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Feasibility Study of the Correlation
of Lifetime Health and Mortality
Experience of AEC and AEC Contractor
Employees with Occupational
Radiation Exposure

Progress Report

by

Thomas F. Mancuso, M.D.
Barkev S. Sanders, Ph.D.
Allen Brodsky, M.A.

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ABSTRACT

The objective of this study is to follow cohort employee populations of selected AEC Contractor installations, to test the feasibility of using personnel, employment, medical and radiation records in establishing the relationships, if any, between mortality patterns and levels of radiation exposure. The reason for the study is the absence of empirically tested information pertaining to human populations exposed to recorded low levels of radiation over long periods of time. The procedure devised for the test runs is: to establish a series of cohorts of populations at each facility, those continuously employed as well as those separated, for each year, by tracing these individuals and sibling controls through Social Security records to determine those who have died and their place and date of death; to obtain death certificates to establish age-sex specific death rates; and to analyze causes of death for those with radiation exposure and work-connected health hazards in comparison to appropriate non-exposed controls. The following AEC Contractor facilities have been selected for the test runs: Oak Ridge X10, Oak Ridge Y12, Oak Ridge K25, Hanford and several small feed materials plants. These facilities provide large populations with long intervals of operation. Pilot studies of radiation exposure records of persons exposed in atomic energy facilities will be carried out to determine the average occupational exposure of these populations and appropriate confidence limits in exposure estimates for individuals and various sub-populations.

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I. INTRODUCTION

This Progress Report summarizes the activities and progress of the first nine months of AEC Project No. AT(30-1)3394. The main objective for the first year of this project, as stated in the original proposal, was to ascertain whether the personnel, medical, and radiation exposure records maintained in about 7-12 representative AEC contractor installations contained adequate information to support an investigation of morbidity and mortality patterns in relation to occupational radiation exposure.

In the first two months of the project, visits were made to review the nature of operations and records at Hanford, the three Oak Ridge facilities, National Lead Company of Ohio, Brookhaven National Laboratory, and to review reports retained at the AEC Health and Safety Laboratory processing plants. These reviews made it apparent that, although records had been maintained in different ways according to the administrative needs of each facility, there was still a wealth of material of unknown level of accuracy available that would allow employees to be traced with respect to health effects, mortality, and general levels of radiation exposure. However, the information available had been collected only for practical administrative use or control of occupational hazards and not for purposes of obtaining maximum precision in long-term studies of employee health status and the possible influence of employment on the health status. In general, the record systems had not been designed to answer questions concerning the long-term trends in employee health status relative to other industries or between groups exposed to different radiation levels. Nevertheless, the

retention of many of these records makes it seem likely that at least the mortality pattern of various cohorts could be traced, and its possible association with radiation explored; although the availability of radiation measurements on individual radiation workers appears to be incomplete in the early years.

Thus, since an early concept of the feasibility of health studies had been obtained, an informal report on these findings was delivered to the AEC at Germantown headquarters on July 31, 1964, to present an outline of some of the types of health studies that might be conducted utilizing the available data, supplemented by follow-up information obtainable from Social Security records. The July 31st report was submitted informally in order to examine the full dimensions of the many types of studies deemed to be possible and their long range implications for support and financing. It was desirable to expedite at an early date certain steps and administrative decisions necessary for continued studies, and also to narrow down the scope of our feasibility investigation to deal only with projects within the realm of economic feasibility. The main conclusions of the July 31st meeting will be included in this report. A major accomplishment of this meeting was the agreement that studies involving follow-up medical examinations, personal interviews, or other surveys involving employees directly should be excluded from consideration at this time. The great expense of such studies involving personal contacts, the technical limitations of morbidity studies, and the small likelihood of obtaining useful information on low-level exposure effects for small study populations made it advisable to focus on the maximum utilization of recorded data for large study populations.

With the project scope narrowed to emphasize mortality studies, several further visits to AEC facilities were made to obtain a wider review of the availability of pertinent records and additional orientation in AEC operations. Another meeting was held at the AEC on September 28, 1964, to present the outlines of three alternative plans for continuing the feasibility study, representing varying degrees of completeness in examining available medical and personal statistics. The September 28th Meeting resulted in a decision to proceed with plans for the test runs as outlined in NYO-3394-1, October 12, 1964, to validate the supposition that routinely-recorded data is perhaps adequate for a health study of the atomic energy industry and at the same time to initiate the abstracting of data and the development of statistical methods that could be used in an extended study. The plans presented in NYO-3394-1 have been further modified as presented in Section IV of this report. Particular emphasis on this project will now be given to the proposed pilot mortality studies to be carried out on the employee populations of Hanford, Oak Ridge, certain feed materials processing centers, and early involvement of University groups (Chicago, Columbia, and California).

Between October and February several further visits were made, questionnaires were prepared for obtaining more specific data, and criteria and methodology were further developed for conducting the mortality studies. Appendix A presents a list of the items that have recently been included in questionnaires sent to Hanford and Oak Ridge to obtain more specific information for determining the data available and costs for abstracting the requisite data onto punched cards and magnetic tape. A summary of the years for which

information is available in some form on the items deemed most pertinent to the test runs is given in Table 10. Appendix B presents a list of the fourteen (14) installations visited by January, 1965. In Appendix C, a more detailed discussion is presented of the criteria for assessing radiation exposures from personnel monitoring records and their limits of accuracy, and a compilation of data is included in Tables 1-6 and Figures 1-3 for use in determining the accuracy or sensitivity of different film badge systems for various gamma energy spectra that might be encountered in occupational exposure. Tables 7A and 7B present estimates of population size and group radiation exposure risks in person-roentgen-years of those portions of the populations exposed to measurable radiation exposures, as presented in the September 28, 1964 meeting for the Hanford, Oak Ridge, and National Lead Company of Ohio facilities. In round numbers, these estimates are still adequate for preliminary estimation of data evaluation requirements in regard to any chronic diseases of low incidence per roentgen. Table 8 presents a comparison of the population exposures recorded by film badges and pocket chambers for fourteen years of operation of an atomic energy facility. Table 9 presents some preliminary comparisons of recorded cumulative exposures for 21 employees in a Pittsburgh facility over the period 1951-54 with those obtained from re-reading densities of stored films. These densities were compared with a typical manufacturer's calibration curve that was found to agree in the 10 mr-1,000 mr range with the several old sets of calibration films that were still available. Tables 8 and 9, together with results of a previous study of occupational

exposures, suggest an average annual exposure of about 0.5R/year per monitored employee over approximately the 1946-64 period used in the estimates of Table 7. Certain facilities will deviate considerably from this average, however, particularly in the earlier days of the atomic energy program.

The final two sections of this report contain summaries of the main conclusions and recommendations drawn from our initial visits to 14 AEC facilities. Since oral reports have already been given on the feasibility of carrying out useful studies of mortality vs radiation exposure, and since further validation of this tentative conclusion requires test runs on a large sample of available data similar to the studies to be actually carried out on the total atomic energy population, a complete listing of the available data in each facility is not deemed worthwhile at this time. Instead, the available data in the facilities to be included in the test runs is summarized in Appendix A, and the records available in the other facilities are discussed briefly in Section III. The tentative conclusions of feasibility are based at present primarily on this preliminary review of data as well as many discussions with AEC Contractor personnel and the experience of the investigators with previous mortality studies in industrial populations. Conclusions regarding estimates of average occupational exposure of monitored employees are based on a comparison of the results of previous investigations of recorded radiation exposure with the methods and general exposure distributions observed in the fourteen facilities visited. The conclusions and recommendations of this first year of the feasibility study will further substantiate the

recommendations of the Atomic Energy Commission and its Advisory Committee on Biology and Medicine in regard to the timeliness and need of determining the possibility of organizing personnel, health, and exposure data collected in Commission facilities for the continuing investigation of any possible long-term correlations between health effects and occupational exposure.

II BACKGROUND

This project was formally initiated on June 1, 1964, after approval of a proposal submitted with the advice and encouragement of staff members of the Division of Biology and Medicine and the Division of Operational Safety, U. S. Atomic Energy Commission. The Commission decided to initiate this study to determine the feasibility of utilizing AEC contractor records for determining whether any correlation might exist between health events and long-term occupational radiation exposure. Such a study was deemed timely since over twenty years of industrial health experience together with relatively complete records of occupational radiation exposure had accumulated in the atomic energy industry, and other industries were now beginning to organize their records in a manner that would make comparable health data available.

The value of a scientific determination of the presence or absence of associations between health effects and radiation exposure within the large industrial atomic energy population has been discussed many times by members of the AEC staff, their Advisory Committee on Biology and Medicine, and by other national and international scientific organizations.⁽¹⁻⁴⁾ Thus, the following background discussion serves mainly to summarize previous considerations, lend further support and qualifications, and provide some perspective for the coherent presentation of the remaining sections of this report.

Although the prudent judgment of scientific committees has resulted in the lowering of the recommended limits of occupational exposure from about 60 R/year in 1936 to an average of 5 R/year in 1957, the International Commission on Radiological Protection and the National Committee on Radiation Protection have repeatedly pointed out that none of the recommendations for lowering occupational exposure levels has resulted from the actual observation in humans of harmful effects at or below permissible levels of exposure. As the AEC has pointed out, much of the impetus for lowering permissible levels has come from the extrapolation--to lower doses and larger populations--of information obtained on somatic and genetic effects at higher dose levels in smaller numbers of humans or animals, and from the subjective impressions of experts regarding the lack of an unfavorable health picture among atomic energy employees.

The AEC policies in regard to occupational radiation exposure have historically followed the recommendations of the NCRP, which stated in 1957 revision ⁽⁵⁾ of exposure recommendations that "The only statement that can be made at the present time about the lifetime exposure of persons to penetrating radiation at a permissible level considerably higher than the background radiation level, but

within the range of radiological experience, is that appreciable injury manifestable in the lifetime of the individual is extremely unlikely." Of course, one of the purposes of mortality or morbidity studies of the average population of 100,000 or more radiation workers within AEC contractor installations would be to verify the predicted improbability of unfavorable chronic health effects at occupational exposure levels, or to scientifically determine quantitative upper limits to the likelihood (or probabilities) of such "extremely unlikely" health effects. Indeed, published records^(2,3,6) of typical AEC occupational exposure distributions, comparisons between such exposure distributions and those verified in selected facilities,⁽⁷⁾ and the preliminary data and observations made during the first year of this project, indicate that the monitored employees of AEC contractor installations have received an average whole body exposure of only about 0.5R/year since the early days of the Manhattan Project. Average exposures in recent years are probably decreasing to levels appreciably below 0.5R/year. This average annual exposure is only one-tenth of the current upper limit of average permissible exposure of 5 R/year for employees over age 18, and a 5 R/year average exposure is stated by the NCRP to be unlikely to produce observable damage during the lifetime of the individual.

Thus, since the uses of radioactive material are increasing and the advent of an expansion in commercial nuclear power production is approaching, there is an increasing need to verify the appropriateness of current exposure standards for human populations.

The United Nations Committee in its three reports has delineated present knowledge about the effects of atomic radiation on man and the areas of ignorance where more precise knowledge is required. This knowledge is urgently needed for effective efforts on the part of government in developing appropriate laws and regulations to safeguard industrial and related uses of radioactive material. Again, the gap in our present knowledge is largely in the area of the effect of prolonged, low-level, ionizing radiation on man. Thus, "although we have extensive and increasing information about the levels of radiation to which man is exposed from various sources and about the type of harmful effects that may result, we still know very little about the frequency with which such effects are likely to occur, particularly following small doses of radiation received at low dose rates. It is of the utmost importance that investigations of this central problem should be actively pursued by all relevant means, including not only studies of the ways in which radiation may induce malignant and other delayed changes in tissues, but also well-planned surveys of the frequency with which such late effects occur in human populations."

To address ourselves to this central problem, the most appropriate human exposure experience to low levels of radiation which could be investigated is that of the entire AEC Contractor employee population, which has been monitored since the early years of the atomic energy program.

* Reference 2, P. 35.

