulative DE. The highest group also had many years of exposure with an early start year and a late termination in the program. One reason that they may look so different from the group with lower exposures may be the selection of all workers with 30 rem or more into the 5 rem or more sample. Thus, that sample is weighted with higher DE groups. Even workers with 1 to 5 rem as a cumulative DE had some years with no exposure.

2 Methods
2.7 Radiation Exposures (cont'd)

There were discrepancies in the lifetime cumulative DE as reported on the medical and radiation files for 22 workers (8%) with the average difference in DE being 1.151 rem higher on the radiation file for those workers with a discrepancy. As in the Pearl Harbor data, 14 of the 16 annual entries which were in the medical file only, and 4 of the 6 entries in the radiation file only, had blank or zero DEs which represents 81.8 percent of the discrepancies. A comparison of the recorded DEs indicated that 35 (13%) of workers had at least one discrepant DE and 54 or 2 percent of the total annual DEs differed in the two sources. Most of the differences were due to coding errors, double entries, and the failure to correct an assigned DE. It is apparent that, since blank or zero DEs are unimportant in terms of worker exposure, there may be less effort at consistency in recording these measures. The main difference in DE was due to a prior exposure reported on the medical file but not the radiation history file, and an administratively assigned exposure of 36 rem reported on the computer radiation file which subsequently was corrected to zero on the medical file but not on the abstracted computer file. The correlation coefficient between the cumulative DE reported on the medical file and radiation file was 0.9875. For workers with a discrepancy, the dose was 1.151 rems higher in the radiation file but for all workers only 0.094 rem higher. The consistency of recording radiation data is as good at Portsmouth as it was at Pearl Harbor.

Tables 2.7.H through 2.7.M2, and Figures 2.7.E1 through 2.7.F2 present the analyses of the Portsmouth data for patterns of increments of exposure and DE accumulation. A "monthly" increment was defined as a recorded period of less than 45 days; therefore, if the exposure was recorded in two week intervals, there could be up to 26 "monthly" increments for a year.

Table 2.7.H shows, for each annual dose group, the proportion of "monthly" non-zero doses as a percent of all "monthly" DEs for each annual DE. At any annual DE level greater than 0.5 rem, 7 to 23 percent of the "monthly" readings have no recorded exposure. The proportion with zero DEs decreases with increasing annual DE as might be expected. At annual exposures greater than 1.5 rem, approximately 90 percent of the annual DE was comprised of non-zero "monthly" exposures. Therefore, there was not a substantial number of zero readings for higher annual DEs. If zero DEs represented true exposures at very low DE readings, they would not sum to a significant portion of the any annual DE of 0.5 rem or more. As seen on Table 2.7.I, the distribution of non-zero DEs at annual radiation levels of 0.5 rem to 0.9 rem indicates that less than 25 percent of the DEs are at levels where there might be problems in reading film accurately (0.02 rem or less). For all other annual DE levels, the increment at the 25 percentile should be accurately recorded by film badge.

Tables 2.7.J through 2.7.M, and Figures 2.7.E1 and 2.7.F show, for each annual DE, the frequency of specific "monthly" DEs as a percent of all "monthly" DEs. As shown in Table 2.7.J, individuals receiving annual DEs of 0 to 500 millirem had 59 percent of their monthly readings below 50 millirem and 15 percent below 10 millirem. Only 36 percent of the "monthly" readings were above 50 millirem. For those with an annual DE of 500 millirem or more, between 2 to 24 percent of the "monthly" readings were below 100 millirem depending on the size of the annual DE. Thus when workers have recorded 500 millirem in a year, less than one percent of their "monthly" DEs have occurred at readings which are below the minimal detectable level of 8-10 millirem.

It is also noteworthy that at the higher annual DE levels, about 10 percent of the monthly readings were at 1.0 rem or more and the remaining DEs between 0.1 rem and 1.0 rem. This pattern suggests that the high annual DEs were often represented by intermittent exposures at comparatively higher "monthly" DEs, as seen in the Pearl Harbor records as well. The majority of the "monthly" DEs for workers with annual DEs of 500 millirem or greater was represented by recorded DEs at levels of 0.1 to 1.0 rem. The graphic display (Figure 2.7.F) emphasizes how different the distribution of DEs was for workers with less than 0.5 rem in a year compared with those who had annual DEs of 0.5 rem or more. Only annual DEs below 500 millirem were predominately accrued by "monthly" DEs at the low levels close to the detectable minimum, where errors in reading the values are a source of concern.

In summarizing the Portsmouth data, the profile for 50 percent (median) of workers who had 0.5 to 1.0 rem indicated that they had worked in the nuclear program for about 8 years but received their dose in only 6 of the 8 years. In each of the 6 years in which a dose occurred, the median months of exposure is 2 (Table 2.7.G2). In Tables 2.7.L-2.7.M2 the data for this final dose of 0.5 to 1.0 rem were cumulated in 8 months as a median and 69 percent of the known monthly doses represented measurements of 0.1 to 0.9 rem. This again emphasizes that, while there are some doses which may be below accurate reading levels, for any cumulative dose above 0.5 rem the proportion of monthly doses below the 0.01 rem reading level is about one percent. The 14 percent of monthly doses which are between 0.01 and 0.05 rem are probably not affected by the measurement reliability. Therefore, what is reported as the measured dose is probably true representation of badge exposure and not a level artificially constructed through repeated estimates of non-existent exposures at low levels. For workers in the lowest cumulative dose there is clearly a shift to readings at lower levels. Still only five percent of the monthly doses are recorded as 0.001 to 0.01 rem and 72 percent of the readings are in the 0.01 to 0.1 rem range where the accuracy of film badge dosimetry is good.

The next step in assessing the pattern of accumulating DE was a determination of the annual DE levels which represented the total cumulative DE of workers. These data for the six Navy shipyards are presented in Tables 2.7.N through 2.7.R and in Figures 2.7.F3 and 2.7.F4. As can be seen in Table 2.7.Q, the higher the overall DE the greater the number of annual increments needed to reach that DE. It is also apparent from Table 2.7.R, however, that aside from DEs of 4 rem or more, the usual number of years required to reach the lifetime DE was only four to six. For most workers, then, the total DE represented only four to six annual DEs. In all Navy shipyards, anyone with a final DE of 500 millirem or more received 13 percent or less of his annual DEs at less than 100 millirem (Table 2.7.P). Thus most individuals' DEs, which are represented by the cumulative DE group of 500 millirem or more, were received in annual increments of 100 millirem or greater.

These patterns of exposure appear to be similar to those at Portsmouth. Thus, one would expect that the annual 100 millirem dose is represented by a few non-zero exposures per year. These doses would represent levels which are readable within the accuracy of the badge. This pattern of exposure again emphasizes that these shipyard workers get their exposures in short intervals which are spaced between non-exposure periods rather than a gradual daily accumulation of very low doses over many years.

TLDs for the Navy shipyards are read on a daily rather than a monthly basis as were film badge dosimeters. The cumulated DE which was recorded from the film may have represented the summation of daily doses some of which may be below the detectable level of the TLD. Since the shipyards all started to use TLDs in the early 1970s and all had changed to this device by 1974, a comparison of doses in three time periods which are defined by these years is shown in Table 2.7.S. The mean and median annual doses did drop after the introduction of TLDs. However, the shipyards have continued to advocate tighter controls on exposures over the years, so it is not possible to determine the effect of changing dosimetry devices by looking at exposure trends. The emphasis on man-rem reduction in all yards must have had a major effect. Data from Portsmouth did not indicate a similar drop about the time of the change in dosimetric procedures (Murray and Terpilak; 1983). However, the records from all shipyards indicate a 27 percent decline in total man-rems of exposure with only a 3 percent drop in personnel monitored (Occupational Report 1979). Newport News has continued to read the TLD on a monthly basis as with film badge. When the data are completely edited for that yard, the effect of change in the instrument only can be evaluated but for that yard only since a different TLD and variation in workload would influence the data.

It is useful to discuss whether the DE which was collected in the field was representative of the true DE which the worker received. The Navy developed specific recommendations regarding the location at which to wear the dosimetry device as well as procedures for reading of film badges and TLDs

2 Methods
2.7 Radiation Exposures (cont'd)

which have been designed to protect the worker even at the expense of overestimating a dose. Navy reports suggest that film measurements averaged 15 percent higher than actual radiation (Occupational Report, 1979). The difference in dose may represent a film badge's over-response to the lower energy radiation from shielded cobalt-60 which is present at the work site. For many reasons, the tests of reliability (accuracy and precision) of measurements in the laboratory may not reflect the problems of reading dosimetric badges which come from field conditions.

The question arises whether the worker was wearing his dosimeter at all times and whether he wore it at an appropriate spot to record the DE. In most cases, the worker wore the dosimeter on the chest which was usually the most appropriate site since he was working in an area where the radioactive products were present in his work material, such as pipe components. If his back was turned to the source of radiation for a significant period of time, measurements from a dosimeter worn on the chest could obviously lead to an underestimate of dose. The Navy has required dosimeters to be worn on the torso or head depending on where the worker was expected to receive the highest dose. This was obviously done for safety reasons. But from an epidemiologic viewpoint, this may have resulted in artificially high exposure measures in a few instances. Extremity monitors would be worn in addition to whole body dosimeters, if indicated. The intense level of supervision in the radiation control program should assure that the workers were appropriately monitored for compliance with work practice rules in regard to radiation.

Humidity, temperature, and other working conditions as well as degradation of gamma ray energy from scattering, may change the level of indicated exposure, based on dosimeter readings. It was impossible to determine what these error rates may have been on any given day in any given situation. Therefore it was impossible to do anything except recognize error factors which were not necessarily constant in all the DE data. If the major variation in these factors differed by yard because of the location of yards in geographic areas with different temperatures and humidities, then these variables could be standardized by controlling for yard of work. This was done in selecting the sample for analysis. The samples are matched by yard of employment.

There were two problems with field collection of badge data that needed to be addressed: unmeasured exposure and variation in field conditions. The serious concern regarding inadvertent exposures was that a high dose could have occurred without appropriate recording of dose, as in an accident or emergency situation where a dosimeter was lost. As noted, where the worker was in a high radiation area or reactor compartment there were at least two sources of information, the film badge or TLD and a pocket dosimeter.

In the absence of these devices, reconstruction of the events and area survey would be used in estimating the DE. There is no evidence of unmeasured exposures within the shipyard operations. Workers involved in ship decontamination following nuclear weapons tests and some off site exposures may have resulted in estimated doses but they are noted.

The second problem with information collected in the field involved the appropriateness of the film reading where there may have been differences in humidity, heat, and background exposure compared to the usual laboratory conditions which were used for standardizing badges. This could mean that the error rate for badges exposed in the field might be somewhat different than the error rate for badges under control situations such as those described in the laboratory tests which will be discussed later.

The shipyards placed a control badge at several badge racks located near the actual worksites. The purpose of the control badge was to help correct for incidental, non-occupational exposure of the film badge while it was not being worn and for effects of temperature and humidity; the effects of all of these factors could be taken into account in assessing doses provided the control badge was kept in a realistic environment which approximated that in which the employee's badge was stored while it was not being worn.

All DEs represent only the exposure at the surface of the body. No attempt has been made to estimate organs doses based on surface measures. The decision was made to use the reported DEs as reported and, if any risks are observed then to extrapolate to determine organ dose.

The Radiation Dosimetry Advisory Committee (see Appendix 3) addressed the issue of the true dose which was represented by a zero dose on a dosimeter. There seemed to be a lack of consensus about whether a zero or very low dose from a dosimeter reading actually represented an over- or underestimate of a worker's true exposure. It was clear that at exposures below about 1 millirem per day there was no way of distinguishing small and zero doses using a TLD read daily. The film badge might have detected a monthly increment of 10 or more millirems which could have represented 0.5 millirem a day if workers had been exposed in this way. Therefore an individual may have repeatedly experienced low levels in monthly increments using the film badge and daily increments using the TLD without the exposure being reflected in the record.

Since we have no way of being sure that a zero dose was actually a dose recorded by a worker who was working in a radiation area, or simply a zero dose for a worker who was qualified to work nuclear but actually was not in a radiation area, it is impossible to determine how many of those zero doses may have actually represented a small increment to his yearly dose.

One way of examining this problem was to look at the average number of years worked by a radiation worker at low dose levels, i.e., under 0.5 rem, and then calculate a "worst-case" scenario. The average number of years worked in radiation is 3.5. If the worker had received an amount of radiation representing about 20 millirem for every single monthly badge that was read as zero, the maximum amount that could have been achieved in a year was 240 millirem times the average number of years worked, which would equal 3.5 x 240 = 840 millirem. This meant that a person with a zero recorded dose, (if one determines the maximum exposure they could have received), might have really belonged in the lowest level of the radiation group, 0.5 to 1.0 rem. A similar exercise could be done for potential exposures of individuals with zero DE measurements using the TLD. In this case, the average of 3.5 years worked in radiation at 220 working days per year might represent a total of 770 exposure days. If a true exposure of 2 millirem per day is read as zero, an individual with a recorded cumulative DE of zero might have had an exposure as high as 1.5 rem. It is highly unlikely that these extremes would have occurred since, as indicated previously, individual DEs appeared to occur episodically suggesting that on other occasions there was no radiation in the vicinity of the worksite. However, the problem of under- as well as over-estimation must be kept in mind. These figures represent an estimate of the extremes in dose which might have been missed. It does mean that we should not try to separate individuals with recorded zero DEs who worked in the radiation areas, from those with actual DEs below 500 millirem.

Other concerns have been expressed that DEs might have been recorded for individuals which represented background levels. The Navy used a control badge to identify local background levels, and these readings were subtracted from the worker's readings. Individual technicians might have introduced some variation in measurements. But standardization and quality control procedures in the yards probably minimized individual variation.

It is recognized that it was difficult to interpret badge readings at the low dose range when base fog was present. Therefore, it was possible that some workers at low DEs actually might have received less than what was recorded but, again, with the average number of years worked by this group, it was unlikely that this error represented a higher cumulative DE than that described above. Therefore, if groups below 0.5 rem are considered as essentially control groups of workers, these potential errors in DE should not introduce problems. Compared to the measurement errors in other populations exposed to radiation, these errors in dosimetric measures in these shipyard workers must be small.

Reliability of Measured Dose

Concern has been expressed about the reliability of doses at the lower end of the range. It is clear that if one is to estimate a dose response curve that the important aspect of any errors is that they produce the same relative difference in doses throughout all dose levels so that the true shape of the dose response curve is maintained. In such a situation it might be possible to account for the shift in dose as it related to outcome. To examine this issue we asked the shipyards to provide information on their quality control audits as well as information which had been collected by an external review group. One external review was conducted by Battelle Memorial Institute in Richland, Washington in 1966 as part of a review of several private and governmental organizations who used radiation dosimetry. The second review was done in cooperation with the University of Michigan in 1980. The Navy also conducted quality control audits internally to determine the accuracy of the information provided by the dosimetry program. These audits were done both with the shipyard as well as by the Naval Sea Systems Command and the Bureau of Medicine and Surgery. In all these tests, film badges or TLDs were exposed to known levels of radiation usually from gamma ray sources and the dosimeters were then processed and read by the usual procedures in the shipyard. The results were then checked either by the external review group or within the Navy program. Table 2.7.T gives the sources of the audit check film data.

The data are presented in Figures 2.7.G and 2.7.H. The sources of the information varied as did the number of test readings available from each yard, as shown in Figure 2.7.G. The original results from these tests were provided to the Shipyard Study staff. The readings from the various studies have been computerized by variables and evaluated for discrepancies. For example, the Portsmouth Naval Shipyard received film irradiated by Battelle Memorial Institute in Richland in 1966 and evaluated the film density to determine exposure. The exposures ranged from 60 milliroentgen to 1,000 milliroentgen and radium daughter gamma rays were apparently the type of radiation from the source.

In general, the Portsmouth Shipyard reported exposures read higher than the actual exposure level, and there was remarkable consistency in the excess levels which were reported for specific doses. Of the six DEs at 500 millirem, for example, the shipyard read four out of the six at 554 millirem and two at 542 millirem. For those in which the exposure was 240 millirem, the DE in five out of six samples was 260 millirem, and only one of the samples was read as 252 millirem. Thus the technician performance was remarkably consistent.

The proportional error was higher at lower DEs such as those at 60 millirem, in which case the error was about 16 percent compared to known exposures at 1,000 millirem, where the error was only about 9 percent. But the absolute error level was highest for high doses. As reported by Battelle, the Portsmouth performance was very good in relation to other non-shipyard groups tested. In 28 films, 20 were read within ±10 percent and all 28 within ±20 percent of the exposure value.

Internal audit checks were done routinely, and summary reports have been provided for the years 1966, 1967, and 1968. The term "audit check" has been used by the shipyards to refer to evaluation of the performance of radiological technicians in reading film badges and TLDs following a known gamma ray dose. The yards varied in the number of samples which were submitted for this audit check. In addition, Portsmouth produced the film badge audit checks for 1975-79. At this time the Navy had discontinued using film badges for the nuclear propulsion workers although the radiographers still were using the film badges, as were materials test lab workers. So although the data indicated the proficiency of the radiological technicians in reading the film appropriately, it did not provide additional information on the accuracy of doses for workers in the nuclear propulsion program. It was useful, however, to determine whether the proficiency seemed to change at all between the years 1966-68 when one type of film was used and the period when other film such as Kodak type 3 was used in order to establish any potential change in measurement errors based on procedural changes over time. The later period, 1975-79, should represent the reading procedures at the end of the film badge period.

As shown in Figures 2.7.H1 and 2.7.H2, it was apparent that most of the shipyards were able to read film within the accepted range of errors, which were generally at plus or minus 25 percent. The percent error rates were obviously larger for lower ranges of readings even though the absolute difference was generally smaller. For example, at 175 millirem true dose, the reading of 203 would represent a 16 percent error rate even though the difference was only 28 millirem, but at upper ranges one could have an 8 percent or a 10 percent error rate, which actually represented a large difference in the absolute dose which the individual would have received. Figures 2.7.I and 2.7.J show the corresponding percent errors by actual dose for TLDs.

The important question is how much of an absolute difference there would be in an individual's measurements based upon any potential error in reading the film badge. An examination of Figures 2.7.K and 2.7.L on film badge audits, which compared delivered and measured doses at 1,000 millirem or less and at greater than 1,000 millirem, indicated an almost perfect correlation of 0.99 and 0.96 for each dose group, respectively. The difference in the means for the lower dose group was minus 2.96 millirem, and the difference for the higher dose group was minus 68.19 millirem. The actual mean percent error was much smaller than the acceptable standard for both dose levels, being 0.2 percent for the low dose (Figure 2.7.H2) and minus 4.57 percent (Figure 2.7.H) for the high dose measurements.

The data in Table 2.7.U examine the exact error rates for the early and late periods of badge readings. In the early period, the overall error rate was minus 1.2 percent and in the later period, it was plus 4.5 percent. The absolute variation in the error, however, was large in the early period. The yards involved in the testing in the two periods differed.

Table 2.7.U1 displays the errors in measured doses based on the actual dose level for all doses. These data indicate that the percent error and the absolute error became larger with increasing dose. The error changed sign and became negative at higher doses. However, the sample is small and so these errors might differ with a large number of measurements. Thus, although there was a tendency to read low at high doses, the measurements at low doses (which is the important range for this study) were actually higher than the true dose. In general, however, the readings are accurate, indicating that measurements recorded in this study should be very reliable.

The overall error rates were extremely small and the correlations were excellent. However, both the error rates and the absolute measured change differed by dose. Thus, the size of the error in a total dose would depend on whether that dose had been accumulated in many small increments or in a few relatively large doses. The other consideration would be the degree of variation in errors at each dose level. If the errors at low doses for example could be either positive or negative in an apparent random error, the total dose reported might be very close to the true dose. If, however, there was a consistent tendency to read the high doses lower than the actual value, the final error in a total dose which was accumulated from only true high doses might be read as a few percent lower than the actual dose.

To develop estimates of the error of exposure we would need to divide the errors into smaller increments and examine the patterns of exposure by month as reported in Portsmouth. Suppose, for example, two individuals have cumulated a dose of 5.0 rem in a year. On a case by case basis, it would be possible to examine the potential error rate. If one individual cumulated the dose monthly with ten doses just under 500 millirem and two at approximately 0 millirem, the weighted mean error might be 0.93 percent. If the pattern of accumulating annual dose was such that the individual had six doses at 800 millirem and six at approximately 0 millirem, the weighted mean error would be minus 1.63 percent.

It would be important to examine the effects of the complete change in dosimetric monitoring that occurred when there was a change from the use of film badges to the use of TLD dosimeters. All procedures changed in the yards at different points in time, but, from that point on, a different method of recording was used. In fact, most of the yards changed to more frequent measurements and therefore, the potential compounding of errors might differ from what it was in the original period of monitoring monthly with film badges. Preceding TLD conversion in the yards, the Navy conducted a careful trial of the reliability of TLD reading. This included delivery of known doses under controlled conditions and dual film/TLD use in the field.

Several of the yards participated with the University of Michigan in 1978-1982 in an evaluation of the accuracy of TLD measurements. Reports were made available to us for comparison of the performance of dosimetry using TLD to the previous tests in other reviews which used film badges. The yards involved were Portsmouth, Charleston, and Puget.

The results of these comparisons done by the University of Michigan are shown in Figures 2.7.I, 2.7.J, 2.7.M, and 2.7.N and Table 2.7.V. The correlations were excellent. The percent errors as shown on Figures 2.7.I and 2.7.J were larger than those seen with the film badge measurements and were all in the negative direction; that is, the reading was lower than the delivered exposure. However, these tests were not actually designed to compare the two methods so the samples were not large. Of course, these tests were done by an external review group, which differed from the internal comparison of film badge data which was reported. All of the yards involved had very low error rates both at doses which represented accident levels as well as the usual low occupational exposure doses.

Further consideration must be given to the possibility that this change in the direction of the error between film badge and TLD might influence potential trends in dose based on the time at which the dose occurred. Generally, TLD is considered very accurate whereas film is biased slightly upward. The error and the level of the reading may also be influenced by the fact that some of the yards read the dosimeter daily, one read it weekly, and one monthly.

One of the yards which was not investigated was Newport News, which uses a different type of TLD with lithium fluoride. Variations in dosimetry by yards have not been investigated at this time but there should be few differences because of the standardization of all procedures in the yards. Newport News was also the yard that read TLDs monthly. Since the samples were selected by yard, the analyses considered yard as a control variable to try to account for any potential differences.

In summary, the radiation programs in the shipyards are carefully designed and monitored with central oversight. Procedures for quality control are in place and review of internal and external checks of the reliability of the measurements indicate that the reported doses should represent the exposures closely. The consistency of major procedures across yards makes it possible to combine the data to increase population. Therefore, the shipyard workers represent an important population for the study of radiation effects.

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.A Sources of Potential Radiation Exposure at Portsmouth Naval Shipyard

Activity	Internal Exposure	External Exposure
Overhaul, repair, refueling of nuclear submarines	Corrosion and activation products [including cobalt-60], tritium, carbon-14 Fission products	Corrosion and activation products [including cobalt-60] Neutrons Fission products
Non-destructive testing (industrial radiography)	Radium in remote past, cobalt-60, iridium-192	Cobalt-60, iridium-192 X-ray

From: Murray WE, Terpilak MS "The Radiological Control Program of the Portsmouth Naval Shipyard", April 1983

[Editorial change]

Table 2.7.B
Results of Radiation Record Matching Between the NSWS and the Oak Ridge Associated Universities (OARU) 5-rem Study

Shipyard[1]	Total Workers Identified ≥5 rem in a Year by Either Study	By Both ≥5 rem	By Both NSWS <5 rem	Only OARU	Only NSWS	Difference OARU-NSWS
Charleston	167 (100%)	167 (100%)	0 (0%)	0 (0%)	0 (0%)	0
Groton	320 (100%)	292 (91%)	3 (1%)	0 (0%)	25 (8%)	-22
Mare Island	134 (100%)	114 (85%)	12 (9%)	1 (1%)	7 (5%)	+6
Norfolk	145 (100%)	114 (79%)	0 (0%)	1 (<1%)	30 (21%)	-29
Pearl Harbor	90 (100%)	55 (61%)	0 (0%)	0 (0%)	35 (39%)	-35
Portsmouth	179 (100%)	171 (96%)	0 (0%)	0 (0%)	8 (4%)	-8
Puget Sound	8 (100%)	0 (0%)	0 (0%)	0 (0%)	8 (100%)	-8
Total	1043 (100%)	913 (88%)	15 (1%)	2 (1%)	113 (11%)	-96

1 Data for the Newport News Shipyard was not available at the time of the comparison.

Table 2.7.C
Investigation of 99 Self-Reported Radiation Workers Who Had No Computer Record Indicating Radiation Work at the Norfolk Naval Shipyard (3/25/85)

- A total of 99 out of 14,387 interviewed reported wearing a film badge or TLD, but were not on the computerized file of radiation workers

- A total of 67 workers out of the 99 workers contacted by telephone follow-up still reported wearing a film badge or TLD

- Of the 67, 50 had a medical record at Norfolk
  16 did not have a medical record present
  1 was missed in pulling medical records

- For the 67 workers, their employment status is as follows:
  46 still employed
  20 terminated (of which 4 still had a medical record present)
  1 unknown

- A review of 50 available medical records resulted in the following explanations for misclassification:

  - The worker is qualified to work radiation at Norfolk and he was exposed in 1982 or after 1982. This is a definitional problem of timing as the Shipyard Study defines the nuclear worker population on the basis of dose received through 1981. Total in this group = 26.

  - The worker worked at another yard (usually Newport News) and was possibly exposed in that yard. No record of exposure is present in the Norfolk medical record and the Shipyard Study database for Newport News was not complete at the time of review. Total in this group = 15.

  - Worker was a radiation worker in Norfolk and was exposed in Norfolk --possibly missed because record was a special assignment or an edit (missing record) problem. Total in this group = 3.

  - The worker is qualified to work radiation in Norfolk but he has never been exposed. Total in this group = 3.

  - The worker was possibly exposed in the military (Army, Air Force, Navy) but there was no record and he has not been exposed at Norfolk. Total in this group = 3.

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.D Comparison of 1981 and 1982 Cumulative Radiation Databases for Missing Workers and Missing Annual Workers

Shipyard[1]	Workers in 1981 Radiation Database	Workers Missing from 1982 Database	Annual Records in 1981 Database	Annual Records Missing from 1982 Database	Adequate Explanation of Missing
Charleston	6,551	1	36,097	4	4
Groton	25,777	[UA]	109,199	[UA]	[UA]
Mare Island	12,768	137	69,104	538	538
Newport News	[UA]	[UA]	[UA]	[UA]	[UA]
Norfolk	7,901	9	32,946	29	29
Pearl Harbor	6,419	0	36,822	5	0
Portsmouth	11,138	0	54,093	0	-
Puget Sound	11,203	1	58,901	9	9
Total	55,980 (100%)	148 (<1%)	287,963 (100%)	585 (<1%)	580

[1] Data from Groton and Newport News Shipyard databases had not been received at the time this table was created.

Table 2.7.E
Description and Results of the Pearl Harbor Radiation Exposure Data Validation

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- In August 1980, a sample was selected of 100 Pearl Harbor Naval Shipyard Radiation workers' medical records.
- The sample was stratified by cumulative DE--twenty (20) records of workers with a cumulative DE of <1 rem, twenty (20) records of workers with a cumulative DE of 1-4.999 rems and sixty (60) records of workers with a cumulative DE of 5 rems or greater were selected for retrieval.
- Of the 100 records selected, 84 records could be retrieved from the Regional Medical Center or from the Radiation Control office. (The Radiation Control office had recalled charts of inactive workers from the St. Louis federal records repository, but some were not received in the initial request.)
- All Form DD1141's (Form DD1141 records occupational exposure to ionizing radiation) were microfilmed for each worker in the sample. In addition all documents pertaining to employment medical exams and previous exposure were filmed.
- The data on microfilm were coded and validated independently.
- A cumulative life DE was computed for each worker in the sample by summing the annual DEs reported in the worker's medical record.
- The medical records file, containing 826 annual entries for the 84 workers in the sample, was matched to the Pearl Harbor radiation exposure files on social security number and year of exposure.
- All workers matched to the radiation file. A total of 836 annual entries were output from the match, of which 820 entries were present in both the radiation and medical files. A total of 2482 quarterly DE entries were included in these annual doses. Six annual entries were present in the medical but not radiation file. Of these, the medical record reported a zero DE for that year for four entries, and a blank DE for the year for two entries. Ten annual entries were present in the radiation but not the medical file. Of these, the radiation record reported a zero annual DE for one entry, a blank DE for eight entries, and a DE of 1.720 rems for one entry.
- Additionally, seven Form 600 records indicating a body scan only as part of an employment medical examination were present in the medical records but not noted in the radiation file.

(cont'd)

Table 2.7.E Description and Results of the Pearl Harbor Radiation Exposure Data Validation (cont'd)

- Each annual DE and each worker's lifetime cumulative DE were compared from the medical and radiation files. Discrepancies occurred in nine (1%) of the annual DEs in seven (8%) of the worker's records. The average difference between the radiation and medical annual DEs was 0.14 rem higher on the radiation file. On seven records, the discrepancies were due to one annual DE being a recorded zero versus a blank DE (either recorded or due to missing records). Two records had actual DE differences - one of 1.720 rems and other of 0.450 rem. This resulted in discrepancies in the cumulative lifetime DE of two (2%) of the workers.
- One of the annual DE discrepancies is likely due to a number reversal in coding on the radiation file. The medical records reported a DE of 2.830 rems, while the radiation records reported 2.380 rems.

2 Methods
   2.7 Radiation Exposures (cont'd)

Table 2.7.E1 Summary Statistics for Non-Zero Quarterly DE Increments by Annual DE[1] in 84 Pearl Harbor Radiation Workers

Annual DE Group (rems)	No. of[3] Quarterly DEs in Each Annual DE Group	Quarterly Dose Increments (rems)				
		Mean	Median	SD[2]	Percentiles 25	Percentiles 75
0.0-	1347	0.042	0.020	0.065	0.000	0.050
0.5-	310	0.206	0.143	0.020	0.050	0.326
1.0-	206	0.348	0.255	0.315	0.097	0.525
1.5-	175	0.466	0.379	0.408	0.118	0.670
2.0-	109	0.588	0.468	0.487	0.190	0.877
2.5-	95	0.757	0.740	0.564	0.303	1.181
3.0-	141	0.977	0.960	0.729	0.320	1.395
4.0-	80	1.148	1.110	0.706	0.572	1.645
5.0+	19	1.505	1.520	0.839	0.840	2.310

[1] DE information abstracted from the worker's medical record.
[2] SD = Sample Standard Deviation.
[3] For example, for annual doses of 0.0 to 0.5 rem, there were 1347 quarterly dose reports.

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.F
Average Percent of Annual DE by Size of Quarterly Increments[1] in 84 Pearl Harbor Radiation Workers

Annual DE Group (rems)	No. of Quarterly DEs in each Annual DE Group	Percent of Annual DE Quarterly Increments (rems)						
		0.001-	0.01-	0.05-	0.1-	0.5-	1.0-	2.0+
0.0-	1347	1%	21%	22%	55%	0%	0%	0%
0.5-	310	<1%	2%	6%	65%	27%	0%	0%
1.0-	206	<1%	<1%	2%	36%	46%	16%	0%
1.5-	175	<1%	1%	2%	26%	36%	36%	0%
2.0-	109	<1%	<1%	1%	17%	43%	29%	10%
2.5-	95	<1%	<1%	<1%	11%	28%	51%	10%
3.0-	141	0%	<1%	<1%	6%	17%	54%	23%
4.0-	80	0%	<1%	<1%	3%	14%	51%	32%
5.0+	19	0%	<1%	0%	0%	11%	31%	58%

[1] DE information abstracted from the worker's medical record.

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.G
Strategy for Selecting Records for Microfilming at Portsmouth Naval Shipyard

Cumulative DE Group[1]	Total[1] Workers	Intended Sample	Actual Sample Size[2]
<0.5	1495	10%	129
0.5-0.9	842	10%	73
1.0-4.9	2012	10%	162
5.0-9.9	631	100%	542
10.0-19.9	371	100%	368
20.0-29.9	167	100%	167
≥30	60	100%	59
Total	5578		1500

1 Of the total workers with cumulative DE ≥0.5 rem (4083), 605 (15%) only worked in the yard after 1974. These workers were excluded from the sample of radiation validation. Only workers employed at least one year during years of film badge use, 1959-1974, are included.

2 The intended sample size was not always achieved because not all medical records are kept onsite (Federal Records Center stored records were recalled but some could not be located).

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.G1 Description of the Portsmouth Naval Shipyard Radiation Exposure Data Validation

- In May 1986, in response to the Radiation Dosimetry Advisory Committee's request, records of exposure data (DD1141 records) and audit check film data for the Portsmouth yard were made available.
  - The DD1141 records consist of entries for each individual's film badge readings. Prior to 1960, film badges were read every 2 weeks. From 1960 to 1974, readings were made monthly. After 1974, records contain monthly badge entries based on summations of daily TLD readings.
  - A total of approximately 10,000 individual folders of DD1141's are on file at Portsmouth.
  - Audit check film data for the years 1966-68 and 1975-79 were obtained. The film badge audit data for 1975-79 is not directly relevant to workers in the Naval Nuclear Propulsion program since all workers in this program were on TLD by 1974 at Portsmouth.
- A sample of DD1141 folders stratified by cumulative DE and time in the radiation program was selected. After excluding workers who received all of their dose post 1974 (that is, they were never on film badge and both data sources appear to be from a computerized record) a 10 percent sample of workers in the <0.5-4.9 rem group and a 100 percent sample of the workers with cumulative DEs ≥5 rem were identified. The total number of individuals in the two samples = 1500.
- All of the records for the identified 1500 individuals were obtained and microfilmed. In addition, for a stratified random sample of the 1441 individuals with <30 rems lifetime exposure and all workers with ≥30 rems cumulative exposure (n = 119), information and documents pertaining to employment medical exams, previous exposures and estimated/assigned DEs were microfilmed.
- Data for the above sample of 119 workers and a second stratified random sample of 150 workers have been coded and extensively edited. A third stratified random sample of 266 workers has been coded but not edited.
- Analyses of DE validation against the annual radiation exposure tapes for the edited sample of 269 workers has been completed and presented in Table 2.7.G2 and 2.7.G3.
- Analyses of the data for patterns of increments of exposure and DE accumulation have been completed and are presented in tables and figures that follow. A "monthly" increment was defined as a recorded period of exposure <45 days; therefore if the exposure was recorded in 2 week intervals, there could be up to 26 "monthly" increments for a year.

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.G2 Characterization of Worker's Exposure in the Portsmouth Validation Sample

Description	All Workers	Final Dose Group (rems) 0.0-	0.5-	1.0-	5+
Number of Workers	269	31	30	31	177
Total Number of Annual Records	3357	132	207	229	2789
Total Number of Reported Periods of Exposure:	26,345	367	690	1024	24,264
Median Interval (days)	30.0	30.0	30.0	30.0	30.0
Mean Interval (days)	32.2	56.3	37.5	42.1	31.3
SD of Interval (days)	35.1	91.5	54.5	65.7	30.5
Number of Reported Periods of Exposure for Given Year:					
Median	9	2	2	3	10
Mean	7.8	2.8	3.3	4.5	8.7
Median Number of Annual Records Per Worker	13	3	6	6	16
Median Duration Worked in Radiation Program	13 yrs	4 yrs	8	8	16 yrs
Median Year of Entry Into Radiation Program	1960	1961	1963	1962	1959
Median Year of Last Reported Exposure	1973	1968	1970	1969	1976

Table 2.7.G3 Results for Portsmouth Naval Shipyard Radiation Exposure Data Validation

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- The exposure data recorded on the medical Form DD1141 was compared to the data recorded on the annual 1982 radiation exposure file for a sample of 269 workers receiving some exposure at Portsmouth prior to 1974.

- The sample included all 59 workers with a lifetime exposure of ≥30 rems and a random sample stratified by cumulative DE (210 workers).

- All workers matched to the radiation file. A total of 3,087 annual records were output from the match, of which 3,065 were present in both the medical and the radiation files. Sixteen annual records were present in the medical but not the radiation file. Of these, the medical reported a zero or blank DE for that year for fourteen records. There was one prior exposure record (XX) on the medical file but not the radiation file which contained an assigned exposure of 11.250 rem that could not be verified. Six annual records were present in the radiation file but not the medical file. Of these, the radiation record reported a zero or blank DE for four records. There was one prior exposure (XX) on the radiation file but not the medical.

- For 62 workers (23%), there were annual records with zero exposure reported on the DD1141 but no corresponding radiation report. After consultation with Mr. Keith Dinger, it was noted that for 1957-58 and 1963-66, zero exposures were not required to be reported on the NAVMED annual exposure file. These differences between reported blank and zero DEs were not counted as discrepancies.

- Each annual DE reported on the radiation file was compared to the sum of all period exposures reported in the medical record for a given year. There were a total of 35 workers (13%) with at least one annual DE discrepancy between the two sources occurring in their exposure history and a total of 54 annual records (2%) with discrepant DEs. The number of discrepancies for these workers ranged from 1 to 6, with 12 of the workers (4%) having more than one annual DE discrepancy in their exposure history. The average difference between the radiation and medical annual DEs for those records with discrepancies was 0.503 rem higher on the radiation file, with an overall difference of 0.009 rem higher on the radiation file. The difference was predominately due to a prior exposure assignment of 36 rem on the radiation file which was changed to zero on the medical but not on the radiation file. Discrepancies were determined to be due to coding errors (reversals, double counting of DEs, assigned DEs not getting corrected after previous employer report received) on the radiation file for 14 of the workers.

(cont'd)

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.G3 Results for Portsmouth Naval Shipyard Radiation Exposure Data Validation (cont'd)

- Each worker's lifetime cumulative DE was compared from the medical and radiation files. There were discrepancies in the lifetime DE for 22 workers (8%). The average difference was 1.151 rem higher on the radiation file for those workers with a discrepancy. Over all workers, the average difference in lifetime exposure was 0.094 rem higher on the radiation file. The main difference was due to the prior exposure of 11.250 rem reported on the medical file but not radiation file, and the uncorrected prior exposure of 36 rem reported on the radiation file. The correlation coefficient between the cumulative DE reported on the medical file and the radiation file was 0.9875.

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.H Number of Periods[1] Reporting Zero and Non-Zero Exposure by Annual DE Group for a Sample of 269 Portsmouth Radiation Workers

Annual DE Group (rem)	Non-Zero DEs		Zero DEs		Total DEs
	No.	%	No.	%	No.
0.0-	4410	48	4732	52	9142
0.5-	2328	77	690	23	3018
1.0-	1804	81	428	19	2232
1.5-	2163	87	333	13	2496
2.0-	1549	87	229	13	1778
2.5-	1492	90	170	11	1662
3.0-	2402	90	265	10	2667
4.0-	1593	91	151	9	1744
5.0+	1275	93	102	7	1377
Total	19016	73	7100	27	26116

[1] Period = exposure reported in an increment $\leq$45 days.

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.I Summary Statistics for Non-Zero Monthly Dose Equivalent[1] Increments by Annual DE for 269 Portsmouth Radiation Workers

Annual DE Group (rems)	No. of Monthly DEs	Monthly DE Increments[2] (rems)				
					Percentiles	
		Mean	Median	SD	25	75
0.0-	4410	0.036	0.017	0.057	0.007	0.040
0.5-	2328	0.100	0.058	0.118	0.023	0.129
1.0-	1804	0.151	0.098	0.162	0.040	0.207
1.5-	2163	0.190	0.126	0.195	0.052	0.261
2.0-	1549	0.237	0.171	0.225	0.066	0.350
2.5-	1492	0.263	0.194	0.235	0.077	0.384
3.0-	2402	0.315	0.256	0.262	0.105	0.466
4.0-	1593	0.368	0.319	0.285	0.140	0.552
5.0+	1275	0.422	0.358	0.599	0.153	0.587

[1] Dose equivalent data from the worker's medical record.
[2] Monthly increment = <45 days.

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.J Percent of Annual DE[1] by Size Of Monthly Increments[2] for 269 Portsmouth Radiation Workers

Annual DE Group (rems)	No. of Annual DEs	Percent of Annual DE Monthly Increments (rems)							
		0.001-	0.01-	0.05-	0.1-	0.5-	1.0-	2.0+	NM[3]
0.0-	1162	15%	44%	16%	20%	0%	0%	0%	6%
0.5-	335	<1%	9%	15%	59%	10%	0%	0%	6%
1.0-	236	<1%	4%	10%	62%	15%	3%	0%	6%
1.5-	242	<1%	3%	7%	58%	26%	2%	0%	4%
2.0-	175	<1%	2%	4%	51%	34%	3%	0%	6%
2.5-	149	0%	1%	4%	50%	36%	4%	0%	5%
3.0-	229	0%	1%	2%	45%	40%	6%	<1%	5%
4.0-	140	0%	1%	2%	36%	46%	9%	<1%	7%
5.0+	108	0%	1%	1%	31%	44%	5%	2%	16%

1 DE data from the worker's medical record.
2 Monthly increment = <45 days.
3 NM = Period of exposure not reported in months.

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.K Number of Reported Non-Zero Monthly DEs[1] Summed to Reach Annual DE for 269 Portsmouth Radiation Workers

Annual DE Group (rems)	No. of Annual DEs[2]	Number of Monthly Increments[3] Summed				
		Mean	Median	SD	Percentiles 25	Percentiles 75
0.0-	1162	3.8	2	3.5	1	6
0.5-	335	7.0	7	3.6	4	10
1.0-	236	7.6	8	3.6	5	10
1.5-	242	8.9	10	3.5	7	12
2.0-	175	8.9	9	3.5	7	12
2.5-	149	10.0	10	3.6	9	12
3.0-	229	10.4	11	3.7	9	12
4.0-	140	11.4	12	3.8	10	13
5.0+	108	11.8	13	5.7	11	15
Total	2776	6.8	7	4.6	2	11

[1] DE data abstracted from the worker's medical record
[2] A total of 581 zero annual DEs are not included in this table
[3] Monthly increment = a reporting period of ≤45 days

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.L Number of Monthly Periods[1] Reporting Zero and Non-Zero Dose Equivalent[2] by Cumulative DE for 269 Portsmouth Radiation Workers

Cumulative DE Group (rems)	Total Monthly DEs		DE for Monthly Period			
			Non-Zero		Zero	
	No.	%	No.	%	No.	%
0.0-	345	100%	76	22%	269	78%
0.5-	683	100%	262	38%	421	62%
1.0-	1005	100%	536	53%	469	47%
5.0+	24083	100%	18142	75%	5941	25%
Total	26116	100%	19016	73%	7100	27%

1 Monthly period = <45 days
2 DE data abstracted from the worker's medical record.

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.M Summary Statistics for Non-Zero Monthly Dose Equivalent[1] Increments by Cumulative DE for 269 Portsmouth Radiation Workers

Cumulative DE Group (rems)	No. of Monthly[2] DEs	Monthly DE Increments (rems)			Percentiles	
		Mean	Median	SD	25	75
0.0-	76	0.041	0.017	0.067	0.012	0.040
0.5-	262	0.074	0.028	0.113	0.012	0.080
1.0-	536	0.116	0.031	0.199	0.012	0.114
5.0+	19016	0.200	0.104	0.272	0.029	0.294

[1] DE data abstracted from the worker's medical record.
[2] Monthly increment = <45 days.

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.M1 Average Percent of Cumulative Dose Equivalent[1] by Size of Monthly Increments for 269 Portsmouth Radiation Workers

Final DE Group (Rems)	No. of Workers[2]	Percent of Cumulative DE Monthly Increments (rems) 0.001-	0.01-	0.05-	0.1-	0.5-	1.0-	2.0+	NM[3]
(0) 0.0-	27	4%	46%	8%	17%	0%	0%	0%	25%
(1) 0.5-	30	1%	12%	13%	52%	8%	0%	0%	13%
(2) 1.0-	31	1%	7%	7%	34%	25%	10%	0%	16%
(3) 5.0+	177	<1%	3%	5%	44%	32%	4%	1%	10%

[1] DE information abstracted from the worker's medical record.
[2] Four workers had a final DE of zero and are not included in this table.
[3] NM = Period of exposure not reported in "months" (intervals <45 days).

Table 2.7.M2 Number of Reported Non-Zero Monthly DEs Summed to Reach Final Cumulative DE for 269 Portsmouth Radiation Workers

Final DE Group (Rems)	No. of Workers[1]	Number of Monthly Increments[2] Summed				
					Percentiles	
		Mean	Median	SD	25	75
(0) 0.0-	27	2.8	2	2.2	1	5
(1) 0.5-	30	8.7	8	6.9	4	12
(2) 1.0-	31	17.3	11	19.7	3	23
(3) 5.0+	177	47.1	46	28.9	24	72
Total	265	34.8	28	30.5	6	59

[1] Two workers had a final DE of zero and are not included in this table.
[2] Monthly increment = a reporting period of <45 days.

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.N Summary Statistics for Non-Zero Annual Dose Equivalent[1] Increments for Navy Radiation Workers

Shipyard	No. of DEs Annual	Annual DE Increments (Rems)						
		Mean	Median	SD	Percentiles 25	75	90	99
Charleston	18239	0.835	0.319	1.188	0.057	1.14	2.48	5.02
Mare Island	29866	0.845	0.373	1.174	0.078	1.15	2.44	4.57
Norfolk	13145	0.843	0.251	1.388	0.043	1.01	2.62	5.29
Pearl Harbor	21545	0.661	0.190	1.580	0.050	0.78	1.95	4.25
Portsmouth	27084	0.743	0.276	1.144	0.051	0.94	2.15	4.88
Puget	23716	0.652	0.265	0.927	0.044	0.86	1.95	4.18
Total[2]	133595	0.759	0.280	1.232	0.054	0.97	2.26	4.63

1 Limited to Radiation workers with a cumulative DE of at least 0.5 rem by January 1, 1982. All annual DEs on these workers which were not zero represents the basis used for calculating the other table values.

2 Excludes the private yards, Groton and Newport News

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.0
Summary Statistics for Non-Zero Annual Dose Equivalent[1] Increments by Cumulative DE Group for Navy Radiation Workers

Cum. DE Group (rems)	No. of Annual DEs[2]	Annual DE Increments (Rems)						
		Mean	Median	SD	Percentiles 25	75	90	99
0.5-	15735	0.163	0.076	0.205	0.023	0.221	0.481	0.861
1.0-	10956	0.249	0.109	0.321	0.028	0.346	0.758	1.312
1.5-	9154	0.333	0.143	0.432	0.032	0.459	0.946	1.800
2.0-	7498	0.389	0.170	0.513	0.037	0.535	1.101	2.234
2.5-	6113	0.455	0.200	0.610	0.040	0.621	1.301	2.669
3.0-	10392	0.549	0.230	0.752	0.050	0.738	1.595	3.410
4.0-	8992	0.657	0.281	0.906	0.052	0.874	1.889	4.160
5.0+	64755	1.169	0.635	1.565	0.129	1.794	3.096	5.293
Total[1]	133595	0.759	0.280	1.232	0.054	0.974	2.259	4.632

1 Limited to Radiation workers with at least 0.5 rem cumulative DE by January 1, 1982. All annual DEs on these workers which were not zero represents the basis used for calculating the other table values.

2 Includes only the Navy Shipyards -- Charleston, Mare Island, Norfolk, Pearl Harbor, Portsmouth, and Puget Sound

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.P
Percent of Cumulative Dose Equivalent[1] by Size of Annual Increments for Navy Radiation Workers

Cum. DE Group (rems)	No. of Workers[2]	Percent of Final DE Annual Increments (rems)						
		0.001-	0.01-	0.05-	0.1-	0.5-	1.0-	2.0+
0.5-	3614	1%	5%	7%	51%	36%	0%	0%
1.0-	2296	1%	4%	4%	34%	32%	24%	0%
1.5-	1801	1%	2%	3%	27%	30%	38%	0%
2.0-	1353	1%	2%	3%	23%	26%	32%	13%
2.5-	1058	1%	2%	2%	19%	24%	30%	22%
3.0-	1713	1%	2%	2%	15%	20%	30%	30%
4.0-	1370	1%	1%	1%	12%	17%	27%	40%
5.0+	6727	0%	1%	1%	7%	11%	24%	55%

1 Limited to Radiation workers with at least 0.5 rem cumulative DE by January 1, 1982

2 Includes only the Navy Shipyards -- Charleston, Mare Island, Norfolk, Pearl Harbor, Portsmouth, and Puget Sound

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.Q
Number of Non-Zero Annual Dose Equivalent[1] Summed for Cumulative DE for Navy Radiation Workers

Cum. DE Group (rems)	No. of Workers[2]	Number of Non-Zero Annual Increments Summed: Mean	Median	Mode	SD	Percentiles: 25	75	90	99
0.5-	3614	4.4	4	3	2.8	2	6	8	13
1.0-	2296	4.8	4	3	3.3	2	6	9	15
1.5-	1801	5.1	4	3	3.4	3	7	10	16
2.0-	1353	5.5	5	3	3.5	3	7	11	16
2.5-	1058	5.8	5	4	3.6	3	8	11	16
3.0-	1713	6.1	5	4	3.7	3	8	12	17
4.0-	1370	6.6	6	5	3.7	4	9	12	18
5.0+	6727	9.6	9	8	4.6	6	13	16	21
Total	19932	6.7	6	3	4.3	3	9	13	19

1 Limited to radiation workers with at least 0.5 rem cumulative DE by January 1, 1982

2 Includes only the Navy Shipyards -- Charleston, Mare Island, Norfolk, Pearl Harbor, Portsmouth, and Puget Sound

Table 2.7.R
Years Required to Accumulate Cumulative Dose Equivalent[1] for Navy Radiation Workers

Cum. DE Group (rems)	No. of Workers[2]	Mean	Median	Mode	SD	Percentiles 25	75	90	99
		Years to Cumulative Dose							
0.5-	3614	5.4	4	2	4.6	2	8	12	20
1.0-	2296	5.7	4	2	4.8	2	8	13	20
1.5-	1801	5.9	5	2	4.8	2	8	14	19
2.0-	1353	6.3	5	2	4.8	2	9	14	20
2.5-	1058	6.8	6	3	4.9	3	10	14	21
3.0-	1713	7.1	6	3	5.1	3	11	15	22
4.0-	1370	7.6	7	5	5.1	4	11	15	22
5.0+	6727	10.3	10	7	5.3	6	14	17	23
Total	19932	7.6	7	2	5.4	3	11	15	22

1 Limited to Radiation workers with at least 0.5 rem cumulative DE by January 1, 1982

2 Includes only the Navy Shipyards -- Charleston, Mare Island, Norfolk, Pearl Harbor, Portsmouth, and Puget Sound

Table 2.7.S
Summary Statistics for Non-Zero Annual Dose Equivalent[1] Increments by Time Period (Film Badge Versus TLD)

Time Period[2]	No. of DEs[3]	Annual DE Increments (Rems)						
		Mean	Median	SD	Percentiles			
					25	75	90	99
1957-1973	80393	0.931	0.353	1.438	0.070	1.301	2.783	5.000
1973-1974	11827	0.720	0.361	0.937	0.070	1.051	2.035	3.523
1974-1981	41375	0.435	0.176	0.685	0.028	0.552	1.211	2.841

1 Limited to Radiation workers with at least 0.5 rem cumulative DE by January 1, 1982

2 Time period <1973 corresponds to use of film badges primarily, 1973-74 is a transitional period, and >1974 corresponds to use of TLDs primarily

3 Includes only the Navy Shipyards -- Charleston, Mare Island, Norfolk, Pearl Harbor, Portsmouth, and Puget Sound

Table 2.7.T
Sources of the Audit Check Film Data and TLD Intercomparison Data.

Type of Dosimeter	Yard	Years	Review Group
Film Badge[1]	Charleston	1967-68	Internal
	Groton	1966-68	Internal
	Mare Island	1967-68	Internal
	Newport News	1967-68	Internal
	Norfolk	1968	Internal
	Pearl Harbor	1967	Internal
	Portsmouth	1967-68, 1975-79	Battelle Internal
	Puget Sound	1966-68	Internal
TLD	Charleston	1978-82	U. of Michigan
	Portsmouth	1978-82	U. of Michigan
	Puget Sound	1978-82	U. of Michigan

[1] Results of the film processing checks were provided by the Navy for the given yards and years. These were independent checks performed without the knowledge of the photodosimetrist.

Table 2.7.U
Dosimetry Audits: Summary Statistics for Film Badge Audit Tests of Known Radiation Below 1,000 mrem by Time Period of Test

	Time Period of Audit Test		
	Total	Before 1969	1975 and after
Delivered Dose (mrem)			
N	733	551	182
Mean	367.4	398.4	273.4
S.D.	249.9	273.3	117.0
SE Mean	9.23	11.64	8.67
Min	0	0	10
1/4	175	164	200
Median	300	365	250
3/4	500	550	350
Max	1000	1000	600
Percent Error			
N	731	549	182
Mean	0.2	-1.2	4.5
S.D.	9.8	10.2	6.6
SE Mean	0.36	0.44	0.49
Min	-32	-32	-25
1/4	-5.71	-7.6	2
Median	0	-1.4	4.9
3/4	6	4.8	8.3
Max	35.3	35.3	17.3
Technical Error (sigma)			
N	733	551	182
Mean	24.7	27.1	17.4
S.D.	26.5	28.9	15.7
SE Mean	0.98	1.23	1.16
Min	0	0	0
1/4	7	7	7
Median	16	18	12.5
3/4	34	40	22
Max	222	222	93

2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.U1 Dosimetry Audits: Summary Statistics for Film Badge Audit Tests of Known Radiation Doses at All Dose Levels

	True Radiation Dose		
	<100	100-500	500-5000
Delivered Dose (mrem)			
N	89	488	272
Mean	58.0	297.6	1205.8
S.D.	30.6	118.0	686.1
SE Mean	3.25	5.34	41.60
Min	0	110	501
1/4	38	200	743
Median	58	300	971
3/4	80	400	1370
Max	100	500	4000
Percent Error			
N	87	488	272
Mean	0.1	1.1	-3.4
S.D.	13.9	9.3	8.3
SE Mean	1.49	0.42	0.51
Min	-32	-28.3	-29.6
1/4	-7.6	-4.5	-8.8
Median	0	2.3	-3.8
3/4	9.1	6.6	1.8
Max	29	35.3	46.0
Technical Error (sigma)			
N	89	488	272
Mean	6.2	20.3	87.7
S.D.	6.4	17.4	99.8
SE Mean	0.68	0.79	6.0
Min	0	0	0
1/4	1	8	28
Median	4	15	62.5
3/4	11	27	115
Max	29	110	930

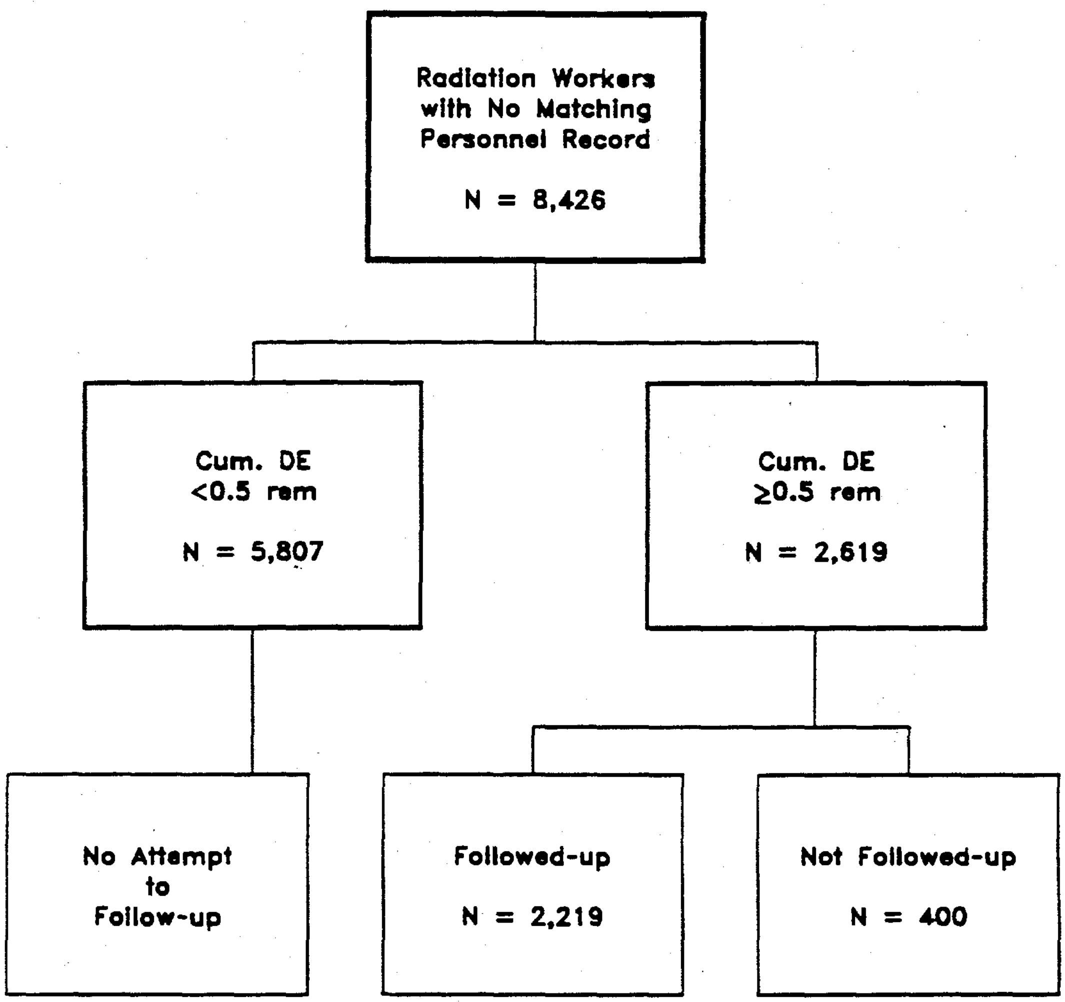
2 Methods
2.7 Radiation Exposures (cont'd)

Table 2.7.V Dosimetry Audits: Summary Statistics for All TLD Tests by Actual Radiation Dose

	Actual Radiation Dose (mrems)			
	<100	100-500	500-5000	5000+
Delivered Dose (mrem)				
N	31	45	26	74
Mean	63.3	207.4	1990.8	226821.8
S.D.	23.7	98.6	1583.0	243301.3
SE Mean	4.3	14.7	310.4	28283.2
Min	33	103	530	5064
1/4	41	138	714.2	20940.8
Median	55	186	1152.5	113000
3/4	86	247.5	3308	381750
Max	99	495	4941	790000
Percent Error				
N	31	45	26	74
Mean	-1.7	-7.3	-6.1	-4.0
S.D.	9.8	8.2	7.2	7.4
SE Mean	1.8	1.2	1.4	0.86
Min	-17.2	-22.3	-16.7	-21.4
1/4	-10.9	-14.2	-10.9	-8.8
Median	-2.0	-7.8	-6.7	-4.6
3/4	4.2	-2.0	-2.5	-0.3
Max	21.7	10.1	13.0	14.0
Technical Error (sigma)				
N	31	45	26	74
Mean	5.3	17.9	143.7	15816.7
S.D.	4.8	11.3	142.0	21914.7
SE Mean	0.87	1.7	27.8	2547.5
Min	0	1	15	0
1/4	1	9.5	51	913.2
Median	4	17	107.5	6695
3/4	7	23	193.5	19250
Max	18	50	643	90000

2 Methods
2.7 Radiation Exposures (cont'd)

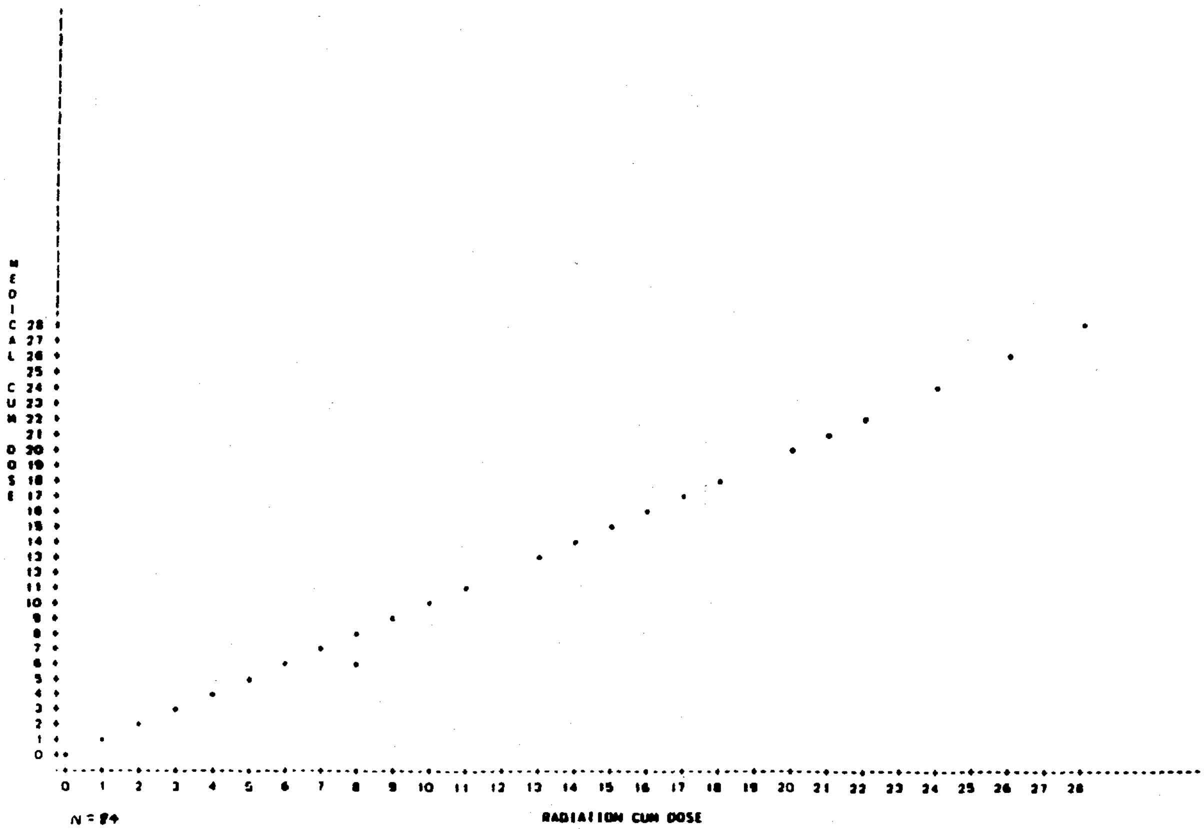
Figure 2.7.A Followup Status of Radiation Workers Excluding Newport News With No Matching Personnel Record



2 Methods

2.7 Radiation Exposures (cont'd)

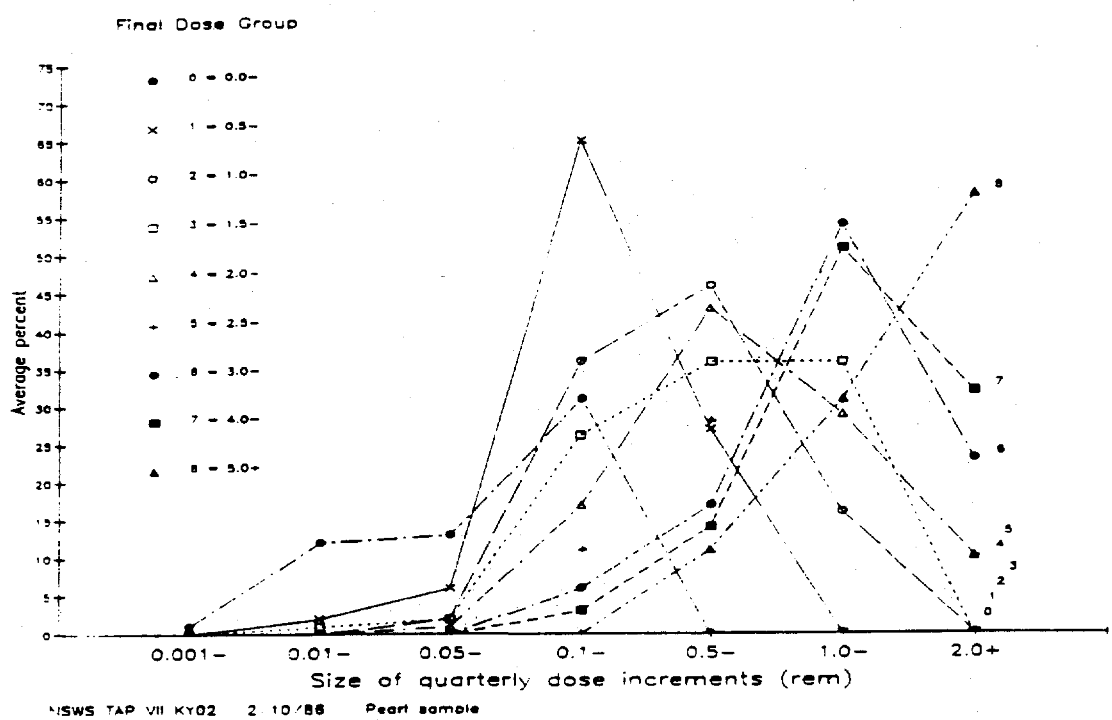
Figure 2.7.B Comparison of Cumulative Doses: Computerized Radiation Records vs. Medical Record, in 84 Pearl Harbor Radiation Workers



NOTE: Doses measured in rems (truncated to an integer). Two dose discrepancies occurred between the lifetime dose reported in the medical versus the radiation exposure records. The average difference in cumulative dose is 0.635 rems higher on the radiation records; the correlation coefficient is 0.9996.

2 Methods
2.7 Radiation Exposures (cont'd)

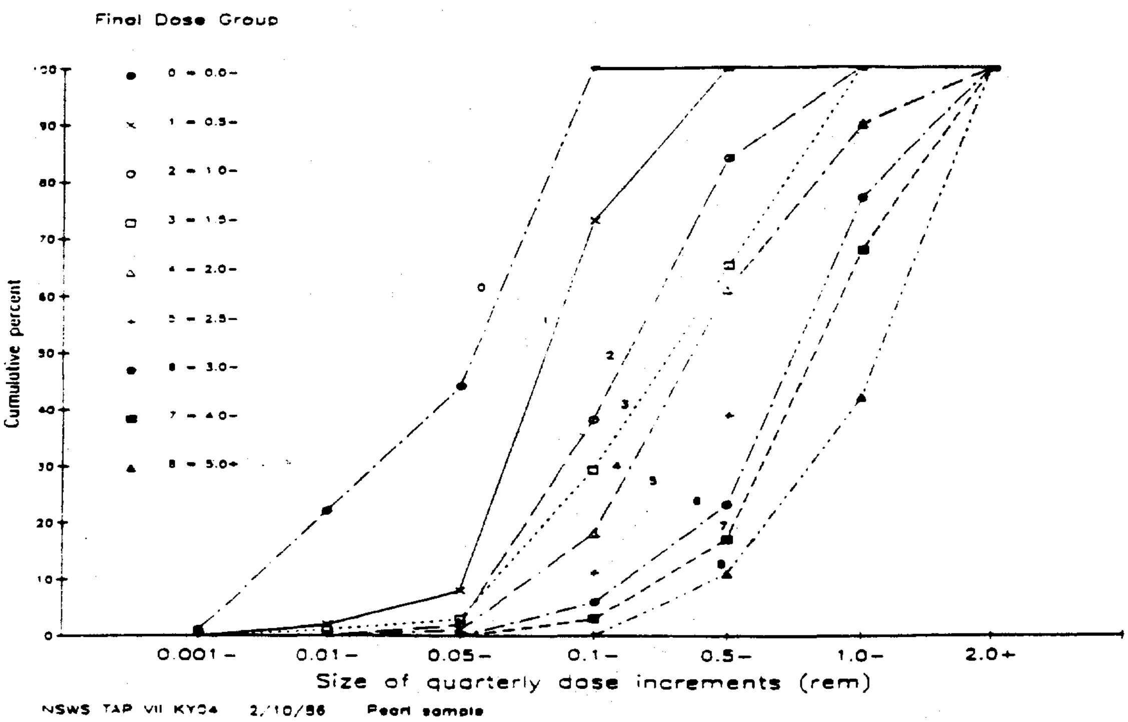
Figure 2.7.C Average Percent of Annual Dose by Size of Quarterly Increments for 84 Pearl Harbor Radiation Workers



2 Methods

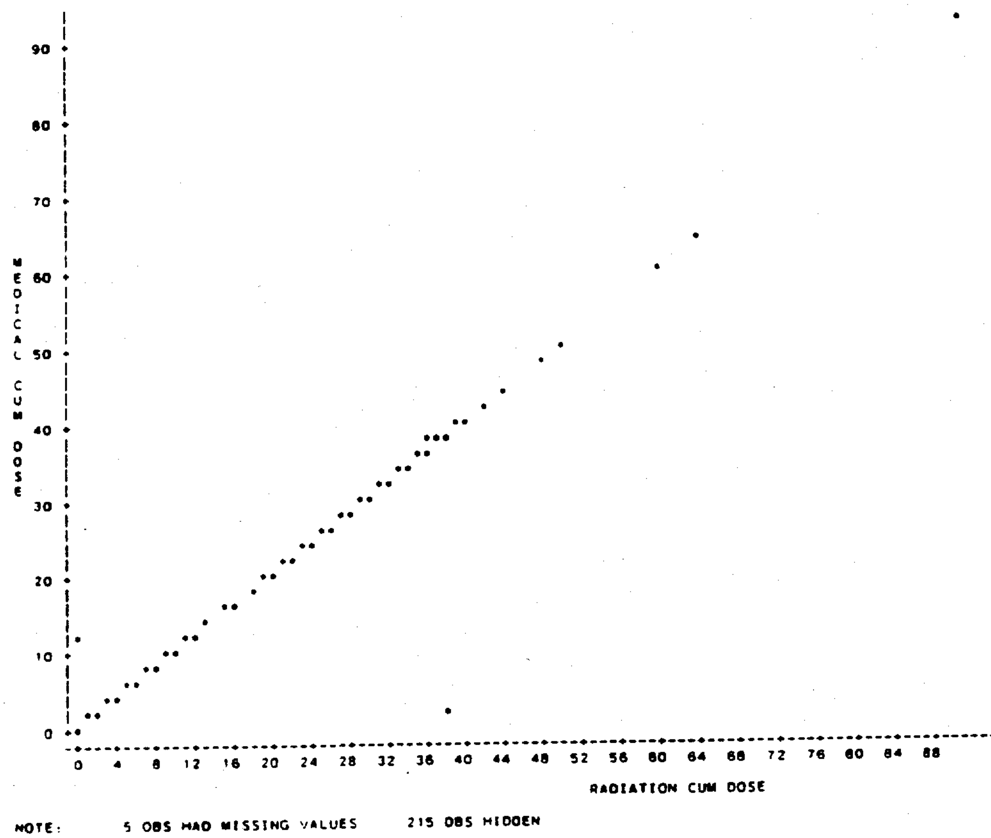
2.7 Radiation Exposures (cont'd)

Figure 2.7.D Cumulative Percent of Annual Dose by Size of Quarterly Increments for 84 Pearl Harbor Radiation Workers



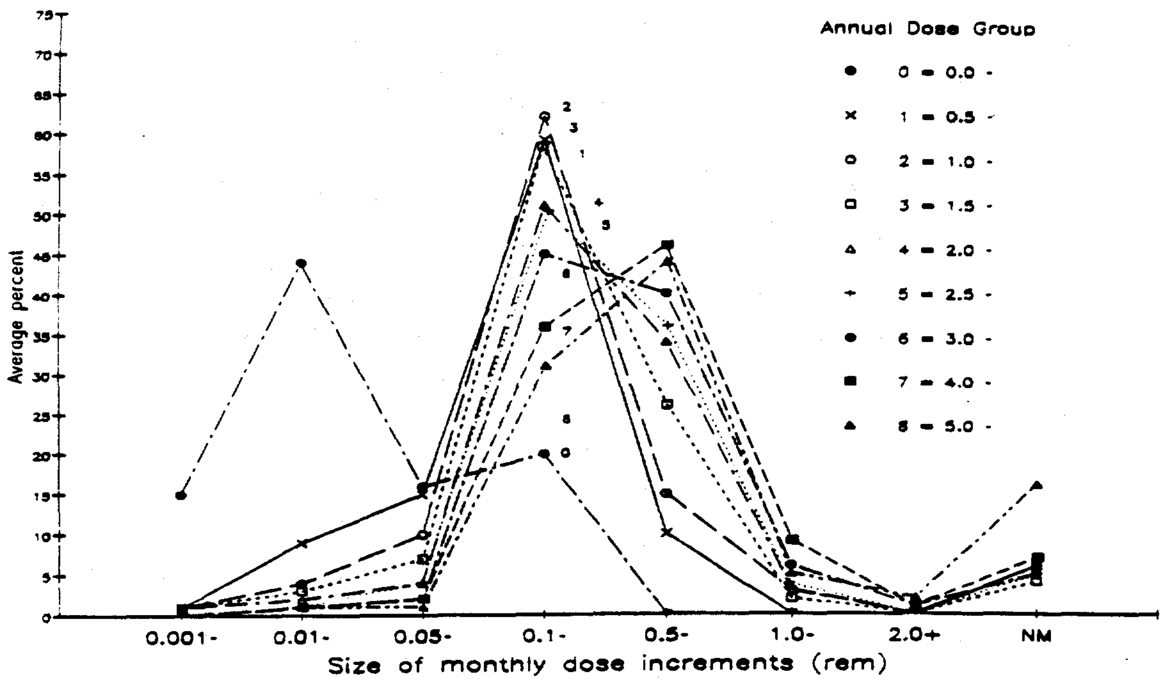
2 Methods
2.7 Radiation Exposures (cont'd)

Figure 2.7.E Comparison of Cumulative Doses: Computerized Radiation Records vs. Medical Record, in 269 Portsmouth Radiation Workers



2 Methods
   2.7 Radiation Exposures (cont'd)

Figure 2.7.E1 Average Percent of Annual Dose By Size of Monthly Increments for 269 Portsmouth Radiation Workers

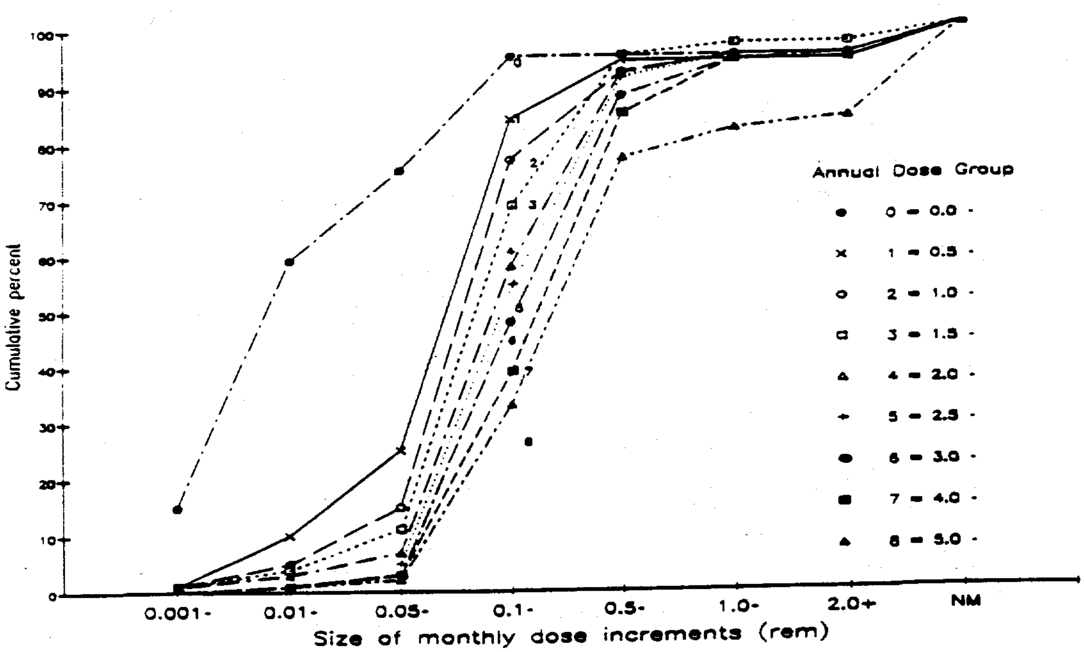


Note: NM = Exposure not recorded in monthly interval
NSWS FINAL KY02 1/20/88 Portsmouth sample 1.2.

2 Methods

2.7 Radiation Exposures (cont'd)

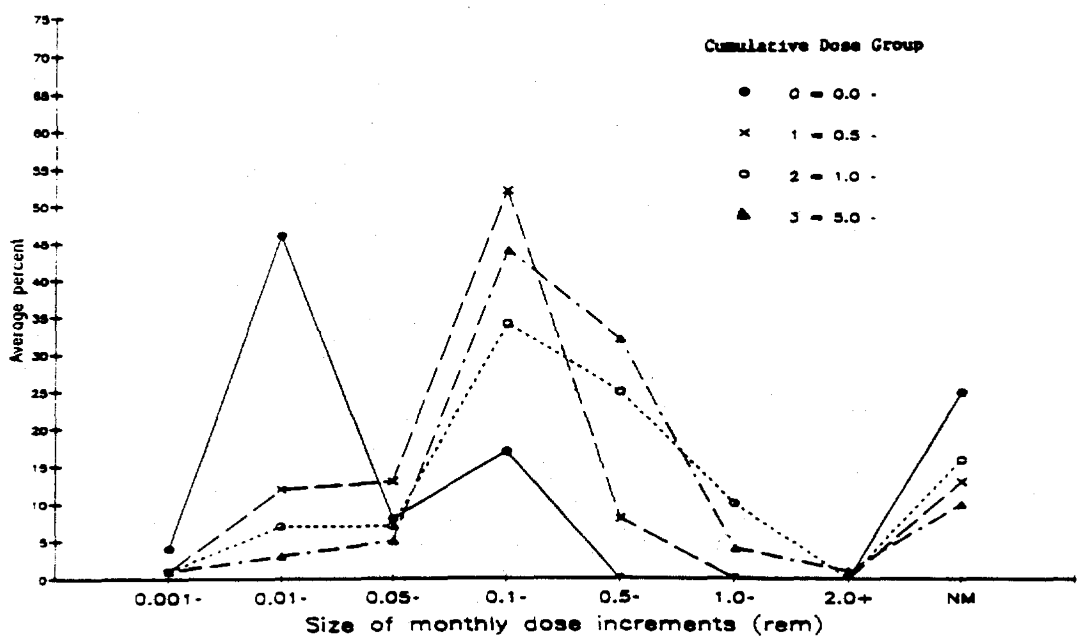
Figure 2.7.F Cumulative Percent of Annual Dose by Size of Monthly Increments for 269 Portsmouth Radiation Workers



Note: NM = Exposure not recorded in monthly interval
NSWS FINAL KY04 1/20/88 Portsmouth sample 1.2.

2 Methods
   2.7 Radiation Exposures (cont'd)

Figure 2.7.F1 Average Percent of Cumulative DE by Size of Monthly Increments for 269 Portsmouth Radiation Workers

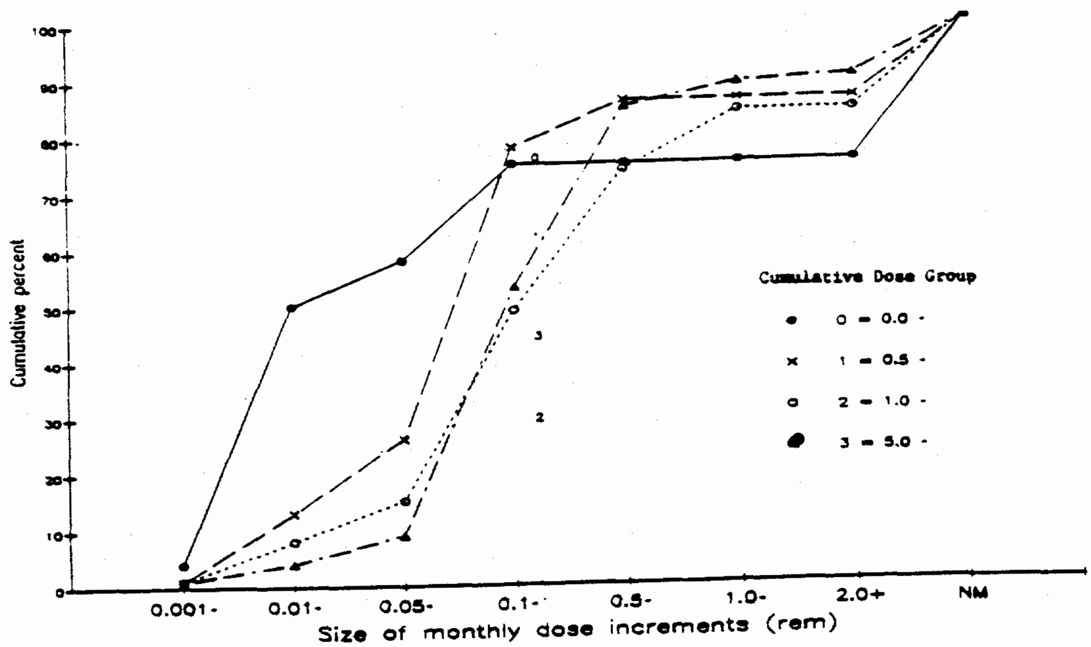


Note: NM = Exposure not recorded in monthly interval
NSWS FINAL KY01 1/20/88 Portsmouth sample 1.2.

2 Methods

2.7 Radiation Exposures (cont'd)

Figure 2.7.F2 Cumulative Percent of Cumulative DE by Size of Monthly Increments for 269 Portsmouth Radiation Workers

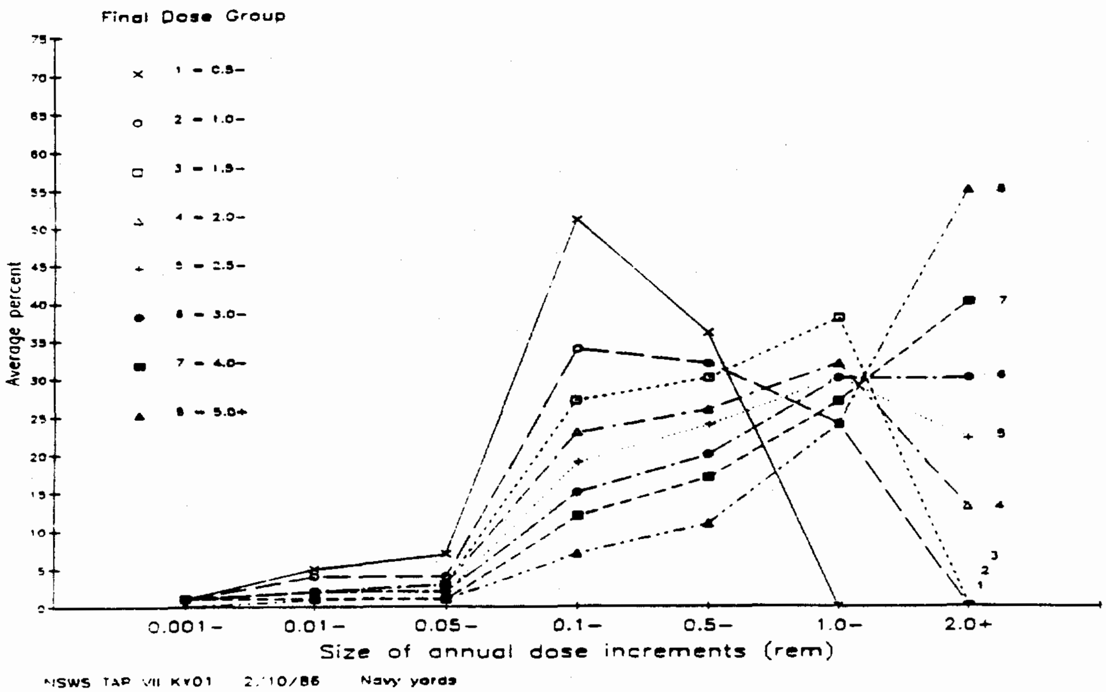


Note: NM = Exposure not recorded in monthly interval

NSWS FINAL KY03 1/20/88 Portsmouth sample 1.2.

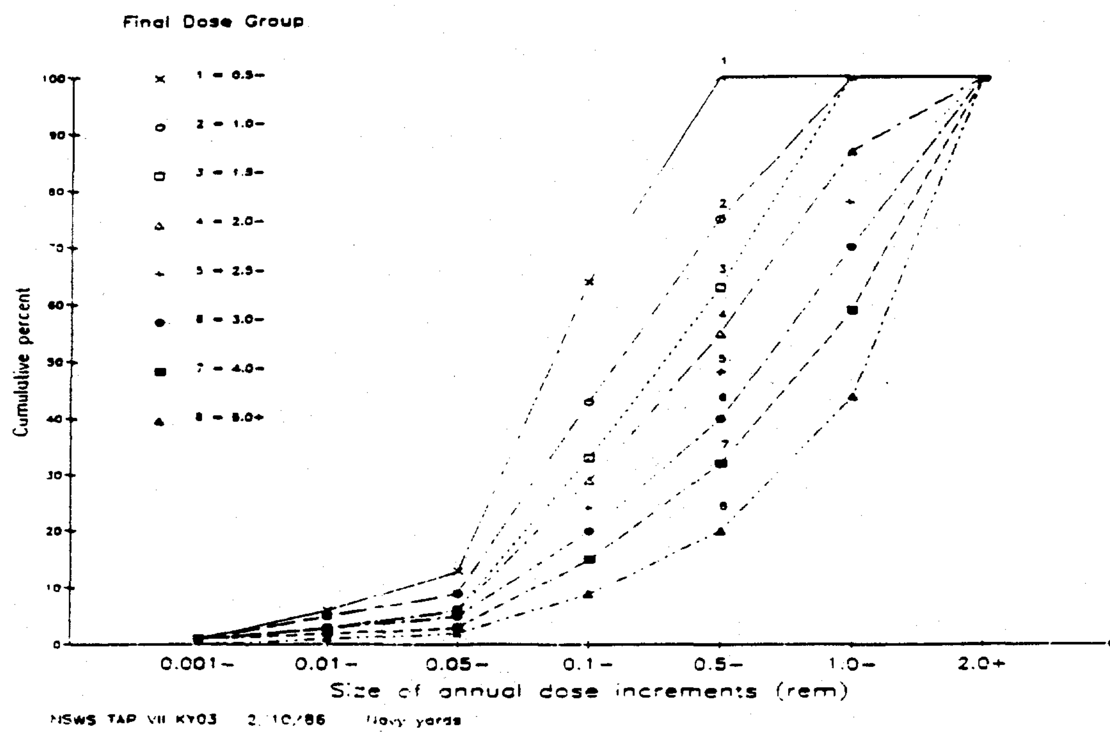
2 Methods
2.7 Radiation Exposures (cont'd)

Figure 2.7.F3 Average Percent of Cumulative DE by Size of Annual Dose Increments for Navy Shipyard Radiation Workers with at Least 0.5 Rem Cumulative DE



2 Methods
2.7 Radiation Exposures (cont'd)

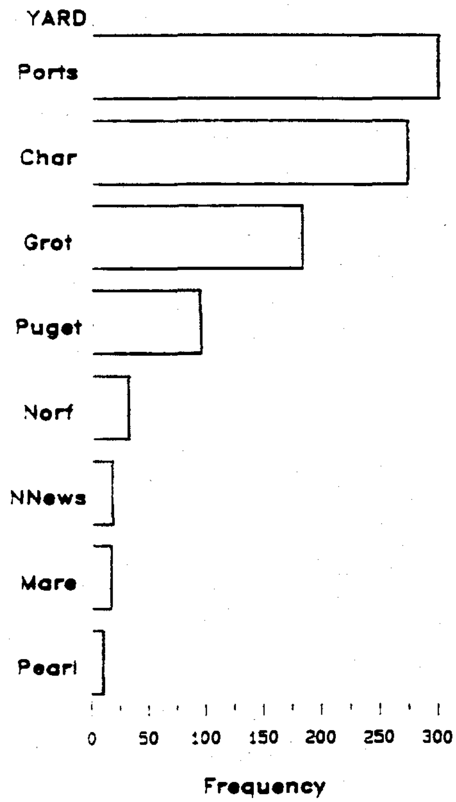
Figure 2.7.F4 Cumulative Percent of Cumulative DE by Size of Annual Increments for Navy Shipyard Radiation Workers with at Least 0.5 Rem Cumulative DE



2 Methods
2.7 Radiation Exposures (cont'd)

Figure 2.7.G Dosimetry Audits: Number of Tests by Shipyard

No. of Tests by Yard



YARD	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
Ports	398	398	38.83	38.83
Char	273	671	26.63	65.46
Grot	183	854	17.85	83.32
Puget	95	949	9.27	92.59
Norf	32	981	3.12	95.71
NNews	18	999	1.76	97.46
Mare	16	1015	1.56	99.02
Pearl	10	1025	0.98	100.00

Note: Dosimetry audits represent only those tests readily available for initial review.

2 Methods

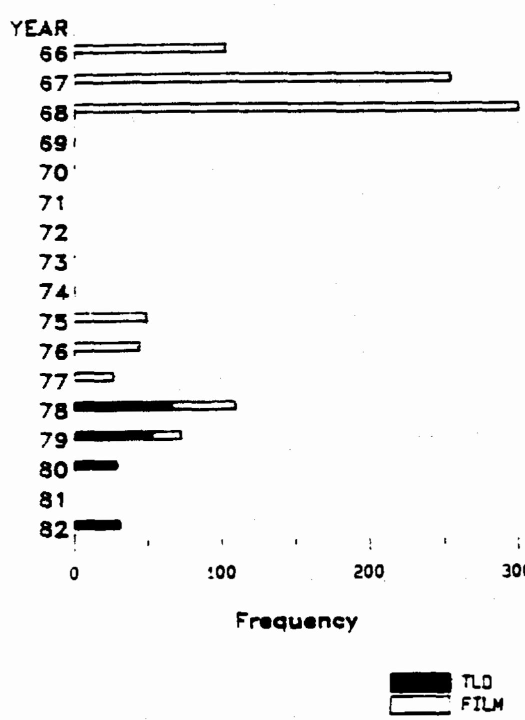
2.7 Radiation Exposures (cont'd)

Figure 2.7.H Dosimetry Audits: Number of Tests by Year and Whether for Film Badge or TLD

Dosimetry Audits

No. of Tests by Year

(Film vs. TLD)

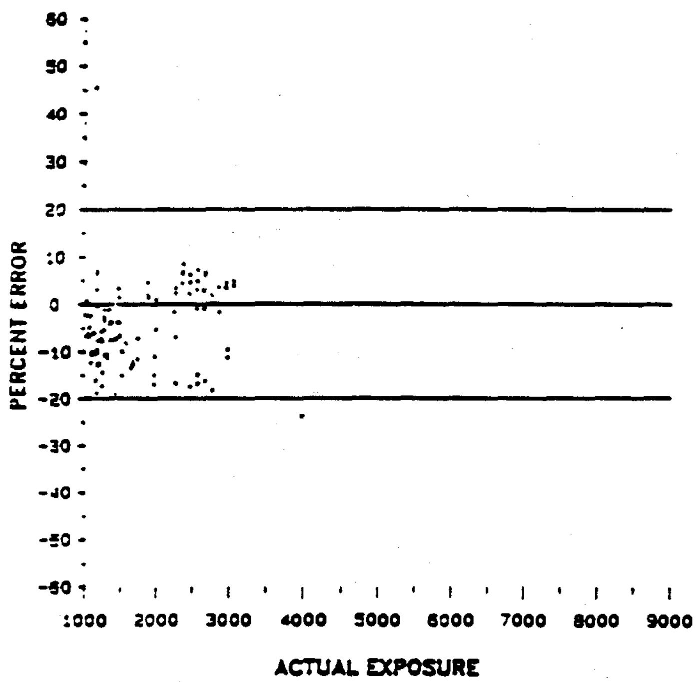


YEAR	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
66	103	103	10.05	10.05
67	254	357	24.78	34.83
68	310	667	30.24	65.07
75	49	716	4.78	69.85
76	44	760	4.29	74.15
77	26	786	2.54	76.68
78	109	895	10.63	87.32
79	72	967	7.02	94.34
80	28	995	2.73	97.07
82	30	1025	2.93	100.00

2 Methods

2.7 Radiation Exposures (cont'd)

Figure 2.7.H1 Dosimetry Audits: Percent Error of Actual Versus Measured Radiation Doses at >1000 mrem Using Film Badge (Internal)

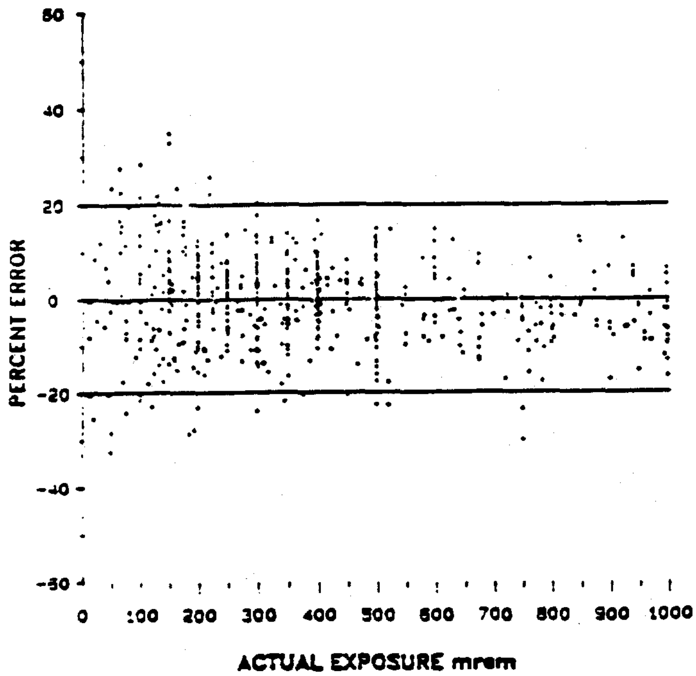


N = 116 r = 0.17

Mean (SD) Actual: 1802.75 (671.31)
P.E.: −4.57 (8.88)

2 Methods
2.7 Radiation Exposures (cont'd)

Figure 2.7.H2 Dosimetry Audits: Percent Error of Actual Versus Measured Radiation Doses at ≤1000 mrem Using Film Badge (Internal)

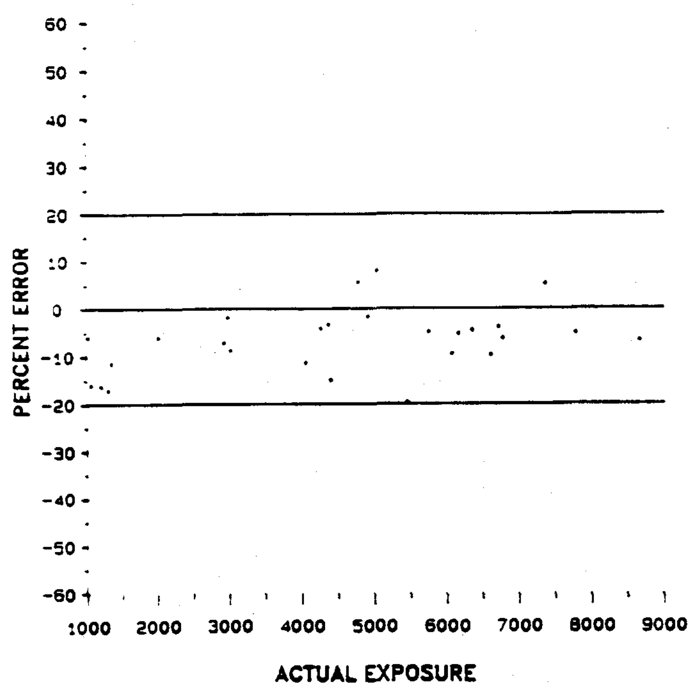


N = 731 r = 0.13

Mean (SD) Actual: 368.38 (249.48)
P.E.: -0.2 (9.78)

2 Methods
2.7 Radiation Exposures (cont'd)

Figure 2.7.I Dosimetry Audits: Percent Error of Actual Versus Measured Radiation Doses at >1000 mrem Using TLD (U. of Michigan)

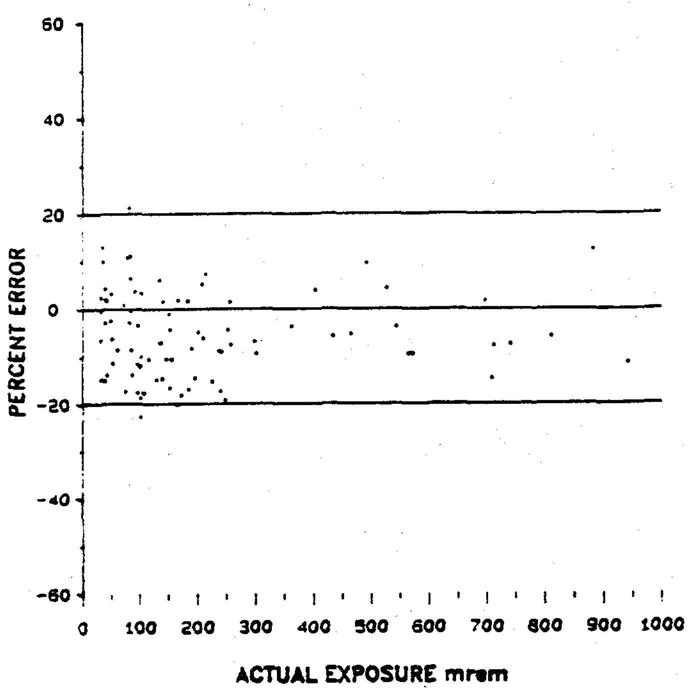


N = 30 r = 0.49

Mean (SD) Actual: 5031.53 (2570.91)
P.E.: -5.42 (7.13)

2 Methods
2.7 Radiation Exposures (cont'd)

Figure 2.7.J Dosimetry Audits: Percent Error of Actual Versus Measured Radiation Doses at ≤1000 mrem Using TLD (U. of Michigan)



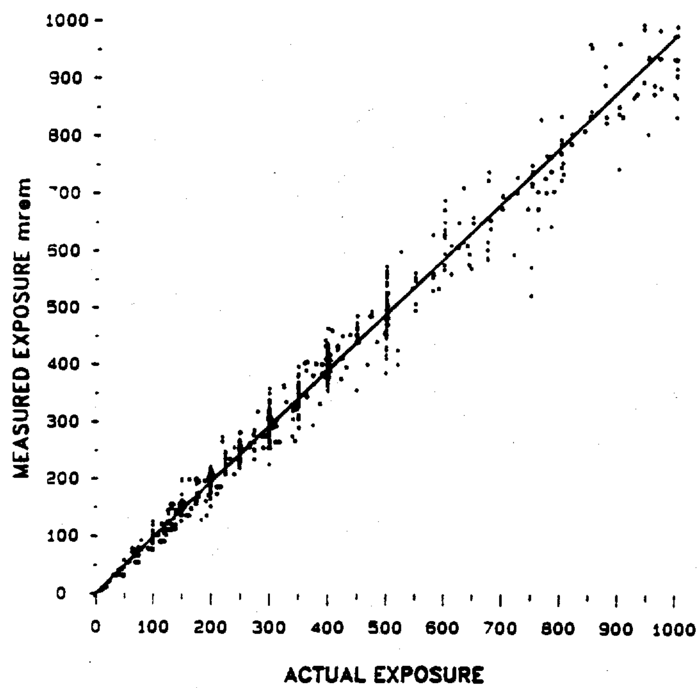
N = 87 r = 0.02

Mean (SD) Actual: 218.72 (215.07)
P.E.: -4.9 (9.07)

2 Methods

2.7 Radiation Exposures (cont'd)

Figure 2.7.K Dosimetry Audits: Measured Dose vs. Actual Dose at ≤1000 mrem Using Film Badge



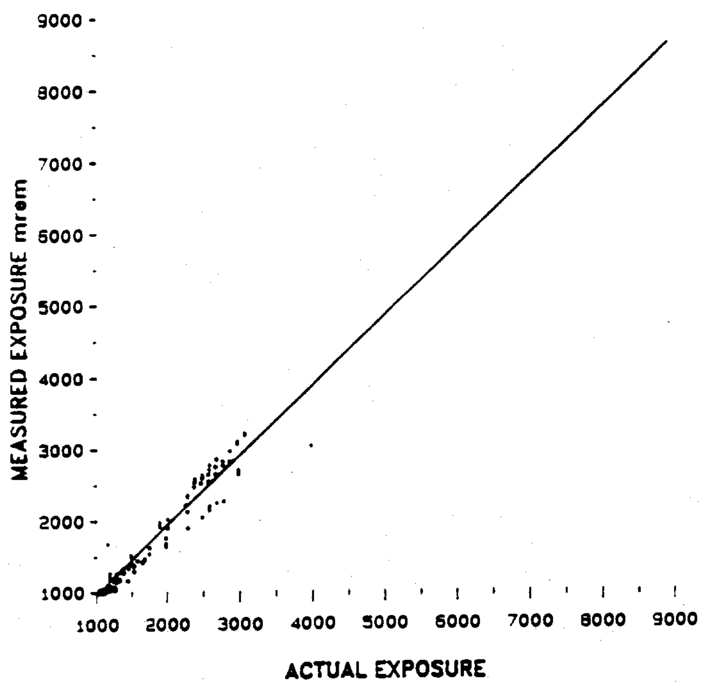
N = 728 r = 0.99 b = 0.98 (thru origin)

Mean (SD) Actual: 363.21 (245.6)
Measured: 360.25 (237.24)

2 Methods

2.7 Radiation Exposures (cont'd)

Figure 2.7.L Dosimetry Audits: Measured Dose vs. Actual Dose at >1000 mrem Using Film Badge

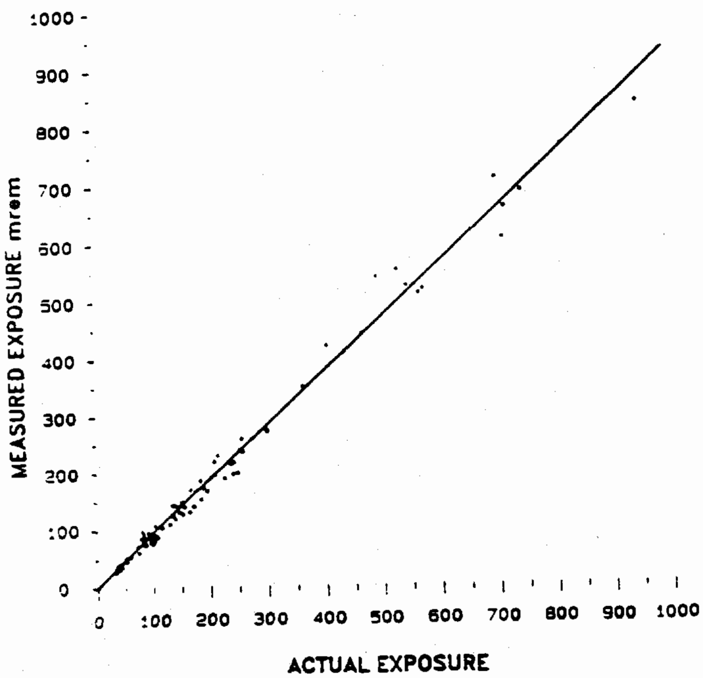


N = 109 r = 0.96 b = 0.97 (thru origin)

Mean (SD) Actual: 1846.08 (669.52)
Measured: 1777.89 (685.64)

2 Methods
2.7 Radiation Exposures (cont'd)

Figure 2.7.M Dosimetry Audits: Measured Dose vs. Actual Dose at ≤1000 mrem Using TLD



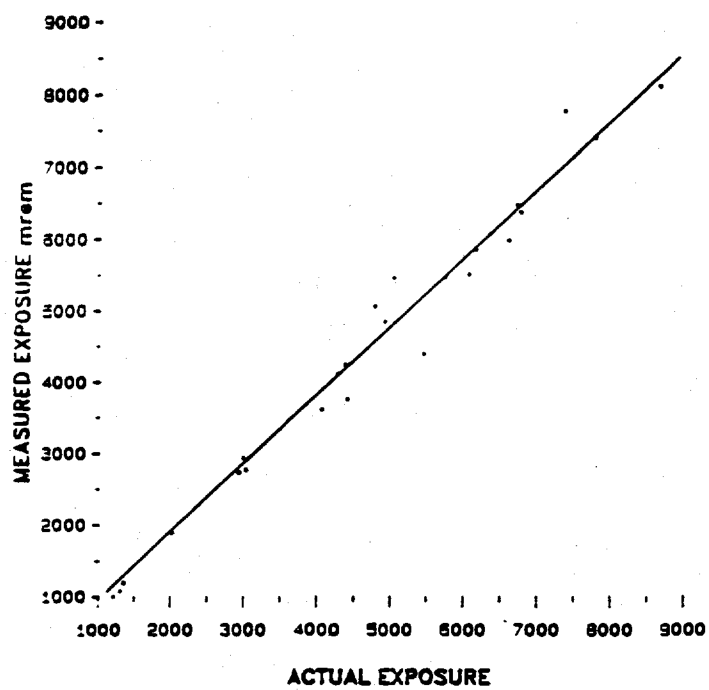
N = 87 r = 0.99 b = 0.96 (thru origin)

Mean (SD) Actual: 218.72 (215.07)
Measured: 208.34 (209.77)

2 Methods

2.7 Radiation Exposures (cont'd)

Figure 2.7.N Dosimetry Audits: Measured Dose vs. Actual Dose at >1000 mrem Using TLD



N = 28   r = 0.99   b = 0.97 (thru origin)

Mean (SD) Actual: 5315.14 (2418.25)
Measured: 5124.04 (2485.11)

2 Methods
2.8 Shipyard Occupations

The shipyard occupations held by nuclear and non-nuclear workers may represent an important confounding variable when considering the potential cancer risks from radiation. It was not practical to match nuclear and non-nuclear workers on specific shipyard occupations. However, an effort was made to control for the risks from occupations using a general classification scheme called the job hazard index. In addition, specific job titles were examined with regard to specific exposures. The methods used to assign specific exposure scores to job titles are described in Section 2.9.