Occupational exposure of the 200,000 or more employees of AEC contractors is relatively well-documented for most years of operation and the population is relatively homogeneous and continuous in time, but no comprehensive longitudinal study of this large and available population has yet been conducted. The literature deals mainly with relatively small occupational groups such as radiologists, radiology technicians, luminescent dial painters, and uranium miners, and although these studies have yielded valuable information on which present exposure limits are based, they cannot yield complete information on the probabilities of long-term effects such as leukemia or cancer incidence in large populations after many years of exposure at low dose-rates. (1-4, 8-11)

Previous studies (2,3,7) indicate that the average monitored AEC worker has received an average of about 0.5 R/year from occupational exposure, significantly above average background and medical exposures. (1-3) These exposure rates have now been received over periods of 22 to 23 years and the exposed population is still growing. Those workers whose exposures were significant in the 1942-45 period have had a long-enough time lapse so that one can begin to look for the appearance of latent effects, if the exposed individuals in these early years of operation can be identified and followed.

Systematic continued studies of the chronic effects of occupational exposure to ionizing radiation and arrangements to continue the follow-up of exposed employees to the end of their life (which would be relatively easy to do) appears more promising

in yielding valid information on low-level, continuous exposure effects than any other avenues of approach. Animal experimentation, while important, could never be extrapolated to predict human experience with any certainty without independent confirmation on humans. We know of no better body of past and future data on occupational radiation exposure that approaches in value the exposure experience of workers in the U. S. atomic energy programs. We therefore recommend that a start be made in the systematic development of studies to exploit all that can be learned from this experience.

(12)
 Brues, Grahn, and Auerbach have reviewed some of the problems of radiation epidemiology indicated from previous studies and have pointed out very aptly that the requirements for extrapolating dose-effect relationships to very low radiation exposures "brings a new dimension to epidemiology, but one that may need to be brought into future studies in the statistical diseases such as cancer." Each of the studies reviewed by Brues, Grahn and Auerbach of human populations exposed to radiation from various sources contain confounding factors that could make a causal interpretation of radiation effects more or less questionable.

(1-4)
 The AEC staff and other national scientific bodies have already stressed the social and economic as well as scientific significance of our gaining, as rapidly as possible, a more precise knowledge of the possible somatic and genetic effects of low-level, prolonged radiation exposure in man.

The previous studies of human exposure to radiation that have contributed to our knowledge of chronic effects of radiation include the studies of atomic bomb survivors in Hiroshima and Nagasaki, those persons exposed to fallout from Operation Castle in 1954, radiologists and patients exposed to medical x-rays, those survivors involved in a few radiation accidents that have occurred in the atomic energy program, and the radium dial painter (1-3) (13-17) incidents. With respect to the Japanese population, its scientific contribution is valuable but not applicable in terms of ascertaining low-dose, continuous-irradiation effects. The instantaneous dose received per individual was uncertain and the study populations are select populations that have survived blast, heat, and emotional stresses that the more sensitive did not survive. Also, in the 1962 U.N. Report, (2) it has been shown that the incidence of leukemia versus distance from the hypocenter followed a straight line on a semilog plot of incidence versus distance in a similar way to which radiation decreased with distance. Since blast and heat also decreased with distance, the correlation of leukemia with distance may not necessarily be an indication of (18) pure radiation effects alone. The Marshall Island exposures also involved acute whole body irradiation of 10-200 R delivered within 12-24 hours as well as skin exposures up to 500 rad or more. Data on this incident will be of value in the planning of retrospective studies of individuals who have received similar acute exposures to beta "burns" in industry, but may not be

pertinent to the search for any long-term effects of low-level occupational exposure.

Information on the relatively small number of persons in the United States, USSR, and in Yugoslavia who have suffered severe and sometimes fatal radiation in criticality accidents may be ^(13,14,19) useful for studying acute biomedical phenomena and some long-range effects, but the fortunately small number of individuals involved and the nature of the exposures cannot supply information relevant to exposure of large populations within the limits of current occupational standards and regulations.

Estimates of individual exposures to medical x-rays have been difficult to obtain in the retrospective studies of persons with specific diseases, and the radiation effects may be confounded by the influences of the disease treated, or other therapeutic ^(1-4, 12) measures used in the treatment of the patient.

However, medical radiation exposures could be an important source of error in estimating the cumulative exposure of individuals, particularly in retrospective studies over long periods of time on limited size populations. Any contemplated continuing surveillance system of employee health status versus radiation exposure should eventually include some kind of provision for assessing the medical exposure contributions to the cumulative dose of individual employees or groups.

Previous pilot studies of work absence rates and medical data recorded by plant physicians have not suggested any likely routinely recorded data that at present might be expected to reveal associations between radiation exposure and health effects, (7,20-25) although chromosomal damage has been discovered in employees exposed to more than about 10 R. (25) Also, a number of complicating factors and changes with time in methods of recording results of physical examinations indicate that morbidity studies based on facility records would probably be much more expensive than mortality studies at present. Morbidity studies might be better conceived after further experience in the test runs on mortality.

The past attempts found in the literature to exploit the occupational exposure experience of atomic energy workers have been very limited and not always soundly conceived. While we have not made an exhaustive search to turn up every study of radiation exposure made on employees in the AEC installations, in the course of our visits to the different installations we have inquired with respect to the existence of such studies. Only a few small studies have come to our attention that deal with populations receiving long-term occupational radiation exposure. This observation, of course, excludes studies and papers based on various criticality incidents in the different AEC installations. Our review of the international compilations of the three United Nations publications, (1-3) and the summaries prepared by our own National Research Council, (4) has made it apparent that no important scientific

use has been made of the exposure experience of U. S. atomic energy workers.

An additional indication that there have been no serious attempts to appraise this experience to date is found in a paper prepared by Dunham and Bruner,⁽¹¹⁾ in which they were asked to discuss "... individual and population responses to prolonged low-level exposure to toxic substances." Dunham and Bruner, who would be familiar with any important studies based on employees of AEC contractors, cite no study of this type.

One of the earliest studies that came to our attention was Moshman's study based on the population of Oak Ridge.⁽³⁶⁾ This early work by Moshman exhibits many of the typical pitfalls encountered by others who have attempted limited investigations of morbidity and mortality in occupationally exposed groups. Moshman addresses himself to the question: "Will working in an area where there is possible exposure to radioactive chemicals make one more likely to develop cancer?" Moshman's answer to this question in 1948 was unequivocally "No!" However, the evidence presented in his report does not lend itself to such definitive conclusions even if only the limited period is considered and latent effects are neglected. Moshman indicated that he chose for his study morbidity instead of mortality because "The people of Oak Ridge present a very mobile and a typical group". However, it would seem that if the mobility of the population makes it difficult to study mortality, which is a more easily definable

state, it would make it difficult to study incidence of diseases such as cancer. How can one be sure that cancer incidence rates would be the same (correcting for age, sex, etc.) for the more mobile groups as compared with the less mobile? Moshman thus appears to have been unaware of the difficulties that mobility introduces in measuring incidence of cancer in a region. He states "it was decided to have the data on incidence per 100,000 population for the aggregate number who have lived or worked in the Oak Ridge Area."^{1/} There is no consideration of duration of exposure and length of period at risk, which are essential dimensions in any measurement of incidence of disease. As a matter of fact, not enough details are given to be certain whether duration of exposure was taken into consideration in arriving at the age-adjusted, overall incidence rate of 123 per 100,000 population.

(26)
Table 1 of Moshman's report, titled "Minimal Estimate of Badges Issued by Issuing Agency," shows 425,000 adults to which are added 80,000 children, thus giving a total of 505,000. The length of time that these individuals were in Oak Ridge is not considered here; the question is taken up later, but we are not sure what is done with it. The author does indicate that 505,000 do not represent different individuals, since an individual would have been issued several badges--but no evidence is presented to show how prevalent this practice was. On the basis of this assertion about multiple assignments the author concludes: "In the light

1/ Ref. 26, p.2

of all the information available, and in order not to understate the morbidity data, a minimal population estimate of 300,000 has been adopted for the pupose of the study."

The population at risk is only one of the uncertain parameters in the 1948 study. Also in question was the age composition of the population at risk. No information could be obtained regarding the age composition of the population prior to August, 1945. After that date, the area residents were asked to list all their dependents and the ages of these dependents, but no information was obtained from the residents regarding the age of the employee, who was the head of the household. To obtain information on the age composition of employees, "The resident population was stratified by type of housing and a sample of between five and six present was taken in each stratum."^{2/} The names of heads of these households were checked against personnel records to obtain the ages. The ages of non-resident employees were also said to be obtained from the personnel records. Since personnel records had ages listed, it is not clear why samples could not have been taken of age composition of employees no longer at Oak Ridge to be sure that it reflected the age of all the population who had been at the site. Thus, although sampling errors were computed, the frequency distribution by age was based largely on conjecture for the years prior to 1945.

^{2/} Ref. 26, p.4

Many additional limitations in Moshman's 1948 study included: inappropriate use of cancer morbidity data published by Dorn for ten large cities, for a different time period and gathered by different criteria. Most important of all, the study fails to present or discuss the marked excess of cancer reported in the Oak Ridge population in ages 25 to 45. In fact, there is no indication that Moshman went beyond comparing the overall rate contributed primarily by persons in older ages of whom there were very few, and who were probably highly selected, in the Oak Ridge population. Moshman's work was published, except for some of the statistical methodology, in a later paper.⁽²⁷⁾ This later paper also contains no reference to the apparent reasons for the discrepancy in the incidence rates of cancer in highly important ages between the Oak Ridge population and Dorn's findings from 10 city surveys, again limiting the comparison only to over-all incidence rates.

A third publication by Moshman⁽²⁸⁾ dealing with medical records is of special interest since it seems to have been a forerunner of the current feasibility study, sponsored also by the Division of Biology and Medicine. The medical record study was undertaken as a preliminary pilot study to be used as a guide in planning future studies. It was not intended that the medical record pilot study be a conclusive statistical survey. Since there was insufficient data for case studies of morbidity, Moshman narrowed the study to a general search for blood changes with time in less than 200 exposed employees, most of whom had small or negligible exposure. The results were again inconclusive, but led to the recommendations

for standardizing laboratory procedures that would still be pertinent to any long-range studies based on these types of measurements.

Other investigations⁽²⁹⁾ have more recently established that medical measurements taken in the course of routine attendance of patients are in general subject to wide variations. Bell and Gilliland⁽²³⁾ have shown a number of variations in various physiological measurements of employees of certain AEC contractors that would prohibit long-term morbidity studies unless more standardized procedures and means of measuring morbidity are developed.

Moshman ultimately came to the above conclusion as reflected in the following quote: "Such a study (a large scale study of white blood cells in relation to radiation) should not properly commence until uniform methods of reporting hematological data are adapted. Uniform methods should also include a uniform form which would be conducive to statistical analysis. The optimum method would be to have each series of laboratory examinations recorded on a properly indicated punch card for every individual so that it would only be necessary to secure copies of these cards as the working data for the study. This would by far eliminate the greatest cost involved in making such a study."^(7, 28) We strongly endorse Moshman's recommendation.

Knowlton has studied hematological measurements made on workers in Los Alamos from December, 1946, to March, 1949 (117 weeks).⁽³⁰⁾ His observations show temporary depressions in white cell counts

of exposed workers, but he emphasizes the large inherent variations in cell counting and states that, "Unfortunately, although the routine blood count is the best chemical test available at the present time, it is actually not a very satisfactory means of discovering radiation injury," and he recommends further studies in other laboratories.

A more extensive study of blood changes has been carried on at Hanford more or less continuously since 1948.⁽³¹⁾ The only observation of special interest is that with respect to individuals who had worked at different sites with different radiation hazards:

"The data for males were analyzed to determine if the average values for personnel coming from the University of Chicago Metallurgical Laboratory and Clinton Laboratories were different from those for personnel from other locations. No significant difference was found in the red blood count, hemoglobin content, or number of lymphocytes, but the white blood count and neutrophil count were significantly less for those personnel coming from Chicago and Clinton."⁽³¹⁾

In this study as in Moshman's, the procedure used was to measure a one directional change. Moreover, in this study instead of using measurements of exposure data on individuals, the area where the individual worked was used as the gradient for exposure to radiation -- which could involve too great a dilution to show any significant change.