In this section, we describe the assembly of the occupational title catalog which was used for coding occupational information from personnel records, the data coded, the coding procedure, the validity of using the last job title held as a marker of a worker's shipyard occupational history, and the development of the general job hazard index which was used for stratifying nuclear and non-nuclear workers for sampling.

Occupational Title Catalog (OTC)

The Occupational Title Catalog (OTC) is the manual for numeric coding of job titles. Essentially, it is a complete roster of all job titles and the variations in their form which have been used by the eight shipyards. Each title in the OTC has an associated two digit numeric code; this code represents a somewhat homogeneous cluster of job titles according to tasks.

The OTC was initially assembled from titles abstracted from existing shipyard rosters and files; it was expanded by reviewing a sample of Shipyard Study personnel records. Several thousand occupational titles were identified from these sources. The list was reviewed by the study team, including industrial hygienists, in order to define broad occupational title groups which combined those job titles which were thought to be associated with similar tasks and activities.

The occupational title groups were then reviewed by industrial hygienists, industrial relations managers, and radiation control officers from two shipyards to determine whether the groupings were appropriate and whether a group was comprised of titles with common but undefined industrial exposures. As a result of these reviews, 49 occupational title (OT) groups were defined. These are displayed in Table 2.8.A. Each OT group was assigned a two digit code.

Data Abstraction

With construction of the OTC completed, abstraction of occupation related data could begin. Occupational data abstracted from the personnel record included the last job title, the associated OT group code, the associated prefix, and the shop. The prefix indicates the worker's skill or designated management responsibility (e.g., apprentice, foreman, planner, etc.). Prefix codes are displayed in Table 2.8.B. The shop code indicates the worker's place of work or work group to which that job title belonged. The code can indicate an actual shop enclosure (e.g., machine shop) or a subspecialty (e.g., marine machinists whose primary place of work is on board the ship). Shop codes and associated job titles are displayed in Table 2.8.C.

The last job title of each male employed during the nuclear overhaul period (yard specific) and who had a social security number recorded on his personnel record was coded. The advantages and disadvantages of coding the last job title are described below.

Comparison of Occupational Titles: Last, Longest Held, All

Several options were considered for coding job titles: all titles, job title held longest, last job title held. Coding all job titles was desirable because the worker's complete exposure history could be profiled. A worker could then be included with any group in which he had spent time. Any definition for the time during employment when the job was held could also be used to characterize the worker. The major disadvantages of such an endeavor were the enormous amount of resources required, the large volume of data generated, and the technical difficulties in coding all job titles. The resources required to code all job titles on this large target population which was defined before sample selection exceeded the funds available. Second, the decision rules for identifying changes in job titles are complex, limiting this activity to highly skilled coders only. As a substitute for complete work history we considered coding only the job title held longest. While this would be the best single job title to use as a marker of complete shipyard work history, the task of identifying the job title held longest is also complex and time consuming, and in our experience, is done with a high rate of coding errors. In contrast, coding the job title held last is relatively easy. Thus, we opted for coding last job title as a proxy for complete work history at the shipyard and decided to reserve the very labor intensive task of coding all job titles for subsequent case-control studies or case-cohort studies.

The primary concern in using the last job title was that it may not, in fact, be a valid marker for the individual's complete work exposure history. Thus, to examine the relationship between last job and the individual's work exposure history, all job titles were abstracted on a random sample of 2,070 records. Last job title could be considered a valid marker of complete work history if a high proportion of an individual's employment in the shipyards (e.g., >80%) has been spent in work identified by the last job. For example, the last job title is a valid marker in those workers who hold the same trade (e.g., welder) but may change their shop or prefix (apprentice, journeyman, etc.) during their tenure.

A comparison of the composite proportion of person-time represented by the last job title (versus the total person-time employed) is displayed in Figure 2.8.A for the major job categories. With few exceptions the last job title in this study population is a highly valid marker of complete work history and similar to the job title held longest (Figure 2.8.B). This is not surprising, given that most of the workers at the shipyard are tradesmen who are invested in their trade by virtue of the time spent in training and so are unlikely to change trades.

Last job title was not a valid marker for three categories: laborer (23), engineman (09), and not specified (99). Laborers comprise a numerically large proportion of the workforce, but a much smaller percent of the person-time employed. Enginemen comprise a small and insignificant proportion of the workforce. Category 99 is unspecified and it is not surprising that the person-time represented by last job is low.

Job Titles for Nuclear vs. Non-Nuclear Workers

Following coding of all workers' last jobs in four yards, the distribution of jobs and prefixes for nuclear and non-nuclear workers were compared to identify whether differences existed between the groups. As shown in Table 2.8.C1, few jobs occurred with high frequency even though job titles had been combined to limit the number of possible groups to 49. Machinist is the most common occupational title in the yard, representing 13 percent of the workers. However, that title has two distinct groups within it, those employees who work in shops on shore and those who work on the ship. The other common occupational titles are electricians, engineers, pipefitters, shipfitters and welder -- each of which classified 7 to 8 percent of workers. All other occupational codes occurred in 4 percent or less of the employees.

Nuclear workers are more likely to hold jobs as engineers and pipefitters than non-nuclear workers. The nuclear worker is also more likely to be a boilermaker, electronics mechanic, electrician, physical science technician, pipecoverer, insulator, and rigger although absolute differences for these jobs are less than for engineers and pipefitters. The non-nuclear workers are clearly more likely to be laborers, shipfitters, welders, and to hold administrative posts.

As shown in Table 2.8.C2, the level of experience as indicated by the job prefix demonstrates that nuclear workers have superior skill ranks within their jobs or trades in their last jobs compared to non-nuclear workers. This observation may indicate a selection of the skilled employees into nuclear work or a longer duration of work among nuclear workers which has resulted in their advancement into high skill categories compared to non-nuclear workers. As can be seen, over half of the jobs have no prefix. This may reflect the fact that non-trade jobs have no skill rank.

A further analysis of the date of entry into last job indicates that nuclear workers entered the last job at a later date than non-nuclear workers. This suggests that nuclear workers have remained in the workforce longer than non-nuclear workers. If, however, we remove the individuals who must have been working in the early years of overhaul because they entered the last job before 1954, the distribution of dates of entry are more similar in the two groups but the nuclear workers still enter the last job at later dates, probably due to long periods of employment.

Potentially Hazardous Jobs: Job Hazard Index

It was not feasible to stratify the nuclear and non-nuclear workers for the 49 specific occupational titles as well as the other stratification variables in order to create a sampling frame for selecting the non-nuclear and <0.5 rem workers. The number of strata is too high and many of the OTC strata might have no individuals in subgroups. As an alternative, occupational titles were clustered into seven categories corresponding to a range of industrial hazards. The nuclear and non-nuclear workers were group matched on these seven categories in the stratified random sample.

The list of 49 occupational title categories and a sample of specific job titles included in each category were sent to seven industrial hygienists who were asked to score them on a nine-point scale of hazard exposure. The scoring was to be based on potential exposure to hazardous substances excluding radiation, noise, thermal changes, and physical forces. The hygienists were instructed to indicate multiple scores for a category if they believed the jobs included were not homogeneous in exposure. The scoring definitions read as follows:

- 0: insignificant or no exposure
- 1-2: minimal or low and infrequent exposure
- 3-4: low and occasional exposure
- 5-6: low to moderate exposure at frequent intervals or occasional exposures at high levels
- 7-8: high and frequent exposure

The industrial hygienists were asked to explain their ratings and to note the substances which were associated with that job. Most of these hygienists had some experience with work in shipyards, but the extent and time of that experience varied.

Most job groupings received a single rank from all respondents.

2 Methods

2.8 Shipyard Occupations (cont'd)

The job categories which were included in "high", "medium" and "low" rankings for subsequent sampling purposes are shown in Tables 2.8.D. Because some titles had wide differences in the scores, outliers were removed and a score was given to the jobs. The scores were grouped into high, 5-8; medium, 2-4; and low, 0-1 for sampling purposes with the fourth category a "missing" score. The score was simply to be used to separate administrative and non-hazardous types of jobs from those with potential exposures in order to provide a general balance between nuclear and non-nuclear workers in the sample. Since all workers have a last job, it was possible to classify the majority of the population by hazard scores for sampling purposes.

As can be seen in the Table 2.8.D, in general, jobs such as welder, pipecoverer, boilermaker, firefighter, etc., were ranked at highest potential exposure because of agents associated with the work. As might be surmised from this job grouping, the presumed hazardous exposures for jobs within a group are not consistent. Categories such as machinist, mechanic, and shipfitter were classified as intermediate in rank. Medical personnel and stockroom workers as well as the administrators and engineers are at low risk. Since engineers are common among nuclear workers, the sampling scheme which balances hazard index might balance engineers in nuclear workers with administrative jobs in non-nuclear workers. While this may not be a perfect balance of potential hazards, it would be an important first step in creating sample groups that have similar general occupational hazards. It would certainly distinguish blue collar from white collar workers and balance the nuclear and non-nuclear groups at least in terms of these general categories.

2 Methods
2.8 Shipyard Occupations (cont'd)

Table 2.8.A
Occupational Title Groups (49 Categories) for the Occupational Title Catalog

Code	Occupational Title Group	Code	Occupational Title Group
88	Administrative	25	Machinist/maintenance/marine
01	Aircraft workers	26	Marine engineer
02	Air conditioning equipment mechanic	27	Mechanic
		28	Medical group
03	Boilermaker	29	Motor vehicle operator
04	Crane operator		
05	Electrician	30	Nuclear engineering
06	Electronics mechanic	31	Oiler
07	Electroplater	32	Painter
08	Engineer	33	Physical science technician
09	Engineman	34	Pipe coverer & insulator
10	Facilities & public works	35	Pipefitter
11	Firefighter	36	Plumber
12	Forgers	37	Rigger
13	Foundry molder	38	Ropemaker
14	Galvanizer	39	Sandblaster
15	Gas detection monitor	40	Sawsmith
16	Gas plant operator	41	Sheetmetal mechanic
17	Guards & police	42	Shipfitter
18	Heavy mobile equipment mechanic	43	Stockman
19	Industrial hygiene	44	Student/summer aide
20	Industrial test lab	45	Tank & equipment cleaner
21	Instrument mechanic	46	Upholsterer
22	Joiner	47	Welder
23	Laborer	99	Not specified
24	Loftsman		

Table 2.8.B Prefix Codes for Shipyard Occupations

Prefix Code	Prefix description
01	Apprentice
02	Helper/Trainee/Aide/Learner
03	Worker/Limited/Repairer/Installer/Handyman
04	Journeyman
05	Junior/Assistant/Under
06	Instructor/Training Leader/Training Instructor
07	Leader/Snapper/Head/Chief
08	Foreman/Leadingman/Supervisory/Asso. Supervisory/Senior/ Superintendent/Associate
09	General Foreman/Quarterman/Chief Quarterman/Senior Supervisory
10	Inspector Shipboard/Inspector Surveillance
11	Inspector Other
12	Planning & Estimating
13	Production Shop Planning/Production
14	Quality Assurance/Control/Quality Inspector Division/Quality Analyst
15	Ship Progressman
16	Ship Scheduler
17	Ship Surveyor
18	Ship Systems/Ship
19	Shop Analyst & Scheduler/Production Scheduler/Scheduler
20	Shop Planner
21	Test Specialist/Systems Test/Ship Test/Test Technician

Table 2.8.C Job Titles Most Frequently Associated with Shops and Series Codes

Shop or Series Code	Associated Job Titles
Part A.	Shops
01	Shipyard Commander's Office Administrative Jobs
02	Transportation Shops Crane Operator, Electrician, Engineer, Engineman, Heavy Mobile Equipment Mechanic, Laborer, Mechanic, Motor Vehicle Operator, Oiler
03	Utilities Shop Boilermaker, Electrician, Instrument Mechanic, Laborer, Pipefitter, Plumber
05	Radiological Control Office Physical Science Technician
06	Central Tool Room Air Conditioning/Refrigeration Equipment Mechanic, Electrician, Electronics Mechanic, Laborer, Machinist/Maintenance/Marine, Oiler, Sawsmith
07	Maintenance Shop Air Conditioning/Refrigeration Equipment Mechanic, Electrician, Joiner, Laborer, Machinist/Maintenance/Marine, Marine Engineer, Mechanic, Motor Vehicle Operator, Painter, Pipe Coverer & Insulator, Pipefitter, Plumber, Rigger, Sheetmetal Mechanic
09	Safety Office Industrial Hygiene/Health & Safety
10	Data Processing Office Administrative Jobs
11	Shipfitter's Shop Forgers, Loftsman, Shipfitter
12	Ship Management Officers **[No titles given]**
13	Quality Assurance Office Electrician

(cont'd)

Table 2.8.C Job Titles Most Frequently Associated with Shops and Series Codes (cont'd)

Shop or Series Code	Associated Job Titles
Part A.	Shops (cont'd)
14	Management Engineering Office Engineer
15	Industrial Relations Office Administrative Jobs
17	Sheetmetal Shop Electroplater, Sheetmetal Mechanic
19	Combat Systems Office **[No titles given]**
20	Planning Department **[No titles given]**
22	Planning & Estimating Div. **[No titles given]**
23	Forge Shop Forgers
24	Design Division **[No titles given]**
25	**[Shop name unknown]** Gas Detection Monitor
26	Welding Shop Gas Plant Operator, Welder
27	**[Shop name unknown]** Galvanizer
30	Production Department Electrician
31	Inside Machine Shop Electroplater, Instrument Mechanic, Machinist/Maintenance/Marine
32	Nuclear Engineering Department Engineer, Nuclear Engineering

(cont'd)

Table 2.8.C Job Titles Most Frequently Associated with Shops and Series Codes (cont'd)

Shop or Series Code	Associated Job Titles
Part A.	Shops (cont'd)
33	Non-Nuclear Inspection Div.
	[No titles given]
34	Laboratories Division
	Industrial Test Laboratory, Physical Science Technician
35	Non-Destructive Test Division
	[No titles given]
36	Weapons Shop
	[No titles given]
38	Outside Machine Shop
	Machinist/Maintenance/Marine, Mechanic
39	Nuclear Inspection Division
	Physical Science Technician
40	Public Works Department
	[No titles given]
41	Boiler Shop
	Boilermaker
45	Public Works - Shop Division
	[No titles given]
46	Pending Disability Retirement
	[No titles given]
50	Supply Department
	Laborer, Stockman
51	Electrical Shop
	Electrician, Instrument Mechanic
56	Pipe Shop
	Air Conditioning/Refrigeration Equipment Mechanic, Pipe Coverer & Insulator, Pipefitter, Plumber

(cont'd)

2 Methods

2.8 Shipyard Occupations (cont'd)

Table 2.8.C Job Titles Most Frequently Associated with Shops and Series Codes (cont'd)

Shop or Series Code	Associated Job Titles
Part A.	Shops (cont'd)
60	Comptroller Department
	Administrative Jobs
62	**[Shop name unknown]**
	Administrative Jobs
64	Woodworking Shop
	Joiner
66	**[Shop name unknown]**
	Administrative Jobs
67	Electronics Shop
	Electronics Mechanic
68	**[Shop name unknown]**
	Electronics Mechanic
70	**[Shop name unknown]**
	Medical Group
71	Paint Shop
	Laborer, Painter, Sandblaster, Tank and Equipment Cleaner
72	Riggers and Laborers Shop
	Laborer, Rigger, Tank and Equipment Cleaner, Upholsterer
75	**[Shop name unknown]**
	Medical Group
77	Severance Pay
	Administrative Job
80	Administrative Department
	Administrative Job
81	**[Shop name unknown]**
	Foundry Molder, Joiner
82	**[Shop name unknown]**
	Firefighter

(cont'd)

2 Methods
2.8 Shipyard Occupations (cont'd)

Table 2.8.C Job Titles Most Frequently Associated with Shops and Series Codes (cont'd)

Shop or Series Code	Associated Job Titles
Part A.	Shops (cont'd)
83	**[Shop name unknown]**
	Guards/Police
91	Youth Opportunity
	Student/Summer Aid
92	Structural Shop Group
	[No titles given]
93	Mechanical Shop Group
	Mechanic
94	**[Shop name unknown]**
	Joiner
95	Electrical/Electronic Shop Group
	[No titles given]
97	Service Shop Group
	[No titles given]
99	Temporary Service Group
	Electrician, Student/Summer Aid
Part B.	Series Codes
105	Radiation Health
106	Safety Director
133	Head of non-nuclear inspection
134.3; 134.4	Quality Assurance
150	Industrial Hygiene (Safety Director)
185	Industrial Hygiene (Safety Director)
200	Planning

(cont'd)

2 Methods
2.8 Shipyard Occupations (cont'd)

Table 2.8.C Job Titles Most Frequently Associated with Shops and Series Codes (cont'd)

Shop or Series Code Associated Job Titles
Part B. Series Codes (cont'd)
280 Planning
400 Public Works
500 Supply
600 Comptroller
700 Naval Regional Medical Center (NRMC)
730 Industrial Hygiene
800 Administrative Dept.
2300 Nuclear Engineering

<u>Note</u>: See Appendix 11 which is a modification of the above table and is current information provided by the Charleston Naval Shipyard. The table above represents the jobs titles and shops as used in the current analysis.

Table 2.8.C1 Frequency Distribution of Last Occupational Title Codes for Norfolk, Portsmouth, Charleston and Newport News Shipyard Workers by Radiation Status

Job Title	Total N	Total %	Nuclear Workers N	Nuclear Workers %	Non-Nuclear Workers N	Non-Nuclear Workers %
(01) Aircraft worker	7	<1%	1	<1%	6	<1%
(02) A/C Equipment Mechanic	460	<1%	178	1%	282	<1%
(03) Boilermaker	1554	1%	398	2%	1156	1%
(04) Crane Operator	811	1%	176	1%	635	1%
(05) Electrician	11029	7%	1942	8%	9087	7%
(06) Electronics Mechanic	2941	2%	723	3%	2218	2%
(07) Electroplater	232	<1%	66	<1%	166	<1%
(08) Engineer	10493	7%	2418	10%	8075	6%
(09) Engineman	311	<1%	20	<1%	291	<1%
(10) Facilities & Public Works	2941	2%	388	2%	2553	2%
(11) Firefighter	487	<1%	221	1%	266	<1%
(12) Forgers	454	<1%	9	<1%	445	<1%
(13) Foundry Molder	1671	1%	337	1%	1334	1%
(14) Galvanizer	23	<1%	1	<1%	22	<1%
(15) Gas Detection Monitor	73	<1%	9	<1%	64	<1%
(16) Gas Plant Operator	53	<1%	0	0%	53	<1%
(17) Guards & Police	1026	1%	257	1%	769	1%
(18) Heavy Mobile Equip Mechanic	554	<1%	104	<1%	450	<1%
(19) Industrial Hygiene	146	<1%	73	<1%	73	<1%
(20) Industrial Test Lab	469	<1%	158	1%	311	<1%
(21) Instrument Mechanic	457	<1%	139	1%	318	<1%
(22) Joiner	4948	3%	701	3%	4247	3%
(23) Laborer	6320	4%	200	1%	6120	5%
(24) Loftsman	180	<1%	52	<1%	128	<1%
(25) Machinist	19305	13%	3090	13%	16215	13%
(26) Marine Engineer	205	<1%	41	<1%	164	<1%
(27) Mechanic	662	<1%	280	1%	382	<1%
(28) Medical Group	108	<1%	22	<1%	86	<1%
(29) Motor Vehicle Operator	1436	1%	158	1%	1278	1%
(30) Nuclear Engineer	2804	2%	989	4%	1815	1%
(31) Oiler	302	<1%	10	<1%	292	<1%
(32) Painter	3982	3%	553	2%	3429	3%
(33) Physical Science Technician	879	1%	515	2%	364	<1%
(34) Pipe Coverer & Insulator	1658	1%	380	2%	1278	1%
(35) Pipefitter	10572	7%	2777	12%	7795	6%
(36) Plumber	169	<1%	5	<1%	164	<1%
(37) Rigger	5977	4%	1103	5%	4874	4%
(38) Ropemaker	1	<1%	1	<1%	0	0%
(39) Sandblaster	517	<1%	86	<1%	431	<1%
(40) Sawsmith	17	<1%	1	<1%	16	<1%
(41) Sheetmetal Mechanic	5743	4%	703	3%	5040	4%
(42) Shipfitter	11820	8%	1426	6%	10394	8%
(43) Stockman	2753	2%	194	1%	2559	2%
(44) Summer/Student	761	<1%	7	<1%	754	1%
(45) Tank & Equip. Cleaner	568	<1%	234	1%	334	<1%
(46) Upholsterer	183	<1%	88	<1%	95	<1%
(47) Welder	12654	8%	1348	6%	11306	9%
(88) Administrative	5217	3%	323	1%	4894	4%
(99) Not Specified	14122	9%	1225	5%	12897	10%
Total	150055	100%	24130	100%	125925	100%

* A nuclear worker is defined in these tabulations as any individual who matches to the Radiation Tapes (1981) for all yards on the basis of a social security number.

Table 2.8.C2 Frequency Distribution of Last Job Prefix for Norfolk, Portsmouth, Charleston and Newport News Shipyard Workers by Radiation Status

Prefix	Total N	Total %	Nuclear Workers N	Nuclear Workers %	Non-Nuclear Workers N	Non-Nuclear Workers %
(01) Apprentice	5119	3%	752	3%	4367	3%
(02) Helpers	24124	16%	648	3%	23476	19%
(03) Workers	8689	6%	467	2%	8222	7%
(04) Journeymen	10	<1%	1	<1%	9	<1%
(05) Assistants	1243	<1%	25	<1%	1218	1%
(06) Instructors	528	<1%	242	1%	286	<1%
(07) Leaders	262	<1%	33	<1%	229	<1%
(08) Foremen	7528	5%	2517	10%	5011	4%
(09) General Foremen	1383	1%	647	3%	736	1%
(10) Inspectors Shipboard	663	<1%	579	2%	84	<1%
(11) Inspectors Other	1213	1%	650	3%	563	<1%
(12) Planners & Estimators	1274	1%	565	2%	709	1%
(13) Production Shop Planners	3132	2%	1141	5%	1991	2%
(14) Quality Assurance & Control	882	1%	335	1%	547	<1%
(15) Ship Progressmen	216	<1%	124	1%	92	<1%
(16) Ship Schedulers	168	<1%	77	<1%	91	<1%
(17) Ship Surveyors	94	<1%	21	<1%	73	<1%
(18) Ship Systems & Structures	1262	1%	287	1%	975	1%
(19) Shop Analysts & Schedulers	225	<1%	20	<1%	205	<1%
(20) Shop Planners	153	<1%	34	<1%	119	<1%
(21) Test Specialists	1005	1%	391	2%	614	1%
No Prefix	90882	61%	14574	60%	76308	61%
Total	150055	100%	24130	100%	125925	100%

* A nuclear worker is defined in these tabulations as any individual who matches to the Radiation Tapes (1981) for all yards on the basis of a social security number.

2 Methods
2.8 Shipyard Occupations (cont'd)

Table 2.8.D Job Hazard Index by the 49 Job Title Groups

Job Hazard Index	Job Category	Hazard Exposure Score (1 to 9) (N = 7 Industrial Hygienist Raters) Median	Range
HIGH	Welder	7	5.5 - 7
	Pipe coverer & insulator	6	6 - 7
	Sandblaster	6	5.5 - 7
	Painter	6	5 - 7
	Firefighter	6	3 - 6
	Electroplater	5.5	5 - 6
	Tank & equipment cleaner	5.5	5 - 6
	Boilermaker	5	4 - 5
	Pipefitter	5	3 - 5.5
	Foundry Molder	5	3.5 - 7
MEDIUM	Laborer	4	3 - 5.5
	Plumber	4	3 - 5.5
	Shipfitter	3.75	2 - 5
	Heavy mobile equipment mechanic	3.75	2 - 5
	Galvanizer	3.5	3 - 5
	Crane operator	3.5	2 - 4
	Machinist/maintenance/ marine	3	3 - 3.5
	Industrial test lab	3	1 - 3.5
	Joiner	3	2 - 5
	Air cond. equip. mechanic	3	1 - 4
	Mechanic	2.5	1.5 - 3
	Ropemaker	2.5	0 - 4
	Electronics mechanic	2	1.5 - 3
	Engineman	2	1 - 3
	Sheetmetal mechanic	2	1 - 3
	Loftsman	2	0 - 2
	Motor vehicle operator	2	1 - 3.5
	Electrician	2	1 - 4
	Forger	2	1.5 - 5
	Nuclear engineering	2	0 - 3.5
	Gas detection monitor	2	1 - 5
	Aircraft workers	2	0 - 4
	Oiler	2	0 - 4
	Gas plant operator	2	0 - 5

(cont'd)

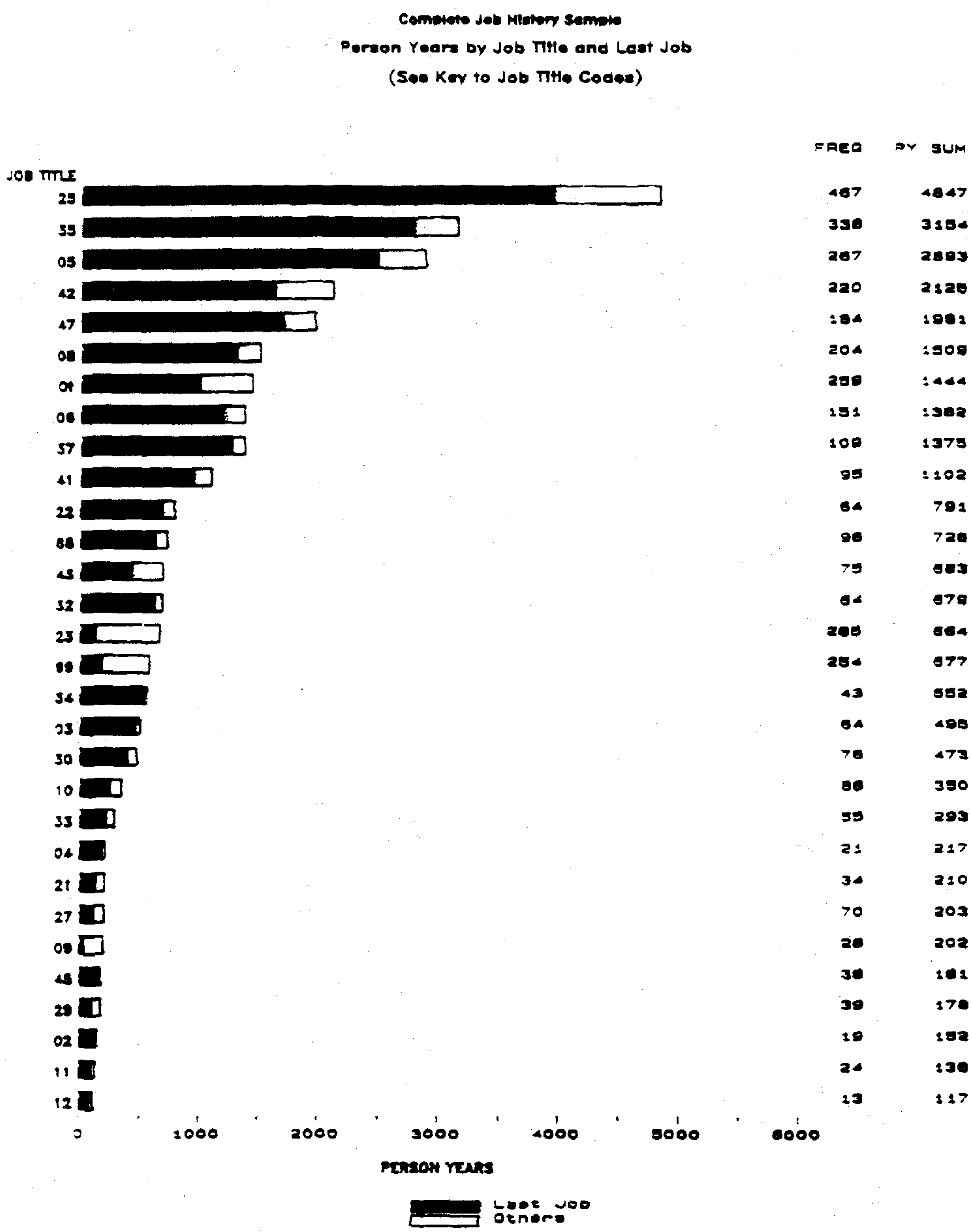
2 Methods
2.8 Shipyard Occupations (cont'd)

Table 2.8.D Job Hazard Index by the 49 Job Title Groups (cont'd)

Job Hazard Index	Job Category	Hazard Exposure Score (1 to 9) (N = 7 Industrial Hygienist Raters) Median	Range
LOW	Facilities & public works	1.5	1 - 2
	Instrument mechanic	1.5	0 - 3
	Marine engineer	1.5	0.5 - 4
	Physical science technician	1	0 - 1
	Student/summer aide	1	0 - 1
	Stockman	1	0 - 2
	Medical group	1	1 - 4
	Rigger	1	0 - 3
	Industrial hygiene	1	1 - 5
	Upholsterer	0.5	0 - 2
	Guards & police	0	0 - 1.5
	Sawsmith	0	0 - 5
	Administrative	0	0
	Engineer	0	0

2 Methods
   2.8 Shipyard Occupations (cont'd)

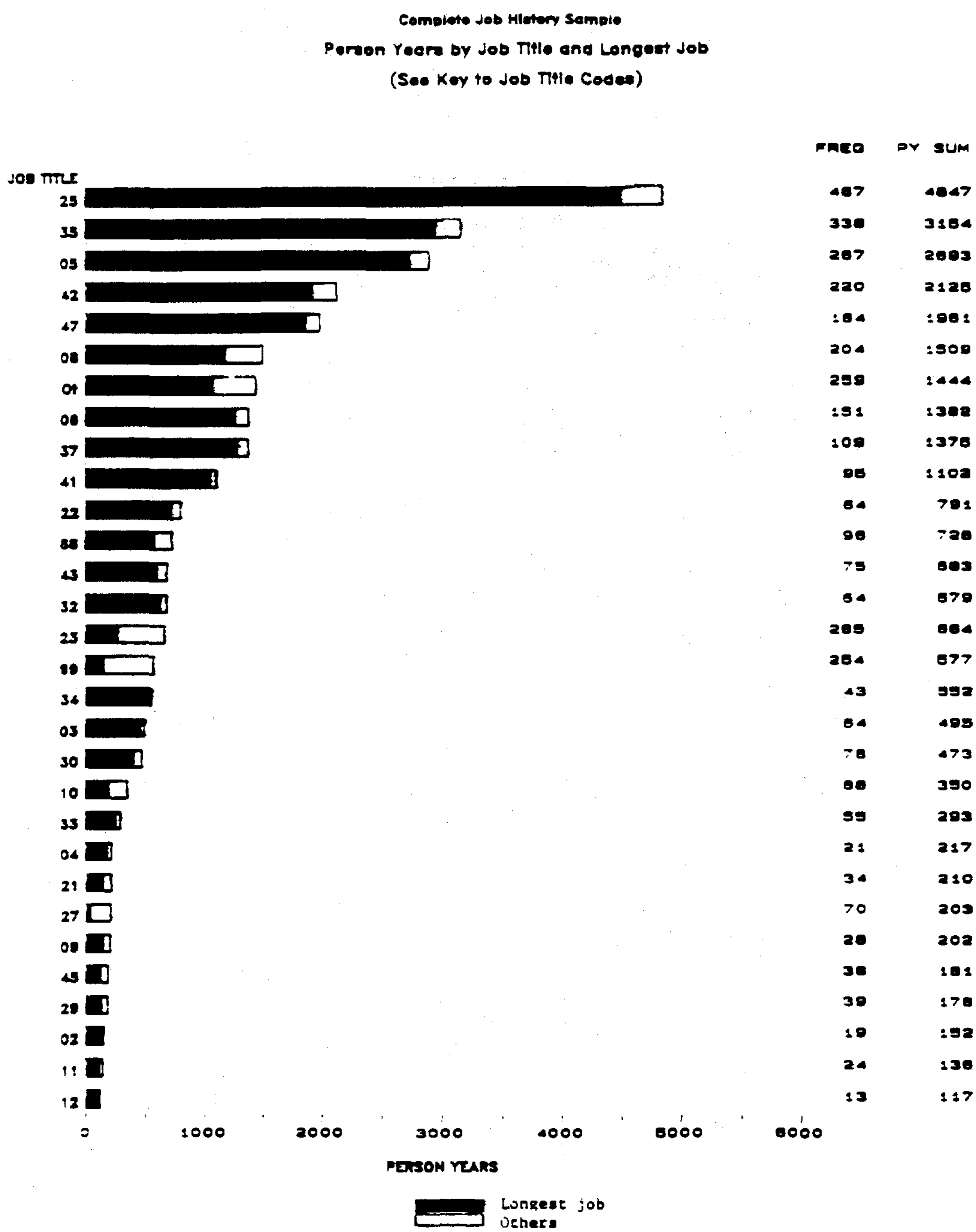
Figure 2.8.A Person-Years by Job Title and Last Job



2 Methods

2.8 Shipyard Occupations (cont'd)

Figure 2.8.B Person-Years by Job Title and Longest Job



2 Methods

2.9 Potential Hazards Other Than Radiation

The risks from exposure to low-level radiation in the shipyards cannot be adequately assessed unless occupational exposures to other potentially confounding chemical or physical agents are also considered. The bone marrow and lung are accepted as being two of the sites which are sensitive to radiation-induced cancer. The evaluation of other agents has been limited to those which are suspected will produce leukemia or lung cancer in humans.

The agents were selected on the basis of two criteria: the chemical had to be included in IARC cancer category 1 (causally associated with cancer in humans), 2a, or 2b (probably carcinogenic to humans) and be carcinogenic for bone marrow or lung; and the carcinogen had to be common to the shipbuilding and repair work environment. Incidental exposures were not considered. Exposures which occurred in nuclear shipyard work and which met these criteria were: arsenic compounds; asbestos; benzene; chromium and chromium compounds; soots, tars, and oils; vinyl chloride; nickel and nickel compounds; polynuclear aromatic hydrocarbons (PAHs); epichlorohydrin; and some exposures common to the rubber manufacturing industry. Relatively infrequent exposures were not considered since the attributable risk would be low. Also, exposures limited to single identifiable job titles or shops were not considered since either of these variables alone could be used to define the exposure without the necessity of summing the exposure to the agent over several jobs. Finally, exposures which were widespread but very difficult to define, such as PAHs from hydrocarbon combustion, were not considered.

Asbestos, benzene, chromium, and nickel were determined to be substances of primary interest for exposure assessment. Asbestos is the most significant and ubiquitous exposure of those identified and has received the most attention.

Since benzene was generally used in combination with other organic solvents or was an impurity in other aromatic chemicals, it would be extremely difficult to isolate the specific exposure to benzene in the shipyard setting. Thus, exposure to organic solvents in general was the target of investigation.

Welding and cutting operations produced the greatest potential exposure to carcinogenic chromium and nickel compounds. Welding also was associated with exposure to other potential carcinogens such as hydrocarbons. Therefore, welding as a task was investigated as being potentially carcinogenic because of the known exposures.

In summary, three carcinogenic substances were selected for exposure assessment: asbestos, organic solvents, and welding fumes. Reliable individual or environmental data on exposure to these substances were generally not available from the shipyard. As a substitute, the job titles which each worker held were used as a proxy measure of exposure to these substances.

Two major activities were directed to assigning exposure levels to job titles: examining the 49 occupational title categories (groups of job titles) for heterogeneity of job titles; and surveying industrial hygienists from each of the shipyards to obtain information on the nature and magnitude of asbestos, organic solvent, and welding fume exposures associated with each job title. As noted, special attention has been devoted to asbestos both because of its ubiquity in the yard, the high frequency of nuclear workers who were in jobs with suspected asbestos exposure, and the relatively high risk of lung cancer associated with asbestos especially in smokers.

2 Methods
2.9 Potential Hazards Other Than Radiation (cont'd)

The original 49 occupational title categories, consisting of anywhere from a single to several job titles, were considered to represent jobs associated with generally similar work tasks. However, exposures such as absestos might not be similar. In order to resolve this problem, job titles within the categories were regrouped into subcategories such that the job titles within that group had potential exposures to similar substances and, therefore, could be called synonyms of each other. These subcategories have been referred to as synonym groups. The original 49 job categories were expanded to 183 synonym groups.

Asbestos Exposure

To assess exposures by a job, a group of industrial hygienists who had worked in one or more of the shipyards was assembled. These shipyard industrial hygienists were surveyed in two phases to obtain information on the asbestos level associated with each job title. In the first phase, a workshop was held. The first objective of the workshop was a process objective, i.e., to test methods of obtaining expert opinion on shipyard workplace exposures, using questionnaires and group discussions; the second and prime objective was to begin collecting information to determine the asbestos exposure associated with each job title. The workshop was successful in developing a survey strategy which was both feasible and amenable to industrial hygienists. In the second phase, a large group of current and former industrial hygienists from the eight shipyards were surveyed using a modified questionnaire. Industrial hygienists were first called and invited to participate in the survey. If they agreed, a letter was sent explaining the purpose of the survey in greater detail. Enclosed with the letter were instructions and the questionnaire which would be completed during a follow-up telephone interview.

When an industrial hygienist indicated that the synonym group was associated with asbestos exposure, information was obtained on whether the exposure was direct or indirect, the degree or level of exposure, and the usual percent work time spent on those tasks with potential exposures. Industrial hygienists were asked to provide the following information on each of the 183 synonym groups.

(1) Their familarity with the usual tasks performed, materials used, and exposures encountered by an individual with this job title. The following definitions were provided:

High - You have extensive familiarity with the job title (JT), including the job description and the job tasks it entails. You have done monitoring or sampling of individuals with the JT on one or more occasions, and have spent time <u>observing</u> individuals holding this JT. You may have reviewed or helped to write job descriptions for this JT.

Moderate - You are fairly familiar with the JT. You know what the job description is, but are not familiar with all the job tasks. You know generally what the responsibilities of individuals with this JT are. You may have done some sampling or monitoring which did not necessarily involve extensive observation of the job.

Low - You have minimal familiarity with this JT. While you know that the JT exists, and know <u>generally</u> the work that individuals with this JT will do, you haven't had occasion to observe the work or monitor exposures associated with this JT.

None - You are not familiar with this JT and its associated exposures.

(2) If the industrial hygienist had no knowledge, he was instructed to go to the next job title. If he was knowledgeable, he was asked: Was there exposure to asbestos, and if so, was it direct or indirect exposure? The industrial hygienist was specifically instructed to keep in mind the different job tasks associated with asbestos exposure, including in-shop preparation of materials, on-ship application or installation of asbestos-containing products, removal/ripout activities, and clean-up/housekeeping tasks. The following definitions for types of exposure were used:

Direct - Denotes certain or probable asbestos exposure through direct handling of asbestos-containing materials, or performance of tasks with asbestos. This classification considered exposures that occurred as part of usual work done on a regular or intermittent basis. It did not include exposures that were due to unusual tasks, or that were not generally part of the job.

Indirect - Denotes certain or probable indirect exposure. Individuals are indirectly exposed if asbestos is present in their general working environment, but they are not directly handling the substance. This can be due to work which requires proximity to other workers who are installing or removing asbestos materials (bystander exposure) or working where asbestos-related tasks have been recently completed by other workers (because of the persistence of asbestos dust in the work environment), or frequent passage through an area where asbestos work was in progress or recently completed. Exposures that were due to unusual or incidental events, such as occasionally passing through an exposure area, were not included in this classification.

None - Indicates that neither direct or indirect exposure was likely to have occurred. Ignore incidental exposures.

DK - Indicates that the hygienist had no knowledge of whether exposure occurred.

(3) If direct or indirect exposure was indicated, information was obtained on the level and duration of exposure. The following definitions were used to describe the level of exposure, i.e., the highest relative level of exposure for a person holding this job title during the time the industrial hygienist worked in the shipyard. The industrial hygienist was asked to rate the average relative level of (direct/indirect) exposure for all asbestos-related tasks using the following guidelines:

Low - no visual dust, levels at or below the TLV or PEL Standard.

Medium - some visible dust, with levels up to 10 times the Standard.

High - visibly dusty, with levels up to 100 times the Standard.

Very High - extremely dusty, levels comparable to doing insulation ripout without control measures.

(4) The industrial hygienist was asked about days per week of exposure:

On the average, how many days per week would an individual with this job title experience direct or indirect exposure to asbestos? This question was considered separately for each direct exposure task. Days per week may range from less than one (<1) to five.

Hours per day on exposed days was also addressed. How many hours per day, on the average (on the days when exposure occurred) was there exposure to asbestos? Hours per day may range from less than one (<1) to eight.

(5) Finally, an inquiry was made regarding changes in exposure. Specific questions were asked to determine whether the level of direct or indirect asbestos exposure associated with a job title decreased substantially (one exposure category or more, e.g., from very high to high or from medium to low) during the time the industrial hygienist worked in the shipyard. The industrial hygienist was asked if exposure had decreased. Possible responses included NO, DON'T KNOW, and YES. If YES, the industrial hygienist was asked to estimate the year that this decrease in exposure took place. If there was more than one substantial exposure decrease, the industrial hygienist was asked to provide information for the first of these exposure reductions. Finally, the industrial hygienist was asked to describe the level to which exposure decreased.

Data reported by industrial hygienists on the number of hours per week of direct or indirect exposure were reviewed. In a number of instances, the number of hours per week was zero or negligible indicating incidental exposure. These job titles were classified as having negligible exposure.

Industrial hygienists did not consistently agree on whether direct or indirect exposure was associated with specific synonym groups nor on the level or amount of time exposed. In the absence of complete agreement, criteria were established to decide on the asbestos exposure level associated with synonym groups. The criteria were designed to minimize "contamination" of the "no exposure" group with job titles which had some exposure. That is, we minimized false negative errors in the no exposure group at the cost of including some job titles which actually had no exposure in the lower exposure categories, i.e., false positive errors. The reason for this approach was to establish an exposure free reference group. This was likely to result in a small differential classification error that was, for the most part, limited to the group with lowest exposure.

The following criteria were used to define whether direct or indirect asbestos exposure was associated with a job title.

Strong Agreement - no exposure was defined as No:Yes vote ratio of 3:1 or greater. Positive exposure was defined as a vote ratio of 1:1 (No:Yes) or less; that is, more than 50 percent of those voting yes or no actually voted yes.

Weak Agreement - limited to positive exposure for vote ratios greater than 1:1 (No:Yes) but less than 3:1, i.e., the no votes outnumbered the yes votes.

Possible Agreement - the vote ratios for direct and indirect exposure were each greater than or equal to 3:1 (No:Yes) but the combined vote was 1:1 or less. All of these job titles were defined as having indirect exposure.

2 Methods

2.9 Potential Hazards Other Than Radiation (cont'd)

Insufficient Data - no respondents who were knowledgeable about the job title.

The concordance among industrial hygienists as to whether asbestos exposure occurred within all synonym job groups is displayed in Table 2.9.A. As indicated, three out of five industrial hygienists from four shipyards agreed on the classification of 48 of these synonyms or job exposure groups. For 56 groups there was lack of concordance. For at least 28 percent of the jobs the hygienists indicated insufficient knowledge about asbestos exposure to classify the job. Thus, for those 104 groups for which the hygienists had knowledge, in only 46 percent of them did the majority of the hygienists agree on the asbestos classification. The sample of hygienists has since been increased in order to stabilize these figures with a larger number of participants. Seventy-seven percent of the decisions for direct exposure and 68 percent of the decisions for indirect exposure were made on the basis of strong agreement. The remaining decisions for direct exposure were based on weak agreement (10%) or the absence of data (12.5%). When data were insufficient it was primarily limited to job titles which were idiosyncratic to Groton and Newport News, the two private yards. The exposure status assigned to these job titles was the same as that assigned to the Navy job title which appeared to be similar. Proportionately, more of the decisions for indirect exposure were based on weak agreement (20.5%). These decisions were almost exclusively for low exposure. In general, for those job titles with indirect exposure the level is predominantly low (71%) or low-moderate (27%). When direct and indirect exposure are considered for job titles with sufficient data, 32 percent of the job titles are defined as having no associated exposure, 57 percent as low or low-moderate, the 11 percent as moderate exposure or greater.

The final decision for each job title is displayed in Table 2.9.B and incorporates information obtained from industrial hygienists related to the amount of time exposed. In general, if a job title was classified as having associated asbestos exposure, but the level was defined as negligible, the exposure was considered to be incidental.

At present, the data on exposure to asbestos have been reviewed. Data on other substances have not yet been considered. Asbestos levels by job have not been used in the analyses to date to control for confounding. However, Figure 2.9.A indicates the general plans for using estimated exposures to asisgn to individuals in future analyses.

2 Methods
2.9 Potential Hazards Other Than Radiation (cont'd)

Table 2.9.A Job Groups by Industrial Hygienist[1] Asbestos Exposure Assessment Concordance Level[2]

Industrial Hygienist Concordance	Job Groups	
	Number	Percent
Yes	48	33.1
No	56	38.6
No knowledge	41	28.3
Total	145	100.0

1 Industrial hygienists from four shipyards

2 Concordance on a job group exposure was defined as agreement between at least three of the five industrial hygienists

2 Methods
2.9 Potential Hazards Other Than Radiation (cont'd)

Table 2.9.B Job Title and Asbestos Exposure Category

Code	Job Title	Asbestos Category Exposure
05-002	Armature Winders	1
05-061	Electrician, Ship Progressman	1
06-029	Fire Control Mechanic	1
06-040	Radio Mechanic (Layer-out)	1
08-000	Architect	1
08-050	Engineering Draftsman Mechanic	1
08-074	Industrial Engineer	1
08-120	Plant Engineer	1
08-156	Tracer	1
08-276	Ordinance Man (Inert Materials)	1
08-277	Ordinance Equipment Worker	1
09-000	Engineman	1
10-101	Maintenance	1
10-194	Staff Supervisor Yard Operations	1
10-257	Production Material Controller	1
13-007	Foundry Chipper	1
13-029	Molder	1
17-000	Guard	1
17-022	Security Clerk	1
20-000	Chemist	1
20-012	Metallurgist	1
21-000	Instrument Mechanic	1
21-010	Instrument Maker	1
22-000	Carpenter	1
22-001	Boatbuilder	1
22-030	Rubber Worker	1
22-032	Shipwright	1
24-000	Loftsman	1
25-017	Equipment Repairer (Machinist Marine)	1
25-020	Equipment Specialist (Electrical)	1
25-025	Equipment Specialist (Missiles)	1
25-049	Machine Installation	1
25-056	Machinist Maintenance	1
26-000	Engineer (Marine)	1
27-000	Mechanic	1

(cont'd)

2 Methods
2.9 Potential Hazards Other Than Radiation (cont'd)

Table 2.9.B Job Title and Asbestos Exposure Category (cont'd)

Code	Job Title	Asbestos Category Exposure
27-031	Inspector Mechanic Nuclear Quality Control	1
29-000	Automotive Equipment Operator	1
29-003	Chauffer	1
29-007	Drayage	1
29-029	Motor Vehicle Operator (Supply)	1
29-039	Truck Driver	1
42-002	Anglesmith	1
42-026	Hull Outfitting	1
42-038	Puncher & Shearer	1
42-040	Rivet Heater	1
42-041	Riveter	1
42-047	Shipfitter Layer-out	1
43-000	Equipment Clerk	1
43-030	Storeworker	1
45-005	Industrial Cleaner	1
47-024	Steel Fabrication	1
47-032	Welder Engineer	1
47-053	Lead Bonder	1
88-000	Accounting Cleark	1
88-028	Budget Officer	1
88-134	Job Printer	1
88-175	Office Clerk	1
88-197	Photocopy Equipment Operator	1
88-496	Systems Development Specialist	1
99-036	Production Controller	1
99-037	Production Controller Ships	1
99-038	Production Dispatcher	1
99-042	Production Specialist	1
99-043	Production Superintendent	1
99-060	Ship Scheduler	1
99-062	Ship Shed	1
99-063	Ship Surveyor	1
99-070	Shop Superintendent	1
99-071	Snapper	1
99-075	Supervisory Planner & Estimator	1

(cont'd)

2 Methods
2.9 Potential Hazards Other Than Radiation (cont'd)

Table 2.9.B Job Title and Asbestos Exposure Category (cont'd)

Code	Job Title	Asbestos Category Exposure
99-084	Technician	1
99-104	Senior Test Operator	1
99-106	Ship Superintendent	1
99-117	Test man	1
02-000	Air Conditioning/Refrigeration (Equipment Mechanic)	2
04-000	Crane Operator	2
04-024	Operating Engineer	2
05-019	Electrical Systems Inspector (Ships)	2
05-022	Electrician	2
05-028	Electrician (Power Plant)	2
05-046	Planner & Estimator (Electrician)	2
06-019	Electronics Mechanic (Shipboard Systems)	2
06-021	Electronics Technician	2
10-000	Blueprinting Machine Operator	2
10-015	Boiler Plant Operator	2
10-067	Handyman	2
10-091	Janitor	2
10-148	Planning & Estimating (Public Works)	2
10-158	Production Controller (Shipbuilding)	2
10-242	Maintenance Laborer	2
11-002	Fire Communication Operator	2
12-000	Blacksmith	2
13-006	Foundry	2
13-012	Furnace man	2
13-013	Furnance man, Foundry	2
13-019	Inspector (Metals) C	2
15-000	Tank Tester	2
23-004	Laborer	2
25-000	Machinist	2
25-065	Marine Equipment Mechanic	2
25-078	Ship Maintenance Mechanic	2
25-135	Ship Repairer Supervisor	2
27-009	Mechanical Systems Inspector (Ships)	2
27-025	Shipbuilding Inspector (Mechanic)	2
30-000	Nuclear Engineer	2

(cont'd)

2 Methods
2.9 Potential Hazards Other Than Radiation (cont'd)

Table 2.9.B Job Title and Asbestos Exposure Category (cont'd)

Code	Job Title	Asbestos Category Exposure
31-003	Oiler	2
32-000	Painter	2
32-013	Painter Cleaner	2
35-004	Coppersmith	2
35-008	Inspector (Ship's Piping Systems)	2
37-000	Rigger	2
37-004	Laborer (Rigger or Yard Rigger)	2
39-001	Sandblaster	2
41-007	Sheetmetal Mechanic	2
41-008	Sheetmetal Worker	2
42-000	Shipfitter	2
42-011	Caulker & Chipper	2
42-019	Driller	2
42-034	Planner & Estimator (Shipfitter)	2
42-035	Pneumatic Tools Operator	2
42-048	Shipfitter Loftsman	2
42-049	Shipfitting Inspector	2
47-013	Gas Cutter & Burner	2
99-011	General Helper	2
99-016	Helper Trainer	2
99-019	Inspector	2
99-023	Leadingman	2
99-031	Planner & Estimator (General)	2
99-056	Service Shop General Foreman	2
06-000	Electronics Mechanic	3
19-000	Industrial Hygienist	3
25-057	Machinist Marine	3
35-000	Pipefitter	3
47-029	Welder	3
47-030	Welder Combination	3
47-031	Welder Electric	3
03-000	Boilermaker	4
18-000	Heavy Mobile Equipment Mechanic	4
18-002	Automotive Mechanic	4
34-000	Pipe Coverer & Insulator	4

(cont'd)

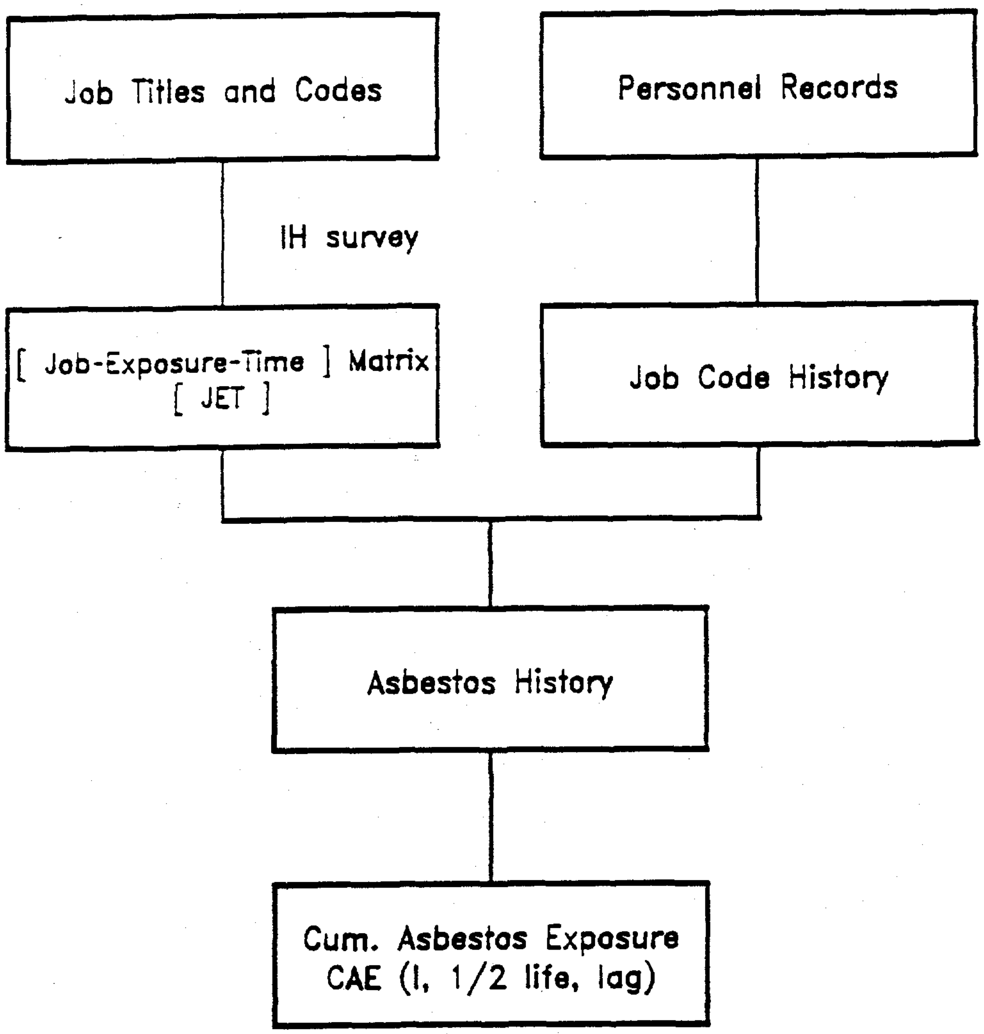
2 Methods
2.9 Potential Hazards Other Than Radiation (cont'd)

Table 2.9.B Job Title and Asbestos Exposure Category (cont'd)

Code	Job Title	Asbestos Category Exposure
36-000	Plumber	4
47-036	Welder (Special)	4

2 Methods
   2.9 Potential Hazards Other Than Radiation (cont'd)

Figure 2.9.A   Flow Chart for Derivation of Cumulative Asbestos Exposure



2 Methods

2.10 Personal Characteristics and Exposures Outside the Shipyard

Questionnaires sent to current workers in the Norfolk Naval Shipyard in 1980 and in the Charleston Naval Shipyard in 1986 served two purposes: to determine whether any worker reported nuclear work who did not appear on the radiation tape produced by the yard and to determine whether personal characteristics which might influence the risk of the cancers of interest differed between nuclear and non-nuclear workers. The use of these data to validate the completeness of the population of nuclear workers, as identified on the radiation tape, was discussed in Section 2.7. The comparison of nuclear and non-nuclear workers in regard to potentially confounding variables, the second important reason for conducting the interview study, will be discussed in this section. No attempt was made to collect data on confounding variables for former workers.

The Norfolk survey was divided into two parts in order to try to maximize the amount of information retrieved at a low cost. A 95 percent sample of the total population received short mailed questionnaires which included a limited number of questions regarding use of a radiation badge, smoking habits, employment in multiple study shipyards, and demographic characteristics. The form included a simple return mailer. Three successive mailings of the identical form occurred for all nonrespondents who remained after previous attempted contacts. The overall response rate for all mailings combined was 63 percent, as shown in Table 2.10.A. Telephone interviews of the remaining non-respondents who were located and agreed to participate increased the response to 80 percent or a total of 10,944 individuals out of the original sample.

2 Methods

2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

In order to get more extensive information on this population than was possible through the cost-effective but brief survey form, a longer questionnaire was mailed to a five percent sample of the original population. The long form included the same set of questions contained on the short form plus additional questions regarding exposure to radiation outside of the shipyard and medical radiation as well as queries related to hazardous workplace exposures. The returns on the three mailings of this form yielded information on 49 percent of the original five percent sample, as seen in Table 2.10.B. Again, telephone follow-up of the remaining population of workers brought the cumulative percent response to 69 percent of the original sample.

The second survey of the current (1985) Charleston workers used the short form and long form questionnaires with a different survey scheme. All workers were mailed the short form questionnaire and a five percent random sample of these same workers was selected for a telephone interview using the long form. The workers received three mailings of the short form questionnaire but there was no telephone followup of nonrespondents because the study terminated. The inclusion of a telephone survey using the long form questionnaire boosted the total response to 78 percent. The response rates are shown in Table 2.10.C. The results from the second survey have not been completely analyzed at the time of preparation of this report.

Despite the fact that the mailings used recent addresses of employees, residence changes of workers were the major reasons for loss of information in the samples. The nonrespondents probably are young, recent hires, and short term workers. This assumption needs to be confirmed. Interviewers noted that elderly wives were reluctant about giving information regarding their shipyard worker husbands. This behavior may indicate the recent death of the spouse but this has not been confirmed.

Workers were asked to self-report whether they were certified to work in radiation areas by indicating whether they had worn either a film badge or a dosimeter. There was confusion regarding the term "badge", and many workers who were not listed on the radiation tape indicated that they wore a badge. As indicated in the discussion of validation of radiation dose, most of these individuals had misinterpreted the question and were incorrectly classified. In all of the analyses, workers were classified as nuclear or non-nuclear based on their inclusion on the radiation tapes, not on their response to the survey question. The results could differ depending on whether nuclear workers were categorized by self-classification or by radiation record files.

Sometimes respondents did not appear on the shipyard database following the match for nuclear and non-nuclear worker status. This situation occurred because some employees on the current employment tape had been hired after the records were collected for the study or they had changed their classification. If a respondent did not appear on the database with the classification as designated in the database he was not included in the current analysis of the survey. Thus although 10,944 returned the short and 496 the long forms (Tables 2.10.A and 2.10.B), only 8,812 records are available for analysis of demographic characteristics for all surveyed (Table 2.10.D.) and only 404 provided detailed answers (Table 2.10.I).

2 Methods
2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

Survey Results

Data collected from workers in the Norfolk shipyard using the short form questionnaire only are presented in this section. In reviewing the data each item was examined to determine whether the nuclear and non-nuclear shipyard workers differed in regard to that characteristic. When differences were observed, the factor was reviewed to see whether it might confound the comparison of the mortality in the two populations and, thus analysis would need to control for this factor. If some of the variables in the survey were interrelated then controlling for one might remove the influence of others. For example, the two populations differ by age which would be controlled in all analysis. The two groups also differed by smoking habits, but the data as presented have been age-adjusted in order to determine whether smoking would still be an important confounding variable in the analysis after correcting for age. Obviously the study has limited information with which to control individually for smoking if that varies in the population, but there is adequate data for age-adjustment. Wherever the data are age-adjusted, the direct method is used. The pooled population of nuclear and non-nuclear worker respondents is used as the standard.

The data from the survey indicated differences in nuclear and non-nuclear workers in regard to demographic characteristics (Table 2.10.D1). Some of these differences were anticipated, such as an increased mean age in the nuclear workers and a higher proportion of males in the nuclear group than in the non-nuclear group. In adjusting for age (Table 2.10.D), there are still differences between the two groups in sex as well as race. These differences prompted the effort to control for age and sex in selecting the

2 Methods

2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

study sample. The survey indicated that nuclear workers are generally similar to non-nuclear workers in educational levels, but nuclear worker have a slightly higher probability of having earned advanced degrees than do the non-nuclear workers. The original study sample did not control for education although the job hazard index may have partially adjusted for differences in this factor. The study sample included only males and balanced the nuclear and non-nuclear workers by age and job hazard index. Information on race was not available on shipyard personnel records for all yards although for some yards the overall racial distribution could be inferred. Balancing the samples by time of hire and job may have partially controlled for this variable in shipyards which employed a proportion of black workers. As noted in section 2.2, although race may still have resulted in some confounding in comparing NW and NNW groups, it could not have been a problem in comparing subsets in the NW group. Nuclear workers do not smoke differently than non-nuclear workers after correcting for age. The only observed difference is that those nuclear workers who have ever smoked cigarettes are more likely to have discontinued smoking currently.

The short questionnaire included items about shipyard exposure to asbestos. As shown in Table 2.10.F, the nuclear workers reported a high probability of direct exposure to asbestos probably because of the specific trades in which they worked. Among nuclear workers, 63 percent reported direct exposure compared to 49 percent in non-nuclear workers despite the adjustment. Both groups had a high frequency of reported exposures. This exposure will be an important confounding variable in the evaluation of the risk of lung cancer from radiation.

2 Methods

2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

As shown in Table 2.10.G, nuclear workers were more likely to have worked in other nuclear shipyards than were non-nuclear workers. This might be expected because of the specialized skills of this group. Approximately one percent of those surveyed indicated they had not worked in the yard from which the record originated. It is possible that these are individuals who were hired but never reported for work, were contractors, or that we contacted the wrong person.

Finally, all workers answering the short survey form were asked about the presence of certain diseases that are known to be associated with radiation, such as leukemia, lung cancer, and myeloma. As reported in Table 2.10.H, there were no differences between the two groups with respect to the age-adjusted prevalence of the diseases covered by the survey. Since none of these cases are confirmed, it is difficult to place much weight on the results. When self-reported rather than recorded exposure to radiation was used as a marker for nuclear work, the prevalence of leukemia was reportedly higher among nuclear workers. This again suggests potential bias from self-reported radiation exposure via the questionnaire.

The long survey queried the workers as to other industries in which they might have been employed. These data related to jobs have not been age-adjusted but such adjustment will probably not change these observations substantially. Workers exposed to radiation in the shipyards were more likely than non-nuclear workers to have exposure to radiation outside the shipyard, to have worked at multiple shipyards and to have had their radiation exposure in the Navy or the power industry (see Table 2.10.I). As previously shown in Table 2.10.F, while in the shipyards they were more likely to have asbestos exposure compared to workers not exposed to radiation. Table 2.10.J displays the frequency of exposure to specific chemicals. The list used in the questionnaire was not designed to be exhaustive but selected specific agents which had been reported to be associated with the risk of lung cancer or leukemia, which were the two target outcomes for evaluation. Radiation exposed workers reported exposure to other substances, such as chromium, grinding, dusts and silica, as well as asbestos, but not to chemicals in the chemical industry. This suggests that jobs associated with radiation work in the shipyards may involve the types of construction work which are often associated with dusty exposures. The industries to which workers had been exposed in the past (Table 2.10.I) would support these conclusions.

No major difference in frequency of dental and other health x-rays and fluoroscopic examinations was observed between the nuclear and non-nuclear workers (Table 2.10.K). Nuclear workers had more frequent chest x-rays than non-nuclear workers, probably as part of their industrial experience. The nuclear workers do report a small increase in the use of radioactive isotopes for diagnoswtic purposes as compared to non-nuclear workers.

In summary, the survey of recent shipyard workers indicates that the nuclear workers differ from the non-nuclear workers primarily in regard to age and asbestos exposure. The original differences in smoking habits disappeared when corrected for variations in age distributions in the two work groups. The only small difference in smoking characteristics between the two groups is that nuclear workers are more likely to have stopped smoking than non-nuclear workers. There are some interesting differences in job histories and even in use of chest x-rays which may be related to the type of construction industry

2 Methods

2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

jobs which are common among the nuclear workers. These data will be examined further in regard to their influence on the analysis. The results emphasize the importance of considering other workplace exposures in analysis.

2 Methods

2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

Table 2.10.A Response to the Short Form Health Survey Questionnaire by Recent (1980) Norfolk Naval Shipyard Workers

	Total Sought	Number of Completed Questionnaires	Percent Response	Cumulative Percent Response
First Mailing (12-30-81)	13676	5245	38%	38%
Second Mailing (02-12-82)	8006	2533	19%	57%
Third Mailing (03-31-82)	5158	859	6%	63%
Telephone & Other	4330	2307	17%	80%

Table 2.10.B Response to the Long Form Health Survey Questionnaire by Recent (1980) Norfolk Naval Shipyard Workers

	Total Sought	Number of Completed Questionnaires	Percent Response	Cumulative Percent Response
First Mailing (01-29-82)	719	211	29%	29%
Second Mailing (03-25-82)	476	100	14%	43%
Third Mailing (05-03-82)	364	44	6%	49%
Telephone & Other	320	141	20%	69%

2 Methods
2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

Table 2.10.C Current (03/01/87) Response to the Health Survey Questionnaire by Recent (1985) Charleston Naval Shipyard Workers

	Total Sought	Number of Completed Questionnaires	Number of Refusals	Percent Response	Cumulative Percent Response
First Mailing (Short form)	9346	3636	179	41%	41%
Second Mailing (Short form)	5531	1607	99	18%	59%
Third Mailing (Short form)	3825	784	123	10%	69%
Telephone (Long form)	2918	784	36	9%	78%

Table 2.10.D Age Distribution of Respondents to the Norfolk Health Survey Questionnaire (Short + Long)

				Nuclear Worker Status			
	Age	Total		Nuclear		Non-Nuclear	
Variable	Group	No.	%	No.	%	No.	%
Item (1)							
Age	18-25	308	3%	4	1%	264	5%
in	26-35	2920	33%	1002	30%	1918	35%
1982	36-45	2175	25%	1010	31%	1165	21%
	46-55	1738	20%	638	19%	1100	20%
	56-65	1500	17%	535	16%	965	17%
	>65	158	2%	57	2%	101	2%
	NR, Unk[1]	13	<1%	4	<1%	9	<1%
	*Total	8812	100%	3290	100%	5522	100%

[1]NR, Unk - Age not recorded or listed as unknown

* Total represents those respondents who matched with the original database.

2 Methods
2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

Table 2.10.D1 Demographic Characteristics of Respondents to the Norfolk Health Survey Questionnaire (Short + Long)

Variable		Total No.	%	Nuclear Worker Status: Nuclear Age adj. rate per 1000	Nuclear Worker Status: Non-Nuclear Age adj. rate per 1000
Item (3)					
Sex	Males	7866	89%	978	842
	Females	813	9%	7	142
	NR	133	2%	15	16
	Total	8812	100%	N/A	N/A
Item (4)					
Race/Ethnic Group	White	6206	70%	793	652
	Black	2432	28%	190	326
	Other	99	1%	8	14
	NR	75	1%	9	8
	Total	8812	100%	N/A	N/A
Item (5)					
Education	<12	1978	22%	202	238
	12	4243	48%	485	480
	12+	2457	28%	297	266
	NR, Unk	134	2%	16	15
	Total	8812	100%	N/A	N/A

NR= No record

2 Methods
2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

Table 2.10.E Smoking Characteristics of Respondents to the Norfolk Health Survey Questionnaire (Short + Long)

Variable		Total No.	Age adj. %	Nuclear Worker Status: Nuclear rate per 1000	Nuclear Worker Status: Non-Nuclear Age adj. rate per 1000
Item (6)					
Ever Smoked	No	2871	33%	321	329
100 Ciga-	Yes	5857	66%	670	661
rettes	NR	84	1%	9	10
	Total	8812	100%	N/A	N/A
Item (6a)					
Age First	<15	938	16%	106	107
Smoked	15-19	3606	62%	420	403
	20+	1192	20%	131	137
	Unk	121	2%	13	14
	Total	5857	100%	N/A	N/A
Item (6b)					
Amount	<10	736	13%	66	95
Smoked	10-19	1311	22%	146	150
(# of	20-39	2983	51%	368	320
cigarettes	40-59	508	9%	58	57
per day)	60+	58	1%	5	8
	Unk	261	4%	26	31
	Total	5857	100%	N/A	N/A
Item (6c)					
Current	No	2624	45%	326	279
Smoker	Yes	3187	53%	338	378
	NR,Unk	46	1%	6	4
	Total	5857	100%	N/A	N/A
Item (7)					
Pipe Smoker	No	7876	89%	881	902
	Yes	844	10%	108	87
	NR	92	1%	11	10
	Total	8812	100%	N/A	N/A
Item (8)					
Cigar Smoker	No	8007	91%	903	912
	Yes	709	8%	85	78
	NR	96	1%	12	10
	Total	8812	100%	N/A	N/A

Table 2.10.F Asbestos Exposure of Respondents to the Norfolk Health Survey Questionnaire (Short + Long)

Variable		Total No.	%	Nuclear Worker Status: Nuclear Age adj. rate per 1000	Nuclear Worker Status: Non-Nuclear Age adj. rate per 1000
Item (12)					
Worked with	No	2474	28%	208	322
Asbestos in	Yes	4755	54%	631	485
Shipyard	Around it	684	8%	75	81
	Don't know	788	9%	75	99
	NR	111	1%	11	13
	Total	8812	100%	N/A	N/A
Item (13)					
Worked with	No	6526	74%	764	723
Asbestos	Yes	1332	15%	142	159
Outside	Around	92	1%	9	11
of	Don't know	667	8%	62	85
Shipyard	NR	195	2%	23	22
	Total	8812	100%	N/A	N/A

NR = No record

2 Methods

2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

Table 2.10.G Shipyards Worked as Reported by Respondents to Norfolk Health Survey Questionnaire (Short + Long)

Variable		Total No.	%	Nuclear Worker Status: Nuclear Age adj. rate per 1000	Nuclear Worker Status: Non-Nuclear Age adj. rate per 1000
Item (14)					
Shipyards	Norfolk	5578	63%	581	668
Worked in	Norfolk + 1	2429	28%	319	248
	Norfolk + 2	663	8%	86	67
	Never Norfolk	50	1%	5	6
	NR	92	1%	9	12
	Total	8812	100%		

NR = no record

2 Methods
2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

Table 2.10.H Medical Conditions Reported by Respondents to the Norfolk HealthSurvey Questionnaire (Short + Long)

Variable		Total No.	%	Nuclear Worker Status: Nuclear Age adj. rate per 1000	Nuclear Worker Status: Non-Nuclear Age adj. rate per 1000
Item (15) Reported Health Conditions[1]	Leukemia	9	<1%	1	1
	Lung Cancer	34	<1%	5	3
	Myeloma	12	<1%	2	1
	Other Cancer	162	2%	18	19
	Heart Disease	347	4%	38	40
	Chronic Lung Disease	332	4%	38	38
	Other	278	3%	29	33
	None	7096	81%	809	803
	NR	659	7%	74	76
	Total	8812	100%	N/A	N/A

[1] Could report more than one

2 Methods
2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

Table 2.10.I Industries Worked in Other Than Shipyards as Reported by Respondents to the Norfolk Health Survey Questionnaire (Long)

Survey/ Variable		Total No.	Total %	Nuclear Worker Status: Nuclear No.	Nuclear %	Non-Nuclear No.	Non-Nuclear %
Item (17)							
Radiation	Yes	53	13%	25	14%	28	12%
Exposure	No	344	85%	152	85%	192	85%
Outside the	NR, Unk	7	2%	2	1%	5	2%
Shipyard	*Total	404	100%	179	100%	225	100%
Industry							
Item (19)							
Industries	Agriculture	34	8%	14	8%	20	9%
Worked	Asb. Manu.	4	1%	1	1%	3	1%
	Auto. Serv.	39	10%	15	8%	24	11%
	Chemical	8	2%	0	---	8	4%
	Construction	74	18%	30	17%	44	20%
	Mining	6	1%	4	2%	2	1%
	Petroleum	5	1%	2	1%	3	1%
	Rubber	4	1%	1	1%	3	1%
	Smelting	4	1%	2	1%	2	1%
	Tanning	0	---	0	---	0	---
	Textile	14	3%	3	2%	11	5%
	Wood Treat.	5	1%	1	1%	4	2%
	None of these	230	57%	111	62%	119	53%
	NR	20	5%	8	4%	12	5%
	*Total	404	100%	179	100%	225	100%

NR = No record

* Total represents those repsondents who matched with the original database.

2 Methods
2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

Table 2.10.J Exposure to Specific Chemicals as Reported by Respondents to the Norfolk Health Survey Questionnaire (Long)

Survey/ Variable		Total		Nuclear Worker Status: Nuclear		Nuclear Worker Status: Non-Nuclear	
		No.	%	No.	%	No.	%
Item(21)							
Job	Arsenic	8	2%	3	2%	5	2%
Exposures	Asbestos	293	73%	147	82%	146	65%
	Benzene	17	4%	10	6%	7	3%
	Chromium	30	7%	20	11%	10	4%
	Coal, tar, etc.	69	17%	32	18%	37	16%
	Dye stuff	11	3%	5	3%	6	3%
	Grinding dust	251	62%	120	67%	131	58%
	Leather dust	3	1%	1	1%	2	1%
	Mineral dust	17	4%	6	3%	11	5%
	Silica dust	49	12%	28	16%	21	9%
	Wood dust	54	13%	31	17%	23	10%
	Other dust	60	15%	25	14%	35	16%
	M, C, F oils[1]	80	20%	36	20%	44	20%
	Nickel	19	5%	11	6%	8	4%
	Pesticides	9	2%	4	2%	5	2%
	None of these	46	11%	8	4%	38	17%
	NR, Unk	15	4%	6	2%	9	4%
	Total	404		179		225	

[1]Mineral, Cutting or Fuel Oil
NR = No record

2 Methods
2.10 Personal Characteristics and Exposures Outside the Shipyard (cont'd)

Table 2.10.K Medical Exposures Reported by Respondents to the Norfolk Health Survey Questionnaire (Long)

Survey/ Variable		Total No.	Total %	Nuclear Worker Status: Nuclear No.	Nuclear %	Non-Nuclear No.	Non-Nuclear %
Item (23)	Never	12	3%	7	4%	5	2%
Dental	<1 in 5 yrs.	96	24%	41	23%	55	24%
x-rays	1 in 2-5 yrs.	140	35%	65	36%	75	33%
	1 per yr.	93	23%	35	20%	58	26%
	>1 per yr.	21	5%	6	3%	15	7%
	NR, Unk	42	10%	25	14%	17	8%
	Total	404	100%	179	100%	225	100%
Item (23)	Never	3	1%	1	1%	2	1%
Chest	<1 in 5 yrs.	65	16%	24	13%	41	18%
x-rays	1 in 2-5 yrs.	149	37%	70	39%	79	35%
	1 per yr.	143	35%	69	39%	74	33%
	>1 per yr.	22	5%	5	3%	17	8%
	NR, Unk	22	5%	10	6%	12	5%
	Total	404	100%	179	100%	225	100%
Item (24)	Yes	280	69%	122	68%	158	70%
Other	No	73	18%	29	16%	44	20%
Health	NR, Unk	51	13%	28	16%	23	10%
X-rays	Total	404	100%	179	100%	225	100%
Item (25)							
Radioisotope	Yes	93	23%	48	27%	45	20%
exposure	No	276	68%	117	65%	159	71%
	Unk	35	9%	14	8%	21	9%
	Total	404	100%	179	100%	225	100%
Item (26)	Yes	16	4%	9	5%	7	3%
Radiation	No	345	85%	154	86%	191	85%
treatment	Unk	43	11%	16	9%	27	12%
	Total	404	100%	179	100%	225	100%

2 Methods

2.11 Statistical Methods

Several different statistical analyses will be conducted using the data set. For each analysis, the following outcomes are considered separately: death from leukemia, death from lymphoma, death from mesothelioma, death from lung cancer, and total mortality. Leukemia is used throughout this section as the outcome for illustrative purposes.

External Comparison

When the disease experience from the standard population is available, it is of interest to compare the death rate of the radiation workers with that of the standard population. A formal set up can be described as follows. Denote by u_i the observation time for the ith radiation worker. Let $\lambda_i(u)$ be the ith worker's risk of dying from leukemia at time u and let $\lambda_i^*(u)$ be the corresponding risk for a worker from the standard population who shares the same demographic information (age, sex, race, calendar time, and, if necessary, the geographic location of the shipyard) as the ith radiation worker. The following model

$$\lambda_i(u) = \exp(\beta)\, \lambda_i^*(u) \qquad (1)$$

expresses the risk for a group of nuclear workers as a simple multiple, exp(b), of the risk in the standard population. This multiplier is known as the standardized mortality ratio (SMR = exp(b)), for the particular group of nuclear workers. It should be noted that the only unknown parameter in model (1) is exp(b); therefore, the usual maximum likelihood approach can be used to make inferences on the SMR (Breslow, 1977, 1978).

One major drawback of model (1) is that the variations among workers in date and age at first employment, job classification, duration of employment prior to entry, shipyards worked, and more importantly, amount of radiation exposure, are not taken into account. Two approaches are possible to include such information in a model. One is to further divide workers into strata and compute a separate SMR for each stratum provided that comparable data for the external comparison group are available. Another approach is to replace exp(b) in (1) by

$$\exp(\underset{\sim}{\beta}' \underset{\sim}{Z}_i) \tag{2}$$

where $\underset{\sim}{Z}_i$ represents the available information from the ith worker. While these two approaches are helpful in correcting the problems noted above, a serious problem posed by most occupational studies still remains. That is, exposure and follow-up periods overlap; consequently, cumulative exposures are generally greatest for those longest in the study and underestimation of the SMRs will be the result when data are analyzed by cumulative exposure (Enterline, 1976). To be more specific, should a worker who accumulated 10 rem over the course of a working career, but who has had only 5 of those rem in the 10 years just prior to the diagnosis of lung cancer, be treated the same as an individual who received 10 rem 10 years ago and developed the cancer 10 years after his last exposure? If 10 rem were assigned to the first worker, the SMR for the 10 rem DE category will be underestimated.

A more appropriate approach is to use the "time dependent" concept introduced by Cox (1972) and to replace the $\underset{\sim}{Z}_i$ in (2) by $\underset{\sim}{Z}_i(u)$. Conceptually, a worker may contribute person-years to several exposure groups but will contribute an event (or be censored) in only one group.

Internal Comparison

There are a number of obvious deficiencies in the external comparison approach, the most prominent of which is the so called "healthy worker effect." The availability of a reasonably large population of non-nuclear workers from the same shipyard affords a means for selecting an internal group to control for many of the potentially important biases inherent in using a standard population comparison. An approach that might be adopted is the proportional hazard model proposed by Cox (1972). The Cox model has long been used, especially in clinical trials, when length of follow-up is probably the most sensible time variable to be modeled. The application of the same model to the epidemiological cohort studies was not started until recently (Clayton, 1978; Prentice and Breslow, 1978; Breslow et al., 1983). One controversy which remains unsettled is the choice of the continuous time variable to be used in such a cohort study. There are two possibilities: length of follow-up or age. While both may be informative, the latter has special appeal in occupational studies for the following reasons. First, since death rates for leukemia (also for lung cancer) rise rapidly with age, control for age is essential. Second, the hazard function described below has the easy interpretation of being the age-specific death rate. Third, the overlap between follow-up intervals and exposure periods may eventually lead to insoluble computing difficulties due to the "over-match" problem. For these reasons, age will be hereafter used as the time variable in the analysis, although plans also include analyses by length of follow-up controlled for age. Any important inferential discrepancies between the two approaches would have to be resolved.

2 Methods

2.11 Statistical Methods (cont'd)

Denote by t the age at the time of death from leukemia. The model we propose is

$$\lambda(t, k) = \overset{*}{\lambda}(t, k) \exp\{\underset{\sim}{\beta}'_k \underset{\sim}{Z}(t, k)\}, \quad k = 1, \ldots, K \tag{3}$$

where k(t, k) denotes the leukemia death rate at age t. The indicator variable k is used here to indicate the level of stratified variables (birth year, job classification, time of first hire in yard, etc.) to which the worker belongs. The covariates $\underset{\sim}{Z}(t,k)$ include the exposure variables and some other potentially confounding variables which may or may not depend on time. The quantity $\exp\{\underset{\sim}{\beta}'_k \underset{\sim}{Z}(t,k)\}$ is then the risk of Z relative to 0 at time t. Finally, $\overset{*}{\lambda}(t,k)$ is the death rate when $\underset{\sim}{Z} = \underset{\sim}{0}$, i.e., the death rate for non-radiation workers, which is unknown and needs to be estimated as well.

To estimate the parameter $\underset{\sim}{\beta}_k$'s, the workers who died from leukemia are identified. For each such death, a risk set is formed consisting of all workers who are alive and under observation at the same age and who belong to the same level of stratified variables as the corresponding case(s). A comparison is then made between the covariates of cases and the covariates of those alive in the same risk set. In using duration of follow-up as the time variable, the period from entry into radiation work or the comparable dummy variable for non-nuclear workers to the time of death will be used to form the risk set instead of age at death.

Two different analyses will be considered in the study. One is simply to treat the exposure variable as a dichotomous variable, i.e., one, if exposed to radiation and zero, if otherwise. Note that the score test for testing the radiation effect of this model, based on the partial likelihood described above, gives rise to the log rank test for the two sample problem. Another approach we intend to take is to treat the exposure variable as a time dependent continuous variable. The choices of representations of the exposure variable are numerous and sometimes arbitrary. The one which might be appropriate in this study for leukemia is the two year lagged cumulative radiation exposure, i.e. the total amount of exposure up to two years prior to the time under consideration. The concept of time dependence comes in since the total amount of exposure for the same worker will be varied and actually increased as a function of the time variable, age or duration of follow-up, in this study. Several other lag periods will be tried especially for solid tumors.

Even though only a portion of the whole shipyard population has been selected for analysis, the resulting sample size remains large. Some non-trivial computational problems may arise if, as expected, there are many ties among the ages at death or if the drop out rate is low as it may be. As a remedy, we can draw for each risk set, a sample of small size, say 20 or 30, from those who are still alive. Instead of examining all in the risk set, the covariates of the deaths are compared with that of randomly selected subgroups. Breslow et al. (Breslow et al, 1983) found in their data set that the results based on this so-called "case-control" analysis with sizes 5 to 10 were in remarkable agreement with those derived from the whole data set.

More recently, Prentice (1984) proposed the following "case-cohort" (his term) design in which a random (stratified) sub-cohort is selected and then any cases that develop in the sub-cohort are pooled with other cases arising in the remainder of the cohort while taking the sub-cohort members as controls. He found through his example that the proposed sampling scheme and analysis is fairly efficient relative to a full-cohort analysis.

While the use of Cox' model in applications has been widespread, the work on model checking is still in the developing stage. Viewing Cox' model as a special case of regression model, the following three key components of regression diagnostics can be addressed.

Goodness-of-fit

The following two implicit assumptions are essential to the Cox proportional hazards model. First, the covariates act multiplicatively on the hazard function (in our case, the death rate for leukemia); second, the relative risk function has exponential form as opposed to the additive form $1 + \underset{\sim}{\beta}\underset{\sim}{Z}$, for example. A formal test of each of the above two assumptions has been derived in recent unpublished work by Liang and Self. These tests provide overall assessment on the goodness-of-fit of the Cox model from two totally different approaches.

Outlier detection

It is important to have a way to detect potential outliers since the radiation exposure distribution of this data set is heavily skewed to the right. Some techniques are available for the time independent covariates (Crowley and Hu, 1977; Kay, 1977). Basically, if the model (3) is correct with $\underset{\sim}{Z}$ independent of t, then, for each k, the cumulative hazard transformation:

$$\exp(\underset{\sim}{\beta}_k \underset{\sim}{Z}) \int_0^T \overset{*}{\lambda}(t, k)\, dt = \exp(\underset{\sim}{\beta}'_k \underset{\sim}{Z}) H(T) \tag{4}$$

2 Methods
2.11 **Statistical Methods** (cont'd)

has the unit exponential distribution. So by plotting

$$e_i = \exp(\hat{\underset{\sim}{\beta}}_k \underset{\sim}{Z}_i)\hat{H}(T_i) \qquad (5)$$

where $\hat{\underset{\sim}{\beta}}_k$ and $\hat{H}$ are the estimates of $\underset{\sim}{\beta}_k$ and H against expected order statistics provides a check of the assumed model (3). More importantly, any observation which is far from the approximate straight line may be an outlier. However, there are two drawbacks to the above approach. First, as pointed out by Lagakos and Schoenfeld (1981), the distribution of e_i, which approximates (4), departs substantially from the presumed distribution. Second, the extension of the above work to time dependent situations is not clear. Recently, a different approach by examining the "influence" of each data point on the estimation of parameters has been worked out by Storer and Crowley (1985) which can be used to address the above problems.

Model specification

One of the statistical issues in the variable selection is to decide whether a variable should be included in the model and whether a quadratic form, for example, is more appropriate for the covariate already in the model. Lagakos and Schoenfeld (1981) defined, for each individual, the residual under the Cox model and showed that the expectations of these newly defined residuals are approximately one and hence are independent of the fitted covariates. Therefore, plotting the ordered residuals against the ordered covariates should provide useful graphical evaluation of covariates, either included or omitted.

A question of interest to a certain degree is whether a variable should be treated as a covariate and put into the exponent of the risk function or should it be used as a stratification variable. The former approach will enable us to make statements about the effect of that variable on the outcome, death from leukemia. However, we are forced in the meantime to make a much stronger structural assumption on that variable than the latter approach does. Kay (1977) and Andersen (1982) offer ways to make the correct decision.

Recently, more attention has been given to the modelling of the temporal nature of the excess mortality. This may be appropriate for the studies in which the follow-up period is long or the mortality excess from the agent occurs within a relatively narrow latency.

Andersen (1984) proposed the following model

$$\lambda_i(u) = \overset{*}{\lambda}_i(u)\, \nu(u) \exp(\underset{\sim}{\beta}' \underset{\sim}{Z}_i(u)) \qquad (6)$$

where $\lambda_i(u)$ is the same as in (1) and m(u) is an unknown underlying excess mortality, i.e., the excess mortality at u for an individual $\underset{\sim}{\beta}'\underset{\sim}{Z}(u) = 0$.

Thus, the covariates $\underset{\sim}{Z}(u)$ are assumed to have a multiplicative effect on the excess mortality. It should be pointed out that the model (2) is the special case m(u) = 1 of (6). It assumes constant excess mortality across time and is fully parametric. Model (6) is more flexible since it does not require specification of the underlying excess mortality.

No additional computational problem will occur for (6) since it can be written as

$$\lambda(u) = \nu(u) \exp\{\underset{\sim}{\beta}' \underset{\sim}{Z}_i(u) + 1 \cdot \log \overset{*}{\lambda}_i(u)\} \qquad (7)$$

Thus the log $\overset{*}{\lambda}_i(u)$ enters into the mortality functions as a time-dependent covariate with a known regression coefficient equal to 1. Consequently, any computing package handling the Cox proportional hazard model can be adapted for estimation purposes.

Another model considered by Pierce et al. (1984) in analyzing the RERF A-bomb data is described as follows. Denote time since exposure by u and t the same as before. They suggest the following additive model

$$\lambda(u;\, t) = w(t) + f(\underset{\sim}{d})\, \rho(u;\, \underset{\sim}{Z};\, \underset{\sim}{d}), \qquad (8)$$

where $\underset{\sim}{d}$ is a vector containing exposure information and $\underset{\sim}{Z}$ is a vector of nonexposure covariates. The function w is the underlying mortality while the function q models the excess. The approach they took is via cross-classification of the data and is a fully parametric one. Some caution is needed for this approach: (a) the choices of function w, f and q can be arbitrary, (b) the subjects in that study were exposed to the radiation at only one point of time while in ours, the exposure period is overlapped with the follow-up time.

All the analyses we described above will be preceded by some preliminary analyses, namely, by grouping the data so that the elementary contingency table analyses can take place (Holford, 1980; Berry, 1983; Pierce, et al., 1984). Even though this kind of analysis might not be fully efficient, it does have advantages: (a) both time and cost savings, (b) avoiding the measurement error problem which is of concern for the radiation exposure variable, and (c) actual efficiency loss is probably small (Gilbert, 1983).

Extensive exploration of the accumulating exposure as a function of time will be undertaken. The results will be used for descriptive purposes and might play a role in specification of the radiation variable in the regression models.

If any statistically significant dose-response relationships are detected, they will be compared with existing estimates (BEIR III, for example) for consistency.

Available statistical software have been used where possible including GLIM, SAS and BMDP. Other commercial software from the University of Washington which will be used include:

- COXREG - Internal comparison with multiplicative models
- EPICOX - External comparisons with multiplicative models (SMR's)
- PECAN - Conditional logistic regression models for matched data sets (includes diagnostics for Cox's model, logistic regression models).

For the present report, only initial analyses will be presented. They will include an indirect adjustment of death rates using U.S. white male rates as the standard since the majority of the population is white. All causes of death as well as the specific causes leukemia, lymphoma, lung cancer and mesothelioma will be examined for each group in the sample, ≥0.5 rem workers, <0.5 rem workers, and non-nuclear workers. The group of ≥0.5 rem workers was also examined by dose within the group using a life table approach to mortality analyses. Since the groups were comparable to each other in age and calendar time of start of follow-up, the SMR comparisons between groups should be appropriate. Analyses will include allowance for latency periods of 2, 5, 10 and 15 years. For these time periods, the follow-up years were included for risk estimates but the dose during that period was not added to the total cumulative dose.

3 Results

3.1 Characteristics of Population for Analysis and Total Morality

The initial sample was selected to include all workers with $\geq$0.5 rem DE accumulated by January 1, 1982 and a proportion of those with <0.5 rem accumulated to the same date. The addition of the sample of non-nuclear workers resulted in an original sample of 72,357. However, after sample selection, 39 workers were deleted due to edits which resulted in a true sample of 72,318. As shown in Table 3.1.A., 603 additional deletions occurred for the current analysis because of interyard duplicates. Thus, the starting population was 71,715 as indicated by the groups in Part A of Table 3.1.B. Another 985 workers were excluded in subsequent steps due to incorrect or missing variables (766), apparent unreasonable ages at start of employment or start of follow-up (44), and missing dates of deaths (167). The total population includes 70,730 workers for analysis in Part B, Table 3.1.B.

Workers who belonged to the <0.5 rem group entered follow-up at the time of entry into the radiation monitoring program. This was represented as the time when the worker received the first dosimeter reading even if that reading was zero. Nuclear workers in the group with DEs of 0.5 rem or greater did not follow-up until at least 0.5 rem had been reached as the total accumulated DE at the end of that year. If any worker had a recorded year of entry before nuclear overhaul, the year of start of follow-up was equated to the year overhaul began. Non-nuclear workers were selected initially to be similar to the workers with DEs of 0.5 rem or more in regard to the total duration worked prior to the years of start of nuclear work for the $NW_{\geq 0.5}$ group. In each stratum, the non-nuclear worker had to have worked at least as long or longer than the $\geq$0.5 rem nuclear workers to whom they were compared by the year when the nuclear worker had started nuclear work. The two groups were selected to

3 Results
3.1 **Characteristics of Population for Analysis and Total Mortality** (cont'd)

be similar on the distribution of times worked before the start of the $NW_{\geq 0.5}$ group in the nuclear program. A dummy variable was entered into the record of the non-nuclear workers selected in each stratum which represented the times of entry of nuclear workers into radiation work. This start time represented the start of follow-up for non-nuclear workers.

The age distributions of the non-nuclear workers and <0.5 rem groups have a higher proportion of workers under the age 25 and over 55 or 60 at entry into follow-up than would be expected compared to the ≥0.5 rem group and weighted by the sampling ratio. These distributions are shown in Table 3.1.A1. However, in general, the balance is good. Some of the difference is due to the required delay in start of follow-up for the ≥0.5 rem group until they had met the minimum criterion of dose. Based on the median ages of entry into follow-up, the median time interval to accumulate 0.5 rem must be 0.7 years.

The start of major nuclear overhaul varied by shipyard, beginning in 1957 with Groton and ending with Puget Sound in 1967. The median calendar year of entry into follow-up reflects the start of overhaul for the combined yards. The ongoing population was established from that time forward. Table 3.1.A2 indicates that the major proportion of the nuclear worker population entered follow-up in 1965-1969 with the median year being 1967.0 for the <0.5 rem and 1968.1 for the ≥0.5 rem group. Only half of the population has been followed for 13 years or more (median length of follow-up 13 years). Even this follow-up is a relatively short period in which to expect development of many solid tumors.

3 Results

3.1 Characteristics of Population for Analysis and Total Mortality (cont'd)

The distribution of deaths by age group and calendar time indicates major differences in both of these variables by sample groups (Table 3.1.A3). The deaths are infrequent in the first decade primarily due to the establishment of the initial cohort during that period. In this period, as in all subsequent time intervals, the number of deaths is much greater in the non-nuclear worker group than in the ≥0.5 rem group and exceeds the expected excess due to the over-sampling fraction in the non-nuclear worker group. This difference also occurs despite the fact that the groups are balanced by age. Deaths in the 1975-1981 period represent a larger proportion of all deaths among the ≥0.5 rem population than in the other groups (Table 3.1.A3). Selective factors which lead to the accumulation of higher doses of radiation and longer survival have probably resulted in fewer deaths in the ≥0.5 rem group despite the slightly older median age of that group compared to the other groups at start of follow-up.

The mortality of each group is displayed in the tables for sections 3.1-3.5. The analyses in each of these sections include crude all cause mortality rates and death rates for the following specific causes: leukemia, lymphatic and hematopoietic cancer, lung cancer and mesothelioma. These same causes have been analyzed and adjusted for age and calendar time using an indirect adjustment with U.S. white male rates as the standard.

A total 920,907 person-years was used in the analysis with 38.7 percent of these person-years distributed in the ≥0.5 rem group, 15.2 percent in the <0.5 rem group and 46.2 percent in the non-nuclear worker group. The worker's person-years were credited from entry into follow-up with 1/2 year counted for both the year of entry and the year of death and a full year for any other

3 Results
3.1 **Characteristics of Population for Analysis and Total Mortality** (cont'd)

period of observation after entry. The only exception was for workers who entered and died in the same period, in which case they were credited with 1/3 year. As stated previously, the year of entry of the ≥0.5 rem group represents the first year in which they have accumulated a DE of 0.5 rem or greater. As seen in Table 3.1.B., the overall crude death rates for workers in both nuclear groups are lower than in the non-nuclear worker group and the lowest rate is for the workers in the ≥0.5 rem group. The adjusted SMRs shown in the last line of the table indicate that nuclear workers have significantly lower death rates than those of the U.S. white male population whereas the non-nuclear worker group has a ratio similar to that of the standard population. The mortality ratio of 0.76 for the ≥0.5 rem group probably represents not only the usual healthy worker selection bias found in occupational populations but also an additional selection bias which occurs at entry of the worker into radiation work and occurs again when the workers are selected by the fact that they have reached ≥ 0.5 rem or more.