However, Knowlton's study and other observations suggest that a significant temporary decline in blood components might be discerned by a larger, long-term study of blood changes relative to

time and degree of radiation exposure. If so, the available data at Hanford and Los Alamos is becoming large enough to establish considerably better estimates of dose effects and temporal relationships or their upper limits, than have been obtainable previously. The medical staffs are eager to undertake such a study if they are given the necessary technical assistance for a task of this nature.

In the 1963 Annual Report on Health Operations at Hanford⁽³²⁾ we found the following observation:

"Correlation of the health of employees with exposure to radiation is carried out by means of epidemiological studies using cohort groups. Mortality rates of employees and retirees from causes such as leukemia and certain forms of cancer are carefully compared with control groups to detect statistically any evidence of radiation effect. Such studies have continued since 1944 and have shown no correlation to date. When autopsies are performed on people dying in the local hospital, specimens of various tissues are examined for radioactivity. This is used to detect any deposition of radioactive material which might have been missed during life. A study continues to determine if there are any changes of statistical significance in offspring of HAPO employees who have secured the greatest exposure to radiation at work as compared to the offspring of unexposed people living in the same community and otherwise comparable. Blood elements of employee groups have been carefully tabulated and periodically subjected to statistical analysis for comparison with control groups.

These attempts of the Occupational Health Operations to study the comparative health status of the employed population are most gratifying, but the findings cannot be considered to prove that there are absolutely no adverse physiological effects from ionizing radiation at the low levels to which most Hanford employees are exposed. There is also serious question whether the death-rate criteria chosen, i.e., the death rates of the Metropolitan Life Insurance Company's Industrial Policy Holders, and that of the general population, are appropriate "controls". We know that persons currently employed are a select group. This selection is demonstrated by comparing death rates of workers who are currently employed under Social Security coverage with those not in current employment. Myers⁽³³⁾ shows the age-adjusted death rate for all males in 1955 was 12.0 per 1,000. For all males insured under Social Security coverage, the rate was 10.8 per 1,000; for insured males with earnings in 1955, the rate was 7.1 per 1,000; and for insured males without earnings in 1955, the rate was 18.2 per 1,000. The death rate for insured male workers in comparison to the death rate for all males in the population is 90% for all Social Security-covered males, 59% for covered workers with earnings in 1955, and 152% for covered workers with no earnings in 1955. Thus, death rates of the general population are not appropriate controls for death rates of currently employed groups. This is even more true with respect to Industrial Policy Holders of Metropolitan Life Insurance Company.

A second serious limitation of these studies is that they have all been limited to the population that has stayed at Hanford and have not been extended to those who worked at Hanford and then left. There could be an adverse selection for those who have left Hanford. To be able to assess any possible adverse health effect from working at Hanford, we must consider the entire "exposed" population and not merely those who have remained on the job. The health staff has not had the means to make studies that are free from these and other limitations. Another factor that one must account for is the greater availability of health care for Hanford employees, who (other things remaining equal) should show a somewhat lower death rate. These limitations are equally applicable to a number of specific published studies⁽³⁴⁻³⁶⁾ by the Hanford Health Staff, the findings of which are more or less summarized in the 1963 Annual Report. All of the findings fail to show any adverse effects from continuous exposure to low levels of radiation.

All of the studies examined so far have dealt with somatic effects of ionizing radiation which, if not lethal, appear to be largely reversible when the dosage is relatively low. This may be the probable nature of many somatic changes in response to low-level of dose. In other words, for most if not all somatic effects, there may be a threshold dose. In fact, in some respects there may be several thresholds: a threshold below which there may be no adverse effect; another threshold below which the effects might be reversible; and a third threshold for non-reversible lethal effects. Genetic effects, which may have no threshold, will not be

included in the present studies. However, information and procedures developed in the present studies could be helpful in any future genetic studies of the occupationally-exposed populations and their progeny.

By and large, the occupational exposure studies that have come to our attention are extremely limited in scope and conception, and fail to do justice to the extensive body of data that is available to enlarge man's knowledge of any effects resulting from low-level, chronic exposure to ionizing radiation. To establish effects where reversible changes are possible or where responses are dose-rate and time dependent, the time of exposure in relation to various physiological changes must be studied, yet little attention has been paid in previous occupational exposure studies to pin-pointing the time of exposure in relation to the time of observation of effects.

Methods are now available⁽³⁷⁾ for tracing previous employees through the Social Security Administration and removing some of the limitations that were unavoidable in previous studies. Deaths as well as causes of death may be traced with sufficient accuracy for mortality studies, and other important parameters^(37,38) such as age, sex, and previous employment may be obtained through Social Security Administration resources. Also, computer facilities are now more widely available throughout AEC facilities and other agencies.

Therefore, higher priority should be given to mortality studies in the proposed test runs. Records of external radiation exposure

for the entire population of atomic energy workers since 1943 will probably show to date a population exposure of about 10^6 man-rem with an average period under observation since exposure of about 10 years per individual. This is a rough estimate utilizing validated exposure records at two atomic energy facilities,⁽⁷⁾ information accumulated in the first year of this feasibility study, and certain similarities between the operations and the exposure distributions in the facilities examined and those found in the total atomic energy worker population.

This value of 10^6 man-rem of occupational exposure, above natural background and medical exposure, may be compared with an estimated acute exposure to the Hiroshima and Nagasaki population of no more than several million man-rem received under conditions of less certain dosimetry and associated adverse stress from other causes. Also, the cumulative employee population dose will continue to increase for years to come. Thus, over a period of years the routine data recorded within the atomic energy industry, with perhaps some further additional record-keeping practices, will be a most valuable and continuing source of data for studying the effects of long-term, low-level irradiation of human populations.

One of the purposes of this report is to emphasize the full dimensions and nature of this undertaking and its long range implications, and to expedite steps and administrative decisions for the establishment of a central resource for the orderly accumulation and analysis of past and forthcoming experience and the continued surveillance of all workers in AEC installations. This undertaking preferably should be carried out concurrently with any

test run of selected facilities, or as soon as possible.

A major objective of the proposed test runs would be to develop the personnel, data handling systems, and scientific methods that can be utilized in more comprehensive studies of the entire population of employees in the atomic energy industry.

The concept of feasibility may be considered within the objectives of: (1) determining the long-term biological effects of radiation and other environmental exposures in AEC installations, which may occur up to 40 years or more subsequent to exposure or in subsequent generations, and (2) utilizing the human exposure data of large numbers of employees in these installations for the development of further criteria for permissible levels of radiation exposure. The concept of feasibility then, in terms of these objectives, may be expressed in the form of a number of related and important questions:

- (a) Is it possible or feasible to derive meaningful information from the records of AEC and AEC Contractor installations, which have accumulated over the past 20 or more years? Or, will this early human experience of a unique nature be lost forever?
- (b) In what way, or by what methods and combinations of resources, can the accumulated records of the past 20 or more years be utilized for the objectives specified? What supplementary data, effort and resources are required?

- (c) Are the populations large enough to establish with reasonable certainty the consequence of exposure to low-level radiation over protracted periods? This question is considered further in Section IV.
- (d) What would be the magnitude of the costs of accomplishing (a) and (b)? Can such expenditures be justified in the light of our available knowledge or the lack of it?

The emphasis, then, of the feasibility study relates to the past, in order to derive from this unique human experience of exposure to radiation the pertinent observations on mortality and morbidity. However, while the central interest of the Commission is in hazards from ionizing radiation, the study of occupational hazards of employees in the different installations should not be restricted to radiation only. It is believed that the project should encompass the complete industrial environment in which the employees of the different installations work, and the impact of this environment on the worker as a biological specimen. Indeed, an investigation of all environmental factors is essential if we want to avoid erroneous conclusions and interpretations of the data, perhaps attributing to radiation certain biological effects that may be due to other factors in the working environments of the AEC installations.

Similarly, it is important that there be no further delay in the development of resources and procedures for the conversion of accumulated records into forms accessible for comprehensive analysis and correlation studies, so that no further loss of information is incurred through the death of current or former employees, the death or resignation of key medical and industrial hygiene personnel, or the loss or destruction of early employment, medical or exposure records by governmental, industrial, or insurance agencies. It is believed that the proposed studies would make it possible to develop the methodology and the approaches necessary to answer the basic questions raised pertaining to the effects of chronic low-level radiation exposures. It would not be expected that definitive answers could be derived from a test run study of selected facilities over a limited period of time. To accomplish this purpose, continued surveillance and analysis is required of persons already exposed, followed to the end of their life span.

III ACTIVITIES AND OBSERVATIONS OF CURRENT YEAR

A. General

Fourteen major AEC contractor installations (listed in Appendix B) were visited in the first eight months of this project and the nature and extent of personnel, medical, and radiation exposure records was ascertained in terms of completeness and suitability for epidemiological studies of the kind carried out on other (37) environmental factors of industrial exposure. During these visits we found that the questions posed by the Industrial Health programs of these facilities had been concerned mainly with selection of suitable employees and the overall protection of individual health.

The nature of the product and purpose of the AEC installations, and the rapid development of these installations in the early years of operation, required the adoption of policies and procedures of relative caution in regard to radiation exposure. However, the practices pertaining to personnel, employment, and medical records were necessarily set up in an ad hoc manner according to the needs of each installation, and these practices tended to continue over the years, with some exceptions. In general, no long range plans have yet been initiated to provide records systems for the scientific evaluation of biological effects of lower-level radiation exposure for the various population groups in all AEC installations. However, some of the pioneers of the AEC industrial medical programs and health physics programs recognized the potential value of the long term retention of

medical and health physics data and this has established a considerable basis for the epidemiological investigation of occupational exposures vs. health effects.

On the basis of these visits, and questionnaires sent to Hanford and Oak Ridge (Appendix A and Table 10), it has become apparent that each installation is unique and different, and that it would be unwise to generalize from some of them to all, regarding the availability, reliability, completeness and accessibility of their basic records over the years. However, as indicated in the review of activities and conclusions given in the introductory section of this report, sufficient information is available in the various facilities to make the initiation of mortality studies worthwhile at this time.

In this section of the report, a brief summary is presented of the visits to the various AEC installations during the current project year that lead in the following sections to the proposed procedures for continuing studies, the conclusions, and the recommendations. The summary cannot convey all of the detailed information obtained in the many interviews conducted by the several project investigators, but will cover only some of the more important observations pertinent to planning the further studies that are deemed feasible. Detailed transcriptions of the recorded interviews and notes will be retained in project files at the University for further reference as needed.

Also included in this section are: a discussion of the availability of radiation exposure records and tentative criteria for abstracting radiation exposure data, discussed in more detail in

Appendix C; a discussion of a preliminary verification of population exposures recorded in an atomic energy facility by re-reading and re-evaluating 11-14 year-old films under relatively adverse conditions typical of some early atomic energy operations (see Table 9); crude estimates of the minimum number of person-roentgen-years at risk in several AEC installations (Table 7); and a summary of personnel, medical and radiation exposure data retained at the Hanford and Oak Ridge facilities, as obtained from questionnaires submitted in March, 1965 (Appendix A and Table 10).

B. Type of information Requested during Visits to AEC Installations

In general, the preliminary visits to fourteen major AEC installations were made to determine what types of personnel, medical, and exposure records had been kept over the years and retained so that they might be useful in a radioepidemiologic investigation of any possible long-term effects of occupational exposure to radiation. A relatively large fraction of the atomic energy population was included in the initial series of visits since the nature of operation and types of records retained varied from one facility to another. Thus, it was necessary to ascertain: (a) whether the test run feasibility studies suggested in Section IV could be efficiently extended to the entire atomic energy population at a later date, and how the initial studies would have to be designed if such a later extension were to be feasible; (b) what facilities would be the most desirable facilities in which to begin test runs as a result of:

- (i) relatively large populations of workers exposed to radiation;

- (ii) relatively long periods of operation to allow any diseases with long latent periods a chance to appear;
- (iii) relatively complete records identifying the employed population, their radiation exposures, and other environmental exposures, dating back to as early a period in the atomic energy program as possible to include also the experience during the early years when exposure limits were not as low or as well observed as in more recent years;
- (iv) relatively complete representation of the types of radiation exposure and other environmental exposure to which employees of the atomic energy program may be exposed.