Tables 3.1.C and 3.1.C1 examine the risks of mortality in the three groups with the ≥0.5 rem group divided according to cumulative DE into three (Table 3.1.C) or four separate subgroups (Table 3.1.C1). The crude rates in Part A indicate that the death rates decrease with increasing DE. Since both age and survival time may be correlated with increasing DEs, for these analyses, the workers' person-years are not just accumulated in a single dose group but are distributed across all DE groups to which the worker belonged as he accumulated the final dose. This is designated as a "time-dependent" analysis. The <0.5 rem group and the non-nuclear worker group were handled as individual groups. Using time-dependent analyses and age and calendar time adjustment of rates, there is still a decline in the highest DE subgroup whether that subgroup is 5.0^{+} rem or is 10.0^{+} rem. This decline in mortality may represent survival bias even with finer subdivisions of dose groups. That is, the individual who continues to accumulate dose must continue to survive. The individual who dies may terminate work prior to death and thus stop adding dose. Thus, the healthy person continues to work and accumulate dose; the unhealthy person cannot work and so will not receive a dose and may soon die.

In the case of a chronic disease, the dose needed to cause the disease may occur several years before the clinical onset of disease and these may be additional years before death, the outcome used in this study. In order to account for the latent period before the disease is manifest, four "lag periods" have been used. These periods represent selected time intervals before death when no additional dose has been added to the cumulated DE. Any DE occurring in that period is omitted. These DE reductions are imposed on both the diseased and non-diseased subjects in all groups. This adjustment would be expected to improve the problem of survival bias as well. However, the number of cases is also reduced by lagging. Any case occurring within the lag period is omitted.

In comparing ratios, the 0.5 - 0.999 rem group was used as a comparison. That group represents all workers who not only reached that level but any of the higher dose groups as well; thus, the 0.5 - 0.999 rem subgroup included all the population in the $\geq$0.5 rem group. The < 0.5 rem group have the same selective factors of enrollment in the radiation program as the higher level group but it represents only a sample of that population and has not been included in the time-dependent analysis. Thus it was not considered to be as comparable a group for evaluation of changes in mortality with dose. The NNW group was not selected for nuclear work and was viewed as representing the mortality of all shipyard workers.

As seen following "lagging", the standardized mortality ratio does increase in the DE subgroups of 1.0 and 5.0 rem as well as the subgroup of 10.0^{+} rem as compared to the group with 0.5 rem but these differences are not significant. There is no consistent dose response with increasing rem level, and the standardized mortality ratios at each dose level are usually lower than those for the <0.5 rem DE as well as the non-exposed group. Crude relative risks have been calculated using the ratios of the indirectly adjusted SMRs to make it easier to compare subgroups, and confidence intervals have been calculated for these values.

As can be seen in the tables the number of deaths decreases with lagging as expected. By 15 years of lag, for example, the number of deaths is only 25 percent of those which were in the complete analysis. For those in the ≥0.5 rem group, only 20 percent remain. The small numbers at these long lag period represent the limited follow-up which still exists in this population. Future examination of the long lag periods of 5, 10 and 15 years may be more interesting when there are more deaths in each subset.

3 Results
3.1 Characteristics of Population for Analysis and Total Mortality (cont'd)

Table 3.1.A Derivation of Analysis Subset

- Starting population: all members of $NW_{<0.5}$, $NW_{\geq 0.5}$ and NNW study sample from the six Navy yards: Charleston, Mare Island, Norfolk, Pearl Harbor, Portsmouth and Puget Sound (N = 49,809) and the 2 private yards: Groton (N=13,725) and Newport News (N = 8,784) totalling 72,318 workers. A total of 39 workers were deleted from the original sample (N = 72,357) due to edits from the shipyards.

- Exclude 603 inter-yard duplicates (N = 71,715)

- Exclude workers no longer eligible for inclusion in sampling frame due to edits as follows: 62 workers no longer in sampled dose group,98 non- shipyard workers, 94 workers working less than 1 year in the shipyard, 250 women, and 262 workers with missing data for the stratification variables (N = 70,949)

- Exclude workers due to unlikely or invalid data as follows: 44 workers less than 16 or greater than 80 years of age at entry into the radiation program, 8 workers less than 18 or greater than 91 years of age at death or with year of death less the year of entry into follow-up (N = 70,897)

- Exclude 167 workers with unknown date of death; not all dates of death have been confirmed by certificate review (N = 70,730)

- Identify cumulative radiation exposure as of 1/1/82:

  32,510 workers are non-nuclear
  10,348 workers have <0.5 rem exposure
  18,788 workers have ≥0.5-4.9 rem exposure
  9,084 workers have ≥5.0 rem exposure

- Person-years accumulation: each worker receives credit for 1/2 year of observation during the entry year and year of death, and 1 full year of observation otherwise; workers who enter and exit during the same year received credit for 1/3 year of observation. Person-years are counted from year of entry into follow-up to year of death or 1981. Year of entry into follow-up is defined as: year of entry into shipyard adjusted for minimum duration worked for NNW, year of entry into radiation program for $NW_{<0.5}$, and year of entry into radiation program or year 0.5 rem lifetime exposure received for $NW_{\geq 0.5}$. Additionally, if any year of entry is before nuclear overhaul in the shipyard, it is equated to the year overhaul began.

Total person-years observed = 920,907

(cont'd)

3 Results

3.1 Characteristics of Population for Analysis and Total Mortality (cont'd)

Table 3.1.A Derivation of Analysis Subset (cont'd)

- Data items included in the analysis subset include: (1) social security number (2) yard (3) date of birth (4) year of entry into yard (5) year of entry into "radiation program" (6) year of entry into follow-up (7) duration worked in shipyard (8) grouped job hazard index (9) vital status indicator (10) date of death (11) death certificate cause of death - ICD-9 (12) cause of death - medical abstracts (13) annual exposure in millirem for each year of follow-up (14) cumulative exposure in millirem for each year of follow-up (15) prior exposure in millirem

3 Results
3.1 Characteristics of Population for Analysis and Total Mortality (cont'd)

Table 3.1.A1 Population by Age at Time of Entry into Followup by Dose Equivalent Group

Ages	≥ 0.5 rem	< 0.5 rem	NNW
16-19	162	218	1,180
20-24	3,800	1,775	5,762
25-29	6,173	2,160	6,124
30-34	4,444	1,431	4,644
35-39	3,364	1,223	3,762
40-44	3,620	1,286	3,901
45-49	3,052	981	2,809
50-54	1,919	708	1,859
55-59	990	364	1,374
60-64	306	172	809
65-69	39	26	257
70+	3	4	29
Total	27,872	10,348	32,510
Median age at entry	34.3	33.6	33.4

3 Results
3.1 Characteristics of Population for Analysis and Total Mortality (cont'd)

Table 3.1.A2 **Population by Year of Entry Into Followup by Dose Equivalent Group**

Calendar Year Start Followup	≥ 0.5 Rem	< 0.5 Rem	NNW
1955-59	1,057	826	2,157
1960-64	5,770	2,697	9,031
1965-69	11,502	4,060	11,171
1970-74	5,005	1,156	5,065
1975-79	3,379	1,222	4,156
1980-81	1,159	387	930
Total	27,872	10,348	32,510
Median year of entry	1968.1	1967.0	1967.3

3 Results
3.1 Characteristics of Population for Analysis and Total Mortality (cont'd)

Table 3.1.A3 Deaths by Age and Year of Death for Each Dose Equivalent Group

DE Group by Death Year		Age Group (Years) <40	40-49	50-59	60-69	70+	Total
≥ 0.5 NW	1955-64	9	16	28	12	1	66
< 0.5 NW	1955-64	9	8	19	10	2	48
NNW	1955-64	41	31	71	58	22	223
	Total	59	55	118	80	25	337
≥ 0.5 NW	1965-74	109	171	331	205	36	852
< 0.5 NW	1965-74	55	77	126	116	32	406
NNW	1965-74	192	297	458	445	210	1,602
	Total	356	545	915	766	278	2,860
≥ 0.5 NW	1975-81	70	137	376	517	197	1,297
< 0.5 NW	1975-81	42	45	136	181	115	519
NNW	1975-81	154	242	493	514	517	1,920
	Total	266	424	1,005	1,212	829	3,736

3 Results

3.1 Characteristics of Population for Analysis and Total Mortality (cont'd)

Table 3.1.B **Deaths From All Causes, Person-Years and Death Rates[1] for NNW, $NW_{<0.5}$ and $NW_{\geq 0.5}$**

	$NW_{\geq 0.5}$	$NW_{<0.5}$	NNW
Part A. All Workers Sampled			
Workers in sample	28,089	10,413	33,213
Total deaths	2,797	1,168	4,453
Part B. Workers Selected for Analysis[2]			
Workers in subset	27,872	10,348	32,510
Person-years	356,091	139,746	425,070
Deaths	2,215	973	3,745
Death Rates Per 1,000[3]	6.4	7.1	9.0
SMR[4] (95% C.I.)[5]	0.76 (0.73, 0.79)	0.81 (0.76, 0.86)	1.00 (0.97, 1.03)

1 Rates calculated per 1,000 person-years.

2 See Table 3.1.A for derivation of analysis subset.

3 Adjusted for deaths excluded from analysis due to unknown date of death.

4 Adjusted for age and calendar time with the indirect method of adjustment using age-calendar time specific rates for U.S. white males.

5 C.I. = 95% Confidence Intervals

3 Results

3.1 Characteristics of Population for Analysis and Total Mortality (cont'd)

Table 3.1.C All Cause Mortality for NNW, $NW_{<0.5}$, and 3 Recorded DE Groups[1] Within $NW_{\geq 0.5}$

	$NW_{\geq 0.5}$ (rem)				
	0.5-	1.0-	5.0+	$NW_{<0.5}$	NNW
Part A. Unadjusted					
Workers	5,431	13,357	9,084	10,348	32,510
Person-Years	69,489	172,531	114,071	139,746	425,070
Deaths	454	1,110	651	973	3,745
Rate[2] per 1,000	6.7	6.6	5.9	7.1	9.0
Part B. Adjusted[3]					
SMR	0.72	0.79	0.74	0.81	1.00
Relative Risk	1.00	1.10	1.03	1.13	1.39
(95% C.I.)		(0.98,1.23)	(0.91,1.16)	**(1.01,1.26)**	**(1.26,1.53)**
Part C. Adjusted With Time Lags					
Lag: 2 years					
Deaths	430	1,068	627	938	3,516
SMR	0.70	0.81	0.78	0.82	1.00
Relative Risk	1.00	1.16	1.11	1.17	1.43
(95% C.I.)		**(1.03,1.30)**	(0.98,1.26)	**(1.04,1.31)**	**(1.29,1.58)**
Lag: 5 years					
Deaths	385	945	539	812	2,991
SMR	0.72	0.78	0.82	0.83	1.00
Relative Risk	1.00	1.08	1.13	1.15	1.39
(95% C.I.)		(0.96,1.22)	(0.99,1.30)	**(1.02,1.30)**	**(1.24,1.55)**
Lag: 10 years					
Deaths	280	685	322	566	2,042
SMR	0.76	0.84	0.85	0.85	1.03
Relative Risk	1.00	1.10	1.12	1.12	1.36
(95% C.I.)		(0.96,1.27)	(0.94,1.32)	(0.91,1.30)	**(1.20,1.54)**
Lag: 15 years					
Deaths	145	318	92	270	898
SMR	0.83	0.94	0.79	0.90	1.02
Relative Risk	1.00	1.13	0.95	1.08	1.23
(95% C.I.)		(0.93,1.39)	(0.72,1.24)	(0.88,1.34)	**(1.03,1.47)**

[1] DE groups for the $NW_{\geq 0.5}$ are time dependent, ie., a worker could contribute person-years to each of the 3 dose groups.

[2] Adjusted for deaths excluded from analysis due to unknown date of death.

[3] Adjusted for age and calendar time with the indirect method of adjustment using age-calendar time specific rates for U.S. white males.

3 Results

3.1 Characteristics of Population for Analysis and Total Mortality (cont'd)

Table 3.1.C1 All Cause Mortality for NNW, $NW_{<0.5}$ and 4 Recorded DE Groups[1] Within $NW_{\geq 0.5}$

	$NW_{\geq 0.5}$ (rem)					
	0.5-	1.0-	5.0-	10+	$NW_{<0.5}$	NNW
Part A. Unadjusted						
Workers	5,431	13,357	4,846	4,238	10,348	32,510
Person-Years	69,489	172,531	63,819	50,253	139,746	425,070
Deaths	454	1,110	367	284	973	3,745
Rate[2] per 1,000	6.7	6.6	5.9	5.8	7.1	9.0
Part B. Adjusted[3]						
SMR	0.72	0.79	0.76	0.72	0.81	1.00
Relative Risk	1.00	1.10	1.06	1.00	1.13	1.39
(95% C.I.)		(0.98,1.23)	(0.92,1.22)	(0.86,1.16)	(1.01,1.26)	(1.26,1.53)
Part C. Adjusted With Time Lags						
Lag: 2 years						
Deaths	430	1,068	358	269	938	3,516
SMR	0.70	0.81	0.81	0.75	0.82	1.00
Relative Risk	1.00	1.16	1.16	1.07	1.17	1.43
(95% C.I.)		(1.03,1.30)	(1.00,1.33)	(0.92,1.25)	(1.04,1.31)	(1.29,1.58)
Lag: 5 years						
Deaths	385	945	308	231	812	2,991
SMR	0.72	0.78	0.83	0.81	0.83	1.00
Relative Risk	1.00	1.08	1.15	1.13	1.15	1.39
(95% C.I.)		(0.96,1.22)	(0.99,1.34)	(0.95,1.33)	(1.02,1.30)	(1.24,1.55)
Lag: 10 years						
Deaths	280	685	203	119	566	2,042
SMR	0.76	0.84	0.89	0.79	0.85	1.03
Relative Risk	1.00	1.10	1.17	1.04	1.12	1.36
(95% C.I.)		(0.96,1.27)	(0.98,1.41)	(0.83,1.29)	(0.97,1.30)	(1.20,1.54)
Lag: 15 years						
Deaths	145	318	64	28	270	898
SMR	0.83	0.94	0.79	0.84	0.90	1.02
Relative Risk	1.00	1.13	0.95	1.01	1.08	1.23
(95% C.I.)		(0.93,1.39)	(0.70,1.29)	(0.65,1.52)	(0.88,1.34)	(1.30,1.47)

[1] DE groups for the $NW_{>0.5}$ are time dependent, ie., a worker could contribute person-years to each of the 3 dose groups.

[2] Adjusted for deaths excluded from analysis due to unknown date of death.

[3] Adjusted for age and calendar time with the indirect method of adjustment using age-calendar time specific rates for U.S. white males.

3 Results

3.2 Mortality from Leukemia

The analysis of mortality from leukemia has followed the same methods as described for total mortality. The crude death rates per 100,000 workers are highest for the non-nuclear worker group (7.36) but with a similar rate for the ≥0.5 rem group (6.40) and a very low rate for the <0.5 rem group (3.07). Indirect standardization of the rates by age and calendar time cause specific rates for U.S. white males indicates that the leukemia mortality rates for all groups are lower than the death rate for that disease in the general population. The SMR for the $NW_{<0.5}$ group is remarkably low being only 42 percent of the mortality in the general population. However, none of these ratios are significantly different from those of the general population of U.S. white males.

When the adjusted death ratios for leukemia are examined by DE subgroups, in the ≥0.5 rem group, the SMR for the group at 0.5-0.9 rem is close to that of the <0.5 rem group and very low, about 40 percent of the rate for the general population. The SMR is higher for the DE subgroup of 1.0-4.9 rem, but there is no indication of a dose-response, and the SMRs are similar to that of the general population and the non-nuclear worker group.

Lagging the dose for two years increased the SMR for the DE group of 1.0-4.9 rem partly because one of the cases which had previously been included at 5 rem now fell into the lower dose level two years before. However, the SMR is still not significantly higher than the comparison rates and there is no dose-response based on the adjusted SMRs.

Leukemia was the cause of major interest because of the recognized risk of this disease with radiation. The number of cases are few at present and although there is a sharp rise in the SMR between the DE of 0.5-0.9 rem and

3.2 Mortality from Leukemia (cont'd)

1.0-4.9 rem, there is no evidence of a dose-response from the exposure. All ratios are similar to those of the general population. All types of leukemia have been included in this analysis both in the cases and in the comparison standard population. Future analyses will remove chronic lymphocytic leukemia from the causes since it is not associated with exposure to radiation. However, the specific types of leukemia have not been identified for all cases at the time of this report.

3 Results

3.2 Mortality from Leukemia (cont'd)

Table 3.2.A Deaths from Leukemia, Person-Years, and Death Rates for NNW, $NW_{<0.5}$, and $NW_{\geq 0.5}$

	$NW_{\geq 0.5}$	$NW_{<0.5}$	NNW
Workers	27,872	10,348	32,510
Person-Years	356,091	139,746	425,070
Deaths (Leukemia[1])	21	4	29
Death Rate[2] Per 100,000	6.40	3.07	7.36
SMR[3] (95% C.I.)	0.91 (0.56,1.39)	0.42 (0.11,1.07)	0.97 (0.65,1.39)

[1] Defined as ICD-9 codes 204-208

[2] Adjusted for deaths excluded from analysis due to unknown date or cause of death.

[3] Indirectly adjusted for age-calendar time using U.S. white male age-calendar time specific rates.

3 Results
3.2 Mortality from Leukemia (cont'd)

Table 3.2.B Leukemia Mortality for NNW, $NW_{<0.5}$, and 3 Recorded DE Groups[1] Within $NW_{\geq 0.5}$

		$NW_{\geq 0.5}$ (rem)				
		0.5-	1.0-	5.0+	$NW_{<0.5}$	NNW
Part A.	Unadjusted					
	Workers	5,431	13,357	9,084	10,348	32,510
	Person-Years	69,489	172,531	114,071	139,746	425,070
	Deaths (Leukemia)	2	12	7	4	29
	Rate[2] Per 100,000	3.12	7.55	6.66	3.07	7.36
Part B.	Adjusted[3]					
	SMR	0.41	1.08	0.99	0.42	0.97
	Relative Risk	1.00	2.63	2.41	1.02	2.37
	(95% C.I.)		(0.6,24.2)	(0.5,23.8)	(0.2,11.3)	(0.6,20.5)
Part C.	Adjusted With Time Lags					
	Lag: 2 years					
	Deaths	2	13	6	4	29
	SMR	0.41	1.25	0.94	0.44	1.04
	Relative Risk	1.00	3.05	2.29	1.07	2.54
	(95% C.I.)		(0.7,27.8)	(0.4,23.2)	(0.2,11.9)	(0.6,21.9)
Lag:	5 years					
	Deaths	0	10	5	2	24
	SMR	0.00	1.12	0.96	0.26	1.02
	Relative Risk	-	-	-	-	-
	(95% C.I.)		-	-	-	-
Lag:	10 years					
	Deaths	0	5	3	2	17
	SMR	-	0.82	0.99	0.38	1.09
	Relative Risk	-	-	-	-	-
	(95% C.I.)		-	-	-	-
Lag:	15 years					
	Deaths	1	2	0	0	6
	SMR	0.76	0.74	0	0	0.85
	Relative Risk	1.00	0.97	0	0	1.11
	(95% C.I.)		(0.1,57.4)	-	-	(0.1,51.4)

1 DE groups for $NW_{\geq 0.5}$ are time dependent
2 Adjusted for deaths excluded from analysis due to unknown date or cause of death
3 Adjusted for age and calendar time with the indirect method of adjustment using age-calendar time specific rates for U.S. white males

3 Results

3.2 Mortality from Leukemia (cont'd)

Table 3.2.B1 Leukemia Mortality for NNW, $NW_{<0.5}$, and 4 Recorded DE Groups[1] Within $NW_{\geq 0.5}$

	$NW_{\geq 0.5}$ (rem)					
	0.5-	1.0-	5.0-	10+	$NW_{<0.5}$	NNW
Part A. Unadjusted						
Workers	5,431	13,357	4,846	4,238	10,348	32,510
Person-Years	69,489	172,531	63,819	50,253	139,746	425,070
Deaths (Leukemia)	2	12	4	3	4	29
Rate[2] Per 100,000	3.12	7.55	6.80	6.48	3.07	7.36
Part B. Adjusted[3]						
SMR	0.41	1.08	1.03	0.94	0.42	0.97
Relative Risk	1.00	2.63	2.51	2.30	1.02	2.37
(95% C.I.)		(0.6,24.3)	(0.4,27.8)	(0.3,27.5)	(0.2,11.3)	(0.6,20.5)
Part C. Adjusted With Time Lags						
Lag: 2 years						
Deaths	2	13	3	3	4	29
SMR	0.41	1.25	0.85	1.06	0.44	1.04
Relative Risk	1.00	3.05	2.07	2.58	1.07	2.54
(95% C.I.)		(0.7,27.8)	(0.2,24.8)	(0.3,31.0)	(0.2,11.9)	(0.6,21.9)
Lag: 5 years						
Deaths	0	10	2	3	2	24
SMR	0	1.12	0.68	1.32	0.26	1.02
Relative Risk	-	-	-	-	-	-
(95% C.I.)		-	-	-	-	-
Lag: 10 years						
Deaths	0	5	2	1	2	17
SMR	0	0.82	1.10	0.83	0.38	1.09
Relative Risk	-	-	-	-	-	-
(95% C.I.)		-	-	-	-	-
Lag: 15 years						
Deaths	1	2	0	0	0	6
SMR	0.76	0.74	0	0	0	0.85
Relative Risk	1.00	0.97	0	0	0	1.11
(95% C.I.)		(0.05,57.4)	-	-	-	(0.1,51.4)

[1] DE groups for $NW_{\geq 0.5}$ are time dependent

[2] Adjusted for deaths excluded from analysis due to unknown date or cause of death

[3] Adjusted for age and calendar time with the indirect method of adjustment using age-calendar time specific rates for U.S. white males

3 Results

3.3 Mortality from Lymphatic and Hematopoietic Cancer

All lymphatic and hematopoietic cancer (LHC) mortality rates include ICD codes 200-208. Lymphosarcoma, Hodgkin's disease, non-Hodgkin's lymphoma, multiple myeloma and leukemia are the common cancer types in this group. Leukemia usually constitutes a major portion of the cancers in this category. In this case, 21 of the 50 cancers (42%) in the ≥0.5 rem group and 29 of 84 (35%) in the non-nuclear worker group are leukemias so that the mortality characteristics of the population from this group of cancers would be strongly influenced by the leukemia mortality.

The crude death rates per 100,000 person-years as shown in Table 3.3.A for each group are highest for non-nuclear workers (21.31 deaths/100,000), followed by the ≥0.5 rem group (15.24 deaths/100,000), and finally the <0.5 rem group which has the lowest rate (9.98 deaths/100,000). The standardized mortality ratios for the groups indicate the same relative ranking for the groups as did the crude death rates, but only the non-nuclear worker group has an SMR that is slightly and non-significantly higher than the death rate for U.S. white males. The SMR for the $NW_{\geq 0.5}$ is 1.6 times higher than for the $NW_{<0.5}$ group, but only because of the unusually low rate of leukemia in the $NW_{<0.5}$ group.

When the adjusted death rate for the ≥0.5 rem group is divided into three or four dose groups (Tables 3.3.B and 3.3.B1), then, as with leukemia, the group with 0.5 to 0.9 rem has a very low rate which is similar to that of the $NW_{<0.5}$ group. Therefore, the other dose groups are comparably higher although none have rates which are significantly higher than those of the general population. As with leukemia, there is a sharp increase in the SMR between 0.5-0.9 (SMR = 0.31) and the 1.0-4.9 dose subgroup (SMR = 1.00) with a

3 Results
3.3 Mortality from Lymphatic and Hematopoietic Cancer (cont'd)

slightly higher SMR of 1.08 in the group 5.0-9.9 rem. The non-nuclear worker group has the highest SMR of 1.11. Even the NNW group does not have a ratio significantly higher than that of the general population at the 95% confidence interval. There is no continuously increasing dose-response curve because the highest levels, 5^+ or 10^+ rem in the two tables, are lower than the previous dose subgroups.

Lagging the dose for the LHC deaths increases the SMR as it did for the leukemias. However, for the total group the ratios are highest with ten years lag (not two years as in the case of leukemia). The highest SMR is 1.40 which occurs in the 1.0-4.9 rem group at 10 years lag, but low ratios occur in the highest DE subgroup. No dose-response is demonstrated.

3 Results
3.3 Mortality from Lymphatic and Hematopoietic Cancers (cont'd)

Table 3.3.A Deaths from Lymphatic and Hematopoietic Cancers, Person-Years, and Death Rates for NNW, $NW_{<0.5}$, and $NW_{\geq 0.5}$

	$NW_{\geq 0.5}$	$NW_{<0.5}$	NNW
Workers	27,872	10,348	32,510
Person-Years	356,091	139,746	425,070
Deaths (Lymphoma[1])	50	13	84
Death Rate[2] Per 100,000	15.24	9.98	21.31
SMR[3] (95% C.I.)	0.82 (0.61,1.08)	0.53 (0.28,0.91)	1.1 (0.88,1.37)

[1] Defined as ICD-9 codes 200-208

[2] Adjusted for deaths excluded from analysis due to unknown date or cause of death.

[3] Indirectly adjusted for age-calendar time using U.S. white male age-calendar time specific rates.

3 Results
3.3 Mortality from Lymphatic and Hematopoietic Cancers (cont'd)

Table 3.3.B **Lymphatic and Hematopoietic Cancer Mortality for NNW, $NW_{<0.5}$, and 3 Recorded DE Groups[1] Within $NW_{\geq 0.5}$**

	$NW_{\geq 0.5}$ (rem)				
	0.5-	1.0-	5.0+	$NW_{<0.5}$	NNW
Part A. Unadjusted					
Workers	5,431	13,357	9,084	10,348	32,510
Person-Years	69,489	172,531	114,071	139,746	425,070
Deaths (Lymphoma)	4	29	17	13	84
Rate[2] Per 100,000	6.25	18.25	16.18	9.98	21.31
Part B. Adjusted[3]					
SMR	0.31	1.00	0.91	0.53	1.11
Relative Risk	1.00	3.23	2.94	1.71	3.58
(95% C.I.)		(1.1,12.6)	(1.0,12.0)	(0.5,7.2)	(1.3,13.5)
Part C. Adjusted With Time Lags					
Lag: 2 years					
Deaths	4	30	16	13	80
SMR	0.32	1.10	0.95	0.56	1.12
Relative Risk	1.00	3.43	2.97	1.75	3.50
(95% C.I.)		(1.2,13.4)	(1.0,12.2)	(0.5,7.4)	(1.3,13.2)
Lag: 5 years					
Deaths	2	26	14	11	64
SMR	0.19	1.11	1.02	0.56	1.07
Relative Risk	1.00	5.84	5.37	2.95	5.63
(95% C.I.)		(1.5,50.8)	(1.2,48.7)	(0.6,27.4)	(1.5,47.5)
Lag: 10 years					
Deaths	2	22	7	9	40
SMR	0.27	1.40	0.90	0.68	1.02
Relative Risk	1.00	5.19	3.33	2.52	3.78
(95% C.I.)		(1.3,45.4)	(0.6,32.9)	(0.5,24.0)	(1.0,32.3)
Lag: 15 years					
Deaths	2	7	2	4	16
SMR	0.61	1.03	0.90	0.67	0.92
Relative Risk	1.00	1.69	1.48	1.10	1.51
(95% C.I.)		(0.3,16.7)	(0.1,20.4)	(0.2,12.1)	(0.4,13.5)

1 DE groups for $NW_{\geq 0.5}$ are time dependent
2 Adjusted for deaths excluded from analysis due to unknown date or cause of death
3 Adjusted for age and calendar time with the indirect method of adjustment using age-calendar time specific rates for U.S. white males

3 Results
3.3 Mortality from Lymphatic and Hematopoietic Cancers

Table 3.3.B1 Lymphatic and Hematopoietic Cancer Mortality for NNW, $NW_{<0.5}$, and 4 Recorded DE Groups[1] Within $NW_{\geq 0.5}$

	$NW_{\geq 0.5}$ (rem)					
	0.5-	1.0-	5.0-	10+	$NW_{<0.5}$	NNW
Part A. Unadjusted						
Workers	5,431	13,357	4,846	4,238	10,348	32,510
Person-Years	69,489	172,531	63,819	50,253	139,746	425,070
Deaths (Lymphoma)	4	29	11	6	13	84
Rate[2] Per 100,000	6.25	18.25	18.71	12.96	9.98	21.31
Part B. Adjusted[3]						
SMR	0.31	1.00	1.08	0.71	0.53	1.11
Relative Risk	1.00	3.23	3.47	2.31	1.71	3.58
(95% C.I.)		(1.1,12.6)	(1.0,15.0)	(0.5,11.0)	(0.5,7.2)	(1.3,13.5)
Part C. Adjusted With Time Lags						
Lag: 2 years						
Deaths	4	30	10	6	13	80
SMR	0.32	1.10	1.07	0.80	0.56	1.12
Relative Risk	1.00	3.43	3.34	2.50	1.75	3.50
(95% C.I.)		(1.2,13.4)	(1.0,14.6)	(0.6,12.0)	(0.5,7.4)	(1.3,13.2)
Lag: 5 years						
Deaths	2	26	9	5	11	64
SMR	0.19	1.11	1.17	0.84	0.56	1.07
Relative Risk	1.00	5.84	6.16	4.42	2.95	5.63
(95% C.I.)		(1.5,50.8)	(1.3,58.6)	(0.7,46.4)	(0.6,27.4)	(1.5,47.5)
Lag: 10 years						
Deaths	2	22	6	1	9	40
SMR	0.27	1.40	1.28	0.32	0.68	1.02
Relative Risk	1.00	5.19	4.74	1.18	2.52	3.78
(95% C.I.)		(1.3,45.5)	(0.9,48.0)	(0.02,22.8)	(0.5,24.0)	(1.0,32.3)
Lag: 15 years						
Deaths	2	7	2	0	4	16
SMR	0.61	1.03	1.29	0.00	0.67	0.92
Relative Risk	1.00	1.69	2.11	0.00	1.10	1.51
(95% C.I.)		(0.3,16.7)	(0.2,29.2)	-	(0.2,12.1)	(0.4,13.5)

1 DE groups for $NW_{\geq 0.5}$ are time dependent
2 Adjusted for deaths excluded from analysis due to unknown date or cause of death
3 Adjusted for age and calendar time with the indirect method of adjustment using age-calendar time specific rates for U.S. white males

3 Results

3.4 Mortality from Mesothelioma

The mortality from mesothelioma was examined, not because there was a known association of this cancer with ionizing radiation, but because there was known exposure to asbestos in this population and mesothelioma mortality is considered to be a marker for asbestos exposure. The ICD-9 codes which were used to identify cases were 158 and 163. Cases were only included if hospital review confirmed the diagnosis of pleural or peritoneal mesothelioma because of the difficulty in making this diagnosis. Expected cases were estimated using U.S. incidence rates for white males since they also are based on hospital diagnosed cases. Since mesothelioma is associated with a very short survival (median about 15 months), it was felt that incidence rates were a good approximation to mortality rates. Mortality rates for mesothelioma reported nationally were not considered to be sufficiently accurate in the diagnosis of mesothelioma.

The number of deaths in this group is small as would be expected because this is a very rare disease even in a population with known asbestos exposure. The crude death rates per 100,000 person-years in Table 3.4.A are higher in the nuclear workers (5.49 and 6.14 deaths/100,000, $\geq$0.5 rem and <0.5 rem respectively) than in the non-nuclear worker group (2.41 deaths/100,000). The age and calendar time adjusted SMRs indicate that both the radiation-exposed groups have mortality ratios that are higher than the incidence standard of U.S. white males ($\geq$0.5 rem group SMR=5.11 and <0.5 rem group SMR=5.75). The ratios for all three groups are significantly different than expected for the standard population.

Since this finding might be expected on the basis of asbestos exposure in the shipyard as well as better diagnosis of disease in these workers

3 Results
3.4 Mortality from Mesothelioma (cont'd)

compared to the general population, the question is whether there is any sign of change in the ratios on the basis of radiation exposure. As seen in Tables 3.4.B and 3.4.B1, there is an increase in risk with an increase in radiation exposure but as in previous comparisons, the SMR decreases in the highest dose group of 10^{+} rem. In this case, unlike the previous analyses of other types of cancer, comparing the SMRs for the higher dose groups to the subgroup with 0.5-0.9 rem does not indicate as large a relative increase as for other cancers, but the increase over U.S. expected rates is high for all groups.

Lagging the dose causes the SMRs to increase for many DE subgroups within the $NW_{\geq 0.5}$ rem group but did not show much increase for those in the $NW_{<0.5}$ rem group. The non-nuclear worker group also had a slight increase in the SMR with lagging. The highest SMR occurs after 15 years lag in the 5.0-9.9 rem group, but the numbers are very small at that lag period.

These high SMRs are difficult to attribute to radiation because of the known strong association between mesothelioma and asbestos. The nuclear workers appear to have had more exposure to asbestos as judged by their jobs. In addition, the higher SMR for mesothelioma in the $NW_{<0.5}$ group which has essentially no radiation when compared to the non-nuclear worker group would suggest that the workers selected to do nuclear work had more asbestos exposure. The increase in SMR with increase in radiation might be confounded by an increasing exposure to asbestos. Future efforts will attempt to document that the nuclear workers actually did have more asbestos exposure than non-nuclear workers. The initial sample was balanced by "job hazard index" to ensure the comparability of the groups in regard to blue versus white collar work. However, this does not balance the groups in regard to specific exposures to hazardous agents such as asbestos. The distribution of jobs among nuclear workers suggested that they held more jobs with potential asbestos exposure. It will now be necessary to confirm that these jobs have high asbestos exposure and then determine the dose of asbestos by group. Doses can be estimated for each worker from the job history. These individual dose levels can be used to adjust the radiation data to see whether the apparent radiation effect disappears when adjusted for asbestos.

3 Results
3.4 Mortality from Mesothelioma (cont'd)

Table 3.4.A Deaths from Mesothelioma, Person-Years, and Death Rates for NNW, $NW_{<0.5}$, and $NW_{\geq 0.5}$

	$NW_{\geq 0.5}$	$NW_{<0.5}$	NNW
Workers	27,872	10,348	32,510
Person-Years	356,091	139,746	425,070
Deaths (Mesothelioma[1])	18	8	10
Death Rate[2] Per 100,000	5.49	6.14	2.54
SMR[3] (95% C.I.)	5.11 (3.03,8.08)	5.75 (2.48,11.33)	2.41 (1.16,4.43)

1 Defined as ICD-9 codes 158,163

2 Adjusted for deaths excluded from analysis due to unknown date or cause of death.

3 Indirectly adjusted for age-calendar time using U.S. white male age-calendar time specific rates.

3 Results
3.4 Mortality from Mesothelioma (cont'd)

Table 3.4.B Mesothelioma Mortality for NNW, $NW_{<0.5}$, and 3 Recorded DE Groups[1] Within $NW_{\geq 0.5}$

	$NW_{\geq 0.5}$ (rem)				
	0.5-	1.0-	5.0+	$NW_{<0.5}$	NNW
Part A. Unadjusted					
Workers	5,431	13,357	9,084	10,348	32,510
Person-Years	69,489	172,531	114,071	139,746	425,070
Deaths (Meso.)	3	8	7	8	10
Rate[2] Per 100,000	4.69	5.03	6.66	6.14	2.54
Part B. Adjusted[3]					
SMR	3.96	4.80	6.38	5.75	2.41
Relative Risk	1.00	1.21	1.61	1.45	0.61
(95% C.I.)		(0.3,7.1)	(0.4,9.7)	(0.4,8.5)	(0.2,3.4)
Part C. Adjusted With Time Lags					
Lag: 2 years					
Deaths	3	8	7	8	10
SMR	4.03	4.95	6.72	5.94	2.50
Relative Risk	1.00	1.23	1.67	1.48	0.62
(95% C.I.)		(0.3,7.2)	(0.4,10.0)	(0.4,8.6)	(0.2,3.5)
Lag: 5 years					
Deaths	3	8	6	7	9
SMR	4.33	5.35	6.47	5.65	2.48
Relative Risk	1.00	1.24	1.50	1.31	0.57
(95% C.I.)		(0.3,7.2)	(0.3,9.2)	(0.3,7.8)	(0.1,3.3)
Lag: 10 years					
Deaths	4	5	5	5	7
SMR	7.16	4.18	8.02	5.17	2.52
Relative Risk	1.00	0.58	1.12	0.72	0.35
(95% C.I.)		(0.1,2.9)	(0.2,5.7)	(0.2,3.6)	(0.1,1.6)
Lag: 15 years					
Deaths	1	4	2	2	4
SMR	3.64	6.87	10.33	4.12	2.96
Relative Risk	1.00	1.89	2.84	1.13	0.81
(95% C.I.)		(0.2,92.9)	(0.2,167.4)	(0.1,66.8)	(0.1,40.1)

1 DE groups for $NW_{\geq 0.5}$ are time dependent
2 Adjusted for deaths excluded from analysis due to unknown date or cause of death
3 Adjusted for age and calendar time with the indirect method of adjustment using age-calendar time specific rates for U.S. white males

3 Results
3.4 Mortality from Mesothelioma (cont'd)

Table 3.4.B1 **Mesothelioma Mortality for NNW, $NW_{<0.5}$, and 4 Recorded DE Groups[1] Within $NW_{\geq 0.5}$**

	$NW_{\geq 0.5}$ (rem)					
	0.5-	1.0-	5.0-	10+	$NW_{<0.5}$	NNW
Part A. Unadjusted						
Workers	5,431	13,357	4,846	4,238	10,348	32,510
Person-Years	69,489	172,531	63,819	50,253	139,746	425,070
Deaths (Meso.)	3	8	5	2	8	10
Rate[2] Per 100,000	4.69	5.03	8.51	4.32	6.14	2.54
Part B. Adjusted[3]						
SMR	3.96	4.80	8.48	3.94	5.75	2.41
Relative Risk	1.00	1.21	2.14	1.00	1.45	0.61
(95% C.I.)		(0.3,7.1)	(0.4,13.8)	(0.1,8.7)	(0.4,8.5)	(0.2,3.4)
Part C. Adjusted With Time Lags						
Lag: 2 years						
Deaths	3	8	5	2	8	10
SMR	4.03	4.95	8.87	4.19	5.94	2.50
Relative Risk	1.00	1.23	2.21	1.04	1.48	0.62
(95% C.I.)		(0.3,7.2)	(0.4,14.2)	(0.1,9.1)	(0.4,8.6)	(0.2,3.5)
Lag: 5 years						
Deaths	3	8	4	2	7	9
SMR	4.33	5.35	7.84	4.80	5.65	2.48
Relative Risk	1.00	1.24	1.81	1.11	1.31	0.57
(95% C.I.)		(0.3,7.2)	(0.3,12.4)	(0.1,9.7)	(0.3,7.8)	(0.1,3.3)
Lag: 10 years						
Deaths	4	5	4	1	5	7
SMR	7.16	4.18	10.87	3.91	5.17	2.52
Relative Risk	1.00	0.58	1.52	0.55	0.72	0.35
(95% C.I.)		(0.1,2.3)	(0.3,8.2)	(0.01,5.5)	(0.1,3.6)	(0.1,1.6)
Lag: 15 years						
Deaths	1	4	2	0	2	4
SMR	3.64	6.87	14.84	0	4.12	2.96
Relative Risk	1.00	1.89	4.08	-	1.13	0.81
(95% C.I.)		(0.2,92.9)	(0.2,240.5)	-	(0.1,66.8)	(0.1,40.1)

1 DE groups for $NW_{\geq 0.5}$ are time dependent.
2 Adjusted for deaths excluded from analysis due to unknown date or cause of death.
3 Adjusted for age and calendar time with the indirect method of adjustment using age-calendar time specific rates for U.S. white males.

3 Results

3.5 Mortality from Lung Cancer

The mortality from lung cancer follows a different pattern than that of either mesothelioma or leukemia. This cancer was examined because lung tissue is known to be sensitive to the effects of radiation. However, asbestos is also associated with the risk of lung cancer and this risk is especially high among asbestos-exposed smokers. This study to date can only provide information for individuals on the exposure to radiation. However, the high risk of mesothelioma confirms that one can expect risks associated with asbestos.

As shown in Table 3.5.A. the lung cancer crude mortality rates are highest in the NNW group and lowest in the $\geq$0.5 rem nuclear worker group. The age and calendar time standardized mortality ratios for the three groups indicate that all three groups have small excess risks of lung cancer compared to the general population, but only the risk for the NNW group is significantly higher than the death rate for white males in the general population (SMR = 1.15; 95% C.I.: 1.02-1.29).

The age and calendar time adjusted SMRs for the various DE subgroups within the $\geq$0.5 NW category indicate that the ratios increase with increasing DE levels (Tables 3.5.B and 3.5.B1). There is no decrease in the SMR for the highest DE level whether there are three or four subgroups. This is very different from the relationship of SMR and dose as described for the diseases discussed previously. The subgroups at levels of 5.0 and 10.0 rem have SMRs which are higher than the ratios of either the NNW or the $NW_{<0.5}$ groups. For other deaths, there was always a drop in SMR for the highest dose subgroup.

The SMRs for different lagging periods indicate that the ratios are higher than those of NNW and $NW_{<0.5}$ groups for the DE categories of 5^+ and 10^+

rem for the 2 and 5 year lag periods at least. For all lag periods above 5 years the highest risk among the DE subgroups shifts with peak ratios being at 5.0-9.9 rem for the 10 year lag and at 1.0-4.9 rem for the 15 years. Thus, a 5 year lag is the last period in which there is a dose response and an increase in the SMRs produced by the lagging adjustment. With the five year lag analysis in the four subgroups, the highest SMR is 1.40 in the group with 10^{+} rem compared to 0.95 for the subgroup 0.5-0.9 rem.

As with mesothelioma, lung cancer is known to be associated with asbestos. The fact that asbestos has been present in the shipyards and the fact that these workers have an increased risk of mesothelioma suggest that asbestos and not radiation may be associated with the risk. Even the recently employed nuclear workers who received the questionnaires indicated that they had exposure to asbestos more often than NNW workers. A NIOSH case-control study of lung cancer at the Portsmouth Naval Shipyard (Rinsky et al, 1988) indicated initially a significant risk from radiation in the dose group 1.0-4.9 rem. However, correcting for asbestos and welding exposure decreased the apparent association between lung cancer and radiation. A similar situation is likely to exist here. It would be important to show whether an increasing DE for radiation is related to an increase in the estimated asbestos exposure dose. If so, then correcting for asbestos exposure may eliminate the apparent association between radiation and lung cancer in this population.

3 Results

3.5 Mortality from Lung Cancer (cont'd)

Table 3.5.A Deaths from Lung Cancer, Person-Years, and Death Rates for NNW, $NW_{<0.5}$, and $NW_{\geq 0.5}$

	$NW_{\geq 0.5}$	$NW_{<0.5}$	NNW
Workers	27,872	10,348	32,510
Person-Years	356,091	139,746	425,070
Deaths (Lung Cancer[1])	237	98	306
Death Rate[2] Per 100,000	72.25	75.21	77.63
SMR[3] (95% C.I.)	1.07 (0.94,1.21)	1.11 (0.90,1.35)	**1.15 (1.02,1.29)**

[1] Defined as ICD-9 codes 162

[2] Adjusted for deaths excluded from analysis due to unknown date or cause of death.

[3] Indirectly adjusted for age-calendar time using U.S. white male age-calendar time specific rates.

3 Results

3.5 Mortality from Lung Cancer (cont'd)

Table 3.5.B Lung Cancer Mortality for NNW, $NW_{<0.5}$, and 3 Recorded DE Groups[1] Within $NW_{\geq 0.5}$

	$NW_{\geq 0.5}$ (rem)				
	0.5-	1.0-	5.0+	$NW_{<0.5}$	NNW
Part A. Unadjusted					
Workers	5,431	13,357	9,084	10,348	32,510
Person-Years	69,489	172,531	114,071	139,746	425,070
Deaths (Lung Can.)	46	109	82	98	306
Rate[2] Per 100,000	71.86	68.58	78.03	75.21	77.63
Part B. Adjusted[3]					
SMR	0.95	1.03	1.20	1.11	1.15
Relative Risk	1.00	1.08	1.26	1.16	1.21
(95% C.I.)		(0.8,1.6)	(0.9,1.9)	(0.8,1.7)	(0.9,1.7)
Part C. Adjusted With Time Lags					
Lag: 2 years					
Deaths	43	104	81	97	293
SMR	0.91	1.02	1.27	1.14	1.15
Relative Risk	1.00	1.12	1.40	1.25	1.26
(95% C.I.)		(0.8,1.6)	(1.0,2.1)	(0.9,1.8)	(0.9,1.8)
Lag: 5 years					
Deaths	41	93	71	91	261
SMR	0.95	1.00	1.29	1.19	1.16
Relative Risk	1.00	1.05	1.36	1.25	1.22
(95% C.I.)		(0.7,1.6)	(0.9,2.1)	(0.9,1.9)	(0.9,1.7)
Lag: 10 years					
Deaths	31	70	47	68	187
SMR	0.98	1.03	1.38	1.23	1.19
Relative Risk	1.00	1.05	1.41	1.26	1.21
(95% C.I.)		(0.7,1.7)	(0.9,2.3)	(0.8,2.0)	(0.8,1.8)
Lag: 15 years					
Deaths	17	45	9	33	82
SMR	1.16	1.46	0.88	1.28	1.14
Relative Risk	1.00	1.25	0.76	1.10	0.98
(95% C.I.)		(0.7,2.4)	(0.3,1.8)	(0.6,2.1)	(0.6,1.8)

1 DE groups for $NW_{\geq 0.5}$ are time dependent

2 Adjusted for deaths excluded from analysis due to unknown date or cause of death

3 Adjusted for age and calendar time with the indirect method of adjustment using age-calendar time specific rates for U.S. white males

3 Results
3.5 Mortality from Lung Cancer (cont'd)

Table 3.5.B1 Lung Cancer Mortality for NNW, $NW_{<0.5}$, and 4 Recorded DE Groups[1] Within $NW_{\geq 0.5}$

	$NW_{\geq 0.5}$ (rem)					
	0.5-	1.0-	5.0-	10+	$NW_{<0.5}$	NNW
Part A. Unadjusted						
Workers	5,431	13,357	4,846	4,238	10,348	32,510
Person-Years	69,489	172,531	63,819	50,253	139,746	425,070
Deaths (Lung Can.)	46	109	43	39	98	306
Rate[2] Per 100,000	71.86	68.58	73.14	84.25	75.21	77.63
Part B. Adjusted[3]						
SMR	0.95	1.03	1.17	1.25	1.11	1.15
Relative Risk	1.00	1.08	1.23	1.31	1.16	1.21
(95% C.I.)		(0.8,1.6)	(0.8,1.9)	(0.8,2.1)	(0.8,1.7)	(0.9,1.7)
Part C. Adjusted With Time Lags						
Lag: 2 years						
Deaths	43	104	43	38	97	293
SMR	0.91	1.02	1.23	1.31	1.14	1.15
Relative Risk	1.00	1.12	1.35	1.44	1.25	1.26
(95% C.I.)		(0.8,1.6)	(0.9,2.1)	(0.9,2.3)	(0.9,1.8)	(0.9,1.8)
Lag: 5 years						
Deaths	41	93	37	34	91	261
SMR	0.95	1.00	1.21	1.40	1.19	1.16
Relative Risk	1.00	1.05	1.27	1.47	1.25	1.22
(95% C.I.)		(0.7,1.6)	(0.8,2.0)	(0.9,2.4)	(0.9,1.9)	(0.9,1.7)
Lag: 10 years						
Deaths	31	70	30	17	68	187
SMR	0.98	1.03	1.48	1.24	1.23	1.19
Relative Risk	1.00	1.05	1.51	1.26	1.26	1.21
(95% C.I.)		(0.7,1.7)	(0.9,2.6)	(0.7,2.4)	(0.8,2.0)	(0.8,1.8)
Lag: 15 years						
Deaths	17	45	7	2	33	82
SMR	1.16	1.46	0.99	0.64	1.28	1.14
Relative Risk	1.00	1.25	0.85	0.55	1.10	0.98
(95% C.I.)		(0.7,2.4)	(0.3,2.2)	(0.1,2.3)	(0.6,2.1)	(0.6,1.8)

[1] DE groups for $NW_{\geq 0.5}$ are time dependent.
[2] Adjusted for deaths excluded from analysis due to unknown date or cause of death.
[3] Adjusted for age and calendar time with the indirect method of adjustment using age-calendar time specific rates for U.S. white males.

3 Results

3.6 Mortality from Other Causes of Death

To determine whether there were any other specific causes of death which might be of interest for further study, each of the three sample groups as well as the total study group were screened for any other cause of death which might be in excess in these shipyard workers compared to the general population. The software package developed by Richard Monson (Monson, 1974) was used to calculate the age and calendar time adjusted mortality ratios to screen for causes of possible interest. Tables 3.6.A. - 3.6.D. display the data.

The all cause mortality ratio for the $NW_{\geq 0.5}$ group is lower than that of the NNW group primarily because of a lower mortality from cardiovascular and circulatory system disease. However, the ratios for these diseases indicate death rates in the shipyard workers which are below those of the U.S. population. Cancers of the respiratory system are slightly high but only significantly high in the NNW group at a $p \leq 0.05$. Several cancers of the digestive organs have SMRs above 1.00 such as esophageal cancer. Among the digestive cancers, liver cancer shows the highest excess for this cancer among the ≥ 0.5 rem group with an SMR of 1.61 but it is not significant at $p \leq 0.05$. The SMR for bladder cancer in the group ≥ 0.5 rem is 1.30 but this SMR is also not significant at $p \leq 0.05$. Except for these two cancer sites there are no SMRs related to other causes of death among workers in the ≥ 0.5 rem group except those currently under scrutiny which appear to be sufficiently high to warrant extensive examination.

3 Results

3.6 Mortality from Other Causes of Death (cont'd)

Table 3.6.A Deaths from Other Causes of Death and SMR's for All Shipyard Workers

TOTAL PERSONS = 70730. EXPECTED NUMBERS BASED ON MORTALITY RATES FOR WM

	OBSERVED	EXPECTED	OBS/EXP	LL	UL	CHISQ
0 ALL CAUSES OF DEATH	6933	7734.90	0.90	0.88	0.92	83.03
1 ALL MALIGNANT NEOPLASMS	1724	1671.13	1.03	0.98	1.08	1.64
2 ALL INFECTIVE AND PARASITIC DISEASE	39	59.75	0.65	0.46	0.89	6.86
9 ALL TUBERCULOSIS	7	21.58	0.32	0.13	0.67	9.19
140 CANCER OF BUCCAL CAVITY AND PHARYNX	44	53.64	0.82	0.60	1.10	1.56
149 CANCER OF DIGESTIVE ORGANS AND PERITONEUM (1925- APPROXIMATE)	435	419.20	1.04	0.94	1.14	0.56
150 CANCER OF ESOPHAGUS (1925- APPROXIMATE)	50	39.93	1.25	0.93	1.65	2.29
151 CANCER OF STOMACH	84	66.92	1.26	1.00	1.55	4.11
153 CANCER OF LARGE INTESTINE (1925- APPROXIMATE)	121	141.45	0.86	0.71	1.02	2.81
154 CANCER OF RECTUM (1925- APPROXIMATE)	43	42.49	1.01	0.73	1.36	0.00
155 ALL CANCER OF LIVER (1925- APPROXIMATE) 1970+ - PRIMARY ONLY	35	28.54	1.23	0.85	1.71	1.25
157 CANCER OF PANCREAS (1925- APPROXIMATE)	95	98.25	0.96	0.77	1.19	0.09
160 CANCER OF RESPIRATORY SYSTEM (1925- APPROXIMATE)	692	628.74	1.10	1.02	1.19	6.69
161 CANCER OF LARYNX (1925-, 1930- APPROXIMATE)	17	24.77	0.69	0.40	1.10	2.13
162 ALL CANCER OF LUNG - PRIMARY AND SECONDARY (1925-,1930- APPROXIMATE)	641	595.84	1.08	0.99	1.16	3.35
170 CANCER OF BONE (1925-,1930-,1945- APPROXIMATE)	4	7.21	0.56	0.15	1.42	1.02
172 CANCER OF SKIN	32	37.09	0.86	0.59	1.22	0.57
185 CANCER OF PROSTATE (1925- APPROXIMATE)	95	79.43	1.20	0.97	1.46	2.86
186 CANCER OF TESTIS (OTHER GENITAL ORGANS 1925-49)(1925-,1930- APPROXIM	8	11.36	0.70	0.30	1.39	0.72
188 CANCER OF BLADDER (1925- APPROXIMATE)	41	39.53	1.04	0.74	1.41	0.02
189 CANCER OF KIDNEY (1925- APPROXIMATE)	45	43.89	1.03	0.75	1.37	0.01
190 CANCER OF EYE (1950-1969 ONLY)	0	1.32	0.00	0.00	2.77	0.51
191 CANCER OF BRAIN AND OTHER CENTRAL NERVOUS SYSTEM (1925- APPROXIMATE)	55	58.85	0.93	0.70	1.22	0.19
193 CANCER OF THYROID (1950-1969 ONLY)	5	3.19	1.57	0.51	3.66	0.54
200 LYMPHOSARCOMA AND RETICULOSARCOMA (1950-1969 ONLY)	27	34.47	0.78	0.52	1.14	1.41
201 HODGKIN'S DISEASE (1940-,1945- APPROXIMATE)	18	21.00	0.86	0.51	1.35	0.30
204 LEUKEMIA AND ALEUKEMIA	54	65.03	0.83	0.62	1.08	1.70
208 CANCER OF OTHER LYMPHATIC TISSUE (1950-1969 ONLY)	45	45.85	0.98	0.72	1.31	0.00

3 Results

3.6 Mortality from Other Causes of Death (cont'd)

Table 3.6.A Deaths from Other Causes of Death and SMR's for All Shipyard Workers (cont'd)

209 ALL LYMPHOPOIETIC CANCER	147	168.25	0.87	0.74	1.03	2.56
210 BENIGN NEOPLASMS	18	21.39	0.84	0.50	1.33	0.39
240 ALLERGIC,ENDOCRINE,METABOLIC,NUTRITIONAL DISEASES (1950-1969 ONLY)	91	131.92	0.69	0.56	0.85	12.38
250 DIABETES MELLITUS	72	107.44	0.67	0.52	0.84	11.38
280 ALL DISEASES OF BLOOD AND BLOOD-FORMING ORGANS (1925-,1930- APPROXIM	14	15.99	0.88	0.48	1.47	0.14
319 MENTAL,PSYCHONEUROTIC,AND PERSONALITY DISORDERS (1950-1969 ONLY)	44	57.99	0.76	0.55	1.02	3.14
320 ALL DISEASES OF NERVOUS SYSTEM AND SENSE ORGANS	45	73.44	0.61	0.45	0.82	10.63
390 ALL DISEASES OF CIRCULATORY SYSTEM	3012	3627.70	0.83	0.80	0.86	104.33
393 CHRONIC RHEUMATIC HEART DISEASE(1925- APPROXIMATE)	14	58.98	0.24	0.13	0.40	33.54
410 ARTERIOSCLEROTIC HEART DISEASE,INCLUDING CHD (1925- APPROXIMATE)	2201	2639.49	0.83	0.80	0.87	72.68
430 ALL VASCULAR LESIONS OF CNS	316	390.88	0.81	0.72	0.90	14.15
460 ALL RESPIRATORY DISEASES (1925-,1930- APPROXIMATE)	325	424.88	0.76	0.68	0.85	23.25
480 ALL PNEUMONIA (1925-,1930- APPROXIMATE)	112	134.32	0.83	0.69	1.00	3.54
492 EMPHYSEMA (1950-,1955 APPROXIMATE)	70	102.34	0.68	0.53	0.86	9.90
493 ASTHMA (1925-,1930- APPROXIMATE)	13	10.43	1.25	0.66	2.13	0.41
520 ALL DISEASES OF DIGESTIVE SYSTEM	349	420.67	0.83	0.74	0.92	12.04
531 ALL GASTRIC AND DUODENAL ULCER	27	38.95	0.69	0.46	1.01	3.37
571 CIRRHOSIS OF LIVER	190	256.27	0.74	0.64	0.85	16.88
580 ALL DISEASES OF GENITO-URINARY SYSTEM	64	74.73	0.86	0.66	1.09	1.40
582 CHRONIC NEPHRITIS	4	22.00	0.18	0.05	0.47	13.92
709 ALL DISEASES OF THE SKIN AND CELLULAR TISSUE	3	4.86	0.62	0.12	1.80	0.39
739 ALL DISEASES OF THE BONES AND ORGANS OF MOVEMENT	10	14.16	0.71	0.34	1.30	0.95
799 SYMPTOMS,SENILITY,AND ILL DEFINED CONDITIONS	31	99.81	0.31	0.21	0.44	46.75
800 ALL EXTERNAL CAUSES OF DEATH	799	1016.46	0.79	0.73	0.84	46.31
801 ALL ACCIDENTS	504	649.39	0.78	0.71	0.85	32.33
810 MOTOR VEHICLE ACCIDENTS	265	329.38	0.80	0.71	0.91	12.39
959 SUICIDE	193	238.43	0.81	0.70	0.93	8.47
TOTAL RESIDUAL	365	19.98	18.27			
CANCER RESIDUAL	121	121.43	1.00			

3 Results
3.6 Mortality from Other Causes of Death (cont'd)

Table 3.6.B Deaths from Other Causes of Death and SMR's for $NW_{\geq 0.5}$

TOTAL PERSONS = 27872. EXPECTED NUMBERS BASED ON MORTALITY RATES FOR NM

	OBSERVED	EXPECTED	OBS/EXP	LL	UL	CHISQ
0 ALL CAUSES OF DEATH	2215	2875.91	0.77	0.74	0.80	151.65
1 ALL MALIGNANT NEOPLASMS	603	632.30	0.95	0.88	1.03	1.31
2 ALL INFECTIVE AND PARASITIC DISEASE	19	22.05	0.86	0.52	1.35	0.29
9 ALL TUBERCULOSIS	4	7.76	0.52	0.14	1.32	1.37
140 CANCER OF BUCCAL CAVITY AND PHARYNX	15	20.82	0.72	0.40	1.19	1.36
149 CANCER OF DIGESTIVE ORGANS AND PERITONEUM (1925- APPROXIMATE)	146	156.08	0.94	0.79	1.10	0.59
150 CANCER OF ESOPHAGUS (1925- APPROXIMATE)	16	15.37	1.04	0.59	1.69	0.00
151 CANCER OF STOMACH	23	24.52	0.94	0.59	1.41	0.04
153 CANCER OF LARGE INTESTINE (1925- APPROXIMATE)	41	52.42	0.78	0.56	1.06	2.27
154 CANCER OF RECTUM (1925- APPROXIMATE)	6	5.59	1.03	0.59	1.67	0.00
155 ALL CANCER OF LIVER (1925- APPROXIMATE) 1970+ - PRIMARY ONLY	17	10.53	1.61	0.94	2.58	3.38
157 CANCER OF PANCREAS (1925- APPROXIMATE)	26	33.25	0.78	0.51	1.15	1.37
160 CANCER OF RESPIRATORY SYSTEM (1925- APPROXIMATE)	259	242.27	1.07	0.94	1.21	1.09
161 CANCER OF LARYNX (1925-, 1930- APPROXIMATE)	5	9.53	0.52	0.17	1.23	1.70
162 ALL CANCER OF LUNG - PRIMARY AND SECONDARY (1925-,1930- APPROXIMATE)	237	230.41	1.03	0.90	1.17	0.16
170 CANCER OF BONE (1925-,1930-,1945- APPROXIMATE)	0	2.68	0.00	0.00	1.37	1.78
172 CANCER OF SKIN	7	14.47	0.48	0.19	1.00	3.36
185 CANCER OF PROSTATE (1925- APPROXIMATE)	27	25.99	1.04	0.68	1.51	0.01
186 CANCER OF TESTIS (OTHER GENITAL ORGANS 1925-49)(1925-,1930- APPROXIM	1	4.28	0.23	0.00	1.30	1.81
188 CANCER OF BLADDER (1925- APPROXIMATE)	18	13.86	1.30	0.77	2.05	0.96
189 CANCER OF KIDNEY (1925- APPROXIMATE)	15	16.95	0.89	0.50	1.46	0.12
190 CANCER OF EYE (1950-1969 ONLY)	0	0.49	0.00	0.00	7.45	0.00
191 CANCER OF BRAIN AND OTHER CENTRAL NERVOUS SYSTEM (1925- APPROXIMATE)	22	23.24	0.95	0.59	1.43	0.02
193 CANCER OF THYROID (1950-1969 ONLY)	1	1.21	0.83	0.01	4.62	0.07
200 LYMPHOSARCOMA AND RETICULOSARCOMA (1950-1969 ONLY)	5	13.11	0.38	0.12	0.89	4.42
201 HODGKIN'S DISEASE (1940-,1945- APPROXIMATE)	5	8.00	0.62	0.20	1.46	0.78
204 LEUKEMIA AND ALEUKEMIA	21	24.20	0.87	0.54	1.33	0.30
208 CANCER OF OTHER LYMPHATIC TISSUE (1950-1969 ONLY)	17	17.56	0.97	0.56	1.55	0.00

(cont'd)

3 Results

3.6 Mortality from Other Causes of Death (cont'd)

Table 3.6.B Deaths from Other Causes of Death and SMR's for $NW_{\geq 0.5}$ (cont'd)

209 ALL LYMPHOPOIETIC CANCER	50	63.59	0.79	0.58	1.04	2.69
210 BENIGN NEOPLASMS	4	8.16	0.49	0.13	1.25	1.64
240 ALLERGIC,ENDOCRINE,METABOLIC,NUTRITIONAL DISEASES (1950-1969 ONLY)	25	48.83	0.51	0.33	0.76	11.15
250 DIABETES MELLITUS	24	39.56	0.61	0.39	0.90	5.73
280 ALL DISEASES OF BLOOD AND BLOOD-FORMING ORGANS (1925-,1930- APPROXIM	6	5.82	1.03	0.38	2.24	0.02
319 MENTAL,PSYCHONEUROTIC,AND PERSONALITY DISORDERS (1950-1969 ONLY)	10	22.83	0.44	0.21	0.81	6.66
320 ALL DISEASES OF NERVOUS SYSTEM AND SENSE ORGANS	12	27.78	0.43	0.22	0.75	8.40
390 ALL DISEASES OF CIRCULATORY SYSTEM	970	1325.99	0.73	0.69	0.78	95.30
393 CHRONIC RHEUMATIC HEART DISEASE(1925- APPROXIMATE)	5	22.47	0.22	0.07	0.52	12.82
410 ARTERIOSCLEROTIC HEART DISEASE,INCLUDING CHD (1925- APPROXIMATE)	719	975.47	0.74	0.68	0.79	67.17
430 ALL VASCULAR LESIONS OF CNS	96	132.81	0.72	0.59	0.88	9.93
460 ALL RESPIRATORY DISEASES (1925-,1930- APPROXIMATE)	82	151.58	0.54	0.43	0.67	31.48
480 ALL PNEUMONIA (1925-,1930- APPROXIMATE)	33	47.15	0.70	0.48	0.98	3.95
492 EMPHYSEMA (1950-,1955 APPROXIMATE)	14	35.74	0.39	0.21	0.66	12.62
493 ASTHMA (1925-,1930- APPROXIMATE)	4	3.75	1.07	0.29	2.73	0.02
520 ALL DISEASES OF DIGESTIVE SYSTEM	115	163.48	0.70	0.58	0.84	14.06
531 ALL GASTRIC AND DUODENAL ULCER	7	14.11	0.50	0.20	1.02	3.10
571 CIRRHOSIS OF LIVER	67	102.56	0.65	0.51	0.83	11.99
580 ALL DISEASES OF GENITO-URINARY SYSTEM	11	28.06	0.42	0.21	0.78	8.13
582 CHRONIC NEPHRITIS	0	7.93	0.00	0.00	0.46	6.98
709 ALL DISEASES OF THE SKIN AND CELLULAR TISSUE	0	1.78	0.00	0.00	2.08	0.91
739 ALL DISEASES OF THE BONES AND ORGANS OF MOVEMENT	2	5.39	0.37	0.04	1.36	1.52
799 SYMPTOMS,SENILITY,AND ILL DEFINED CONDITIONS	8	38.17	0.21	0.09	0.41	23.07
800 ALL EXTERNAL CAUSES OF DEATH	253	388.20	0.65	0.57	0.74	48.74
801 ALL ACCIDENTS	168	245.70	0.68	0.58	0.80	24.25
810 MOTOR VEHICLE ACCIDENTS	95	123.52	0.77	0.62	0.94	6.38
959 SUICIDE	60	92.81	0.65	0.49	0.83	11.07
TOTAL RESIDUAL	95	7.54	12.60			
CANCER RESIDUAL	42	46.37	0.91			

3 Results

3.6 Mortality from Other Causes of Death (cont'd)

Table 3.6.C Deaths from Other Causes of Death and SMR's for $NW_{<0.5}$

TOTAL PERSONS = 10348. EXPECTED NUMBERS BASED ON MORTALITY RATES FOR WM

	OBSERVED	EXPECTED	OBS/EXP	LL	UL	CHISQ
0 ALL CAUSES OF DEATH	973	1173.59	0.83	0.78	0.88	34.11
1 ALL MALIGNANT NEOPLASMS	243	254.23	0.96	0.84	1.08	0.45
2 ALL INFECTIVE AND PARASITIC DISEASE	2	9.12	0.22	0.02	0.79	4.81
9 ALL TUBERCULOSIS	0	3.33	0.00	0.00	1.10	2.40
140 CANCER OF BUCCAL CAVITY AND PHARYNX	6	8.18	0.73	0.27	1.60	0.35
149 CANCER OF DIGESTIVE ORGANS AND PERITONEUM (1925- APPROXIMATE)	65	63.72	1.02	0.79	1.30	0.01
150 CANCER OF ESOPHAGUS (1925- APPROXIMATE)	7	6.08	1.15	0.46	2.37	0.03
151 CANCER OF STOMACH	13	10.15	1.28	0.68	2.19	0.54
153 CANCER OF LARGE INTESTINE (1925- APPROXIMATE)	21	21.48	0.98	0.60	1.49	0.00
154 CANCER OF RECTUM (1925- APPROXIMATE)	7	6.46	1.08	0.43	2.23	0.00
155 ALL CANCER OF LIVER (1925- APPROXIMATE) 1970+ - PRIMARY ONLY	3	4.34	0.69	0.14	2.02	0.16
157 CANCER OF PANCREAS (1925- APPROXIMATE)	11	13.43	0.82	0.41	1.47	0.28
160 CANCER OF RESPIRATORY SYSTEM (1925- APPROXIMATE)	110	95.54	1.15	0.95	1.39	2.04
161 CANCER OF LARYNX (1925-, 1930- APPROXIMATE)	4	3.78	1.06	0.28	2.71	0.02
162 ALL CANCER OF LUNG - PRIMARY AND SECONDARY (1925-,1930- APPROXIMATE)	98	90.83	1.08	0.88	1.31	0.49
170 CANCER OF BONE (1925-,1930-,1945- APPROXIMATE)	0	1.10	0.00	0.00	3.35	0.32
172 CANCER OF SKIN	7	5.62	1.25	0.50	2.57	0.14
185 CANCER OF PROSTATE (1925- APPROXIMATE)	13	11.93	1.09	0.58	1.86	0.03
186 CANCER OF TESTIS (OTHER GENITAL ORGANS 1925-49)(1925-,1930- APPROXIM	1	1.73	0.58	0.01	3.21	0.03
188 CANCER OF BLADDER (1925- APPROXIMATE)	6	5.99	1.00	0.37	2.18	0.04
189 CANCER OF KIDNEY (1925- APPROXIMATE)	4	6.68	0.60	0.16	1.53	0.71
190 CANCER OF EYE (1950-1969 ONLY)	0	0.20	0.00	0.00	18.11	0.44
191 CANCER OF BRAIN AND OTHER CENTRAL NERVOUS SYSTEM (1925- APPROXIMATE)	4	8.88	0.45	0.12	1.14	2.23
193 CANCER OF THYROID (1950-1969 ONLY)	2	0.48	4.12	0.46	14.88	2.12
200 LYMPHOSARCOMA AND RETICULOSARCOMA (1950-1969 ONLY)	4	5.26	0.76	0.20	1.95	0.11
201 HODGKIN'S DISEASE (1940-,1945- APPROXIMATE)	1	3.21	0.31	0.00	1.73	0.91
204 LEUKEMIA AND ALEUKEMIA	4	9.87	0.41	0.11	1.04	2.92
208 CANCER OF OTHER LYMPHATIC TISSUE (1950-1969 ONLY)	4	6.96	0.57	0.15	1.47	0.87

(cont'd)

3 Results

3.6 Mortality from Other Causes of Death (cont'd)

Table 3.6.C Deaths from Other Causes of Death and SMR's for $NW_{<0.5}$ (cont'd)

209 ALL LYMPHOPOIETIC CANCER	13	25.59	0.51	0.27	0.87	5.71
210 BENIGN NEOPLASMS	3	3.26	0.92	0.18	2.69	0.02
240 ALLERGIC,ENDOCRINE,METABOLIC,NUTRITIONAL DISEASES (1950-1969 ONLY)	13	20.01	0.65	0.35	1.11	2.12
250 DIABETES MELLITUS	9	16.30	0.55	0.25	1.05	2.84
280 ALL DISEASES OF BLOOD AND BLOOD-FORMING ORGANS (1925-,1930- APPROXIM	1	2.42	0.41	0.01	2.30	0.35
319 MENTAL,PSYCHONEUROTIC,AND PERSONALITY DISORDERS (1950-1969 ONLY)	7	8.78	0.80	0.32	1.64	0.19
320 ALL DISEASES OF NERVOUS SYSTEM AND SENSE ORGANS	4	11.16	0.36	0.10	0.92	3.98
390 ALL DISEASES OF CIRCULATORY SYSTEM	416	549.86	0.76	0.69	0.83	32.34
393 CHRONIC RHEUMATIC HEART DISEASE(1925- APPROXIMATE)	3	9.08	0.33	0.07	0.96	3.43
410 ARTERIOSCLEROTIC HEART DISEASE,INCLUDING CHD (1925- APPROXIMATE)	316	400.79	0.79	0.70	0.88	17.73
430 ALL VASCULAR LESIONS OF CNS	37	56.68	0.63	0.44	0.87	7.65
460 ALL RESPIRATORY DISEASES (1925-,1930- APPROXIMATE)	42	64.41	0.65	0.47	0.88	7.45
480 ALL PNEUMONIA (1925-,1930- APPROXIMATE)	13	20.24	0.64	0.34	1.10	2.25
492 EMPHYSEMA (1950-,1955 APPROXIMATE)	11	15.52	0.71	0.35	1.27	1.04
493 ASTHMA (1925-,1930- APPROXIMATE)	0	1.59	0.00	0.00	2.30	0.75
520 ALL DISEASES OF DIGESTIVE SYSTEM	45	63.95	0.70	0.51	0.94	5.32
531 ALL GASTRIC AND DUODENAL ULCER	3	5.89	0.50	0.10	1.47	1.01
571 CIRRHOSIS OF LIVER	19	38.96	0.49	0.29	0.76	9.74
580 ALL DISEASES OF GENITO-URINARY SYSTEM	9	11.31	0.80	0.36	1.51	0.29
582 CHRONIC NEPHRITIS	0	3.39	0.00	0.00	1.08	2.46
709 ALL DISEASES OF THE SKIN AND CELLULAR TISSUE	0	0.74	0.00	0.00	4.94	0.08
739 ALL DISEASES OF THE BONES AND ORGANS OF MOVEMENT	1	2.16	0.46	0.01	2.58	0.20
799 SYMPTOMS,SENILITY,AND ILL DEFINED CONDITIONS	6	15.13	0.40	0.14	0.86	4.93
800 ALL EXTERNAL CAUSES OF DEATH	133	153.99	0.86	0.72	1.02	2.73
801 ALL ACCIDENTS	91	98.69	0.92	0.74	1.13	0.51
810 MOTOR VEHICLE ACCIDENTS	50	50.04	1.00	0.74	1.32	0.00
959 SUICIDE	27	36.10	0.75	0.49	1.09	2.05
TOTAL RESIDUAL	48	3.03	15.84			
CANCER RESIDUAL	12	18.49	0.65			

3 Results

3.6 Mortality from Other Causes of Death (cont'd)

Table 3.6.D Deaths from Other Causes of Death and SMR's for NNW

TOTAL PERSONS = 32510. EXPECTED NUMBERS BASED ON MORTALITY RATES FOR WM

	OBSERVED	EXPECTED	OBS/EXP	LL	UL	CHISQ
0 ALL CAUSES OF DEATH	3745	3686.41	1.02	0.98	1.05	0.95
1 ALL MALIGNANT NEOPLASMS	878	784.60	1.12	1.05	1.20	11.00
2 ALL INFECTIVE AND PARASITIC DISEASE	18	28.58	0.63	0.37	1.00	3.56
3 ALL TUBERCULOSIS	3	10.50	0.29	0.06	0.84	4.66
140 CANCER OF BUCCAL CAVITY AND PHARYNX	23	24.63	0.93	0.59	1.40	0.05
149 CANCER OF DIGESTIVE ORGANS AND PERITONEUM (1925- APPROXIMATE)	224	199.40	1.12	0.98	1.28	2.91
150 CANCER OF ESOPHAGUS (1925- APPROXIMATE)	27	18.47	1.46	0.98	2.13	3.49
151 CANCER OF STOMACH	48	32.25	1.49	1.10	1.97	7.21
153 CANCER OF LARGE INTESTINE (1925- APPROXIMATE)	59	67.55	0.87	0.66	1.13	0.96
154 CANCER OF RECTUM (1925- APPROXIMATE)	20	20.44	0.98	0.60	1.51	0.00
155 ALL CANCER OF LIVER (1925- APPROXIMATE) 1970+ - PRIMARY ONLY	15	13.66	1.10	0.61	1.81	0.05
157 CANCER OF PANCREAS (1925- APPROXIMATE)	48	41.57	1.15	0.85	1.53	0.85
160 CANCER OF RESPIRATORY SYSTEM (1925- APPROXIMATE)	323	288.93	1.12	1.00	1.25	3.90
161 CANCER OF LARYNX (1925-, 1930- APPROXIMATE)	8	11.46	0.70	0.30	1.37	0.77
162 ALL CANCER OF LUNG - PRIMARY AND SECONDARY (1925-,1930- APPROXIMATE)	306	274.61	1.11	0.99	1.25	3.47
170 CANCER OF BONE (1925-,1930-,1945- APPROXIMATE)	4	3.43	1.17	0.31	2.99	0.00
172 CANCER OF SKIN	18	17.00	1.06	0.63	1.67	0.01
185 CANCER OF PROSTATE (1925- APPROXIMATE)	55	41.51	1.32	1.00	1.72	4.06
186 CANCER OF TESTIS (OTHER GENITAL ORGANS 1925-49)(1925-,1930- APPROXIM	6	5.38	1.12	0.41	2.44	0.00
188 CANCER OF BLADDER (1925- APPROXIMATE)	17	19.68	0.86	0.50	1.38	0.24
189 CANCER OF KIDNEY (1925- APPROXIMATE)	26	20.26	1.28	0.84	1.88	1.35
190 CANCER OF EYE (1950-1969 ONLY)	0	0.63	0.00	0.00	5.83	0.03
191 CANCER OF BRAIN AND OTHER CENTRAL NERVOUS SYSTEM (1925- APPROXIMATE)	29	26.63	1.09	0.73	1.56	0.13
193 CANCER OF THYROID (1950-1969 ONLY)	2	1.50	1.34	0.15	4.82	0.00
200 LYMPHOSARCOMA AND RETICULOSARCOMA (1950-1969 ONLY)	18	16.10	1.12	0.66	1.77	0.12
201 HODGKIN'S DISEASE (1940-,1945- APPROXIMATE)	12	9.78	1.23	0.63	2.14	0.30
204 LEUKEMIA AND ALEUKEMIA	29	30.96	0.94	0.63	1.35	0.07
208 CANCER OF OTHER LYMPHATIC TISSUE (1950-1969 ONLY)	24	21.33	1.13	0.72	1.67	0.22

 (cont'd)

3 Results

3.6 Mortality from Other Causes of Death (cont'd)

Table 3.6.D Deaths from Other Causes of Death and SMR's for NNW (cont'd)

209 ALL LYMPHOPOIETIC CANCER	84	79.07	1.06	0.85	1.32	0.25
210 BENIGN NEOPLASMS	11	9.97	1.10	0.55	1.97	0.03
240 ALLERGIC,ENDOCRINE,METABOLIC,NUTRITIONAL DISEASES (1950-1969 ONLY)	53	63.08	0.84	0.63	1.10	1.45
250 DIABETES MELLITUS	39	51.58	0.76	0.54	1.03	2.83
280 ALL DISEASES OF BLOOD AND BLOOD-FORMING ORGANS (1925-,1930- APPROXIM	7	7.74	0.90	0.36	1.86	0.01
319 MENTAL,PSYCHONEUROTIC,AND PERSONALITY DISORDERS (1950-1969 ONLY)	27	26.37	1.02	0.67	1.49	0.00
320 ALL DISEASES OF NERVOUS SYSTEM AND SENSE ORGANS	29	34.50	0.84	0.56	1.21	0.73
390 ALL DISEASES OF CIRCULATORY SYSTEM	1626	1751.85	0.93	0.88	0.97	8.97
393 CHRONIC RHEUMATIC HEART DISEASE(1925- APPROXIMATE)	6	27.42	0.22	0.08	0.48	15.96
410 ARTERIOSCLEROTIC HEART DISEASE,INCLUDING CHD (1925- APPROXIMATE)	1166	1263.23	0.92	0.87	0.98	7.41
430 ALL VASCULAR LESIONS OF CNS	183	199.38	0.92	0.79	1.06	1.26
460 ALL RESPIRATORY DISEASES (1925-,1930- APPROXIMATE)	201	208.89	0.96	0.83	1.10	0.26
480 ALL PNEUMONIA (1925-,1930- APPROXIMATE)	66	66.93	0.99	0.76	1.25	0.00
492 EMPHYSEMA (1950-,1955 APPROXIMATE)	45	51.08	0.88	0.64	1.18	0.61
493 ASTHMA (1925-,1930- APPROXIMATE)	9	5.08	1.77	0.81	3.36	2.30
520 ALL DISEASES OF DIGESTIVE SYSTEM	189	193.24	0.98	0.84	1.13	0.07
531 ALL GASTRIC AND DUODENAL ULCER	17	18.89	0.90	0.52	1.44	0.10
571 CIRRHOSIS OF LIVER	104	114.72	0.91	0.74	1.10	0.91
580 ALL DISEASES OF GENITO-URINARY SYSTEM	44	37.36	1.18	0.86	1.58	1.01
582 CHRONIC NEPHRITIS	4	10.69	0.37	0.10	0.96	3.58
709 ALL DISEASES OF THE SKIN AND CELLULAR TISSUE	3	2.37	1.27	0.26	3.70	0.01
739 ALL DISEASES OF THE BONES AND ORGANS OF MOVEMENT	7	6.65	1.05	0.42	2.17	0.00
799 SYMPTOMS,SENILITY,AND ILL DEFINED CONDITIONS	17	46.51	0.37	0.21	0.59	18.09
800 ALL EXTERNAL CAUSES OF DEATH	413	474.26	0.87	0.79	0.96	7.78
801 ALL ACCIDENTS	245	305.10	0.80	0.71	0.91	11.64
810 MOTOR VEHICLE ACCIDENTS	120	155.82	0.77	0.64	0.92	8.01
959 SUICIDE	106	109.82	0.97	0.79	1.17	0.10
TOTAL RESIDUAL	222	9.42	23.58			
CANCER RESIDUAL	67	56.57	1.18			

4 Discussion

4.1 Summary of Findings

The study of health effects of low-dose radiation in shipyard worker reports analyses using standardized mortality ratios (SMRs) and an external comparison. The data are presented in two ways: the total experience of all individuals is analyzed according to the dose category which individuals reached either at the time of the death or at the end of the study period or the experience of individuals is counted in each dose category in which individuals contributed person-years of follow-up during the course of the study. The first type of analysis is referred to as "categorical" analyses and the second, "time-dependent" analysis. The analyses represent the results from data available at the end of the contract and include death information collected through December, 1981.

The SMRs from the categorical analysis in which the individual remains in the same group throughout follow-up (Table 4.1.A) indicate that the risks of death in the NNW group of shipyard workers are similar to that of the general population but the risks of total mortality in both groups of nuclear workers are lower than the U.S. rate. The all cause mortality is highest for the NNW group and lowest for the $NW_{\geq 0.5}$ which certainly does not suggest that radiation causes a general risk of death. In fact, in the $NW_{\geq 0.5}$ group, the mortality is only 76 percent of that of the general population and is significantly lower than would be expected.

The SMRs for leukemia and all lymphatic and hematopoietic cancers (LHC) indicate risks of these diseases among nuclear workers which are below those of the general population. The SMR of 1.10 for the NNW group indicates that the observed deaths are similar in number to those expected based on population rates. The only unusual feature of the data is the fact that,

4 Discussion

4.1 Summary of Findings (cont'd)

unlike the SMRs for the all cause mortality, for these two causes of death the SMR for the $NW_{\geq 0.5}$ is higher than the SMR for the $NW_{<0.5}$. Thus, a comparison between these groups suggests that the leukemia ratio is 2.17 times higher and the lymphatic and hematopoietic cancers ratio 1.55 times higher in the $NW_{\geq 0.5}$ group than in the $NW_{<0.5}$ rem group. However, in no case are the ratios significantly higher than those of the external comparison group of U.S. white males at a $p \leq 0.05$. Certainly the risks of leukemia or all hematopoietic neoplasms are not high compared to the NNW group. The questions which one needs to answer are: whether the <0.5 rem group is a more appropriate comparison population for the $NW_{\geq 0.5}$ group than the NNW group, whether the two nuclear groups, $NW_{<0.5}$ and $NW_{\geq 0.5}$, are similar so that they can be compared in this way, whether all comparisons should be made to the 0.5-0.9 DE group within the $NW_{\geq 0.5}$ group as in the time-dependent analysis, and perhaps even more relevant, whether differences in ratios between the groups might not be expected based on the small numbers of deaths in each group. The latter question is probably the most important and can only be answered by further follow-up. Further consideration of the choice of comparisons is warranted.

Selective factors which allowed workers to be enrolled in the radiation program should have been operating similarly in the two nuclear worker populations perhaps making them the most appropriate comparison groups in a categorical analysis. There might be even more justification for using the 0.5-0.9 DE group as a comparison to higher dose groups since all dose groups from 0.5 rem and higher represent part of the same population in time-dependent analysis. All three groups, $NW_{\geq 0.5}$, $NW_{<0.5\ rem}$ and NNW, were balanced in the initial sample to provide comparability on basic demographic characteristics to make between group comparisons appropriate. However, none

4 Discussion

4.1 Summary of Findings (cont'd)

of the comparisons will be perfect on all variables. If those variables are related to differences in disease then they could be confounding factors which influence the results. The two nuclear worker groups might be healthier than the NNW group because they were selected and examined for entry into the radiation program. This might explain the low mortality from leukemia in the $NW_{<0.5\ rem}$ and the lowest DE category in the $NW_{\geq 0.5}$ groups. These workers in the higher DE categories who have had longer work times after the initial selection into the program may have higher mortality simply because the "healthy worker effect" from selection is gradually diminishing with time and the SMR is rising. That does not seem to be a reasonable explanation for the observation since all cause mortality (Tables 3.1.A-3.1.B), cardiovascular mortality (Tables 3.6.B-3.6.D) and lung cancer mortality (Tables 3.5.A-3.5.B) actually show higher mortality rates in the $NW_{<0.5\ rem}$ than in the $NW_{\geq 0.5\ rem}$. It is still possible that selection factors for entry into the radiation program act differently for different diseases. The NNW group is probably not a good comparison population since they have not experienced the unknown "selective factors" which enter workers in the program. They also may not be similar racially to the nuclear group and that may be an important disease factor. The best comparison may be the time-dependent analysis using workers within the $NW_{\geq 0.5\ rem}$ divided into DE groups. However, even that is not a perfect comparison. The higher DE groups are likely to be slightly older since they have accumulated more time and age as they accumulated higher doses. They also are more likely to be blue collar workers who have jobs with greater likelihood of exposure than engineers and radiation health workers who are also in the program. None of these differences can explain why leukemia and lymphatic and hematopoietic cancer mortality show no dose response but

4 Discussion

4.1 Summary of Findings (cont'd)

rather an increase in ratio in the DE group 1.0-4.9 rem unlike the dose response seen in lung cancer and mesothelioma mortality ratios. Further follow up in the groups with higher radiation doses and different analyses which will account for other confounding variables such as jobs may help resolve these issues.

The risk of lung cancer in the categorical analysis is significantly higher ($p<0.05$) in the non-nuclear worker group compared to the general population and is slightly but not significantly higher in the two radiation groups compared to the general population. Examining all three groups does not suggest that the risk is increased more in the radiation exposed groups compared to NNW. Since lung cancer is known to be associated with asbestos which was used as insulation material in the past in shipyards, the SMRs were calculated for mesotheliomas since this cancer could serve as a biological marker for the presence of asbestos exposure in the population. All groups showed very high SMRs for this cancer with about a five-fold higher risk among both nuclear worker groups and a 2.4-fold higher risk in the NNW group compared to the general population. It is likely that some of the excess of mesothelioma mortality is due to better diagnosis of the disease in shipyard workers with suspected asbestos exposure than in a general population. Since most of the cases have been confirmed by hospital record review, if diagnostic bias had caused some of the apparent excess of this disease, it would not be because of over-diagnosis of the disease among shipyard workers but rather under-diagnosis in the general population. Even in this situation, the number of actual cases of mesothelioma in workers was small in absolute terms (36 cases among 70,730 workers in the sample) indicating that the disease is still comparatively rare. The important point in regard to the radiation data is

4 Discussion

4.1 Summary of Findings (cont'd)

not that there may be a higher death rate from mesothelioma among shipyard workers compared to U.S. males but there should be no differences in SMRs among the three groups of workers. The fact that both nuclear worker groups have higher SMRs for mesothelioma than the NNW group suggests that the jobs of workers in the radiation program may have involved more exposure to asbestos than other jobs in the shipyard. If asbestos and not radiation is the reason for the excess in mesothelioma in the nuclear groups, then some of the lung cancer excess may also be due to asbestos. Therefore, before drawing any conclusions about the apparent increase in lung cancer with increasing radiation dose it will be necessary to determine whether asbestos is confounding this observation.

The categorical analyses suffer from a bias which has been noted before, namely that the group who reach the higher DE level of 0.5 rem or more might have been forced to survive longer than workers at lower DE levels or those without any radiation because they had to be healthy enough to live and to get to the higher DE levels. If this does create an analysis problem, then we might expect the SMR to be consistently lowest in the highest DE group. That is, selection of the population to work in the radiation program would cause that group to have lower mortality than the NNW group, and those reaching the higher DE in the radiation program would have even lower mortality. This is the pattern seen for the all cause mortality in Table 4.1.A. and for lung cancer but not for the other diseases. Leukemia and LHC mortality ratios are higher in the $NW_{\geq 0.5}$ group rather than the $NW_{<0.5}$ rem group. The mesothelioma mortality ratios are similar in both of the radiation groups and are about two times higher than the ratio in the NNW group. Thus, the patterns of mortality risk are not the same for all four diseases and all cause mortality. Only all

4 Discussion

4.1 Summary of Findings (cont'd)

cause SMR and lung cancer SMR fit the expected pattern. Since those causes have the largest number of deaths, the variation in pattern for the other causes of death may well be due to the small number of deaths. It is also possible that other characteristics or exposures in the workers have caused the differences.

Many methods of analysis exist by which we might examine the effects of radiation within the $NW_{\geq 0.5}$ rem DE group. However, at present, only an analysis using standardized mortality ratios with time dependency of person-years has been attempted. This method places an individual's person-years in follow-up into the appropriate DE levels for each age and calendar time period. The summary of the results of this method of analysis without any lagging, as shown in Table 4.1.B, indicates that, in general, subdividing the $NW_{\geq 0.5}$ group into three or four levels separates the population into a low 0.5-0.9 rem subgroup which has a SMR similar to or lower than that of the $NW_{<0.5}$ for all four disease categories as well as the total causes of death. The ratios are generally higher at the 1.0-4.9 rem subgroup than the ratios at the lowest DE level. For DE groups above 1.0-4.9 rem, the SMRs compared to the 0.5-0.9 rem group are usually higher. However, for no disease except lung cancer is there a progressive increase in the SMR with each successively higher DE group; that is, there is no trend of increasing risk with increasing dose for the other causes. Usually the highest DE level has a lower SMR than that for the preceding dose category. This may simply reflect variability due to small numbers. The category of 1.0-4.9 rem usually has the highest number of cases which may make the SMRs more stable in this subgroup. At present, however, without a dose response it is hard to associate an exposure with a disease. There could be several factors which make it difficult to assess

4 Discussion

4.1 Summary of Findings (cont'd)

whether there is a dose-response from radiation for these diseases. There is likely to be confounding from asbestos exposure for those workers with mesothelioma and lung cancer, and the effort to collect exposure estimates for that substance must be completed so that multivariate analysis can be completed to evaluate this confounding variable. There is also the possibility that individuals accumulate additional DEs of radiation during a period when the cancer is present but has not yet become clinically manifest. This period of additional accumulated radiation dose is not needed to produce disease.

To investigate whether this latter situation is influencing the dose-response curves, the DE was lagged by several different time intervals and the ratios recalculated. With this procedure, some cases are lost and some are now included in different DE subgroups. The procedure tends to increase the ratios in the 1.0-4.9 and 5.0-9.9 rem subgroups but the DE category of 10.0 rem remains low. The number of cases in any specific DE group is small. In general, with the exception of leukemia mortality, the SMRs are higher with a ten year lag period as compared to shorter lag periods. Fifteen year lags were also used in analyses but the population has not been followed long enough to provide sufficient cases for analysis using this long a lag period. From the data, it would appear that the five year lag period produces stable and consistent results. While the SMRs are increased by lagging for ten years, there is marked variability of the rates because of the reduced numbers of cases in the subgroups.

The three groups in the sample were screened to see if any other risks of specific diseases appeared which might deserve further study. The U.S. white male population was used as comparison. That analysis suggests that

4 Discussion

4.1 Summary of Findings (cont'd)

there are no statistically significant excesses of cancers in this population with the exception of lung cancer in the NNW group and mesotheliomas.

Evaluation of low doses of radiation using the methods described in this report is limited by the fact that, if there is an effect of radiation at these near background levels, then the effect will only increase the risk by a small amount. This method of analysis will have difficulty detecting such an increase. Other types of analysis can be attempted. However, any analysis will suffer from small numbers so that the primary need is for further follow-up of this population to increase the numbers of deaths.

In conclusion, the nuclear worker population does not show a significant increase in the risk of any of the cancers studied except for mesothelioma when compared to the general population. Mesotheliomas are known to be asbestos related and the role of this substance in the apparent risk needs to be determined in future analysis. A lower but significant excess was also noted in non-nuclear workers. The mortality from lung cancer is slightly higher than that of U.S. males for the shipyard population as a whole, but within the subgroups only the NNW group has a statistically significant increase. Among the nuclear workers, the slight risk increase, while not statistically significant compared to the general population, appears to increase with increasing radiation DE level. These results would have to be controlled for asbestos and smoking before any weight can be placed on the observation.

The data clearly indicate that both nuclear worker groups have a lower mortality from leukemia and lymphatic and hematopoietic cancers than does the non-nuclear group. All three groups have lower rates than the general population. However, if the $NW_{<0.5}$ group or the 0.5-0.9 rem group is used for

4 Discussion

4.1 Summary of Findings (cont'd)

comparison, then all dose groups 1.0 rem and above in the $NW_{\geq 0.5}$ group have higher mortality rates than the $NW_{<0.5}$ group for both leukemia and all lymphatic hematopoietic neoplasms. There is no consistent dose response with radiation which would suggest that radiation is not the factor associated with the increase. Therefore, further investigation must be focused on whether variations in jobs or other shipyard exposures or non-job related risk factors may be influencing the risk of disease among the nuclear workers. The SMRs are very sensitive to any changes, such as lagging, due to small numbers, so these within group observations may simply represent chance variations.

4 Discussion
4.1 Summary of Findings (cont'd)

Table 4.1.A Mortality from Selected Causes for NNW, $NW_{<0.5}$, and $NW_{\geq 0.5}$: Summary of Standardized Mortality Ratios

Cause	$NW_{\geq 0.5}$ SMR (95% C.I.)	$NW_{<0.5}$ SMR (95% C.I.)	NNW SMR (95% C.I.)
All Causes	0.76 (0.73,0.79)	0.81 (0.76, 0.86)	1.00 (0.97,1.03)
Leukemia	0.91 (0.56,1.39)	0.42 (0.11, 1.07)	0.97 (0.65,1.39)
LHC	0.82 (0.61,1.08)	0.53 (0.28, 0.91)	1.10 (0.88,1.37)
Mesothelioma	5.11 (3.03,8.08)	5.75 (2.48,11.33)	2.41 (1.16,4.43)
Lung Cancer	1.07 (0.94,1.21)	1.11 (0.90, 1.35)	1.15 (1.02,1.29)

4 Discussion
4.1 Summary of Findings (cont'd)

Table 4.1.B Mortality from Selected Causes for NNW, $NW_{<0.5}$, and Recorded Dose Equivalent Groups within the $NW_{\geq 0.5}$: Summary of Standardized Mortality Ratios

Cause	$NW_{\geq 0.5}$ (rem) 0.5-	1.0-	5.0-	10^{+}	$NW_{<0.5}$	NNW
No lag						
All causes	0.72	0.79	0.76	0.72	0.81	1.00
Leukemia	0.41	1.08	1.03	0.94	0.42	0.97
LHC	0.31	1.00	1.08	0.71	0.53	1.11
Mesothelioma	3.96	4.80	8.48	3.94	5.75	2.41
Lung Cancer	0.95	1.03	1.17	1.25	1.11	1.15
5 Year Lag						
All causes	0.72	0.78	0.83	0.81	0.83	1.00
Leukemia	0	1.12	0.68	1.32	0.26	1.02
LHC	0.19	1.11	1.17	0.84	0.56	1.07
Mesothelioma	4.33	5.35	7.84	4.80	5.65	2.48
Lung Cancer	0.95	1.00	1.21	1.40	1.19	1.16
10 Year Lag						
All causes	0.76	0.84	0.89	0.79	0.85	1.03
Leukemia	0	0.82	1.10	0.83	0.38	1.09
LHC	0.27	1.40	1.28	0.32	0.68	1.02
Mesothelioma	7.16	4.18	10.87	3.91	5.17	2.52
Lung Cancer	0.98	1.03	1.48	1.24	1.23	1.19

4 Discussion

4.2 Statistical Power of the Study

This section presents the statistical power of the study for detecting radiation effects of various sizes as it was calculated prior to the start of the study. Estimates of the benefits of additional follow-up on the study population are also presented. The Shipyard Study has less than a 20 percent chance of detecting an excess risk of leukemia at the level of the BEIR III report estimates. (BEIR III estimates were those available throughout the study.) It is likely that the study would detect an excess risk of leukemia if the BEIR III estimates were low by a factor of five. There would be a gain in the power of the study to detect leukemia effects of approximately 10 percent for excess risks at the level of two to five times BEIR III, if there were six additional years of follow-up.

Statistical power of the study was determined using the analysis subset described in Section 3.1. This subset includes all nuclear workers with $\geq$0.5 rem lifetime DE as of January 1, 1982 and samples of the remaining nuclear and non-nuclear workers. All workers were first screened using the study population criteria for inclusion (see Section 2.2), that is, male civilian shipyard employees who worked at least one year in the shipyard during the nuclear overhaul time period. Additional edits were applied before arriving at the subset used for analysis.

The numbers of workers, person-years, and deaths by selected causes among all workers and the $NW_{\geq 0.5}$ workers by shipyard as used in a final power calculation are given in Tables 4.2.A and 4.2.B. There were a total of 70,898 workers in the sample subset, of whom 27,938 workers had accumulated a lifetime DE of $\geq$0.5 rem by January 1, 1982. There were a total of 7,101 deaths among all workers in the sample subset, of which 54 were due to leukemia and 641 were due to lung cancer. For 168 workers, the fact of death had been recorded but no valid dates of death had been identified. An estimated follow-up time based on their last year of employment was used for these workers. An additional 335 workers were known to be dead and had dates of death, but were missing the cause of death on their record.

A summary of the assumptions used for the power calculations is given in Table 4.2.C. The worker's annual cumulative DEs were lagged by two or five years and reduced by 21% to convert the measured DE in rads ("tissue Kerma in air") to an "organ dose," thereby adjusting for body shielding of the organs of interest (Preston and Pierce, 1987). A two year lag was used for leukemia and LHC effects, and a five-year lag was used for lung cancer effects. The additive linear risk model was used to specify the various alternative risks. The 1970 U.S. white male age-cause specific death rates (in 5-year intervals) were assumed to be the spontaneous risk of dying. The ranges of potential excess risks were derived from the BEIR III risk estimates and multiples of these estimates up to a 40-fold increase over the BEIR III figures. It seemed most appropriate to express the alternative excess risks as multiples of the BEIR III report estimates, rather than simply expressing the alternative in terms of increased relative risks of leukemia.

Power calculations were based on an extension of Mantel-Henszel's Chi-Square (X^2) test to detect a dose-related trend in death rates. This was found to be the most sensitive analytic method for this study. It uses a completely internal control group and allows for simultaneous control of age, interval since onset of exposure, and other confounders as well as time-dependent DE accumulation. Grouping exposures helped to alleviate the problem of non-normality of the test statistic induced by the highly skewed DE distribution and resulted in the same test statistic as the interval method using each worker's actual DEs.

The power formulas for this method have been presented by E.S. Gilbert in "An Evaluation of Several Methods for Assessing the Effects of Occupational Exposure to Radiation" (Gilbert, 1983). The twelve dose categories used were <1, 1-, 5-, 10-, 15-, 20-, 25-, 30-, 35-, 40-, 45-, and 50+ rems (Darby and Reissland, 1981). Each nuclear worker's accumulated radiation DE for each year of the worker's follow-up period lagged by two or five years was grouped into the appropriate dose category. The median DE was used as the group score. The median DE was reduced by 21 percent to approximate the DE to each organ.

The length of follow-up was determined for each worker from time of entry into follow-up as defined in Table 4.2.C to January 1, 1982 or to the worker's death time. The length of follow-up for the extended period of follow-up was calculated to January 1, 1988 or the worker's death time. Since the actual death times were unavailable from December 31, 1981 to December 31, 1987, a random death time based on 1970 U.S. white male life table probabilities was simulated for each worker still alive on December 31, 1981. It was assumed that no additional radiation was received by the nuclear workers after December 31, 1981.

The analyses were controlled for age (in 5-year intervals) and length of time since entry into follow-up. For the power calculations, a linear risk model was chosen, where the spontaneous risk of dying was given by the 1970 U.S. white-male age-cause-specific death rates (in 5-year intervals). A method described by Cramer (Cramer, 1946) was used to determine the power. The method adjusts the normal approximation for non-normality of the test statistic due to the highly skewed dose distribution using the third and fourth cumulants of the test statistic.

The power of the Shipyard Study to detect a radiation effect on leukemia, lymphoma, and lung cancer mortality is presented in Table 4.2.D. If the BEIR III committee's extrapolation of radiation risk is accurate, then only two to three additional leukemia deaths could occur as compared to the 58 expected from the 922,438 person-years accumulated by nuclear workers and their controls. This implies a relative risk of only 1.04. The study has a less than 20 percent chance of detecting increased risks at this level. However, there is a 50 to 80 percent chance that the Shipyard Study could detect an increased leukemia risk of 3 to 5 times BEIR III using the linear dose response model. If the excess risk is 10 to 20 times BEIR III (linear model), then the Shipyard Study would most certainly detect a risk. If the BEIR III risk estimates are too low by a factor of 2 as suggested by the revised dosimetry estimates for the atomic bomb data, then the Shipyard Study will have approximately a 30 percent chance of detecting a leukemia risk.

The study has less power to detect an increased risk for LHC or lung cancer related to radiation than for leukemia. Lymphatic and hematopoietic cancer risks which are less than 5 times BEIR III and lung cancer risks less than 10 times BEIR III would not be detectable. LHC risks greater than 10 times BEIR III, and lung cancer risks greater than 20 times BEIR III have an excellent chance of being detected.