The interviews at the various installations included administrators and employees of the Personnel, Records, Insurance, and Security departments of each facility, as well as the Medical, Health Physics, and Industrial Hygiene departments. The questions asked during the preliminary interviews included questions regarding the identification of employees, the tracing of their employment and medical histories, the measurement and recording of their radiation exposures, the possibilities of exposure to various environmental agents and stresses other than radiation, and the availability of information or records from which such environmental exposures could be assessed. Information on other possible stresses would be needed in any study of health effects of radiation exposure, since many other types of agents can induce or

influence the induction of the same types of diseases that have been found to be produced by radiation in other human studies at higher dose levels. Therefore, a knowledge of other environmental exposures would help in designing the investigation so that effects that might be produced by other agents in exposed or control populations would not be erroneously attributed to the presence or absence of radiation effects.

The following types of questions were asked during the visits to AEC installations:

Questions posed to Personnel, Medical, Insurance, Security, and Records Departments.

- (1) What were the general activities and exposure hazards in the facility over the years since the beginning of operation?
- (2) What were the sizes of the employed populations and the exposed populations over the years of operation?
- (3) Can the total number of separated employees be estimated?
- (4) Can the total number of employees who have worked more than 1 or 2 years be estimated?
- (5) For what years of operation is the name of each employee currently retained on some form of record?
- (6) (a) Is it possible to obtain a complete roster of all applicants who sought employment in each AEC installation? Could the Social Security Numbers be available for these persons? Would PSQ forms be available for these persons?
(b) Could a complete roster of all those who had a pre-employment examination be obtained? Would Social Security Numbers be available for these? Would PSQ forms be available?
(c) Could a complete roster of all those employed at any time in any AEC installation be obtained? Would Social Security Numbers be available? Would PSQ forms be available?

- (7) For what years has the Social Security Number been retained in personnel or other records?
- (8) What other personal identification number may be used to interconnect data from various departments?
- (9) What other identifying characteristics are retained relating to age, place of birth, race, sex, marital status, veterans status, dates of entry and termination of employment, occupation, department, or work assignment?
- (10) What medical records are retained pertaining to pre-employment and periodic physical examinations, or other visits to the medical department or laboratory tests?
- (11) What records are available concerning the reasons for separation or termination?
- (12) What information has been retained on work restrictions for reasons of handicaps or previous environmental exposure?
- (13) For what years has the Personnel Security Questionnaire been retained?
- (14) What type of health insurance plans have been available to employees and what records have been retained of claims processed?
- (15) What Workmen's Compensation claim records have been retained?
- (16) In what form are records retained for current and former employees?
- (17) Where can records be obtained identifying personnel employed in the early development of atomic energy by Universities and other agencies?
- (18) What records have been destroyed and how can they be reconstructed?

- (19) What records have been converted to automatic data processing (ADP) format on IBM cards or magnetic tape? What additional records are currently in process of being put in ADP format?
- (20) What studies have been carried out of employee health status as a function of radiation or other exposure?
- (21) What reports are available regarding radiation exposures, other exposures, and biomedical effects?

Questions on Environmental Exposure Control Methods, Measurements & Records

- (22) For what years of operation have records of individual "whole body" or "penetrating" radiation exposure been retained for monitored employees?
- (23) What other records are available to identify personnel who may have been exposed to external radiation?
- (24) What records are available to identify persons exposed to other environmental agents and to assess their cumulative or average exposures? What records are kept regarding the use of various toxic metals or materials in each plant? What records are available as to the time these materials were used, the areas in the plant where they were used, the nature of the use, and the quantities used?
- (25) For what years of operation would the following items be available on personnel monitoring or personnel records?
 - (a) Name
 - (b) Initials
 - (c) Social Security Number
 - (d) Other employee number linked to personnel records
 - (e) Age or birthdate
 - (f) Sex
 - (g) Job classification
 - (h) Work location
 - (i) Dates entering employment
 - (j) Estimated dose for wearing interval
 - "skin dose"
 - "whole body" or "penetrating dose" total

Total gamma dose (including "Hard" x-rays)

Thermal neutron dose

Fast neutron dose

Beta dose (including x-rays less than 10 kev)

(k) Cumulative Quarterly Whole Body Dose

(l) Cumulative Annual Whole Body Dose

(m) Cumulative Lifetime Occupational Dose

(n) Exposures received in previous employment

(o) Other types of exposure such as medical x-rays, tritium, bioassay results.

- (26) What were the average numbers of persons monitored with film badges each year: total; regular employees; temporary employees; visitors?
- (27) What were the frequencies of badge changes, or what were the total numbers of badges issued each year?
- (28) When were the badge types introduced? Are any report references available?
- (29) When were new methods of interpretation introduced?
- (30) What were the numbers of persons wearing pocket chambers each year?
- (31) Are relatively complete pocket chamber records available on any employees for any years for comparison with film readings?
- (32) Have measurements or estimates of diagnostic or therapeutic medical x-ray exposure dosage in roentgens been made for:
 - (a) In-service medical x-ray procedures carried out by facility physicians?
 - (b) Medical x-ray procedures carried out by private physicians?
 - (c) Medical exposures received prior to employment?
 - (d) Other sources known to the facility physician?
- (33) What previous occupational penetrating radiation exposure information has been requested from employees or former employers? For approximately what percentage of employees with possible exposures in previous employment is the

- previous exposure obtained and included in medical, radiation exposure, or personnel records?
- (34) What radionuclides have been included in excretion analyses?
 - (35) What information is available by calendar year on: the numbers of persons under routine surveillance for internal emitters; the frequencies of sampling or whole body counting for each radionuclide; the form in which records are available for each calendar year; the lower limit of sensitivity for each analytical procedure; and the level above which additional control procedures would be instituted or investigated for reduction of exposure?
 - (36) What records would be available on specific, non-routine, bioassay or in vivo counting investigations of exposed personnel?
 - (37) Is any descriptive material available that would be helpful in understanding methods of internal dose control and analysis?
 - (38) What names and addresses can be provided of any current or former employees who might be helpful in supplying information or leads useful in investigations of early or recent exposure histories?
 - (39) What kinds of records are available for each year of facility operation and where are they located, for the following types of qualitative or quantitative data:

see following page

(a) Results of general air samples for alpha or beta emitters or other environmental agents. Include information available on areas in which samples were taken, any means of determining which employees may have been exposed in these areas, frequency of sampling, duration and volumetric air flow rates of samples, types of collectors, methods of measuring radioactivity and calculating air concentrations and particle-size or radiochemical analyses on collected samples.

(b) Breathing-zone sampling and time-weighted average exposures that may have been carried out either routinely or for special repetitive operations, including information similar to that requested in (a) above for each year of plant operation?

(c) Area surveys for external beta, gamma, or neutron exposure or dose-rate estimation?

(d) Surface contamination measurement records that might provide some additional indication of areas in which loose radioactive materials were present to a degree that could possibly have produced inhalation or ingestion exposures?

(40) Were any respiratory or other protective devices or operational procedures utilized that should be considered in the assessment of the degree of importance of various exposure situations?

(41) How many years of quarterly or annual "whole body dose" or "penetrating dose" are recorded in an automatic data processing (ADP) format - computer tape, IBM cards, etc?

(42) Can cumulative dose information in automatic data processing (ADP) format be retrieved for each employee for each year of exposure?... for each calendar quarter of exposure?

(43) Are "beta", "skin" or "open window" exposures recorded on ADP format for each year or calendar quarter of exposure?

(44) Are penetrating exposures from neutron radiation included in the whole body dose recorded in ADP format? Are other types of radiation included in the "whole body" (penetrating) dose estimates? Approximately what fraction of the population cumulative man-rem dose might be attributable to soft radiation that does not penetrate tissues deeper than about 100 mg/cm²?

Questions on Cost Estimates

(45) What would be the approximate labor requirements and costs for your facility to complete the abstracting and recording of the following information on magnetic computer tape, using any methods already developed or proposed by your staff:

(a) Whole body (penetrating) dose in rem for each employee for retrieval of cumulative annual exposure for each year of plant operation?

(b) Same as in (a) for each calendar quarter of plant operation?

(c) Additional inclusion of "open window", "skin", or superficial tissue dose at about 100 mg/cm² depth or less, for each year or each calendar quarter of exposure?

(46) How much additional cost would be entailed, if any, to provide identification of each employee in ADP format with his Social Security number?... with his identification number in the personnel files?

(47) What types of bioassay or in vivo counting data are currently recorded on ADP format?

(48) What would be the cost and manpower requirements to complete the recording of recordable bioassay and in vivo counting data on tape in terms of:

(a) estimated radiation dose in rem, where possible, for each calendar year to principle body organs involved;

(b) average activity concentrations in principle body organs for pertinent radionuclides;

(c) individual bioassay spot sample measurements by date of measurements;

(d) Any other clues to possible internal exposure?

The answers to most of these questions were obtained in informal interviews during the first round of visits to the fourteen AEC installations (Appendix B) and are recorded in notebooks and in hundreds of pages of tape transcriptions for future review and reference. No extensive tabulation of the data obtained has been attempted. However, the information gained during these interviews lead to an early impression, reported at the July 31, 1964, and September 28, 1964, meetings with the AEC staff, that many types of studies would be feasible, and that the number of studies attempted would be limited primarily by economic considerations. Also, it seemed advisable to begin large-scale studies on a limited basis in order to proceed most efficiently and utilize information gained from the smaller studies to design future investigations for the entire population of AEC contractor employees, if this is subsequently desired.

The September 28 meeting also resulted in narrowing the scope of the feasibility study (NYO-3394-1, Oct. 12, 1964) to emphasize mortality investigations based primarily on death certificates traced through Social Security records of deceased beneficiaries, since the methodology for this approach had already been shown (37) to be useful in other industrial epidemiological studies.

As a result of the early conclusion regarding the feasibility of useful mortality studies, using various methods of classifying "exposed" and "control" populations, plans for further work were made taking into consideration that any test run studies should be carried out on a few facilities in such a manner that the methods and data developed could be easily extended to later studies of the entire AEC contractor population.

From October to December, preliminary visits were made to the Los Alamos Scientific Laboratory, the Sandia Corporation, National Reactor Testing Station in Idaho, and the Argonne National Laboratory in order to further test the previous conclusions regarding the types of test runs desired, and to obtain further comments, suggestions, and information relevant to the project. These further visits did not reveal any strong reasons for changing the general types of test runs discussed at the September 28 meeting.

Thus, in December and January, questionnaires listing the specific items of information (given in Appendix A) that might be useful in planning the proposed 5-year test runs on mortality were prepared for distribution to the major facilities at Hanford and Oak Ridge to be included in the test runs (Section IV of this report).

The requested items of information and cost estimates were explained in more detail in the questionnaires and by telephone and personal interview in March 1965 at Hanford and Oak Ridge. The questionnaires and the March visits to Hanford and Oak Ridge were designed to obtain a more complete picture of the availability of information to be required in the test runs, and cost estimates for abstracting the required data at each of the installations and programming the data for retrieval on the automatic data processing equipment at Hanford and Oak Ridge.

Toward the end of the March visits to Oak Ridge, the minimum number of items required for mortality studies were given to Central Data Processing personnel at K-25 in Oak Ridge, so that they could begin trial runs on data abstracting and processing within Oak Ridge facilities. These essential items to be incorporated on current ADP equipment were (WHERE POSSIBLE):

- (1) Name, with first name spelled out and all initials provided,
- (2) Social Security Number,
- (3) Payroll Number, or other facility identification number,
- (4) Date of Birth-day, month, year,
- (5) Color-white, non-white
- (6) Sex
- (7) Veteran's Status
- (8) Date (s) of entry into employment
- (9) Date (s) of separation (or termination)
- (10) Date of death of deceased, if known
- (11) Occupation

- (12) Job Code (s) and Dates of Change
- (13) Department (s) and Dates of Change
- (14) Annual Total "Whole-Body" Radiation Exposure (including zeros for years monitored without any exposure received)
- (15) Annual "skin" or Superficial Tissue Exposure Indicated by Film Badge
- (16) Dates (by year) of Exposure to Intake of Radioactive Materials, and specific nuclides as indicated by bioassay, whole body counting, or air sampling
- (17) Dates (by year) of Exposure to Other Environmental Agents
- (18) Total "Whole Body" Radiation Exposure Recorded from Previous Employment, where available.