Table 4.2.E presents the statistical power of the Shipyard Study to detect a radiation effect on the occurrence of leukemia, lymphatic and hematopoietic cancers and lung cancer when the length of follow-up is extended by six more years to January 1, 1988. The chance of detecting a leukemia risk of 5 times BEIR III (linear model) was increased by 14 percent with this

4 Discussion

4.2 Statistical Power of the Study (cont'd)

additional follow-up. There is a 92 percent chance that the study would detect a leukemia effect at this level.

The power to detect LHC and lung cancer effects was also increased by 10 to 20 percent for an excess risk of 5 to 10 times BEIR III for LHC and 5 to 15 times BEIR III for lung cancer. LHC risks greater than 10 times BEIR III and lung cancer risks greater than 15 times BEIR III would almost certainly be detected with six additional years of follow-up.

The BEIR III report did not specify an expected level of risk due to low-level radiation on mesothelioma. There were 36 mesothelioma deaths occurring in this study population compared to 9.08 expected deaths using U.S. white male age-calendar time specific rates. This gives an SMR of 4 with confidence limits of 2.80 to 5.54. If follow-up was extended for six more years and the level of mesothelioma risk remained constant, then there would be an expected 72 deaths occurring. This would reduce the width of the confidence limits to 3.13 to 5.04.

The main conclusions regarding the Shipyard Study power are:

- There is almost no chance of detecting leukemia risk equal to the BEIR III extrapolations;
- Leukemia risks as large as 10 times the BEIR III risk estimates would almost certainly be found;
- Some useful information will be provided by the study if actual risks are 5 to 10 times the BEIR III estimates;
- There would be a gain of 10 to 20 percent in the power of the study to detect radiation effects at the level of 5 to 15 times the BEIR III estimates; and
- Leukemia risks as large as 3 to 5 times the BEIR III risk estimates would almost certainly be found if the follow-up period was extended to January 1, 1988, and the current assumptions hold.

4 Discussion

4.2 Statistical Power of the Study (cont'd)

Table 4.2.A Numbers of Person-Years and Deaths from Selected Causes by Yard for the Nuclear Shipyard Workers Study

Shipyard	Number of		Number of Deaths Predicted Based on Population Size and Follow-up				
	Workers	Person-Years	Total	Leukemia	LHC	Mesothelioma	Lung
Charleston	6,716	80,986	666	0	5	2	75
Groton	13,550	202,025	1,428	8	24	3	110
Mare Island	13,557	168,564	1,355	9	28	10	116
Newport News	8,588	116,556	880	8	19	6	81
Norfolk	6,941	84,939	664	9	20	6	73
Pearl Harbor	5,767	81,634	491	5	14	3	42
Portsmouth	7,897	112,973	1,223	8	24	3	111
Puget Sound	7,882	74,761	394	7	13	3	33
All Yards[1]	70,898	922,438	7,101	54	147	36	641

[1] Of the 7,101 total deaths, 503 deaths were missing a cause of death. Using a simple expansion estimate, there would be an expected total of 58 leukemia, 158 LHC, 39 mesothelioma, and 690 lung cancer deaths.

4 Discussion
4.2 Statistical Power of the Study (cont'd)

Table 4.2.B Numbers of Person-Years and Deaths from Selected Causes Among the $NW_{\geq 0.5}$ Workers by Yard

	Number of		Number of Deaths				
Shipyard	$NW_{\geq 0.5}$	Person-Years	Total	Leukemia	LHC	Meso-thelioma	Lung
Charleston	2,597	32,248	179	0	0	1	31
Groton	4,801	67,834	439	3	7	2	40
Mare Island	4,771	57,580	375	3	8	4	31
Newport News	3,049	39,596	244	2	4	5	31
Norfolk	2,391	30,555	181	2	6	3	21
Pearl Harbor	2,830	40,728	206	3	6	2	16
Portsmouth	4,029	56,104	532	5	15	0	58
Puget Sound	3,470	32,093	125	3	4	1	9
All Yards[1]	27,938	356,438	2,281	21	50	18	237

[1] Of the 2,281 total deaths, 158 deaths were missing a cause of death. Using a simple expansion estimate, there would be an expected total of 23 leukemia, 54 LHC, 19 mesothelioma, and 255 lung cancer deaths.

Table 4.2.C **Summary of the Assumptions and Model Specifications Used to Determine Power**

1. Age at Entry Calculation:

   - Year of entry - Year of birth for workers born in the 20th century.
   - Year of entry - Year of birth + 100 for workers born in the 19th century.

2. Death Times:

   - Used actual death times for workers dying before January 1, 1982.
   - Generated using the conditional method of follow-up for the power of the study with an extended period of follow-up for workers alive as of the study end -- December 31, 1981. A worker was at risk of "random death" after the study end -- December 31, 1981.

3. Year of Entry Into Follow-up:

   - Year of entry into shipyard adjusted for minimum duration worked for NNW.
   - Year of entry into radiation program for $NW_{<0.5}$.
   - Year of entry into radiation program or year 0.5 rem lifetime dose accumulated for $NW_{\geq 0.5}$.
   - If any year of entry was before nuclear overhaul began in the shipyard, it was equated to the year overhaul began.

4. Length of Follow-Up Calculation:

   - Calculation from year of entry into follow-up to January 1, 1982 or actual death time.
   - For the 168 workers with fact of but no date of death, the length of follow-up was calculated from year of entry into follow-up to estimated death time.
   - Calculation from year of entry into follow-up to January 1, 1988 or to actual death time if death before 1982, or simulated death time for power of the study with an extended period of follow-up.

(cont'd)

Table 4.2.C **Summary of the Assumptions and Model Specifications Used to Determine Power** (cont'd)

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5. Organ Dose:

- A worker's recorded dose as measured by a dosimeter was multiplied by 0.79 to approximate the dose to the organs.

6. Dose Lag:

- A worker's dose by year of follow-up was lagged by two years for leukemia and LHC cancers.
- A worker's dose by year of follow-up was lagged by five years for lung cancer.
- Additionally, the deaths occurring within the appropriate lag period were ignored.

7. Risk sets:

- Risk sets were defined by age in 5-year intervals and year since entry into the radiation program in 1 year intervals.

8. Risk Projection Model:

- Used the additive linear risk model which states that risk during a particular time interval is

$$\lambda(z) = \lambda + \psi z$$

where z is the organ dose,

k is the spontaneous (background) risk of dying of a particular cancer in the interval, and

w is the excess risk associated with a particular dose in the interval.

9. Spontaneous Risk:

- The white male age-cause-specific death rates in 5-year intervals were used for k, the spontaneous risk of dying.

(cont'd)

Table 4.2.C Summary of the Assumptions and Model Specifications Used to Determine Power (cont'd)

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10. Excess Risk:

- Multiples of the BEIR III estimates for excess leukemia, LHC and lung cancer deaths were used for w, the excess risk per time interval.

- Age-specific estimates were not used since the age interval was narrow for most workers in the study over the average period of follow-up.

- The BEIR III risk estimates used for leukemia were as follows:

    - 2.2 deaths per million person-years per rem (based on a linear dose-response model).

    - 1 death per million person-years per rem (based on a linear-quadratic dose-response model).

- The BEIR III risk estimate used for lung cancer and LHC was 2 deaths per million person-years per rem (based on a linear dose-response model).

11. Power Probability Calculation:

- Power was determined using the normal approximation of the test statistic adjusted for non-normality of the test statistic by Cramer's method.

12. Type I Error:

- A one-sided test with type I error = 0.05 was used.

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4 Discussion

4.2 Statistical Power of the Study (cont'd)

Table 4.2.D Statistical Power of the Nuclear Shipyard Workers Study to Detect Various Assumed Radiation Effects on the Occurrence of Leukemia and Lung Cancer Based on Follow-up Through December 31, 1981[a]

	POWER			
Assumed Radiation Effects	Leukemia (Linear)	Leukemia (Linear Quadratic)	LHC Cancer (Linear)	Lung Cancer (Linear)
No Effect	0.05	0.05	0.05	0.05
*BEIR III[b]	0.16	0.09	0.10	0.07
2*BEIR III	0.32	0.15	0.18	0.09
5*BEIR III	0.78	0.37	0.50	0.19
10*BEIR III	0.99	0.73	0.90	0.42
15*BEIR III	1.00	0.92	0.99	0.66
20*BEIR III	1.00	0.98	1.00	0.84
30*BEIR III	1.00	1.00	1.00	0.98
40*BEIR III	1.00	1.00	1.00	1.00

[a] The lag periods used were: 2 years for leukemia and lymphatic cancer; 5 years for lung cancer.

[b] The BEIR III risk estimates used were: 2.2 leukemia deaths per million persons per rem per year using a linear extrapolation dose-response model; 1 leukemia death per million persons per rem per year using a linear-quadratic dose-response model; 2 lymphatic deaths per million persons per rem per year; 2 lung cancer deaths per million persons per rem per year.

4 Discussion
4.2 Statistical Power of the Study (cont'd)

Table 4.2.E Statistical Power of the Nuclear Shipyard Workers Study to Detect Various Assumed Radiation Effects on the Occurrence of Leukemia and Lung Cancer Based on Follow-up Through December 31, 1987[a]

	POWER			
Assumed Radiation Effects	Leukemia (Linear)	Leukemia (Linear Quadratic)	LHC Cancer (Linear)	Lung Cancer (Linear)
No Effect	0.05	0.05	0.05	0.05
*BEIR III[b]	0.20	0.10	0.12	0.08
2*BEIR III	0.42	0.18	0.23	0.11
5*BEIR III	0.92	0.49	0.66	0.26
10*BEIR III	1.00	0.88	0.98	0.60
15*BEIR III	1.00	1.00	1.00	0.87
20*BEIR III	1.00	1.00	1.00	0.97
30*BEIR III	1.00	1.00	1.00	1.00
40*BEIR III	1.00	1.00	1.00	1.00

[a] The lag periods used were: 2 years for leukemia and LHC cancer; 5 years for lung cancer.

[b] The BEIR III risk estimates used were: 2.2 leukemia deaths per million persons per rem per year using a linear extrapolation dose-response model; 1 leukemia death per million persons per rem per year using a linear-quadratic dose-response model; 2 lymphatic deaths per million persons per rem per year; 2 lung cancer deaths per million persons per rem per year.

5 Conclusion
5.1 Recommendations

The shipyard nuclear worker population represents a large number of individuals exposed to low documented DEs of radiation. They receive this radiation almost exclusively from gamma rays due to decay of cobalt-60. Within the population, there are comparable groups of workers exposed to negligible or no radiation at their shipyard jobs but who engage in similar work. Therefore this is an ideal population in which to examine the risks of ionizing radiation in which confounding variables could be controlled. Long-term followup of this cohort is important. The population does not show any risk which can clearly be associated with radiation exposure in the current analysis. At present, however, the follow-up is not long enough to adequately evaluate risks and, therefore, the continued assessment of mortality in this group is necessary. Also, additional information could be gained from further analysis of the currently available data. Therefore, the following recommendations are made:

1. Analyze further the current file using other analytic methods such as direct internal comparisons and other modeling of expected effects of radiation.
2. Adjust data regarding risks of lung cancer and mesothelioma from radiation for the confounding exposure, asbestos.
3. Add the data from individuals who should have been in the current file but had been omitted because, at the time of analysis, they had incomplete follow-up, missing death information, or uncertainty about radiation dose and then reanalyze the data according to methods selected in steps above as well as the original analysis methods. These individuals would increase the

$NW_{\geq 0.5}$ group by possibly 10 percent, and the added subjects would represent the earliest entries into the cohort.

4. Expand the population to include new and additional workers who would be at low doses and increase the dose level of current workers which should expand the $NW_{\geq 0.5}$ group. In this step, the sample of $NW_{<0.5}$ group should be expanded to represent more than a 10 percent sample because they appear to be the population most comparable to the $NW_{\geq 0.5}$ group in categorical analysis. The NNW sample must be increased to meet the new population size of the nuclear worker sample. Continued inclusion of a NNW sample is important because these subjects identify selection factors which are associated with worker inclusion in the radiation program. The NNW group also provides information on other potential health hazards from shipyard work which could represent confounding factors in analyzing the radiation-exposed workers.
5. Utilize the additional data collected on confounding variables to better assess the risks due to radiation. These would include evaluation of the impact of radiation measurement variations on the results, the assessment of other shipyard exposures and the estimated doses from these exposures, and the evaluation of the potential use of survey data to determine differences in workers' personal characteristics such as smoking histories and non-shipyard exposures.
6. Determine the potential risks due to other shipyard jobs such as

5 Conclusion

5.1 Recommendations (cont'd)

welders and electricians.

7. Examine several disease which appear to be somewhat high in shipyard workers such as asthma and cancers of esophagus, stomach, liver, prostate and kidney. While most of these do not show a significantly high SMR compared to the expected deaths for the general population, the ratios are high enough to warrant further review.
8. Continue follow-up of the expanded and updated sample described in 4 above. Many of these workers will be in the original sample and some will represent new workers who have joined the population or reached DE levels of the $NW_{\geq 0.5}$ group after 1979 and additional non-nuclear workers. This sample will represent an additional ten years of experience in the radiation program which will substantially increase the exposed population. In addition, it will represent follow-up of the population through at least 1987 or 1988 representing an additional six or seven years of mortality experience.
9. Plans should be developed for continuous follow-up of this valuable population into the future.

5 Conclusion

5.2 Further Studies

1. Reanalysis of current and updated database using several other methods including those which assume specific models of radiation effects.
2. Nested case-control studies of mesothelioma, lung cancer, and possibly other cancers to evaluate both interrelated and independent effects of radiation and other shipyard exposures.
3. Expansion of the shipyard sample to include the additional nuclear workers with their exposures to date and expanded samples of $NW_{<0.5}$ and NNW groups with follow-up of the total population at least through 1987.
4. Analysis of data to assess potential risks associated with other jobs among shipyard workers based on last job held.
5. Evaluation of possible shipyard exposures which may be associated with some of the other diseases which had SMRs above 1.00 using the nested case-control approach.
6. An assessment of the impact that measurement variability has on low dose exposures to radiation. This will include the assessment of quality of reported DEs of individuals.
7. Assessment of the accuracy of death certificate evaluation of mortality versus mortality experience based on confirmed causes of deaths from hospital records and cancer registry reviews.
8. Investigation into the use of the collected mortality data for this population.
9. Follow-up of a sample of the population of active and terminated workers and cases of lung cancers to determine the impact of smoking on the

5 Conclusion

5.1 Recommendations (cont'd)

risk of this disease.

10. Investigate other issues related to assessment of the risk of radiation such as:

    a. Potential interactive effects of exposure to radiation and other job exposures.

    b. Differences in results if analyzed taking duration of exposure into account (dose rate).

    c. Further evaluation of methods of lagging and other epidemiological and biostatistical issues related to longitudinal studies.

    d. Evaluation of effect of age at exposure on any possible radiation effects.

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Appendix 1. Staff of the Nuclear Shipyard Workers Study

The following is a list of the personnel at Johns Hopkins University School of Hygiene and Public Health who constitute the senior staff of the study and who have assumed responsibility for the conduct of the research.

Present Members:

Dr. Genevieve M. Matanoski,
Principal Investigator
Professor
Epidemiology

Dr. Helen Abbey
Professor
Biostatistics

Dr. Charles Billings
Associate Professor
Environmental Health Sciences

Dr. Adolfo Correa
Assistant Professor
Epidemiology

Ms. Nancy Fink
Research Associate
Epidemiology

Dr. Katherine Hunting
Post Doctoral Fellow
Epidemiology

Dr. Kung-Yee Liang
Assistant Professor
Biostatistics

Dr. Thomas Mitchell
Associate Professor
Environmental Health Sciences

Dr. Tippavan Nagachinta
Post Doctoral Fellow
Epidemiology

Mr. Bruce Sanders
Research Associate
Health Policy and Management

Ms. Alice Sternberg
Biostatistician
Epidemiology

Dr. Walter Stewart
Assistant Professor
Epidemiology

Dr. James Tonascia
Professor
Biostatistics

Ms. Katherine Yates
Biostatistician
Epidemiology

Past Members:

Genrose Copely, M.D.

Raymond Seltser, M.D., M.P.H.

Susan Tonascia, Sc.M.

Appendix 2. Technical Advisory Panel

The Technical Advisory Panel (TAP) was formed in 1980 as a standing committee of experts who would provide objective advice to the project staff on a continuing basis. The Panel is multidisciplinary. In selecting its members, it was important for each to have had personal research experience with some of the problems related to the Shipyard Study. Disciplines we believed to be important and which were included in the group are: radiation biology and radiation physics, medicine, genetics, industrial hygiene, epidemiology and biostatistics. Also, we believed that the panel should have some skepticism about the project so their reviews could be critical but constructive. We believe that this has improved their objectivity as a group and has enhanced their contribution to the research.

Panel meetings have stimulated new ideas for staff and have led to revised plans in a number of areas. The current membership of the panel has been maintained throughout the study's duration, building upon the accumulating knowledge of the group.

The charge given to the TAP was as follows:

1. Objectives

The objectives of the Technical Advisory Panel (TAP) are to provide an impartial scientifically objective review and opinion as to the course, conduct, and content of the study of health effects of low-level ionizing radiation in nuclear shipyard workers.

2. Representation, Authority, Responsibility

The TAP represents the external scientific community concerned with occupational environmental health effects. The composition of the panel has been carefully chosen to represent individuals with expertise in the fields of epidemiology, biostatistics, industrial hygiene, radiation biology and radiation physics. The panel should include scientists who have had experience in the area of evaluation of radiation effects or of basic methodology in longitudinal studies.

The TAP shall be requested to provide advice based on its review, analysis and recommendations, and has no legal responsibility with respect to such advice.

3. Functions

The TAP shall meet and interact with the technical/administrative members of the project in order to receive reports on plans, progress, and similar matters. The TAP shall review these plans and progress, prepare recommendations and advice, and prepare summary minutes of each meeting for inclusion in the annual report of the project.

It is the current intent of the project to have TAP meetings at least twice a year during the next three years of the study.

Appendix 2. Technical Advisory Panel (cont'd)

A list of members who have served on the TAP is as follows:

Dr. Arthur Upton, Chairman
Professor and Chairman
Department of Environmental Medicine
New York University Medical Center

Dr. Gilbert Beebe
Expert Scientist
National Cancer Institute
National Institute of Health

Dr. John Cameron
Professor of Radiology and Physics
Medical Physics Division
University of Wisconsin

Dr. Carter Deniston (Resigned November, 1983)
Professor of General and Medical Genetics
University of Wisconsin

Dr. Merrill Eisenbud
Professor
Environmental Medicine
New York University Medical Center

Dr. Philip Enterline
Professor and Chairman
Department of Biostatistics
University of Pittsburgh
Graduate School of Public Health

Dr. Philip Sartwell
Professor Emeritus
Department of Epidemiology
The Johns Hopkins University

Dr. Roy Shore
Associate Professor
Department of Environmental Medicine
New York University Medical Center

Appendix 3. Radiation Dosimetry Advisory Committee

The Radiation Dosimetry Advisory Committee (RDAC) was an external review group organized in January of 1985 to address issues relating to the methods and interpretation of the radiation dosimetry employed in the shipyards under study (see below for the RDAC charge). The membership of this committee was as follows:

Dr. Harold D. Wyckoff, Chair
ICRU
Bethesda, Maryland

Dr. Donald E. Barber
University of Minnesota
Minneapolis, Minnesota

Cdr. William McC. Beckner
National Council on Radiation Protection
Bethesda, Maryland

Dr. John Cameron
University of Wisconsin
Madison, Wisconsin

Dr. Margarete Ehrlich
National Bureau of Standards
Washington, DC

The RDAC committee met on April 3, 1986 in Washington D.C.

The Radiation Dosimetry Advisory Committee (RDAC) was charged with evaluating the validity (accuracy, precision and reliability) of radiation dose estimates for the shipyard radiation workers. They were to review information regarding methods by which specific cumulative doses are derived which may place limits on the dose estimates based on innate variability of the measurements. They were to determine whether dose estimates at each yard may be compared directly to those at other yards at all times. They were to determine the significance of internal dosimetry and dose from neutrons. The group considered the extent to which dosimetry data can be used as a quantitative measure of the cumulative dose summed from exposures of the order of 10 mR for film badge and 1 mR for TLD.

Specific Questions Addressed by RDAC

- Procedures

  1. What are the potential factors which could confound the recorded dose?
  2. What were the recommended procedures for badge and film placement?
  3. What was the sensitivity of each device? (Minimal detectable exposure?)
  4. Are there different rates of dose accumulation for periods in which film badge (pre 1974) versus TLD (post 1974) was used?
  5. Were there any accidents or incidents where a worker received a significant internal or external dose that was not properly recorded?

- Quality Control

  1. Describe the standardization procedures used to establish the H + D curves at the initiation of the Radiation Control Program. When and how have these procedures changed?
  2. What data exist concerning standardization of types of film used in badges? Were there changes in recorded dose from one type of film to another?
  3. What are/were the specific procedures for quality control of film badge/TLD readings?
  4. What were the methods used for standardizing photodensitometer operator's readings? Operator variability?
  5. Describe the threshold for incrementing the TLD reader scale.

- Advice from RDAC

  1. Provide recommendations on the reliability of dose data based on level, dose rate, collection period, and methods of measurement used during period of dose accumulation.
  2. Suggest further information which may be needed to establish the reliability of the dose data.

Appendix 3. Radiation Dosimetry Advisory Committee

3. Establish probable validity of dose based on calendar year and method of measurement.

The planned operating procedure for RDAC called for the collection of appropriate background data relevant to the questions to be addressed by RDAC. The data were collected by members of the Shipyard Study staff and assembled for use by the Committee. The sources of the data included information published in the open literature, procedural manuals of the Navy, and the specific records which provide information related to the issues. Additional data were gathered from individuals directly involved with the shipyard radiation program.

DOE/EV/04992

Study of Feasibility of Detecting Effects of Low-Dose Radiation in Shipyard Workers

Introduction

There is very little information available on the chronic health effects from repeated low-level doses of radiation. The current standards are based primarily on a few or single large doses of radiation or a risk of exposure based on persistence of internal-emitters of radiation. These standards have not been adequately evaluated in view of the present occupational situation in which the exposed worker receives annual doses of 5 rem or less throughout his working life. Therefore the majority of workers may be exposed to life-time doses well below 50 rem. Despite this, reports by Mancuso (Health Physics, 1977) and Najarian (Lancet, 1978) have suggested that these workers may have an increased risk of certain cancers. In view of these suggestions and the paucity of information about the cancer risk at low doses of radiation, it is imperative to examine the risks of populations under today's exposure levels.

The objectives of this study were to examine the adequacy of determining radiation exposure doses in shipyard workers, the procedures used in the radiation control programs, and the feasibility of establishing an appropriate population of nuclear and non-nuclear shipyard workers for long-term studies of low-level radiation.

The availability of records and the methods of population identification and of measurement of radiation dose were determined during initial visits to the yards. Personnel, industrial hygiene, radiation and medical records were examined for suitability, completeness and accuracy. It was necessary to assure that no possible errors or omissions in personnel and radiation records existed in order that the final data will have validity.

Preliminary investigations on the methods of follow-up in the Portsmouth population and the time required for each procedure were also undertaken in order to have a better estimate of the total cost for a long term study.

Assessment of the availability of information on shipyards

Radiation data

Until the advent of nuclear powered naval vessels, the principal radiation exposures to shipyard workers had been from (1) roentgen-ray and gamma-ray sources used in industrial radiography; (2) diagnostic (medical) roentgen rays in those cases where the shipyard dispensary was under the auspices of the shipyard radiation control program, rather than of the medical department; (3) radium, radon, and their daughter products found in association with luminous dials formerly used in clocks, compasses, other instruments and guides for illuminating passageways in darkened ships; and (4) gamma ray sources used in calibration of radiac equipment (RADIAC is an acronym for "radiation detection, identification and computation").

These four subgroups of workers are included in the total population of nuclear workers. Some of these groups, especially in the early years, have had assigned doses for brief periods where exposures were not adequately identified. The technique for estimation of both internal as well as external radiation exposure, the reliability of the film badge system used prior to the 1950's and the characteristics of the radiation worker's exposures were such that a high degree of reliability can not be placed on dose estimates for these groups. The accuracy and conservatism involved in the Navy procedures were probably much better than those used in other populations in the same time periods. In some cases workers were assigned the maximum dose allowable for that period. In other instances, doses were assigned to workers based on historical data related to similar exposures in occupations or therapeutics. All doses which have been assigned by these method do not have the same validity as measurements derived under the current program and, therefore, such doses will be evaluated separately from those measured under the current nuclear program guidelines. These guidelines have been in effect since the beginning of the Navy nuclear propulsion program.

The group of shipyard workers who are involved in the Navy's nuclear propulsion program are exposed almost exclusively to whole-body penetrating radiation from gamma rays with well documented exposures and constant surveillance of working conditions. There still exist a few subgroups, the radiographers and radiac workers, whose exposure is atypical of the nuclear radiation workers. These two groups (the radiographers and radiac workers) have exposures of a similar nature to the nuclear radiation workers since they are exposed to primarily high energy penetrating radiation. For purposes of the study, however, they could be included in the population but they should be evaluated separately by job.

A review of the procedures and records which identified exposures in the early days of the program suggested that the system for documentation of workers' exposures has always operated as efficiently as it does not. Dr. Mitchell, who has had experience with the Navy's system for calibration of dosimetric film estimated that the reliability of the film badge dosimetry system in use in the early period (1950's) should lead to an accuracy of ±15% in recorded doses. The films were read at monthly intervals. In those cases where a film badge was lost or rendered unreliable for measurement of radiation dose, the methods that have been used for assessing radiation exposure appear reasonable and neither overly conservative nor liberal. They have included estimates of dose from measurements of other individuals with similar work exposures and from pocket ionization chambers. Dr. Mitchell, after evaluating these methods, concluded that this type of estimated dose has sufficient accuracy to be added to the measured dose. (This method for estimation differs from the assigned doses described previously.)

Since 1974 the Navy has changed to a daily TLD (thermoluminescent dosimeter) system for measuring radiation dose which should be an even more reliable method of recording dose than film badge readings. Despite rigid standardization of all procedures these measurements are also subject to errors as shown by the Navy's quality control records. A TLD removed from service and tested may read as much as 15% below a standard administered radiation exposure of 75 millirem. In summary both methods have some variability in the measurements of radiation dose but we can add together the rem calculated from each method with the expectation that the results will not be too widely discrepant from the earlier to the later time periods. The only problem which was not resolved in the feasibility study was the differences which would arise from readings in early periods which cumulated the dose for a total month and the daily dose read by the TLD which theoretically could miss a very low dose when the levels on a daily basis were below the sensitivity level of the dosimeter. The Navy has accumulated data on the magnitude of this problem at the time of the conversion between the systems. We will review this information subsequently.

Cobalt-60 is the major source of exposure to ionizing radiation among shipyard workers. The exposure only occurs in overhaul of ships since the mechanism by which radioactive material is introduced into the general systems of the ship is through the corrosion of steel and the flaking off of small particles which are carried by the primary heat exchange water into the reactor proper and subsequently out into the external circuits of the compartment. The cobalt-60, present in very low quantities in the water, is a pure source of gamma rays with high energy penetrating radiation. The half-value layer for a narrow beam of Co-60 gamma rays is approximately four inches in water. Therefore, the externally measured dose of radiation is an accurate measure of internal dose to the marrow and other sites. The other principal gamma emitters found in these activated corrosion products have shorter half lives than the 5.3 year Co-60 (Co-58 T-1/2=71.3 days; Fe-59 T-1/2=45.6 days; Cr-51, T-1/2=17.8 days). These latter materials build up to an equilibrium level where their rate of decay equals their rate of formation. (Equilibrium is reached in about six months for Cr-51, in nine months for Fe-59, and in about a year for Co-58). Cobalt-60 activity would continue to grow and would never reach equilibrium during the estimated period of time between reactor overhauls since it would take about 30 years to reach that state. Consequently the relative contribution of the other radionuclides to the total radiation exposure compared to Co-60 decreases the longer the reactor is in operation. Therefore, the monitoring of primary water for Co-60 is a valid measure of the source of total radiation.

Questions have frequently been raised about the appropriateness of the usual methods of measurement to detect problems of accidental and internal exposures. Dr. Mitchell and the other members of our faculty team have carefully evaluated both "incident" reports and methods of measuring internal doses. In the cases of skin or hand contamination, the wounds are immediately cleansed to zero detectable radiation level. Therefore, these exposures probably do not add anything to the total body burden as measured by personal dosimeters.

There have been rare instances of radiation workers exposed to Co-60 via contamination of breathing zone air with a small amount of primary coolant water. Such events are monitored by counting radiation levels in exposed and potentially exposed workers with a 3 x 3 inch NaI crystal scintillator and multi-channel spectro-meter system. This system is designed to detect Co-60 deposited in the lungs with a minimal detectable activity in the range of four nanocuries. An old system in use in the early days of the nuclear propulsion program had a minimal detectable activity ~~in~~ the range of slightly less than ten nanocuries. Requirements today are such that a body burden of ten nanocuries requires notification of specified authorities. Dr. Mitchell has estimated the maximum lung dose which could have occurred in those instances in the past where an individual was exposed to the lowest detectable level of ten nanocuries. Using data from the Medical Internal Radiation Dose Committee of the Society of Nuclear Medicine, he has calculated an annual lung dose of 38 millirems, a level which represents a sufficiently low added burden so that individuals with ten nanocuries or less on bioassay would not need an adjustment of the dose as measured by TLD or film dosimetry. We will note those individuals who have had these additional exposures and if the detectable level is ten nanocuries or above, an assessment of the added dose can be made.

In summary all data or radiation exposures to shipyard workers in the Navy nuclear propulsion program have indicated that doses are accurately recorded, carefully monitored, and are a true reflection of the dose received by the marrow which makes this population ideal for studies of effects of low-dose radiation.

Industrial hygiene data

The measurements of possible toxic substances in the working environment of the shipyard have not been systematically sampled in all yards or even in a single yard over time so that no direct assessment of cumulated exposures to other agents by individuals in the population could be made as has been done for ionizing radiation. In most yards the measurements of other environmental substances have been sporadic and usually have arisen as responses to identified medical problems. In the yards surveyed to date, all but one have extremely limited numbers of industrial hygiene reports. Thus it will be impossible to determine on an individual basis exact exposures to such agents as asbestos, lead, nickel or benzene.

If one has no measurement of individual dose, one method by which to estimate possible exposure is by the use of job categories, cumulating total duration of exposure to the job and specifying the calendar years in which such exposure took place. This method assumes specific exposures related to job and varying exposures over time. There may be minimal information on specific exposure materials or doses to relate to the job classifications. However, this is one of the standard methods which one can use to correct for exposure to agents other than radiation.

Another mechanism for determining exposure to other substances would be to assume that data from one yard is generally applicable in all yards. This is a reasonable assumption since work done on Navy vessels would be done by methods and with materials which meet standard specifications applicable across all installations. By accumulating information from the industrial hygiene programs of each yard one can establish profiles of exposures by job. Estimations of doses of substances by job may also be possible. These data could be expanded further if the industrial hygiene records from non-nuclear shipyards are also included in the estimations. Dr. Billings suspects that the Navy industrial hygiene center in Cincinnati has measurements of substances in addition to those which are available from the yards themselves. This information will be extremely important if radiation dose differs by job because exposure to other substances may also differ by job under those circumstances and precise information on these other exposures may be needed to separate the effects of radiation and other exposures.

The final mechanism by which assessment of specific levels of exposure could be made is through the development of laboratory conditions which simulate those which existed in specific work categories at certain calendar times. This is a feasible procedure and is especially applicable in these yards since material use was rigidly controlled by Navy specifications. This method should be considered as an additional component to the study but would require substantial support as would the activities described above.

Medical records

The medical records in the Navy shipyards are retained on site for active workers but after severance all records are returned to a repository in St. Louis. The medical records of the private yard accumulated over the past 30 years have been kept intact on-site. (Note that subsequent to the initial feasibility study a second private yard had joined the group which had been screened for inclusion and this yard also had medical records on-site for the period before and during nuclear overhauls.) All medical records include routine screening procedures which have been required for nuclear workers regardless of their level of exposure as well as the usual physical examinations and other special tests which are related to other industrial exposures such as chest films for asbestos and blood tests for lead. They also contain complete information on radiation exposure which should be used to validate radiation records from other sources. This is the only official record of dose and should be examined for a sample of all nuclear workers. One could examine these records in relation to the mortality experience of employees. These morbidity records might provide useful information to relate to the mortality data. Such a review can not be done routinely on all installations' records initially since it is difficult to retrieve the records from the Navy yards but a sample of the records can be reviewed to determine the overall value of such data.

Personnel records

For all current workers, the yards have records which include social security number, birth date, address, name of next-of-kin, and all shipyard jobs and times held. These would provide excellent resources for both follow-up for morbidity and other personal variables or for determination of mortality in the future. The completeness of records for severed workers differ depending on the yard. All facilities have records dating from the time of nuclear overhaul. These records have the same type of data as above although the address and name of next-of-kin would represent those listed at the time of employment which is often many years previously. The completeness of records from early periods before overhaul and the ease with which a total population might be established varies by yard. In all cases there are some records which precede the period of overhaul so that baseline data can be established. In some instances the records go back to World War II. In the early periods, social security number was not used as an identifier. Since the Navy yards have always been on the Civil Service System, the usual method of follow-up through the Social Security System may not be adequate for these employees. The Civil Service System does not provide as complete a method for determining mortality since individuals may withdraw benefits at the time of severance.

All individuals who worked in the shipyard received security clearance. These records contain several names and addresses of individuals who might know the whereabouts of workers who have left the yard. These records would provide another resource for follow-up of mortality and morbidity. These records, however, have constraints on their use and, although they are being reviewed in several other studies of radiation effects, it is clear that special clearance would have to be provided to allow the use of such records for purposes other than those for which they were intended. Such clearance should be considered for the future but filming of such records in the initial phases of the study should not be attempted until reasonable justification for their use can be established.

Work characteristics

The shipyard population is ideal for a study of the effects of low-dose radiation because the source of exposure is solely cobalt-60, a material which emits only gamma rays with high penetrability. Thus, any measured exposure to radiation is a true measure of the total body dose. In most work situations, employees exposed to radiation may have a unique job which includes other risks common only to radiation work. Although it is recognized that there are many other hazards which are associated with overhaul and construction of ships, these risks are common to both nuclear and non-nuclear workers. There is no incentive pay for radiation work which might provide a selection bias so that the total population of shipyard workers both nuclear and non-nuclear should be similar in their work exposures other than radiation. Standardized records on all nuclear workers are available from all sites.

It should be recognized, however, that these radiation workers have very low exposures. Therefore, the majority of the workers have under 10 rem lifetime exposure. This means that if we wish to determine the risk of a rare event such as leukemia it will be necessary to collect information on as many individuals as possible from several shipyards in order to develop a stable risk estimate for each dose level.

Identification of deaths in shipyards through certificate review

Attention was called to a possible health hazard in the Portsmouth shipyard through the identification of occupation and industry as listed on death certificates. As part of the feasibility study, a similar examination of all death certificates for the states of Maine and New Hampshire was completed to identify deaths which listed employment in the Navy yard as the industry or in ship building occupations on the certificate. The causes of deaths were also searched for mesothelioma as underlying cause. The latter was not listed as a cause of death on any certificates but it is possible that the search was not complete since the teams were concentrating on identification of industry and occupation.

The study was designed to determine whether the information collected in the previous study could be duplicated. Secondly, this review could provide important information regarding the feasibility of using local certificates to identify shipyard personnel especially in small geographic areas. A total of 2,036 deaths out of 22,000 identified had occurred among shipyard workers who had worked from 1959 through 1978 during the period of nuclear overhaul. A proportional mortality analysis indicated excesses of several cancers among the radiation workers but, in general, the confidence limits for these ratios did not differ when compared to those for the non-radiation workers. It was apparent that over 90 percent of the deaths identified ~~must~~ have occurred in workers who had left employment prior to the time of nuclear overhaul. Therefore, this method of finding deaths among shipyard workers is not very efficient even in areas where the industry employs a high percentage of the workforce. Only about one-third of the deaths identified by the search of certificates were also included in the NIOSH list of deaths. Of those deaths for whom "shipyard" was listed for employment but which did not match the shipyard roster, the majority were much older than those who did match suggesting they had retired before the beginning employment date of the roster. Further consideration of these methods of identifying deaths should be completed if one wishes to use these means of finding deaths in the population.

Summary

These workers provide an ideal population for study of low-dose radiation effects because they are similar demographically, perform the same tasks and are exposed to the same occupational hazards as other shipyard employees except for their potential radiation risk. The workers have a virtually pure exposure to cobalt-60 which produces only gamma rays with high penetrability, so that we can expect that measurements of dosimetry, which have been recorded over the past 20 years will accurately reflect the internal dose received by individuals. An added advantage of this population for study is that all shipyards have implemented the same general rules for and standards of radiation control during the period of their operation so that results can be combined for a large number of workers at various work sites with very low exposures to the same radiation source. Since a high proportion of this population is still young and has had very low exposure it may be necessary to continue follow-up of the population for several years in order to obtain an accurate assessment of the shape of the dose-response curve for radiation of humans over the entire dose range from about 50 rem down to zero exposure.

Appendix 5. Training Activities

Students and fellows have provided an important resource to this project by conducting specific projects to address a variety of questions arising from the overall project. While responsibility for the conduct of the major parts of the project has always been the responsibility of faculty and senior staff who constitute the core of the study group, students have made valuable contributions to the project.

Student projects have included: the problems of analyzing data when cumulative dose, aging and calendar time are interrelated with cross-sectional analysis; studies of cancer effects from asbestos other than lung cancer; and an evaluation of health effects from shipyard exposures other than radiation.

Appendix 6. Dissertations and Theses

The following is a list of the dissertions and theses that have been completed during the Study.

1987

Correa-Villasenor, A: A Case-Control Study of Mesothelioma in the Shipyard Industry, Doctoral Dissertation, 1987

1983

Sternberg AL: The Mortality Experience of American Radiologists. Masters Thesis, April 1983

Stewart W: The Relationship Between Asbestos Exposure and Lung Cancer Cell Type. Doctoral Dissertation, November 1983

Yates KP: Assessing Health Effects of Ionizing Radiation. Masters Thesis, October 1983

Zibulewsky J: Inaccuracies in Death Certificate Occupational Entries Within a Single Industry and Possible Reasons for their Cause. Masters Essay, May 1983

A CASE-CONTROL STUDY OF MESOTHELIOMA IN SHIPYARD INDUSTRIES

Adolfo Correa

A nested case-control study was undertaken to investigate the relationship between occupational exposures to asbestos and low-level gamma radiation and mesothelioma. Cases were identified from death certificate reports canvassed on former employees of eight nuclear shipyards. All cases were diagnosed with mesothelioma between 1960-81. A stratified random sample of controls was selected from among former shipyard workers from the same eight yards as the cases. The sampling strata for selecting controls were defined by shipyard, age, and year of first employment. One hundred nineteen cases and four hundred fifty-two latency-matched controls were selected. Living status ascertainment at the time of diagnosis of the case was determined for four hundred thirty-three of the controls.

Surveys of shipyard industrial hygienists conducted to assess job-asbestos exposure profiles were used to construct a proxy indicator of relative intensity of asbestos exposure associated with each job. Job histories abstracted from the shipyard personnel records on all cases and controls were used in conjunction with the relative exposure intensity indicator to construct cumulative exposure measures for each asbestos intensity type. Radiation exposure data were obtained from dosimetry records kept on the cohort of shipyard workers.

Analyses were conducted using the conditional maximum likelihood estimate of the odds ratio and conditional logistic regression for matched sets. The results from the analyses revealed a relationship between asbestos exposure and mesothelioma; the strength of this relationship increased with the intensity and duration of the asbestos exposure. Exposure to low-level gamma radiation was also associated with an increased risk of mesothelioma. There was no interaction between asbestos and radia-

tion. Shipyard employment in non-asbestos jobs and male gender were also found to be associated with mesothelioma.

The results suggest that exposure to low-level gamma radiation increases the risk of mesothelioma independent of the effect of asbestos exposure. In addition, the results suggest that other exposures, besides asbestos and radiation, may be associated with mesothelioma. Potential misclassification errors related to the assignment of asbestos exposure types to job groups, and potential confounding effects from other occupational exposures limit the conclusiveness of these findings.

THE MORTALITY EXPERIENCE OF AMERICAN RADIOLOGISTS

by

Alice Louise Sternberg

THESIS

submitted to the School of Hygiene and Public Health
of The Johns Hopkins University in conformity
with the requirements for the degree of

Master of Science

Baltimore, Maryland

April, 1983

ABSTRACT

The mortality experience of American radiologists was investigated and compared to the mortality experiences of three other groups of physician specialists: internists, otolaryngologists and ophthalmologists. These specialties reflect a gradient in chronic occupational exposure to low levels of ionizing radiation. The data analyzed consisted of information on 29725 physician specialists. Study entry dates ranged from January 1, 1929 through December 31, 1969. Vital status was ascertained for each individual as of December 31, 1974.

The purpose of the study was twofold: to examine the mortality experience of the radiologists in contrast to the other specialists and to explore methods suitable for analysis of cohort data mortality data collected longitudinally. Such data require control of age effects and calendar time effects. Five methods were explored: direct adjustment for age, classical indirect adjustment for age, actuarial life table, Breslow-Day indirect adjustment and Cox proportional hazards model. While each method examines a particular aspect of mortality and is informative, the Breslow-Day methodology proved to be most flexible, comprehensive and suitable to analysis of cohort mortality data collected longitudinally.

Radiologists in the 1920-1929 and 1930-1939 cohorts of entry were found to have excess risk when mortality from all causes was examined and to have elevated cancer, non-cancer, cardiovascular-renal disease and leukemia death rates as compared to the ophthalmologists. Radiologists in the 1940-1949 cohort of entry were not found to be at excess risk from any of these causes except cancer. No excess (from all causes or any selected specific cause) was observed for the radiologists in the 1950-1959 cohort of entry. These conclusions are consistent with those found in previous investigations of this data set.

The Relationship Between Asbestos Exposure and Lung Cancer Cell Type

by

Walter Francis Stewart

A dissertation submitted to The Johns Hopkins University
in conformity with the requirements for the degree of
Doctor of Philosophy

Baltimore, Maryland

1983

ABSTRACT

A nested case-control study was undertaken to investigate the relationship between asbestos exposure and lung cancer cell type. Cases were former employees of two Virginia shipyards, and were identified from the Virginia Tumor Registry. All cases were diagnosed with lung cancer between 1975-82. A stratified random sample of controls was selected from among former shipyard workers from the same two yards as the cases. The controls were selected from among former employees who resided in Virginia or died in the State between 1975-82. The sampling strata for selecting controls were defined by age, year, and shipyard of first employment and race. Two hundred ninety-eight cases, approximately equal proportions of squamous cell, small cell, large cell, and adenocarcinomas, and four hundred twelve controls were traced for telephone interviews.

Job histories were abstracted from shipyard personnel records on all cases and controls and were the primary source of data used to derive measures of asbestos exposure. The questionnaire interview was used to obtain data on demographics, smoking history, shipyard employment history including reported asbestos exposure, asbestos exposure from work outside the shipyard, occupational exposure to known lung carcinogens, and history of selected diseases including lung cancer.

Analyses were conducted using the conditional maximum likelihood estimate of the odds ratio and logistic regression. The results from the analysis showed that adenocarcinoma had the

strongest association with asbestos exposure and the only case group to be associated with a multiplicative interaction effect between asbestos exposure and smoking. The most significant associations were found for adenocarcinoma cases employed before 1950. Strikingly negative dose-response relationships were found for the other three case groups. The results suggest indirectly that squamous and small cell cancer may have a shorter latency from exposure to diagnosis and that proportionately more of these cases were not captured in this study. Problems which are related to a calendar time criteria for case ascertaiment, i.e., diagnosis between 1975-82, limit the conclusiveness of these findings.

OCCUPATIONAL EXPOSURE TO IONIZING RADIATION:
CAN HEALTH EFFECTS BE ASSESSED DIRECTLY?

by

Katherine Parker Yates

THESIS

submitted to the School of Hygiene and Public Health
of The Johns Hopkins University in conformity
with the requirements for the degree of

Master of Science

Baltimore, Maryland

1983

ABSTRACT

Quantification of the magnitude of the risk following exposure to low doses of ionizing radiation is currently a matter of some controversy. Studies of occupationally exposed groups undertaken to validate the current official risk estimates encounter special design problems due to the nature of the radiation exposure received by the workers (i.e., low-level, fractionated) and the (presumably) small associated cancer risk. Opinions differ over whether direct risk assessment is feasible due to the large samples needed for convincing statistical studies.

Three methods for the analysis of occupational radiation exposure data are presented and evaluated, especially in terms of the statistical power to detect leukemia and lung cancer effects. The traditional Standardized Mortality Ratio (SMR) method which involves an external comparison group is compared to two methods suggested by E. S. Gilbert which make use of all of a worker's dose information and an internal comparison group. The first internal method (INT) is based on Cox's proportional hazards model. The second method (M-H) is an

extension of the Mantel-Haenszel type of analysis using grouped exposure data and the median dose as the group score. Four variations of the M-H type of analysis are compared: two different dose grouping schemes (specifically, 12 and 4 dose categories), and whether the organ dose conversion factor is applied before or after grouping the recorded doses.

Two numerical methods for adjustment for non-normality of the usual normal approximations for power are evaluated. The non-normality of the test statistics is induced by the highly skewed dose distribution. The two methods are Cramer's approximation which uses an Edgeworth series expansion for the distribution, and the Pearson system of frequency curves. In most, but not all, situations the adjustment made a substantial difference in the power results with the Pearson method the more reliable of the two.

Several alternative methods for examining the sample size/power problem are discussed. These are the use of confidence limits, the chance that the study will produce spuriously large relative risks, and the probability of the study excluding the official risk estimates.

The methods of power calculations presented by Gilbert are extended to be appropriate for use at the planning stage of a study. Gilbert's power formulas require the use of workers' death times which are initially unknown. A method to estimate a worker's length of follow-up by simulation of death times is proposed.

The potential of a current study of 40,774 workers in two private and six naval shipyards exposed to a lifetime dose of at least 0.5 rem by January 1, 1982 to detect a radiation effect is presented. The power results are discussed in relation to the literature review of major studies deriving risk estimates for low-dose ionizing radiation exposure.

The M-H method with recorded doses first grouped, then converted to organ doses is the preferable method for this data set. The method uses an internal comparison group, and simultaneously controls for age and time effects. Power is superior to the SMR method and comparable to the INT method. Grouping helps to alleviate the skewness problem and simplifies calculations. The use of Pearson curves is a more appropriate method than Cramer's approximation when the skewness and kurtosis of the test statistic are large, though power results are comparable when the test statistic is nearly normal.

The power calculations indicate that there is very little chance of the shipyard study detecting an effect at the level of the official risk estimates. However, if the true radiation risk of leukemia is 5 to 10 times higher than the official estimates as indicated by several studies, there is a very good chance of the study detecting the risk.

INACCURACIES IN DEATH CERTIFICATE OCCUPATIONAL ENTRIES WITHIN A SINGLE INDUSTRY, AND POSSIBLE REASONS FOR THEIR CAUSE

by: JOSEPH ZIBULEWSKY

for: COMPLETION OF THE MHS DEGREE IN EPIDEMIOLOGY

DR. GENEVIEVE MATANOSKI - THESIS ADVISOR
DR. CAROL NEWILL - ACADEMIC ADVISOR

INTRODUCTION AND PURPOSE

Epidemiologists rely heavily on death certificates as a source of information, both for observational studies and population-based mortality surveillance. Consequently, much study has been devoted to the cause of death entry on death certificates (1-10). This has resulted in a better understanding of the factors involved in the accuracy of this entry, as well as accuracy rates for specific causes of death.

The occupational epidemiologist, however, must also be concerned with the accuracy of the occupational listing on death certificates. Although diseases of occupational etiologies have been recognized for centuries, large scale epidemiologic studies of worker populations are a development of only the past few decades, paralleling an increased emphasis on worker safety. Consequently, the number of studies examining the accuracy of the occupational entry on death certificates are few. This is unfortunate, since this entry is sometimes a factor for inclusion of subjects of a particular occupation into a study.

An early study, published in 1956 by Buechley, et al. (11), interviewed lung cancer patients and controls in California to obtain detailed work histories. The subjects were then followed until death, and their death certificates obtained to determine accuracy. When "usual occupation", as defined by each work history, was used as the comparison criteria, agreement occurred in 52% of the certificates, overall. However, when last occupation was used, agreement rose to 70% (using a three-digit occupational title code). The accuracy for trades and professionals was between eighty and ninety percent, but for non-farm labor it was only 69%. One interesting finding of this study was that almost twice as many misclassifications on death certificates were in socioeconomically higher occupations than lower, thus demonstrating the so called "deification of occupation" effect. A more recent study by Wigle, et al. (12) examined the occupational information of 3039 Canadian men who died of cancer as the underlying cause. These men comprised part of a 450,000 person cohort, who completed an occupational survey questionnaire a number of years earlier. Only 79% of the certificates even had occupational entries. Overall concordance of death certificate and survey occupations for the 3039 workers was 44%. When the workers' individual occupations were grouped into 13 broad occupational divisions (e.g. farmers, managers, professionals), concordance was found in 86% of men who died at less than 65 years old and 60% of older men. Agreement of occupational division was greater for laborers (57%), than for craftsmen (47%), or professionals (33%), quite the opposite results of Buechley, et al. Concordance on individual occupation exceeded 75% for "well-defined, stable occupations", indicated in the paper as bus drivers, plumbers and sheet metal workers, but was lower in managers, auditors and farm workers.

The focus of both these studies tended to be very broad, using worker populations that include multiple industries. This presents a problem in terms of how to uniformly classify occupations which may be defined differently across industries. Death certificate misclassification errors may have been recorded merely due to semantic differences in occupational definitions, especially since the workers provided their own occupational histories. Secondly, the studies defined their worker populations according to a non-occupational factor, namely cancer patients or deaths. However, it is not known if cause of death influences occupational accuracy on the death certificate. Finally, and most importantly, the studies used work histories completed by the workers, themselves, with no verification using company records. They also obtained these histories a number of years prior to workers' deaths, and so the occupation on the history may not be the occupation a worker was involved in at the time of his retirement or death. In fact, Wigle et al. (12) noted that concordance fell from 68%, when histories were obtained within three years of death, to only 48% when obtained six or more years from death. The result of these study design problems is that it becomes impossible to know which death certificate misclassifications were artifactual, due to the design of the studies, and which were actual misclassifications.

The purpose of this study was to attempt to eliminate these problems by: 1) Using only workers of a single industry, specifically those of a navy shipyard, and 2) obtaining work histories directly from the industry's personnel records, which were complete up to the time of retirement or death for each worker included in the study. In addition to determining the overall accuracy of the occupational entry on death certificates, a number of factors which might have effected this accuracy were examined. Specific hypotheses tested were:

1. Would professionals have higher accuracy rates than trades/crafts or laborers, as was found in the study by Beuchley, et al. (11).

2. Does accuracy increase with increasing length of employment in an industry, or with increasing length of employment in the last position held in that industry?

3. Does accuracy go down as the worker's age at death increases, as Wigle et al. found, or synonomously, does a longer period of retirement before death reduce accuracy?

4. Is accuracy effected by the death certificate informant; specifically, do spouses give better information than other sources?

Finally, inaccurate records were examined to determine if the death certificate entry consisted of an occupation of higher socio-economic status than the worker's actual occupation; in other words, was there a "deification of occupation".

To test these hypotheses, data were used on employees of the Portsmouth Naval Shipyard (PNS) in New Hampshire. These data consist of personnel records as well as death certificates listing PNS as the deceased workers' industry. These data were originally collected for use in a large study of low-level radiation exposure in nuclear shipyard workers, being conducted by Dr. Genevieve Matanoski, and described further in the next section.

STUDY POPULATION AND METHODS

The Portsmouth Yard is one of the oldest shipyards in the United States, being established in the 1600's. It is also the Shipyard with the longest history of nuclear work, with the first nuclear submarine being commissioned there in 1958 (13). By 1977 sixty-three nuclear submarines had been constructed, overhauled or repaired at the facility. A case of leukemia occurring in a worker at PNS prompted a study, published in 1978 by Najarian and Colton (14), which demonstrated a significantly greater than expected mortality risk from leukemia for those workers involved in radiation-related jobs. However, death certificate ascertainment was incomplete, since only a cross-sectional search of certificates in three states was made. In addition, radiation exposures were obtained by next-of-kin interviews, with no verification from the Shipyard. In order to improve on these methodological problems, NIOSH carried out a study, published in 1981, which showed no increased risk of mortality for any cause in PNS workers exposed to low levels of radiation (13). To ascertain deaths, NIOSH first obtained a list from the Navy of all PNS workers employed at the Shipyard from January 1, 1952 to August 15, 1977. The starting date was chosen because complete personnel records existed only since then. Death certificates were collected longitudinally using this list, thus attaining better ascertainment than did Najarian and Colton. NIOSH also received a computer printout from PNS of individual annual radiation exposures, from which they were able to calculate each worker's total external radiation dose, thus providing a more accurate way to group workers on this factor.

Because of such contradictory information available on the chronic health effect of low level radiation in humans, the Shipyard Study was initiated by Dr. Matanoski in 1978. The overall aim of the Study is to determine the leukogenic, carcinogenic, and other possible health effects associated with repeated exposure to low-levels of radiation, and to evaluate current standards on radiation exposure. The study population consists of nearly 700,000 workers from eight United States nuclear shipyards, who have been involved in the overhaul of nuclear ships over the past 15 to 25 years. Data on the workers include personnel records, radiation exposures, preliminary data from a questionnaire concerning smoking and medical histories, and vital status. For the purposes of this study on death certificates, data were used only from the Portsmouth Navy Shipyard.

Although the Shipyard Study Protocol is lengthy and detailed, two aspects of it are most pertinent to this study on death certificates: The collection of personnel records and death certificates of PNS workers. Dr. Matanoski was able to obtain the personnel records of PNS employees, on microfilm, originally collected by the NIOSH study. In order to obtain death certificates of PNS workers, a cross-sectional examination was made of all death certificates from the states of Maine and New Hampshire. This was done to repeat the method of death certificate ascertainment used in the study by Najarian and Colton (14). Only certificates which listed industry as "PNS", "Navy Yard", or "Shipbuilding" were abstracted. As with Najarian and Colton, this cross-sectional search identified only about one-third of the deaths which were included in the NIOSH list of deaths. Dr. Matanoski is currently obtaining the remainder of the death certificates by a longitudinal search, as did NIOSH.

In the present analysis of the accuracy of death certificate occupational entries, the initial study population consisted of those workers (male and female), for whom there existed a personnel record on microfilm and an abstracted death certificate indicating PNS as the industry. This initial cohort consisted of 3556 workers. Subjects who left the Shipyard to seek other employment were excluded from further study, since they would not have had complete and verifiable work histories. These workers could have been considered as misclassified, since they left the Shipyard to seek other employment, but still had PNS as their death certificate industrial listing. However, for the purposes of this study, they were not included. Thus, only workers who died while still employed, or who retired from PNS were included for study. This left a final study population of 1964 deceased workers.

METHODS AND ANALYSIS

The following information was abstracted from the personnel records and death certificates of the 1964 workers, coded and placed onto computer tape for the analysis:

1. Social Security Number and Full Name: For identification purposes.

2. Date of Birth and Date of Death (from death certificates)

3. Last Major PNS Occupational Title Code: All occupational codes used in this study were the same as those originally developed for the Shipyard Study. The occupational title consists of a two-digit code that pertains to an actual occupation, such as electrician, machinist, carpenter, etc. To establish these codes, all job titles available from all personnel records were initially recorded and computerized. After purging the lists of duplicates and abbreviations, several decisions were made with the advice of personnel from the Norfolk and Charleston Shipyards, and Dr. Charles Billings, Associate Professor of Environmental Health Science, which allowed the total number of unique codes to be reduced to about 50. In general, these 50 codes consisted of an amalgamation of all titles which were associated with similar radiation exposures, and which represented the same jobs at different times during the period of time the yard was involved in nuclear work. The last PNS occupation title code refers to the last title code which the employee held prior to retirement (or death) from the yard. Last occupation was coded because a previous study (11) showed that death certificate entries are more apt to be last occupation, rather than usual occupation (as the instruction on the death certificate reads).

   It should be noted that different occupation titles often involve similar skills and responsibilities. For this reason a number of these related titles may be included under one occupation title code. For example, carpenter, joiner, patternmaker and shipwright all come under the code "22". If a person's work history at PNS consisted of these four positions, then he would have been coded as a "22" for his entire employment at the Shipyard.

4. Last PNS Occupation Prefix Code: Prefixes include

apprentice, helper, foreman, quarterman, etc. These are not unique occupations, but rather ranks within occupations, and may be used to approximate socio-economic status (for example foreman machinist or helper electrician). They may also be used to roughly rank workers according to radiation exposure, since those workers of a higher prefix usually are involved in less "hands-on" construction, and consequently less radiation exposure. The last prefix code refers to the last prefix the worker held while in his last major PNS occupation (not necessarily the highest prefix).

5. Death Certificate Usual Occupation Code: It was possible in almost every case to use the codes developed from the personnel records for the death certificate occupation entry (both prefix and title). Separate codes were developed for the following entries: "retired", "shipyard worker", "federal employee", and for those entries which were blank.

6. Starting and Ending Dates of PNS Employment: These dates were used to estimate the length of PNS employment. This was an estimate because many work histories showed excused leaves of absence for short periods of time (about one or two years or less). However, where a worker left the Shipyard for ten years or more, the starting date after his return from the absence was used (most often a long absence such as this occurred very early in a worker's PNS career, before the worker was established in any one occupation).

7. Starting and Ending Dates of Last PNS Occupation: These were used to estimate the length of employment in this position.

8. Death Certificate Informant Code: A two-digit code for each of the following categories was developed: spouse, other relative, non-relative, medical or other records, not listed, and unable to determine from information given.

Once the coded data were validated, the following analysis was carried out:

1. Frequency distributions were run to determine:
   a. The number and types of PNS occupational titles and prefixes used in the study, and the proportion of employees in each group (Tables 1 and 2).
   b. The number of workers without a death certificate occupational listing, or with a generalized listing, such as "shipyard worker".
   c. The proportion of workers whose occupations were

misclassified on their death certificates when compared to their personnel records. This was done for title only, prefix only, and for title and prefix combined.

d. The crude proportion of death certificate occupational accuracy for each of six factors: age of worker at death, length of total PNS employment, length of last position employment, time from retirement to death, death certificate informant, and occupational type. To obtain the last variable, all of the occupational titles were grouped into three classes: laborers, crafts/trades, and professionals (Table 1). For the purposes of this and all subsequent analysis, records with PNS occupational title codes indicating "administrative" or "general" work were excluded, since these groups contained workers from all three occupational types, and could not be separated on the basis of their codes. This left 1830 records for the remainder of the analysis.

2. In order to determine the adjusted effect of the above six independent variables, a logistic regression was run, using agreement of personnel record and death certificate occupational <u>title</u> as the outcome variable. Multiple linear regression was not used due to its assumption of normality for the outcome variable. Since a preliminary analysis of the data showed age at death to be significantly correlated to duration of retirement (Spearman $R=0.7374$; $p<0.001$), only age at death was used in the regression.

3. Finally, the list of workers misclassified by title was examined to see what pattern, if any, the death certificate misclassifications took (e.g. was there any "up-grading" of occupation). The same occupational groupings were used as in the logistic regression. As with the regression, those persons with PNS codes indicating "administrative" or "general" work were excluded. Occupational prefixes were not looked at in this part of the analysis because only about one-quarter of the workers (23.3%) had prefixes on their PNS personnel records, and of these less than one-quarter appeared on their death certificates (15.9%).

RESULTS

Tallies of the proportion of workers in each PNS occupational title and prefix encountered in this study are in Tables 1 and 2, respectively. The four largest title groups were machinists, pipefitters, shipfitters, and electricians. Over three-quarters of the workers had no prefixes on their personnel records. The death certificate informant was predominantly the spouse (Table 3). The average age of the workers at death was 64.7, with a range of 20-93 years and a mode of 67 years. The average length of total PNS employment was 23.4 years, with a range of less than one year to 53 years, and a mode of 24 years. The average length of last position employment was similar, being 18.6 years, with a range of less than one year to 53 years, and a mode of 23 years. Finally, the average time from retirement to death was 5.9 years, with the largest group of workers dying while still employed, or within six months of retirement (29.5%).

The crude, overall proportion of agreement between personnel record and death certificate occupational titles was 75.8%. For occupational prefixes it was 83.6%. For those workers agreeing on both prefix <u>and</u> title it was 65.4%. Workers bearing no occupational entry on the death certificate comprised 7.2% of the study group, while 6.9% had an entry of "shipyard or naval yard worker", and 2.1% were listed as "retired". The crude proportions of agreement for the six independent variables studied appear in Table 4. In brief, there was no relationship between length of total PNS employment, length of retirement, or age of worker, and accuracy. However, professionals had higher accuracy than either trades/crafts or laborers ($p < .001$), and length of last position employment was positively related to accuracy ($p < .001$). In addition, higher accuracy was achieved when the death certificate informant was the spouse, than for other sources ($p < .01$).

The results of the initial logistic regression model were seemingly contradictory (Table 5). They showed no significant association between agreement on death certificate occupation and age of worker at death, occupational type, or death certificate informant. Length of last position employment showed a significant positive association on adjustment, but length of total PNS employment showed a significant negative trend. This result was initially considered to be due to the high degree of correlation between the two significant factors, and a simple regression run between the two showed a significant positive relationship (Spearman R=0.6792; p<0.001). Because of this extreme correlation, two new logistic regressions were run, each with one of the two factors removed. The regression run with length of last position employment left in still showed it to have a significant positive relationship to death certificate agreement (Table 6). However, the regression using only length of total PNS employment still revealed a negative relationship, although this time not a significant one (Table 7). Again, no other factors tested in either model were significant. Despite the obvious positive significance of length of last position employment on agreement, there was some concern as to why total PNS employment was still negatively related to agreement, especially since the two factors were so closely related. One theory that proved correct was that as total PNS employment went up, the proportion of the employment that was due to the worker's last position went down. Since last position employment was significantly related to agreement, then as total PNS employment went up, agreement would go down. A simple regression run between proportion of total PNS employment due to last position, and total PNS employment showed the two to have a significant negative correlation (Spearman R= -0.2522; p<0.001).

It should be emphasized that, although they were not statistically significant in any of the regression models, the adjusted rates for death certificate informant and occupational type demonstrated the same positive relationship to accuracy as did their crude rates.

The examination of misclassified occupational titles to determine if any pattern existed in the misclassifications was largely negative in its findings (Table 8). There were 431 misclassifications out of the 1830 workers studied in this part of the analysis. In a cross-tabulation of the three occupational types (laborers, trades, professionals), 25 misclassifications were of a higher category, and 24 of a lower one. The remainder showed no change, or had listings such as "shipyard worker", "retired", or no listing at all.

DISCUSSION

The results of this study, in terms of overall agreement between last occupation and death certificate occupational entry, are similar to those of Buechley et al. (11). This similarity is interesting in light of the design problems of Buechley's study that were noted in the Introduction. However, it also indicates that occupational entry accuracy has not improved markedly over the past 25 years. The low agreement found by Wigle et al. (12) could be due to the fact that Canadian death certificates were studied. In terms of the six variables hypothesized to effect accuracy, crude rates indicated that professionals, spouse informants, and longer lengths of last position employment were positively related to accuracy. However, only the length of last position employment remained significant after adjustment by logistic regression. The negative findings concerning any possible "up-grading" of occupation are not surprising, since only three occupational types were used. Buechly et al. (11), who did find such an "up-grading", used ten occupational types, which was possible since his study population was not restricted to any one industry.

One factor that was not examined, which might have had an effect on accuracy was the total number of positions held by a worker while at PNS. The longer a person worked at his last position (significant for accuracy), then the fewer total positions he may have held. This factor may be more important in similar studies involving less stable worker populations, or in ones involving multiple industries, where a worker may be more likely to skip from industry to industry, possibly changing occupations along the way.

One finding of interest from this study was that about three-quarters of those workers with PNS prefix codes had none listed on their death certificates. In addition, crude, overall accuracy fell from about 75% to 65% when prefix and title were used in the comparison. This presents a problem for studies attempting to use such prefixes as estimates of radiation exposure or socio-economic status, as in the Shipyard Study. It also does not indicate a high degree of sophistication in death certificate listings, a fact that would tend to diminish the effectiveness of routinely coding and storing occupational information from death certificates in order to set up a nationwide data base, as has been suggested (15). One survey of state practices regarding the coding and storage of such information found that eleven states routinely code occupation, seven routinely code industry, and six have coded occupation and/or industry on a limited basis (16). In light of the findings of this, and previous studies, the cost of the coding and storing the occupational entries on death certificates may be far greater than the benefit to epidemiologists, who would use information which is about 25% incorrect, and which is not as specific as it could be.

TABLE 1: OCCUPATIONAL TITLES ENCOUNTERED FROM THE PERSONNEL RECORDS OF PORTSMOUTH NAVAL SHIPYARD EMPLOYEES (N=1964)

Occupational Type and Title	Proportion of Workers with Designated Title
LABORERS	
Industrial cleaner/Component cleaner	0.4%
Laborer	4.1
Stockman/Warehouseman	2.7
Truck Driver/Mobile equipment operator	1.4
	8.6%
TRADES/CRAFTS	
Aircraft worker/attendant	0.1%
Air conditioner/refrigerator mechanic	0.3
Automotive/Heavy mobile equipment mechanic	0.4
Blacksmith/Forger	0.7
Boilermaker	0.2
Carpenter/Joiner/Shipwright/Boatbuilder	5.6
Crane operator/Bridge crane operator	1.0
Electrician/Wireman	7.3
Electronics/Radio mechanic	1.0
Electroplater/Buffer-polisher/Scaler-buffer	0.4
Engineman	0.8
Facilities/Public works	1.6
Firefighter	0.4
Furnaceman/Foundry molder/Foundry melter	0.6
Gas plant operator/Gas maker	0.2
Guard/Police	0.7
Instrument mechanic/Gyrocompass mechanic	0.2
Loftsman	0.3
Machinist/Toolmaker/Cutter and grinder	22.5
Mechanic	0.6
Oiler	0.3
Painter	1.8
Physical Science Technician	0.1
Pipe coverer and insulator	0.4
Pipefitter/Coppersmith	10.2
Plumber	0.3
Rigger	3.3
Ropemaker	0.1
Sandblaster	0.5
Sawsmith	0.1
Sheetmetal mechanic/worker	2.9
Shipfitter/Driller/Caulker-chipper/Riveter	10.3
Sailmaker	0.1
Welder	5.4
	87.2%

TABLE 1 (cont'd)

Occupational Type and Title	Proportion of Workers with Designated Title
PROFESSIONALS	
Chemist/Technologist	0.2%
Engineers (general, marine, nuclear, other)	3.8
Industrial hygienist/Industrial safety officer	0.1
Medical officer (optomotrist)	0.1
	4.2%

TABLE 2: OCCUPATIONAL PREFIXES ENCOUNTERED FROM THE PERSONNEL RECORDS OF PORTSMOUTH NAVAL SHIPYARD EMPLOYEES (N=1964)

Prefix	Proportion of workers with designated Prefix
No personnel record prefix	76.2%
Apprentice	0.3
Helper/Trainee/Aide/Learner	4.9
Worker/Limited/Repairer/Installer/Handyman	0.1
Junior/Assistant/Under	0.1
Instructor/Training leader/Training instructor	0.2
Leader/Snapper/Head	0.1
Foreman/Leadingman/Supervisor/Asso. Supervisor	3.5
General Foreman/Quarterman/Chief Quarterman	2.4
Inspector shipboard	1.4
Inspector other	1.0
Planner & estimator	2.1
Production shop planner	0.8
Ship progressman	0.4
Ship scheduler	0.1
Ship systems	0.2
Shop analyst & scheduler	0.5
Shop planner	0.9
	100.0%

TABLE 3: DEATH CERTIFICATE INFORMANT AS LISTED ON THE DEATH CERTIFICATES OF PORTSMOUTH NAVAL SHIPYARD EMPLOYEES (N=1964)

Informant	Proportion of Death Certificates Listing Designated Informant
SPOUSE	64.7%
OTHER RELATIVE	17.4%
COULD NOT BE DETERMINED	7.9%
MEDICAL RECORDS	6.9%
NON-RELATIVE	2.5%
NOT LISTED	0.6%
	100.0%

TABLE 4: CRUDE RATES OF AGREEMENT BETWEEN PNS AND DEATH CERTIFICATE TITLE BY SIX VARIABLES
(Total N for each variable = 1830)

VARIABLE	CLASS		CRUDE RATE OF AGREEMENT (%)	TEST FOR SIGNIFICANT TREND IN CRUDE RATE
Age (in years)	1. 20-50	(n=192)	74.5	S=0.014
	2. 51-60	(n=375)	75.5	(p > .40)
	3. 61-70	(n=651)	78.5	
	4. 71-80	(n=512)	76.2	
	5. 81+	(n=100)	72.0	
Length of Total PNS Employment (in years)	1. less than 1 to 5	(n=90)	77.8	S=0.065 (p > .40)
	2. 6-15	(n=303)	75.6	
	3. 16-25	(n=753)	75.8	
	4. 26+	(n=684)	77.3	
Length of Last PNS Position Employment (in years)	1. less than 1 to 5	(n=170)	62.9	S=6.416 *
	2. 6-15	(n=584)	69.6	(p < .001)
	3. 16-25	(n=653)	80.8	
	4. 26+	(n=423)	83.2	
Time from Retirement to Death (in years)	1. Death while employed or within 6 months of retirement	(n=535)	77.1	S=0.756
	2. 6 mo.-5 yrs.	(n=449)	76.7	(p > .20)
	3. 6-10 yrs.	(n=428)	77.3	
	4. 11+ yrs.	(n=418)	74.4	
PNS Occupational Type	1. Laborers	(n=169)	60.9	S=5.014 *
	2. Trades/Crafts	(n=1581)	77.7	(p < .001)
	3. Professionals	(n=80)	85.0	
Death Certificate Informant	1. Spouse	(n=1192)	78.4	S=-2.44 *
	2. All Others	(n=638)	72.7	(p < .01)

Based on a test for linear trends in proportions from Armitage (17).

* Significant trend

TABLE 5: RESULTS OF INITIAL LOGISTIC REGRESSION ADJUSTING RATES OF AGREEMENT FOR FIVE INDEPENDENT VARIABLES (Total N = 1830)

VARIABLE	CLASS	CRUDE RATE OF AGREEMENT (%)	ADJUSTED RATE OF AGREEMENT (%)	F-RATIO FOR EACH VARIABLE
Age (in years)	1. 20-50 (n=192)	74.5	74.5	.683338
	2. 51-60 (n=375)	75.5	75.3	(p > .75)
	3. 61-70 (n=651)	78.5	78.6	
	4. 71-80 (n=512)	76.2	76.0	
	5. 81+ (n=100)	72.0	72.9	
Length of Total PNS Employment (in years)	1. less than 1 to 5 (n=90)	77.8	93.5	11.1775 *
	2. 6-15 (n=303)	75.6	85.9	(.025 < p < .05)
	3. 16-25 (n=753)	75.8	74.9	
	4. 26+ (n=684)	77.3	71.7	
Length of Last PNS Position Employment (in years)	1. less than 1 to 5 (n=170)	62.9	48.6	23.1021 *
	2. 6-15 (n=584)	69.6	67.7	(.01 < p < .025)
	3. 16-25 (n=653)	80.8	83.6	
	4. 26+ (n=423)	83.2	86.7	
PNS Occupational Type	1. Laborers (n=169)	60.9	67.9	5.26014
	2. Trades/Crafts (n=1581)	77.7	76.9	(.1 < p < .25)
	3. Professionals (n=80)	85.0	86.1	
Death Certificate Informant	1. Spouse (n=1192)	78.4	77.8	3.13690
	2. All Others (n=638)#	72.7	73.9	(.25 < p < .5)

* Significant at .05 Level

\# Includes other relative, non-relative, medical records, not listed and unable to determine

TABLE 6: RESULTS OF LOGISTIC REGRESSION WITH LENGTH OF LAST POSITION EMPLOYMENT LEFT IN MODEL (Total N = 1830)

VARIABLE	CLASS	CRUDE RATE OF AGREEMENT (%)	ADJUSTED RATE OF AGREEMENT (%)	F-RATIO FOR EACH VARIABLE
Age (in years)	1. 20-50 (n=192)	74.5	78.5	.671903
	2. 51-60 (n=375)	75.5	75.6	(p > .75)
	3. 61-70 (n=651)	78.5	77.9	
	4. 71-80 (n=512)	76.2	75.3	
	5. 81+ (n=100)	72.0	72.0	
Length of Last PNS Position Employment (in years)	1. less than 1 to 5 (n=170)	62.9	63.9	11.4889 *
	2. 6-15 (n=584)	69.6	70.3	(.025 < p < .05)
	3. 16-25 (n=653)	80.8	80.5	
	4. 26+ (n=423)	83.2	82.4	
PNS Occupational Type	1. Laborers (n=169)	60.9	66.3	6.1564
	2. Trades/Crafts (n=1581)	77.7	77.1	(.1 < p < .25)
	3. Professionals (n=80)	85.0	84.7	
Death Certificate Informant	1. Spouse (n=1192)	78.4	77.6	2.3061
	2. All Others (n=638)#	72.7	74.3	(.25 < p < .50)

* Significant at .05 Level

\# Includes other relative, non-relative, medical records, not listed and unable to determine

TABLE 7: RESULTS OF LOGISTIC REGRESSION WITH LENGTH OF TOTAL PNS EMPLOYMENT LEFT IN MODEL (Total N = 1830)

VARIABLE	CLASS	CRUDE RATE OF AGREEMENT (%)	ADJUSTED RATE OF AGREEMENT (%)	F-RATIO FOR EACH VARIABLE
Age (in years)	1. 20-50 (n=192)	74.5	73.9	.809385
	2. 51-60 (n=375)	75.5	74.9	($.5 < p < .75$)
	3. 61-70 (n=651)	78.5	78.6	
	4. 71-80 (n=512)	76.2	76.6	
	5. 81+ (n=100)	72.0	73.1	
Length of Total PNS Employment (in years)	1. less than 1 to 5 (n=90)	77.8	79.8	.227136
	2. 6-15 (n=303)	75.6	77.1	($.5 < p < .75$)
	3. 16-25 (n=753)	75.8	76.1	
	4. 26+ (n=684)	77.3	76.0	
PNS Occupational Type	1. Laborers (n=169)	60.9	61.6	11.6560
	2. Trades/Crafts (n=1581)	77.7	77.6	($.05 < p < .10$)
	3. Professionals (n=80)	85.0	85.0	
Death Certificate Informant	1. Spouse (n=1192)	78.4	78.0	4.52017
	2. All Others (n=638)#	72.7	73.5	($.25 < p < .50$)

Includes other relative, non-relative, medical records, not listed and unable to determine

TABLE 3: MISCLASSIFICATION BY OCCUPATIONAL TYPE FOR DETECTION OF "UP-GRADING" OF OCCUPATION

MISCLASSIFIED ON DEATH CERTIFICATE AS:	PNS OCCUPATIONAL TYPE			
	Laborer	Trade	Profess	Totals
Laborer:	5	19	0	24
Trade:	19	66	5	90
Professional:	0	6	2	8
Administrative:	6	4	0	10
"Retired", or "Shipyard worker":	25	144	3	172
Title not listed:	11	114	2	127
Totals:	66	353	12	431

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Appendix 7. Presentations and Publications

The following is a list of the presentations and publications that have been completed during the Study.

1988

Block G, Matanoski GM, Seltser R, Mitchell T: Cancer Morbidity and Mortality in Phosphate Workers. Accepted for publication, JNCI, 1988

Harvey EB, Boice JD, Matanoski G, Fraumini JF Jr: Incidence of Childhood Cancer in Twins. Submitted for publication, American J Epidemiology, 1988

Matanoski, GM: Issues in the Measurement of Exposure. In: Epidemiology and Health Risk Assessment (Gordis L. ed.) Section III: Refining Epidemologic Approaches to Assessment of Exposure. Measures in the Total Environment. Oxford University Press, pp. 107-119, 1988

Matanoski GM: Screening and monitoring for susceptibility and health. Submitted for publication as part of monograph to be published by Oxford University Press

Stewart W, Hunting K: Mortality Odds Ratio, Proportionate Mortality Ratio and Healthy Worker Effect. American J Ind Med. 14:345-353, 1988

1987

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Stewart W, Tonascia JA, Matanoski GM: The Validity of Work Histories Reported from Live Respondents. J Occupational Med., October, 1987

Appendix 7. Presentations and Publications (cont'd)

1986

Matanoski GM: Health Statistics Among Women at Nuclear Facilities. Presentation at the Center for the Advancement of Radiation Education and Research (CARER). Symposium on Radiation and Women, Baltimore, Maryland, 1986

Matanoski GM: Health Statistics Among Women at Nuclear Facilities. National Council on Radiation Protection and Measurements, National Academy of Sciences, Washington, D.C., April 1986

1985

Fink N, Stewart W, Matanoski GM, Billings C: Development of an Exposure Index in an Epidemiologic Study of Shipyard Workers. Paper presented at the American Industrial Hygiene Conference, Las Vegas, Nevada, May 1985

Matanoski GM: Is There a Protective Effect from Radiation in Radiologists? Paper presented at the Conference on Radiation Hormesis, Oakland, CA, August 1985

Matanoki GM: Latency, an Issue in Assessing Occupational Risks. Paper presented at the Fourth International Symposium, Epidemiology in Occupational Health, Como, Italy, September 1985

Matanoski GM: Issues in the Measurement of Exposure. Conference on Epidemiology and Health Risk Assessment, May 1985

1984

Fink N, Stewart W, Tonascia J, Matanoski GM: Assessment of Questionnaires Used for Deriving Estimates of Occupational Exposures. Paper presented at the annual meeting of the Society for Epidemiologic Research, Houston, Texas, June 1984

Matanoski GM: How to Tell a Random Distribution from an Epidemic. Presented at Toxics and the News: An Environmental Issues Conference for Journalists, Princeton, N.J., May 18-20, 1984

Matanoski GM, Sartwell P, Elliott E, Tonascia J, Sternberg A: Cancer Risks in Radiologists and Radiation Workers. In: Boice JD Jr, Fraumeni JF Jr (eds), Radiation Carcinogenesis: Epidemiology and Biological Significance -Progress in Cancer Research and Therapy, Volume 26, New York, New York, Raven Press, pp. 83-96, 1984

Stewart W, Matanoski GM: The Relationship Between Asbestos Exposure and Lung Cancer Cell Type. Paper presented at the annual meeting of the Society for Epidemiologic Research, Houston, Texas, June 1984

Appendix 7. Presentations and Publications (cont'd)

1983

Block G, Matanoski GM, Seltser RS: A Method for Estimating Year of Birth Using Social Security Numbers. Am J Epidemiol 118-377-95, 1983

Fink N, Tonascia J, Matanoski GM, Sternberg A, Stewart W: The Impact of SSA Policies on Occupational Studies. Paper presented at the annual meeting of the Society of Epidemiology Resarch, Winnipeg, Canada, June 1983

Matanoski, GM: Role of Tumor Registrars in Epidemiology. Presented at Epidemiology for Tumor Registrars, Tumor Registry Training Program, Yale University, New Haven, Connecticut, June 1983

Stewart W, Matanoski GM, Tonascia J, Fink N: The Effect of Using Living and Dead Controls on Measures of Risk in Case-Control Studies. Paper presented at the annual meeting of the Society for Epidemiologic Research, Winnipeg, Canada, June 1983

1982

Matanoski GM: Occupational Exposures to Radiation in Populations of Radiologists, Atomic Energy Workers & Nuclear Shipyard Workers. Paper presented at the NCI Conference on Radiation Carcinogenesis and published in the meeting's proceedings, May 1982

Sandler DP, Comstock GW, Matanoski GM: Neoplasm Following Childhood Radium Irradiation of the Nasopharynx. JNCI, 68:3, January 1982

1981

Matanoski GM: Risk of Cancer Associated with Occupational Exposure in Radiologists and Other Radiation Workers. Proceedings of the 1980 Internation Symposium on Cancer, September 14-18, 1980. Cancer - Achievements, Challenges and Prospects for the 1980, Volume 1:241-254, Grune and Stratton, 1981

Appendix 8. Glossary of Terms and Abbreviations

AEC - Atomic Energy Commission

census file - NSWS computer file corresponding to microfilmed personnel records; one record per personnel record

CSA - Civil Service Active

CSR - Civil Service Retired

CAMLIS - California Automated Mortality Linkage Information System

DE - Dose equivalent

DOE - Department of Energy

DD1141 - exposure data recording form used by the U.S. Navy

HCFA - Health Care Financing Administration

ICD-9 - Ninth Revision of International Classification of Disease

ID - identifier

ISD - Information Systems Division of the Johns Hopkins Hospital

JHMI - Johns Hopkins Medical Institutions

JHU - Johns Hopkins University

JT - job title

MDI - Master Death Index

MLI - Master Living Index

NBS - National Bureau of Standards

NCHS - National Center for Health Statistics

NDI - National Death Index

NIOSH - National Institute of Occupational Safety and Health

NNW - non-nuclear worker study sample

NSWS - Nuclear Shipyard Workers Study

Nuc DB - nuclear workers database

Appendix 8. Glossary of Terms and Abbreviations (cont'd)

$NW_{\geq 0.5}$ - study sample of nuclear workers with cumulative lifetime exposure ≥0.5 rem as of 12/31/81

$NW_{<0.5}$ - study sample of nuclear workers with cumulative lifetime exposure <0.5 rem as of 12/31/87

OEER - Office of Enumeration and Earnings Records

OPM - Office of Personnel Management

ORAU - Oak Ridge Associated Universities

OT - occupational title

OTC - Occupational Title Catalog

Per DB - personnel database; comprised of employment records from all eight yards under study yard-reel-seq. no.

Power - the probability of rejecting the null hypothesis when it is false

QF - quality factor

rad - a unit of absorbed dose of ionizing radiation equal to an energy of 100 ergs per gram of irradiated material

RDAC - Radiation Dosimetry Advisory Committee

rem -the dosage of an ionizing aradiation that will cause the same biological effect as one roentigen of X-ray or gamma-ray dosage

SAS - Stastical Analysis System

SEER - Surveillance, Epidemiology and End Results (tumor registry)

SER - summary earnings record

SMR - standardized mortality ratio

SSA - Social Security Administration

TLD - thermoluminescent dosimeter

TMS - Tape Management System

VA - Veterans Administration

VRO - vital records office

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Appendix 9. Literature Cited (cont'd)

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Appendix 10. Medical Record Abstract Form

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Occupational and Environmental Epidemiology Program
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☎ 301-955-8183
☎ 301-955-3483

MEDICAL RECORD ABSTRACT

PURPOSE

The purpose of this medical record abstract is to obtain information from a medical file of the patient listed on the next page in order to:

1. Validate the diagnosis of specific malignant tumors or other neoplasms as reported on the death certificate, and
2. Describe the histological characteristics of such tumors or neoplasms on the basis of the available medical file information.

ORGANIZATION

The abstract form is divided into three major sections, according to the type of information to be abstracted:

I. General Information (Page 1)

II. Diagnostic Information (Pages 2, 3 & 4)

III. Tumor Information (Pages 5, 6 & 7)

INSTRUCTIONS

1. Please complete each item.
2. If requested information is not available in the medical file please check or write "no data" or "not available" for that item.
3. Please print legibly or type responses to the requested information in order to minimize difficulties in interpretation.
4. Once the form is completed, please return to The Johns Hopkins University in the enclosed self-addressed postage paid envelope.

Appendix 10. Medical Record Abstract Form (cont'd)

Study No. ____________________

I. GENERAL INFORMATION

Patient

a. Name: ______________________________
(Last, First, Middle)

b. Date of Birth (month/day/year): __ __ - __ __ - __ __

d. Social Security No.: ___ - __ - ____

c. Date of Death (month/day/year): __ __ - __ __ - __ __

e. Sex: ☐ Male ☐ Female

Hospital or Tumor Registry

a. Name: ______________________________

b. Address: ______________________________

c. City: ______________ d. State: __________ e. Zip Code: __________

f. ☎: (____) _____ - _______

Person Completing this Abstract

a. Name: ______________________________
(Last, First, Middle)

b. Job Title: ____________________ c. Work ☎ ____________________

4. File Number

Patient's Medical File Number: _ _ _ _ _ _ _ _ _

Ethnicity

Ethnicity: (check one)

☐ Caucasian ☐ Black ☐ Asian/Pacific Islander ☐ Hispanic Surname/Origin

☐ American Indian/Alaskan Native ☐ Other (specify ____________________)

Relative/Follow-Up Contact

a. Name: ______________________________
(Last, First, Middle)

b. Relationship: ☐ Spouse ☐ Son/Daughter ☐ Brother/Sister

☐ Other (specify: ____________________)

c. Address: ______________________________

d. City: ______________ e. State: __________ f. Zip Code: __________

g. ☎: (____) _____ - _______

Appendix 10. Medical Record Abstract Form (cont'd)

Study No. ______________

II. DIAGNOSTIC INFORMATION

A. Primary Tumor(s)

	TUMOR No. 1	TUMOR No. 2	TUMOR No. 3
a. Organ	______	______	______
b. Cell Type	______	______	______
c. ICD Code	______	______	______
d. Date Diagnosis Confirmed	__ - __ - __ (month day year)	__ - __ - __ (month day year)	__ - __ - __ (month day year)

B. Name of Diagnosing Physician and Address of Place (hospital, clinic or office) where diagnosis was confirmed

a. TUMOR No. 1: ______________ (Include Cell Type)

1. Name of Physician: ______________ (Last, First, Middle)
2. Place Where Diagnosis Made: ______________
   a. Name: ______________
   b. Address: ______________
   c. City: ______ d. State: ______ e. Zip Code: ______

b. TUMOR No. 2: ______________ (Include Cell Type)

1. Name of Physician: ______________ (Last, First, Middle)
2. Place Where Diagnosis Made: ______________
   a. Name: ______________
   b. Address: ______________
   c. City: ______ d. State: ______ e. Zip Code: ______

c. TUMOR No. 3: ______________ (Include Cell Type)

1. Name of Physician: ______________ (Last, First, Middle)
2. Place Where Diagnosis Made: ______________
   a. Name: ______________
   b. Address: ______________
   c. City: ______ d. State: ______ e. Zip Code: ______

2

Appendix 10. Medical Record Abstract Form (cont'd)

Study No.________________

II. DIAGNOSTIC INFORMATION (cont'd.)

9 Name and Address of Patients Private Physician if different than those in Item 8

a. **Name:** ________________________________
(Last, First, Middle)

b. **Address:** ________________________________

c. **City:** ______________ d. **State:** __________ e. **Zip Code:** __________

10 Methods of Diagnosis

ONE OR MORE LABORATORY METHODS OR SURGICAL PROCEDURES MAY BE USED TO ARRIVE AT A DIAGNOSIS OF A TUMOR. POSSIBLE DIAGNOSTIC METHODS INCLUDE THE FOLLOWING:

Autopsy	=	*Malignancy found at autopsy*
Histology	=	*Includes microscopic diagnosis made on biopsy or resection (specify biopsy only or resection)*
Hematology	=	*Includes positive hematologic findings*
Cytology	=	*Includes positive smears of sputum, bronchial washings, pleural or peritoneal fluid, and others.*
X-ray	=	*Includes positive X-ray findings*
CAT Scan	=	*Includes positive CAT scan findings*
Clinical	=	*Not microscopically confirmed. Diagnosis made by palpation, surgical exploration, or other clinical findings*
Other	=	*Specify any other methods not included in the above, e.g. liver scans, brain scans, endoscopic procedures*

FOR EACH TUMOR LISTED IN ITEM 7, CHECK ALL APPROPRIATE METHODS OF DIAGNOSIS WHICH RESULTED IN A POSITIVE FINDING.

a. **TUMOR No. 1:** ________________________________
(Include Cell Type)

1. Method(s) of Diagnosis: (check all that apply)

☐ Autopsy	☐ Hematology	☐ CAT Scan
☐ Histology—Biopsy Only	☐ Cytology	☐ Clinical
☐ Histology—Resection	☐ X-ray	☐ Other

2. Results/Comments (describe results for each method used):

____
____
____
____
____
____

3

Appendix 10. Medical Record Abstract Form (cont'd)

Study No. ____________

II. DIAGNOSTIC INFORMATION (cont'd.)

b. **TUMOR No. 2:** ______________________________
(Include Cell Type)

1. **Method(s) of Diagnosis:** (check all that apply)

☐ Autopsy	☐ Hematology	☐ CAT Scan
☐ Histology—Biopsy Only	☐ Cytology	☐ Clinical
☐ Histology—Resection	☐ X-ray	☐ Other

2. **Results/Comments** (describe results for each method used):

____
____
____
____
____
____
____

c. **TUMOR No. 3:** ______________________________
(Include Cell Type)

1. **Method(s) of Diagnosis:** (check all that apply)

☐ Autopsy	☐ Hematology	☐ CAT Scan
☐ Histology—Biopsy Only	☐ Cytology	☐ Clinical
☐ Histology—Resection	☐ X-ray	☐ Other

2. **Results/Comments** (describe results for each method used):

____
____
____
____
____
____
____

4

Appendix 10. Medical Record Abstract Form (cont'd)

Study No. ____________

III. TUMOR INFORMATION

11\. Complete this item if LEUKEMIA is present (specify morphology including subtype)

FIRST. check the box a, b or c, that reflects whether the leukemia is acute (or poorly differentiated) or chronic, or if morphology is not available.

SECOND. If morphology is available:

1. Check the box 1, 2, or 3, that reflects whether the leukemia is myelogenous, lymphocytic or undifferentiated.

2. Check the box in the shaded area that reflects the appropriate subtype.

a. ☐ ACUTE OR POORLY DIFFERENTIATED LEUKEMIA

1. ☐ Myelogenous

- ☐ myelomonocytic
- ☐ myeloblastic
- ☐ monocytic
- ☐ erythroid
- ☐ eosinophilic
- ☐ megakaryocytic
- ☐ other: ____________

2. ☐ Lymphocytic

- ☐ common type
- ☐ Null cell
- ☐ T cell
- ☐ B cell
- ☐ other: ____________

3. ☐ Undifferentiated

b. ☐ CHRONIC LEUKEMIA

1. ☐ Myelogenous

- ☐ Ph1 positive—CML
- ☐ Ph1 negative—CML
- ☐ chronic myelomonocytic
- ☐ other: ____________

2. ☐ Lymphocytic

- ☐ B cell—CLL
- ☐ T cell—CLL
- ☐ prolymphocytic
- ☐ lymphoma cell
- ☐ hairy cell
- ☐ plasma cell
- ☐ other: ____________

c. ☐ LEUKEMIA MORPHOLOGY NOT AVAILABLE

Comments: ____

____

____

____

____

5

Appendix 10. Medical Record Abstract Form (cont'd)

Study No. ____________________

III. TUMOR INFORMATION (cont'd.)

12 Complete this item if LYMPHOMA is present (indicate histopathology including subtype):

FIRST, check the box a, b, or c that reflects whether the lymphoma is Hodgkins or non-Hodgkins, or if histopathology is not available.

SECOND, if histopathology is available:
1. *Check the box numbered 1 through 9 that reflects the appropriate cell type.*
2. *Check the box within the shaded area that reflects the appropriate subtypes.*

a. ☐ **HODGKINS LYMPHOMA**

1. ☐ lymphocytic predominance (paragranuloma)
2. ☐ mixed cellularity
3. ☐ lymphocyte depletion (Hodgkin's sarcoma)
4. ☐ nodular sclerosis
5. ☐ other ____________________

b. ☐ **NON-HODGKINS LYMPHOMA**

1. ☐ malignant lymphoma, lymphocytic
   - ☐ well differentiated lymphocytic (lymphosarcoma)
   - ☐ lymphoblastic lymphosarcoma
2. ☐ poorly differentiated lymphocytic lymphoma
   - ☐ nodular ☐ diffuse ☐ no data
3. ☐ "mixed" lymphoma (lymphocytic-histiocytic)
   - ☐ nodular ☐ diffuse ☐ no data
4. ☐ "histiocytic" lymphoma (reticulum cell sarcoma)
   - ☐ nodular ☐ diffuse ☐ no data
5. ☐ undifferentiated lymphoma
   - ☐ monomorphic (Burkitt's lymphoma)
   - ☐ pleomorphic (stem cell lymphoma)
6. ☐ multiple myeloma
7. ☐ Waldenstrom's macroglobulinemia
8. ☐ malignant histiocytosis
9. ☐ other: ____________________

c. ☐ **LYMPHOMA HISTOPATHOLOGY NOT AVAILABLE**

Comments: ____________________

6

Appendix 10. Medical Record Abstract Form (cont'd)

Study No.__________

III. TUMOR INFORMATION (cont'd.)

13 Complete this item if MESOTHELIOMA is present (specify site, extension, histology and type)

a. **Site:** ☐ pleural ☐ peritoneal ☐ no data

b. **Extension:** ☐ localized ☐ diffuse ☐ no data

c. **Histology:** ☐ epithelial ☐ spindle cell ☐ mixed ☐ no data

d. **Type:** ☐ malignant ☐ benign ☐ no data

Comments:__________

14 Complete this item if LUNG CANCER is present (indicate location and cell type).

a. **Location:** ☐ right lung ☐ left lung ☐ no data

b. **Cell Type:** ☐ squamous cell carcinoma ☐ small cell carcinoma
☐ adenocarcinoma ☐ large cell carcinoma
☐ mixed; specify: ☐ other:

Comments:__________

7

Appendix 11. **Modified Table 2-8-C: Job Titles Most Frequently Associated with Shops and Series Codes** (Charleston, South Carolina)

Shop or Series Code
Associated Job Titles

Part A. Shops

01 Shipyard Commander's Office
Administrative Jobs

02 Transportation Shops
Crane Operator, Electrician, Engineer, Engineman, Heavy Mobile Equipment Mechanic, Laborer, Mechanic, Motor Vehicle Operator, Oiler

03 Utilities Shop
Boilermaker, Electrician, Instrument Mechanic, Laborer, Pipefitter, Plumber

05 Radiological Control Office
Physical Science Technician, Health Physicist, Nuclear Engineer

06 Central Tool Room
Air Conditioning/Refrigeration Equipment Mechanic, Electrician, Electronics Mechanic, Laborer, Machinist/Maintenance/Marine, Oiler, Sawsmith

07 Maintenance Shop
Air Conditioning/Refrigeration Equipment Mechanic, Electrician, Joiner, Laborer, Machinist/Maintenance/Marine, Marine Engineer, Mechanic, Motor Vehicle Operator, Painter, Pipe Coverer & Insulator, Pipefitter, Plumber, Rigger, Sheetmetal Mechanic

09 Safety Office
Industrial Hygiene/Health & Safety Specialists

10 Data Processing Office
Administrative Jobs

11 Shipfitter's Shop
Forgers, Loftsman, Shipfitter

12 Ship Management Officers
[No titles given]

13 Quality Assurance Office
Electrician, Chemist, Metallurgists, Inspectors (Metals, Electrical), Engineers, Administrative jobs

(cont'd)

Appendix 11. Modified Table 2-8-C: **Job Titles Most Frequently Associated with Shops and Series Codes** (Charleston, South Carolina) (cont'd)

Shop or Series Code
Associated Job Titles

Part A. Shops (cont'd)

14 Management Engineering Office
Engineer, Administrative jobs

15 Industrial Relations Office
Administrative Jobs

17 Sheetmetal Shop
Electroplater, Sheetmetal Mechanic

19 Combat Systems Office
Engineers/Electronic Technicians

20 Planning Department
Production Controllers, Engineers

22 Planning & Estimating Div.
Production Controllers, Engineers

23 Forge Shop
Forgers

24 Design Division
Engineers, Naval Architects

25 **[Shop name unknown - Currently Shop 99]**
Gas Detection Monitor

26 Welding Shop
Gas Plant Operator, Welder

27 **[Shop name unknown]**
Galvanizer

30 Production Department
Administrative jobs, Engineers

31 Inside Machine Shop
Electroplater, Instrument Mechanic, Machinist/Maintenance/Marine

32 Nuclear Engineering Department
Engineer, Nuclear Engineering, Nuclear Engineering Technicians

(cont'd)

Appendix 11. **Modified Table 2-8-C: Job Titles Most Frequently Associated with Shops and Series Codes** (Charleston, South Carolina) (cont'd)

Shop or Series Code
Associated Job Titles

Part A. Shops (cont'd)

33 Non-Nuclear Inspection Div.
Inspectors, Training Specialists

34 Laboratories Division
Industrial Test Laboratory, Physical Science Technician

35 Non-Destructive Test Division
Radiographers

36 Weapons Shop
[No titles given]

38 Outside Machine Shop
Machinist/Maintenance/Marine, Mechanic

39 Nuclear Inspection Division
Physical Science Technician, Engineers

40 Public Works Department
Engineers, Administrative jobs

41 Boiler Shop
Boilermaker

45 Public Works - Shop Division
Administrative jobs

46 Pending Disability Retirement
Any job title

50 Supply Department
Laborer, Stockman, Procurement Specialists, Contract Administrators, Administrative jobs

51 Electrical Shop
Electrician, Instrument Mechanic

56 Pipe Shop
Air Conditioning/Refrigeration Equipment Mechanic, Pipe Coverer & Insulator, Pipefitter, Plumber

(cont'd)

Appendix 11. Modified Table 2-8-C: Job Titles Most Frequently Associated with Shops and Series Codes (Charleston, South Carolina) (cont'd)

Shop or Series Code
Associated Job Titles

Part A. Shops (cont'd)

60 Comptroller Department
Administrative Jobs

62 **[Shop name unknown]**
Administrative Jobs

64 Woodworking Shop
Joiner, Insulators, Woodworkers, Fabric workers

66 **[Shop name unknown]**
Administrative Jobs

67 Electronics Shop
Electronics Mechanic

68 Module Maintenance Facility
Electronics Mechanic

70 Medical Department
Physicians, Nurses, Administrative jobs, Medical Technicians

71 Paint Shop
Laborer, Painter, Sandblaster, Tank and Equipment Cleaner

72 Riggers and Laborers Shop
Laborer, Rigger, Tank and Equipment Cleaner, Upholsterer

75 Medical Department (formerly Industrial Hygiene Division & Radiation Health Division combined - called Industrial Hygiene Division)
Industrial Hygienists, Health Physicians

77 Severance Pay
Administrative Job

80 Administrative Department
Administrative Job

81 **[Shop name unknown - Currently Shop 31]**
Foundry Molder, Joiner

82 Fire Department
Firefighter

(cont'd)

Appendix 11. **<u>Modified Table 2-8-C</u>: Job Titles Most Frequently Associated with Shops and Series Codes** (Charleston, South Carolina) (cont'd)

Shop or Series Code	Associated Job Titles
Part A. Shops (cont'd)	
83	Security Division
	Guards/Police/Administrative
91	Youth Opportunity
	Student/Summer Aid
92	Structural Shop Group - Shops 11, 17, and 26
	[Titles above]
93	Mechanical Shop Group - Shops 31, 38, and 56
	Mechanic
94	**[Shop name unknown - Currently Shop 64 (woodworking shop)]**
	Joiner
95	Electrical/Electronic Shop Group - Shops 51, 67, and 68
	[Titles above]
97	Service Shop Group - Shops 06, 64, 71, 72, and 99
	[Titles above]
99	Temporary Service Group
	Electrician, Student/Summer Aid
Part B. Series Codes	
105	Radiological Control Office
106	Occupational Safety & Health Office
133	Non-nuclear Inspection Division
134.3;	Radiochemistry & Water Chemistry Branch
134.4	Metallurgical Branch
150	Industrial Relations Office
185	Safety Division (Currently part of Shop 106)
200	Planning Department

(cont'd)

Appendix 11. **Modified Table 2-8-C: Job Titles Most Frequently Associated with Shops and Series Codes** (Charleston, South Carolina) (cont'd)

Shop or Series Code Associated Job Titles	
Part B. Series Codes (cont'd)	
(240	Design Division)
280	Planning (Question about this series code)
400	Public Works Department
500	Supply Department
600	Comptroller Department
700	Formerly Medical Department
730	Industrial Hygiene Division
800	Administrative Department
2300	Nuclear Engineering Department