With the information available after the Oak Ridge visits in March, another meeting was held on March 22, 1965, with the staffs of the Divisions of Biology and Medicine and the Division of Operational Safety at AEC headquarters. At this meeting some of the additional limitations on information available on early cohorts at Oak Ridge were discussed, and a revised proposal with revised cost estimates was outlined for a five-year test run on the three Oak Ridge facilities, the Hanford facilities, the University scientists connected with the early development of these facilities, and several other plants representing the smaller AEC contractor populations in the early years, as discussed in more detail in Sections IV-VI of this report and the revised contract Renewal Proposal, Report No. NYO-3394-3 (Revised, April 1965).

C. Summary of Observations at Hanford

The interviews at Hanford included various administrators and personnel in the AEC Operations Office, the Medical Department under Dr. W. D. Norwood, the Radiological Sciences (Health Physics) under Mr. Arthur Keene, and the Personnel, Insurance, and Records Departments.

All medical records have been retained that might be pertinent to this project, for cohorts beginning employment in 1944 and those beginning in each subsequent year. The records and original slides of blood smears taken from radiation workers have been retained since 1944. These smears are still obtained at least annually and constitute a possible source of data for continuing hematological studies in this installation, although they have not been included in the currently proposed test runs.

The Hanford staff has carried out some evaluations of this data (a ten-year study having been completed in 1960) and will probably continue these follow up blood studies on a limited basis. The ten-year study was said to show no positive correlations of blood changes with radiation exposure, but they are continuing to retain smears on radiation workers. The smears are apparently retaining their quality over the years.

Pre-employment and periodic examinations also have yielded chest x-rays and urinalysis records since 1944. Periodic examinations are conducted every two years, with laboratory tests, urinalysis, and x-rays in the intervening period. An indefinite retention value is placed on all medical records. The urinalyses for radactivity may include any or all of the following nuclides, depending on where the employee works: Pu-239, H^3 (>1 uc/liter),

C-14, S-35, U-nat, U-235, Sr-90, and Pm-147. Personnel are now measured in the whole body counter for Zn-65, Na-24, Cs-137, K-40 on a regular basis and for several other nuclides in special situations. They are also developing a multi-crystal array for the detection of Pu-239 in the lung. If persons were previously employed in work involving radiation exposure, their previous exposure history would have been requested, but the completeness of this information would not be certain. The Medical Department would not have any record of the subsequent employment of terminated employees.

Beginning in 1949, autopsy data has been obtained on 50 per cent of the former employees who have died in the Richland Hospital (Kadlec Methodist Hospital). About 300 cases have been obtained as of May 1964 in which the pathological findings in one or more organs can be compared with bioassay data on radioactivity taken into the body and external radiation exposure received. Control autopsy data are also obtained on non-exposed members of the community. This program is continuing and statistical analyses will await the accumulation of more data.

The total number of employees who ever worked at Hanford is 137,000, including construction workers. For a number of years, there has been a fairly stable population of about 8,000 monitored workers, who have an average length of employment of about 8-10 years. Before 1946, the plant population numbered over 50,000, but then dropped to 4,000 in 1946, then up to 9,300, and then to a fairly stable population of 8,000. The total number of current and separated GE employees is about 30,000-35,000.

The Records Center has a complete inventory of records and where they are. The Center has been supervised by a Mr. Earl W. Slusher since the early years of the program. Complete lists of persons on the payroll can be constructed from 1946 onward from records at Hanford. The duPont employees who did not remain at Hanford when GE took over in September 1, 1946, would have had their personnel folders transferred to Wilmington, Delaware. The criteria set up for records retention follow the Federal Records Act of 1942, and the requirements are written as AEC policy in the Records Management Handbook. Records of entrance and termination examinations of construction personnel have been destroyed.

The Records Center has also retained all records of radiation surveys, environmental contamination measurements, personnel radiation exposures, radiation instrument calibrations, and radiation exposure incident investigations. Investigations have been made whenever an employee exceeded 1 rem per month. The film badge records alone take up 5,000 cubic feet, including 2500 cubic feet of space for the stored films.

Medical and hospital insurance now covers over 99.9 per cent of the employees and has been written from the beginning with the Metropolitan Life Insurance Company. About 75 per cent of the employees were covered in 1946, 93 per cent in 1955, and 99.9 per cent in 1964. Coverage for Workmen's Compensation has also been in force since 1944. When the plant first began operating the nature of the operation was not clear, so special legislation was passed in 1943 permitting operation under a "war project insurance rating plan". This claims service is similar, however, to that

for any other industry in the State of Washington. Also, there is a one-year statute of limitations, but a person with leukemia 20 years after employment could still file a claim and have it judged as work-connected by the State. The Workmen's Compensation specialist keeps a card file and claim file. Thus, these types of claims could be a possible source for identifying work-connected illness or deaths of former employees.

The employment application form has contained essentially the same information since 1945, including the name; educational background; birth date; social security number; mother and father; husband or wife; number of children; and previous employers.

There are three separate job classification systems: one for monthly salaried employees, a second for union-represented weekly employees; and a third for non-union weekly salaried employees. But there is no code that would point out where the people worked at a given point in time. The union-represented jobs are broken down along craft seniority lines. Millwrights or pipe fitters may work anywhere in the plant with the same job title. Only the organization or department in which a man is assigned would have information regarding his actual work location. If a man worked for maintenance in the Chemical Processing Department, Personnel would know only that he worked either in the "200" areas or one of the separations plants. The operating technicians are divided into four major groups: the reactor operators, the separations operators, the fuels preparation operators, and the power operations group. Out of 8,000 personnel, about 3,700 are represented by unions.

The job codes for the non-union weekly salaried workers may give more information about the environment than the codes for union personnel. For example, a Chemical Analyst, Radox Control, would work as a laboratory assistant in the radox plant. These job categories would include mostly non-production personnel of the technician type and office personnel.

The monthly-salaried category includes supervisory, professional, administrative, and management personnel. There would be a job description for each of these jobs. There are about 2,600 personnel in the monthly category.

Thus, although an individual may also be identified by a payroll-suffix-organization code, giving departments, sections, and sub-sections to which an individual may be assigned, there is no foolproof way of determining what the employee was doing each week. One would have to inquire about the individual employee directly with the supervisor involved. However, the sign in and sign out books kept for individuals entering production or laboratory areas may give an indication of work locations of employees if these have been retained. Also, hand and foot counts used to be recorded for every individual entering a potentially-radioactive area, but these records are kept now only if certain radioactivity limits are exceeded.

There may be a Manhattan Engineering District History that would give a list of the early management personnel associated with the Hanford facilities before General Electric (GE) took over in September 1, 1946. This history would also give the numbers of personnel employed during the early years, but not the names.

Copies are available at Hanford and in Washington, D. C. The duPont Hall of Records, Wilmington, Delaware, was believed to have retained the rosters of individuals who were employed and terminated before GE took over on September 1, 1946. These early workers were divided into the operations and construction groups. For government employees, the individual's "201" file would be maintained in the Federal Records Center in St. Louis. About 1500 of the persons who transferred to GE in 1946 were still employed at Hanford in 1964.

About 1,115 persons had retired from employment at Hanford as of May, 1964; about 800 of these were at normal retirement age. About 400 deaths have occurred among these retired employees, and records of these deaths are retained by the Medical Department. The age-standardized mortality rates for Hanford employees have been running about 60 per cent of the State and National average, as estimated by the Medical Department, which is to be expected for an active working population. (33)

The possibility for appreciable radiation exposure began in 1945 with the start-up of production reactors. It would be difficult to identify control groups of workers who were employed for a long time and not exposed to some amount of radiation. However, policies have been very conservative at Hanford throughout the years and a limit has been imposed of 3 rem/year, below the AEC current limit on permissible average exposure of 5 rem/year after age 18, and the limit of 12 rem in any one year. The majority of persons approaching the 3 rem/year operational limit work in the "outer area", where production reactor operations and chemical separations are conducted. All personnel entering this area wear film badges. Lower average

exposures are generally received in the "non-area" group, but these persons also wear film badges if there is any possibility of exposure.

Even for persons working on the tubes of the reactor, they have not generally missed recording exposures on film badges. Health physics technicians monitor the operations where personnel may be exposed to dose-rates that could cause them to exceed permissible dose limits. A routine operational dose limit of 300 millirem per week is also usually maintained so that the radiation exposures are usually spread out during the year. Unexplained high doses have been almost non-existent. One of the persons interviewed surmised that, "We don't miss any important doses".

Several accidental exposures have occurred that have exceeded the routine occupational exposure limits for whole body exposures, but accidental exposures still have generally remained below 10 rem. One accident occurred in 1962 involving 3 men, one of whom received 111 rem in one instance, the other two receiving 43 rem and 19 rem. However, the highest-exposed worker in 1962 was only 15 per cent in excess of his maximum permissible cumulative lifetime dose of 5(N-18). In 1953, three individuals received high accidental exposures of 300 rem, 300 rem and 430 rem involving the extremities (hands), as indicated by dose calculations. When the film badge cannot be interpreted accurately for some reason, or when a serious exposure has occurred, an independent investigation of the incident is made and film badge readings may be replaced with dose calculations from a mock re-run of the accident. However, the dose recorded from the film badge was generally

believed to be representative of the actual dose. Some field tests were carried out at Hanford that showed badge wearing position and directional dependence were not important variables in most operations.

Only 3 persons have exceeded the permissible body burden (MPBB) of Pu-239. Previously if a person exceeded more than $1/5$ of a body burden, he would be restricted from further external exposure until his burden decreased. Now, a person may be allowed to receive limited occupational external exposure if he contains less than $1/2$ the MPBB. Several hundred persons have had measurable amounts of Pu-239 inside their bodies, mostly obtained by accidental injection of slivers through wounds. However, less than 20 have received significant internal exposures from these body burdens.

In general, to be on the safe side, Dr. Norwood would excise tissue at the site of injection to remove Pu-239 if more than 10 per cent of the MPBB was injected. In one accidental case, for example, 900 MPBB of Pu-239 were excised, another MPBB was washed out of the wound locally using DTPA as a chelating agent, another 25 per cent was removed during the first day by excretion in urine after injection of DTPA, and about another 2-3 per cent was removed by injection of DTPA. After the second day, removal by DTPA was very slow. Generally, when DTPA is first administered it is assumed that the daily urinary excretion is increased by a factor of 75.

The dose to the bone and lung are then estimated from the normal urinary excretion rate, the urinary/fecal excretion ratio, and W. Langham's equations relating organ burdens to excretion

rates. The usual uncertainties are present, but estimates are improved over a period of time. Usually, Pu-239 is taken into the body either by injection or inhalation, as a metal or an oxide. Exposure to uranium and other airborne contaminants would be minor at Hanford.

Film badge records of radiation exposure had been retained since 1944, although about three types of film badges had been used between 1944 and 1965. The first badge was used about 10 years, the second about 5 years. Good calibration data has also been retained over the period. They also can go back and secure the actual individual inputs concerning the estimated measured dose for each person for each film badge wearing interval. The data are in less readily available form for the early years, however, since computer processing of data was begun about 1956-57. Film badge records include name, payroll number, age, and job classification, as well as penetrating and skin doses. Social Security Numbers were included in 1964. No cumulative dose record is retained on pocket chamber readings.

Occupational exposure received in previous employment is requested for employees and recorded where obtainable. No record is made of diagnostic medical exposures, but a study of typical exposures to various procedures has been made.

Eighty per cent of these employees have received less than 1 rem whole body dose. About 200-300 individuals receive measurable exposures to the low-energy 16 kev x-rays from Pu-239, but their film badges have been calibrated to measure the radiation for the past few years. Before that, plutonium x-rays were not a major

part of the external exposure. X-rays between 16 kev and 50 kev are not important at Hanford, but the 16 kev x-rays do produce a significant fraction of the current exposures for these identified plutonium workers. Although most of the 16 kev radiation is absorbed in the skin, the gonadal dose from the 16 kev radiation is assumed to be about 1/3 of the skin dose. The background external radiation dose-rate at Hanford, about 400-700 feet above sea level, is about 120 mr/year.

During the period 1960-62, between 13,178 and 13,597 individuals were provided film badge service, but less than 10% of these persons had annual exposures exceeding 1 rem, according to the Hanford reports. Only 4, 1 and 17 persons during these years 1960-1962, respectively, exceeded 4 rem/year, and the highest exposures each year were 4.6 rem, 4.5 rem, and 111 rem. The figure of more than 13,000 badged individuals includes government, construction and visitor personnel as well as regular GE employees. Of the regular GE employees monitored in 1964, about 1800 were laboratory workers and 7,000 were employed in reactor and production areas. The population has been fairly stable through the years since about 1947-48.

Although the individual dose records for every person ever monitored are being put on microfilm and a monthly breakdown of dose readings will be more easily retrievable in the future, the computer currently retrieves only cumulative exposure as well as current annual exposures.

The distribution in cumulative exposures for the year 1962, for example was:

Percent of MPD*	Percent of Work Force (GE employees only)
< 1%	57.0% (4688 employees)
$\geq 1\%$	43.0% (3533 employees)
$\geq 5\%$	16.0% (1332 employees)
$\geq 10\%$	8.0% (676 employees)
$\geq 20\%$	1.6% (130 employees)

Total 10,359 employees

*The permissible cumulative dose (MPD) = 5 (N-18), where N is the age in years.

About 8,000 out of these 10,359 employees may possibly have received occupational exposure to radiation on a routine basis. Most exposures to gamma radiation except for the 16 kev radiation have been estimated from regular monthly calibration data since the early years of operation. An operational limit of 3 rem/year has been followed for many years. Tritium exposures have also been included in the whole body dose. Beta and neutron radiation exposures have been recorded and identified separately. Thus, the median cumulative per cent of whole body dose MPD for current employees may be expected to be less than 1%; for separated employees, we would expect the median dose to be even lower.

When the data above are fitted by a log-normal distribution on probit of per cent of population vs log (%MPD) scale, the median dose read from the abscissa is about 0.3% of MPD. We were

informed that the average length of employment was 10-12 years. The average age of employees was between 35-40 years. If we assume an average age of 38, with an average of 10 years employment, the allowable MPD for this "average" individual would be about $5(N-18) = 5(20) = 100$ rem, and the median allowable cumulative dose would be about $0.008 \times 100 \text{ rem} = 0.8 \text{ rem}$. From previous studies of cumulative exposure distributions,⁽⁷⁾ the average dose of the log-normal fit to the (skewed to the left) cumulative exposure distribution is about 4 times the median dose. Thus, if the same distribution is assumed for Hanford, the average occupational exposure would be estimated to be about:

$$\frac{4 \times 0.8 \text{ rem}}{10 \text{ years}} = 0.32 \text{ rem/year}$$

over the years of operation of the Hanford facility. A better estimate would have to await the processing of all Hanford exposure data on ADP equipment.

This average occupational exposure would be within the same order of magnitude as, but somewhat lower than, the average dose received by all workers in the United Kingdom Atomic Energy Authority of 0.56 rad/year in 1957, 0.44 rad/year in 1958, and 0.42 rad/year in 1959. (Reference 44, p. 125). It is also similar to the average exposures at two atomic energy facilities in the Pittsburgh area,⁽⁷⁾ and to the reported average occupational exposure of 0.43 rem in 1959 in Argentina. (Reference 3, pp. 23, 388, 409).

Thus, for planning purposes, if we assume an average whole body exposure of 0.3 rem per year to an average employed population

of roughly 8,000 workers over a 20 year period, we obtain an estimated population dose of about

$$0.3 \text{ rem/year} \times 20 \times 8,000 = 48,000 \text{ man-rem}$$

If we assume an average length of employment of 10 years, the average number of years under observation after an incremental exposure would be about 15 years. This would give a population exposure risk estimated in person-roentgen-years at risk (PRY)

$$48,000 \text{ man-rem} \times 15 \text{ years}$$

= 720,000 person-roentgen-years ("PRY" for the Hanford facilities as of 1964. (The PRY unit is used here as an interim indication of the order of magnitude of population exposure, and average years elapsed since exposure over which any long-term health effects that may exist would have a chance to appear. It is recognized that until a complete quantitative theory is available to predict any given disease under all dose, dose-rate, and time-duration conditions, no unique or simple unit can be defined that will yield any precise quantitative indication of risk.) Thus, the Hanford facility may provide one of the largest shares of the occupational population exposures of the AEC installations, as well as one of the best-measured and best-demonstrated sets of records.

Since the above estimate of risk is based on a series of assumptions that may not be valid for the Hanford facility, a lower and more conservative estimate of the population exposure-risk should be used for purposes of designing the utmost care and sensitivity into an epidemiological investigation. If we assume that only about 1,000 employees who were receiving exposures in excess of an average of 0.5 rem per year had real exposures and

that all personnel in the exposure distribution lower than the average had recorded readings produced by densitometry errors rather than radiation exposure, we would obtain a (probably minimum) estimate of about

$$\begin{aligned}
 &1,000 \text{ persons} \times 0.5 \text{ rem/year} \times 20 \text{ years exposure} \\
 &\quad \times 15 \text{ years average time elapsed since the} \\
 &\quad \text{average incremental man-rem exposure} \\
 &= 150,000 \text{ PRY}
 \end{aligned}$$

A better verification of this figure would have to await the abstracting and verification of all exposure data for computer processing. Nevertheless, it seems that Hanford would be one of the more likely facilities to include in further test runs. The estimated PRY value for the Hanford facility is compared with the range of values estimated for the Oak Ridge facilities and the National Lead Company of Ohio in Table 7. These estimates are similar to those presented at the July 31, 1964 meeting at the AEC, and are intended only to give a preliminary idea of the possible magnitude of the population exposure and study period available in these facilities.

The 1964 United Nations report⁽³⁾ (p. 84, Figures 2 and 3, and p-100, Tables II & III) show that the PRY for Hiroshima and Nagasaki victims would be at most 10^8 PRY, delivered in a single acute exposure, if shielding factors were neglected. However, for survivors, the shielding factor may have been 10 or more. From the population in Table IV of the UN report, including the majority of victims for whom shielding corrections were available, the PRY available in Hiroshima and Nagasaki is estimated to be about 30×10^6 or less, as of 1965, assuming that no significant portion of the surviving population could have been exposed to more than 400-600 rem.

D. Observations on Oak Ridge Facilities

Since Hanford was the first facility visited, relatively complete records have been retained since 1944, and many of the procedures are representative of those in other facilities, a more detailed summary of observations was presented for Hanford than this report could include for all fourteen of the facilities visited. However, a brief summary of the observations at Oak Ridge will be included below, since the Oak Ridge facilities have also been included in the proposed continuation of this project.

Under the guidance of Dr. C. S. Shoup and his staff, several visits were made to the three Oak Ridge facilities during the current project year. Each facility will be discussed separately since they operate under separate medical, health physics, industrial hygiene, and personnel programs.

ORNL:

This discussion pertains to those ORNL facilities at X-10, and any other included in the X-10 medical and health physics surveillance programs.

The Oak Ridge National Laboratory began as the "Clinton Laboratories" in the summer of 1943 when about 100-200 scientists arrived from the University of Chicago to join duPont and Army personnel and begin the development of the graphite reactor. Another few hundred technicians were also involved in the possible early exposures to radiation that occurred in the 1944-45 period. The laboratory was originally operated by duPont, then by Monsanto in 1945, and finally Union Carbide and Chemicals Corporation in March 1948. The total number of badges issued as of March, 1965

was 15,253. In no case did two different individuals have the same payroll numbers. Although different payroll numbers were issued to some individuals when they were re-hired in the earlier years, the total number of individuals currently and previously employed at X-10 number about 15,000. The current (March, 1965) employment is about 14,800 and there are about 10,400 terminated employees of ORNL. About 60-70 percent of the 15,000 were estimated to have been employed one year or more, the most rapid turnover having occurred in the 1943-46 period. About 5400 payroll numbers were used up to 1948; 5600 more were used by about 1952. The average turnover now was estimated at only 2-3 percent per year.

(45)

In the 1944-45 period, the film badge designed for energy independence down to about 70 kev was made available to radiation workers. The Health Physics organization surveyed operations at the reactor and in other areas and attempted to insure that the workers wore their badges and pocket dosimeters. However, in the early years, some of the employees who had not been accustomed to health physics procedures in previous radiation work would ignore safety requirements. Thus, it is possible that a significant fraction of the population radiation exposure was not recorded for cohorts beginning in these early years.

Since Carbide took over in 1948, the radiation exposure records are fairly complete and it is not likely that many important exposures have been missed. In a few cases there may have been clerical errors, or fogged films may not have been investigated, but some of these errors are being corrected as the staff abstracts and audits the data for processing by ADP equipment. Since 1953,

the X-10 Health Physics staff has also maintained the exposure records on the ORNL personnel who work at the Y-12 area.

The names of employees for cohorts should be available since 1943, but the Manhattan District employees may have to be sorted out from card files in the Security Office at AEC. Dates and results of medical examinations would be relatively complete after about 1950. All previous medical records are also retained at ORNL, except for the early University of Chicago staff. Occupations are available back to 1943, but PSQ forms at Oak Ridge have been destroyed for persons terminated more than 10 years.

Dr. Lincoln has carried out preliminary studies that indicate studies of morbidity or absence rates using facility records would not be likely to yield any definitive information regarding low-level radiation effects. (21) However, Lincoln has recently processed through the Social Security Administration 204 separated employees of ORNL who were deceased and who had been employed more than 1 year at ORNL. The Social Security Administration correctly identified these 204 deaths, 146 of whom died in Tennessee and 58 of whom died in other states.

Thus, cohorts could be followed for their mortality patterns with identification and radiation exposure data back to 1948, and possibly back to 1943 with some exceptions. Environmental exposure data other than for radiation would be lacking in many years of operation. A large enough population may be expected to receive definite radiation exposures so that it can be characterized by many other environmental and personal factors, and an attempt may be made to develop internal controls who are stratified by these

other factors in the same way as the exposed population. Of course, the population should be divided and stratified a number of ways to help avoid false associations between radiation and health effects.

The main X-10 area exposures have been derived from production and distribution of radiosotopes produced in the reactor, and from research and development work in the chemical processing of fuel elements for recovery of certain fission products and uranium and plutonium. As much as 10,000 or more curies of concentrated fission products may be processed at one time. Most of the population dose at X-10 is external radiation from fission product gammas, although some neutron and beta exposures are encountered. Film badges are currently evaluated for these radiations, and special evaluations are made whenever low energy x-rays are encountered. Very little Pu-239 inhalation exposure is incurred at Oak Ridge, although several individuals inhaled small quantities of Pu-239 when a plutonium processing vessel exploded several years ago. Exposures of ORNL personnel at the Y-12 area include those from biological research uses of radioisotopes and accelerators. Bioassay data indicates that most inhalation exposures at ORNL are very small. In fact, most of the bioassay results are not interpreted, except when more than $\frac{1}{2}$ of the maximum permissible body burden might be exceeded.

Thus, the personnel currently exposed to the highest average levels of radiation include the operators and supervisors in the Isotopes Division, Chemical Technology Division, and Operations

Division--which employ about 700 persons in radiation work. Assuming an average of only 500 persons have been exposed to an average of 0.5 rem per year, for an average exposure period of 10 years followed by 20 years at risk for the appearance of any disease, the estimated minimum number of PRY units for ORNL is:

$$500 \times 0.5 \times 10 \times 20 = \underline{50,000 \text{ PRY}}$$

which could range up to 500,000 if the total population of 5,000 actually was exposed and received an average of 0.5 rem/year through the years. Average exposures have been decreasing through the years, (3,7) and only a complete evaluation of data for the earlier years could establish a better estimate of the cumulative PRY value. However, since records are available back to 1943 and since relatively good control and surveillance has been exercised over occupational radiation exposure since about 1946, the ORNL facilities would be one of the most likely facilities to include in any initial test runs.

Y-12 Area

Most of the exposure at the Y-12 area in the early days resulted from work with soluble natural uranium salts, which could have similar toxicologic chemical effects on the kidneys as radiation. Other sources of radiation exposure at Y-12 were obtained from isotopic uranium separations processes, reduction of UF_6 to uranium metal, machining operations on uranium, and handling, sweeping and cleanup of uranium. These operations usually involved only limited external gamma dose rates of several mr per hour or less, except for the criticality accident, which involved several individuals with serious external exposures. This criticality accident has been thoroughly evaluated radiolog-

ically and medically and is widely reported in the literature.⁽¹⁴⁾ Although only about 1,000 persons required badge service prior to the Y-12 criticality accident, since about 1960 all 5,000 employees at Y-12 have been badged even though most of them do not receive occupational radiation exposure. These badges are worn to facilitate identification of any exposed individuals in the event of another criticality accident that might expose personnel outside of the immediate plant area involved.

Most annual exposures at Y-12 were found to be below 1 rem, as observed from print-outs of annual exposures. Film badge records are continuous back to about 1952 on the computer. However, annual doses must be computed from weekly entries prior to 1956. Records for 1950-51 are available from notebooks, but no records are available on radiation exposures prior to 1950. Some of the early records of exposure may have been taken to Rochester when the Y-12 area was transferred from Tennessee-Eastman Corporation to Union Carbide in May, 1947.

Urinalysis records for indicating personnel exposed to the ingestion or inhalation of uranium are available for 1950 to the present. Since 1961, personnel have also been counted for enriched uranium in the in vivo ("whole body") counter at Y-12. In only 5 individuals was an amount of uranium slightly greater than the permissible continuous body burden present when it had been estimated by urinalysis procedures to be within permissible limits. It was believed that these body burdens represented mostly lung burdens of uranium in forms that were eliminated relatively slowly from the lung. Most internal exposures from Uranium were very

much lower than the permissible limits. Air sampling records are available back to 1943, but it was said that personal exposures would be very difficult to interpret from these records.

Personnel and Medical records provide relatively complete identification of employees after 1947. From 1943-1947, cards are available in Personnel giving names, employment dates, and a limited amount of other data on separated personnel.

At the Y-12 plant, it is very possible that exposures to other environmental agents were more significant biologically than the radiation exposures received. These exposures were not continuously monitored by breathing zone samplers, but personnel involved in the exposed groups may be identified by Medical Department records of those regularly examined for specific signs or symptoms, or from urinalysis records. The toxic agents involved at Y-12 have included phosgene, NO_2 , Hg, asbestos, and various organic solvents and chemicals, among other known agents. For many of these agents, the exposed groups were monitored, and records of the individuals who were monitored are available.

Although an estimate of the number of person-roentgen-years (PRY) available at Y-12 has been made (Table 7), the upper range of error for this estimate is more limited as a result of the limited quantities and concentrations of gamma-emitting material in process. Thus, the PRY estimate in Table 7 made last July has associated with it a revised estimate of the range over which the actual value may fall. At Y-12, the actual PRY would more likely be lower instead of higher than the value indicated, especially since the uranium metals program increased significantly only after 1950.

Although radiation exposures at Y-12 are likely to be lower than those at X-10, and exposure records may not be available prior to 1950, the Y-12 plant is included in the proposed test runs since:

- (a) The facility was one of the earliest to begin operation;
- (b) Unique types of exposure to enriched uranium have been encountered, although exposures are limited;
- (c) Other toxicologic materials used in other AEC facilities are represented in the environment.
- (d) It is possible, although difficult, to establish relatively complete cohorts all the way back to 1943.
- (e) The plant population was relatively large in the early years, dropping from a peak of 25,000 in 1946 to a low of about 1,600, and then rising in 1950-51 to a level of 5,000 or more, which has remained fairly stable to date.

K-25 Area

Exposures at the K-25 area have been centered around activities connected with the separation of the isotopes of uranium by gaseous diffusion. Thus, relatively large quantities of both natural and enriched uranium have been handled in this plant. During the 1950's operations were extended to include the preparation of uranium hexafluoride from various uranium oxides, and these operations were handled under rather dusty conditions as compared with the

gaseous diffusion plant; thus, a sizable number of maintenance and production workers were exposed to uranium inhalation either as an insoluble or soluble compound. Since UF_6 hydrolyzes readily, there was also potential for chemical exposure to HF and UO_2F_2 . These exposures thus have consisted primarily of internal chemical and radiation exposure, and some beta exposure to the skin, but relatively low external gamma radiation levels. It has been shown by in-plant studies that ingestion has been minor compared to inhalation of uranium.

In terms of mass, the quantities of enriched uranium produced are relatively small compared to the natural uranium feed, since isotopic enrichment from 0.7% U^{235} to 2-3% is required for use in power reactors, up to 20% is required for use in research reactors abroad, and greater than 90 per cent enrichment is required for weapons and research reactors in this country. As a result of the lowering of mass per unit activity with enrichment, radiometric methods of urinalysis are used instead of fluorimetry when enrichment exceeds about 5 per cent. Above this enrichment, it is believed also that the internal radiation exposure becomes more important than the chemical toxicity to the kidneys.

In addition to the large gaseous diffusion plant for isotopic separation of U^{235}F_6 , some chemical purification of the uranium feed material has been carried out in the past, as well as conversion of UO_3 and U_3O_8 to UF_4 and UF_6 . In converting these oxides to UF_6 , the beta and gamma emitting daughters of uranium isotopes become concentrated in the ash and produce sources of higher intensity beta and gamma radiation. However, these processes

were introduced in the 1950's after better film badge dosimetry and recording procedures were developed.

Exposures to non-radioactive materials included nickel, fluorines, fluorides, lead, mercury, chromates, asbestos, benzol, CCl_4 , tar, and asphalt. The Health and Safety Division has retained complete records on personnel exposed to nickel, including periodic x-rays of the nasal sinus and chest. Also, records of general air and breathing zone samples are relatively complete. Follow-up examinations are given only to persons currently employed. Exposure to other agents are also fairly well documented after 1948.

From 1944 through 1948, environmental health protection was a function of the operating divisions under the supervision of a Special Hazards Committee composed of members of the medical staff and the Safety Department. These included Dr. Adolph G. Kammer, Mr. A. F. Becher, Mr. R. F. Perkins, Mr. J. H. Bull, and Captain D. M. Brundage, representing the U. S. Corps of Engineers, Manhattan District. In 1948, a formal industrial hygiene program was established under Mr. N. H. Ketcham, who in turn reported to the plant Medical Director. After 1948, more complete exposure records are available in regard to external radiation exposure, internal radiation exposure, and exposure to other environmental agents. A standard 2-filter film badge was in use in 1945-48, but information was retained by badge numbers that would probably not be relatable to individuals. Beginning in 1949, badges were assigned from the health physics section and records of exposure are available for those employees receiving more than 10 per cent

of a maximum permissible dose. These radiation exposure records include the name, payroll number, division, department code (which defines the general type of work activity), external whole body dose, and skin dose. Skin doses generally range up to 5-10 times the whole body doses, but the permissible limit for skin is 6 times that for the whole body.

The period of highest potential exposure was 1950-1960. Now, although all 2300 personnel at K-25 are assigned badges, only those personnel working in radiation areas where they may receive more than 10% of the MPD have their dose readings routinely recorded. For the remaining individuals, a 10 per cent sample of badges is processed and evaluated each calendar quarter to assure that these people are really not exposed. So far, no one in the sampled group of "non-exposed" employees has exceeded more than 2 per cent of the permissible quarterly dose. This result testifies to the limited number of areas and the limited external exposure potential in the K-25 plant. However, during the 1950-60 period when UF_6 was produced at K-25, finger rings containing film were worn by employees likely to receive hand exposures significantly greater than indicated on the body badge.

The relative external exposure risk in PRY units has also been given in Table 7. However, as in the Y-12 facility, this crude estimate is again more likely to be on the high side than the low side.

The K-25 facility is also proposed as part of the test run facilities for reasons similar to those given for Y-12. Also, the Central Data Processing facility is located at the K-25 area and

this data processing facility already has automated the processing of certain personnel, medical, and exposure records for the Oak Ridge facilities.

In Table 10, the items of information available in the Hanford and Oak Ridge facilities are indicated in summary form, and the years for which they are available in some retrievable form are indicated. This information was abstracted from the questionnaire compiled in March, 1965, by Personnel, Medical, Health Physics, and Data Processing Center personnel at Hanford and Oak Ridge.

E. Other Visits

Further detailed summaries of the observations and information gained in the remaining installations listed in Appendix B, which were visited during the first year of this project, would not be worthwhile for the purposes of this report. Extensive notes and tape transcriptions of information gained during these visits is available in project files for future reference. In general, the types of exposure and the various health and safety practices encountered at the Hanford and Oak Ridge facilities constituted a relatively complete representation of the types of exposure and practices encountered at the rest of the fourteen AEC installations visited. Thus, since the facilities visited included the greater part of the entire population of AEC contractor employees, the choice of the Hanford and Oak Ridge facilities as the major part of the test runs should result in the establishment of project procedures and methodologies, tested over population cohorts beginning as far back as 1943, that can be easily extended to a continuing follow-up study of the entire AEC contractor population.

In addition to the visits and interviews at AEC contractor installations, and a review of records of some of the smaller feed materials plants maintained at the AEC Health and Safety Laboratory in New York, interviews with AEC Health and Safety and management personnel were held at each of the AEC Operations offices visited. These interviews were held to explain the purposes of the project, to obtain some general orientation in AEC operations and record-keeping requirements, and to enlist the support of AEC personnel

in obtaining the desired information. In every installation visited, the AEC personnel were most helpful in expediting the scheduling of visits and the acquisition of the desired information.

Visits were also made to Denver to discuss the findings of Bell and Gilliland,⁽²³⁾ who have carried out pilot studies on 100 workers in each of two AEC feed materials plants to determine the possibility of utilizing routine air concentration measurements and plant medical records for following the effects of uranium inhalation exposure on employee health status. Bell and Gilliland will probably present some interesting results in the near future that will be helpful in planning future morbidity studies and in estimating time-weighted average exposures to uranium. However, they helped to solidify our opinion that morbidity studies would not be feasible on a large scale until uniform methods of obtaining and recording quantitative clinical indicators of morbidity are developed.

Discussions were held at the Social Security Administration in Baltimore on several occasions to pursue the possibility of utilizing their capabilities for tracing deaths of covered workers on a larger scale than previously attempted.⁽³⁷⁾ So far, it seems that the Social Security Administration would be able to provide the service necessary for a mortality study of the AEC contractor population, if the required funds can be provided by the Atomic Energy Commission.

A visit was made to the law firm of Woodward and Fondiller, Inc., in New York to determine whether their findings to date regarding the legal value of Workmen's Compensation and exposure records would in any way affect our planning for the project. No changes in our

approach were dictated at this time by the results of their project, which has different objectives.

F. Preliminary Studies of Exposure Record Reliability and Development of Criteria for Abstracting Exposure Data

As a result of the wide variation between facilities and over time within facilities in methods of monitoring personal radiation exposures to external sources of radiation, it was necessary to, decide at an early stage of the feasibility study how much detailed information regarding all of the many physical and biological factors affecting film badge dosimetry would have to be obtained in each facility. A brief review of the considerations and the resulting preliminary criteria^{are} presented in Appendix C. ^{These criteria} are founded partly on the basis that most of the population exposure received by the larger fraction of AEC contractor employees is received from fission product gamma radiation in the energy range where many of the film badges indicated roentgen exposure relatively independent of photon energy at some point of measurement on the film. Also, however, the criteria in Appendix C for abstracting data for automatic computer sorting and retrieval would allow appropriate corrections to estimated exposures of specific populations to be made at a later date, if more precise estimates of exposure turned out to be warranted by the biomedical findings. Thus, by adopting the simplest and most economical dosimetry criteria consistent with any prior notions of accuracy requirements, literally hundreds of thousands of dollars of possibly unnecessary expense may be avoided. Further consideration will be given to dose accuracy requirements and related statistical considerations in other sections of this

report and in future reports.

For the purposes of the present report, some results of previous studies that indicate the nature of the accuracy problem and allow some crude estimates of the order of magnitude of population exposure in AEC contractor operations will be discussed. Also, some preliminary studies recently conducted as part of this project will be presented to evaluate the relative accuracy of individual annual dose records, and average recorded exposures for small sub-cohorts of workers. These preliminary studies involved the re-assessment of exposures on films stored for 11-14 years after processing in an atomic energy installation.

Table 8 presents a comparison, taken from a previous project,⁽⁷⁾ of film badge and pocket chamber cumulative annual man-rem recorded in an atomic energy facility for fourteen years of operation. Also, given in the table are the number of persons wearing film badges and the number wearing pocket chambers for each year of operation. Preferably, in order to compare the actual consistency between film badge and pocket chamber readings without adding in the effect of lower-exposed members of the population, one should compare readings from the two types of dosimeters only for persons who wore both of them at the same time. This has not been done, since it was desired to see whether the man-rem exposures recorded for those persons wearing both pocket chambers and film badges comprised the major fraction of the population dose recorded for all persons wearing film badges. Except for the year 1955, when many pocket chamber readings were not recorded, the man-rem values from film badges were generally within 30 per cent of those from pocket chamber

records. The total man-rem for 14 years of operation as recorded by film badges is within 10 per cent of that recorded from pocket chamber readings.

In 1962-63, the number of personnel wearing pocket chambers was reduced to only the fraction of employees who potentially would receive the higher exposures. Table 8 indicates that the more highly exposed individuals were indeed chosen to wear chambers. This may be seen from a comparison of the average annual doses per film badge wearer and per pocket chamber wearer, and from the fact that the total man-rem received by that fraction of the film badged population who wore both pocket chambers and film badges was more than 70 per cent of the man-rem recorded for all film badge wearers. Thus, this data, as well as other in-plant and laboratory studies^(56, 57, 72-75) indicate that the average readings of film badges in this facility are probably close to the true roentgen exposure, and that most of the population dose in this facility was received over the years from external gamma radiation in the energy region where the response of the film in the badges used was relatively independent of energy.

Another phenomenon is indicated in Table 8 that may be typical of other atomic energy facilities. In 1962 and 1963, the film used in the badges was a more sensitive type, and individual monthly readings below 30 mr were rounded off to about 10 mr increments and recorded down to zero dose, rather than recorded as minimum readings. The results of this change in procedure in smoothing⁽⁵⁷⁾ the cumulative distribution is not given in this report, but the lowering of the median dose for 1962 and 1963 is shown in Table 8. Since the

average annual exposure is seen in Table 8 to be well above the median dose, and above the maximum assumed reading of $12 \times 30 = 360$ mr for years prior to 1961, the average dose is not lowered as much as the median dose by the change in sensitivity of film and in methods of recording low exposures.

The obvious question arose regarding how typical of atomic energy facilities in general was the distribution of occupational exposures in the facility for which the average doses are given in Table 8. A chi-square test was made of the statistical significance of differences between the 1962 distribution of exposures for the facility, and those for all monitored AEC Contractor employees, (6) for exposure divided into the ranges 0-1, 1-2, 2-3, 3-4, and $>4R$. The chi-square test showed (57) that there was no "statistically significant" difference between the two exposure distributions for 1962 - the only year for which both the AEC data was published (6) and also the Pittsburgh facility exposures (57) were recorded unbiasedly in the low-dose range.

Of course, other facilities that do not have the broad range of operations with radioactive material typical of the overall AEC program, or that have varying practices of badging and recording exposures, would show high or low deviations from the "typical" distribution in various dose ranges. This was evident in the dose record of a number of the installations visited. However, if the average dose to film badge wearers over the 1950-1963 period in Table 8 is assumed to be approximately typical of the average exposure of all monitored AEC contractor employees during the period 1946-1964, an estimate of about $0.5R/\text{year}$ per monitored employee

is obtained. This is not out of line with previous estimates of population exposure of atomic energy workers in the United States^(2,3). Also, it is interesting that this value is close to the corresponding average annual exposures of monitored workers of the United Kingdom Atomic Energy Authority: 0.56 rad/year in 1957; 0.44 rad/year in 1958; and 0.42 rad/year in 1959 (Reference 44, page 125). Recorded annual exposures in the United States also seem to be decreasing -- partly (but probably not totally) as a result of the use of more sensitive emulsions and/or longer wearing intervals that encourage the recording of lower exposures and reduce the tendency in some facilities to over-estimate exposures in the low-dose range.

A number of other exposure record studies, field comparisons between ambient dose-rates and recorded exposures, and laboratory investigations of film badge sensitivity and accuracy,^(57,72-75) provide direct and indirect evidence that for many facilities and most years of operation, the annual population exposures for populations of more than 30-100 radiation workers may be estimated from dose records with considerably more accuracy than might be expected from a consideration of the potential magnitude of errors in single individual readings. The relative frequency of the largest errors in film dosimetry seems to be sufficiently low (although important for estimating individual annual exposures) so that exposures in the region where small random negative and positive errors are statistically balanced contribute an appreciable part of the population dose.

Some of the above conclusions may seem contrary to the intuitive expectations of persons knowledgeable in techniques of film dosimetry and the evaluation of individual exposure readings. However, most research and development efforts in personnel dosimetry have been appropriately focussed on the elimination of the occasional large errors that produce most of the problems in managing individual occupational radiation exposures, or in evaluating the higher accidental exposures for which a film badge service is not always prepared. The widespread use of the film badge in the United States has focussed attention on the extremes in the frequency distribution ^{OF ERRORS AND NOT ON} the powerful effect of the statistical law of large numbers on estimates of average population exposure. However, the data and analyses leading to the more encouraging conclusions ^(56, 57, 72-75) regarding possibilities for estimating population exposures from film badge records are too detailed for further presentation in this report. Also, the limitations in estimating population exposure cannot be treated completely here.

As part of the current project, some films stored for periods of 11-14 years after processing were re-evaluated, to determine the validity of some of the earlier sensitometric procedures, and to find out whether the re-densitometry of samples of old film might serve as a method of direct verification of recorded estimates of population exposure. An initial preliminary study was carried out on films processed in the 1951-54 period under the more adverse conditions expected to represent some of the earlier 1944-1954 film badge operations. The film involved was duPont Type 502, and calibration films had not been processed with each

monthly batch as currently recommended.⁽⁵⁰⁾ Films for a group of only 21 individuals with relatively continuous exposure records between 1951-54 could be obtained for this preliminary study.

The recorded cumulative exposures for the 1951-54 period are compared in Table 9 with the cumulative exposures re-evaluated by re-reading the densities behind the "shield" portion of the film. These densities were evaluated in terms of dose using average "control" densities and a single representative calibration curve fitted over the 10 mr - 1,000 mr range to only three sets of calibration films that were found with the stored films. However, it was noted that this calibration curve overlapped fairly well with the "sample" curve given by duPont for the Type 502 film.

A principal difference in the re-evaluations was that the net-densities were read in terms of dose, no matter how low the reading after the density of each film was subtracted from the average control density. This was done to allow the law of large numbers to be effective in extracting the maximum information about cumulative exposures in the low dose range. As a result, one negative dose appears in the right hand column of Table 9. Negative cumulative doses may indeed be expected in some cases if the average background radiation level in a worker's environment is less than the background where the "control" film is maintained. However, in Table 9 the magnitude of the negative reading is obviously less than the errors involved in evaluating the exposure.

Further studies are planned to test the possibilities for estimating the degree of accuracy that might be placed on recorded film badge readings over time in different AEC facilities to be

subsequently studied.

These preliminary data, as well as other unpublished results encountered during the visits to AEC installations also indicate that films will probably be readable at least up to 14 years after processing by most of the developing and fixing procedures used by film badge services. Moreover, the films discussed in Table 9 were stored under varying environmental conditions that were generally more extreme than usually found in most film storage locations.

G. Preliminary Estimates of Population Dose from Occupational Radiation Exposure

One of the objectives of an epidemiological investigation of the health status of atomic energy workers would be the detection of any chronic diseases that might be produced at low incidence, scattered over the total population of exposed workers. Recorded exposure distributions indicate that a significant fraction of the person-roentgen-years at risk may be distributed among workers who receive average exposures less than 1 R/year. Thus, if any effects are to be investigated that may increase in incidence with years at risk and with any increment of dose above background, it would be desirable to include all workers in the study who may have received some finite amount of occupational exposure, while excluding from the "exposed" group all workers who have had no occupational exposure.

Since the early incidence of leukemia among atomic bomb victims seemed to increase linearly with dose, ^(2,3) it might be useful to assume for purposes of estimating data requirements that certain diseases increase in probability of occurrence with the integrated product

$$PRY = \sum_{i=1}^N \int_{t=0}^T R_i(t) dt \cdot (T-t),$$

where N is the size of the population under observation, (corrected for deaths during the time T), $R_i(t)$ is the average occupational/dose rate to the ith person during time dt, T-t is the period at risk under observation after time interval dt, and t=0 is the time at which observations begin. If the probability of disease in excess of that produced by background radiation is assumed to be linearly proportional to the average dose received and the average number of years at risk, then the expression for PRY above would be replaced by the approximation

$$PRY = N \cdot D_{avg}(T) \times T/2 \text{ person-roentgen-years, where}$$

$D_{avg}(T)$ is the average dose per worker accumulated over time T, and T/2 is the average number of years at risk (not weighted by the distribution of dose over time).

Thus, assuming an average annual dose per employee of 0.5R per year, from the previous section of this report, the cumulative population risk from occupational exposure of 100,000 employees over a 20-year period would be:

$$\begin{aligned} PRY &= 10^5 \text{ persons} \times (0.5 \text{ R/yr.} \times 20 \text{ yrs.}) \times 10 \text{ years at risk} \\ &= \underline{10^7} \text{ person-roentgen-years at risk} \end{aligned}$$

This value may be compared with the PRY value of Hiroshima and Nagasaki survivors of 3×10^7 estimated from the U. N. Report⁽⁷⁾ in a previous section of this report.

Thus if the rates on the order of $1-2 \times 10^{-6}$ per unit PRY found for leukemia after acute exposure⁽⁷⁾ were also approximately applicable to chronic low-level irradiation, we might expect on the order of

$$10^7 \times 10^{-6} = 10$$

or 20 additional radiation-induced cases of leukemia to have appeared in the AEC contractor employee population by 1965. However, these radiation-induced cases, if present, would be added to about $100,000 \times 5/100,000 \times 20 \text{ yrs.} = 100$ cases produced by other agents and natural causes. Thus, if rates found for acute exposure are applicable, the accumulation of data on employees occupationally exposed to radiation would have to proceed for at least several generations to detect with any statistical confidence the presence or absence of such levels of radiation-induced disease incidence. Present indications are, of course, that our simplified assumption needs many modifications to take into consideration the radiation effects according to the age of the population at the time of exposure, the genetic make-up of the population, the time distribution of administration of the dose, and many other factors some of which may yet be unknown.

The need for incorporating provisions for possible long-term follow-up studies of the entire AEC contractor employee population, as well as the requirements for studying sub-cohorts classified in multiple ways, is considered in the approaches to further work

given in the next section. It is apparent, however, that the relative errors in estimating population radiation exposures will probably not be a limiting factor in carrying out the proposed test runs on the mortality experience in selected AEC installations. Such errors will probably be small for most sub-cohorts compared to uncertainties in non-occupational radiation exposure, exposure to other materials, errors in classifying or detecting deaths, and statistical fluctuations in the observation of deaths occurring randomly in time.

IV. POSSIBLE APPROACHES FOR FURTHER INVESTIGATIONS

A. Reasons for Initial Emphasis on Mortality

In any comprehensive study of biological effects of radiation, one would wish to consider both genetic and somatic effects and, within the latter category, morbidity and mortality. Morbidity pertains to the deviation from usual health, expressed in terms of sickness or specific illnesses, and presents more difficulties than mortality in the actual design and execution of epidemiologic studies because there are a larger number of variables that come into play -- notably human factors, errors in observation. and measurement.

Until now, there is no demonstrated method short of perhaps physical examination to ascertain deviations from health objectively. It is not possible with sufficient reliability to determine morbidity for this study by a household survey or by questionnaire alone. ⁽²⁰⁾ Even getting the information from physicians attending the individuals whose comparative health is to be appraised will not remedy this situation because of substantial lack of uniformity in diagnostic acumen and practices of different physicians. The medical examinations that have been conducted over the years at the various installations have been carried out by different doctors with varying skills, experience, and interest, and with different clinical tests, examinations, techniques and thoroughness, which constitute a formidable array of observer errors in the comparability of medical findings.

It is realized however, that morbidity changes may be found to be more sensitive to radiation exposure, and efforts to eventually develop more quantitative morbidity parameters should continue. Unfortunately, the present lack of biochemical and physiological "markers" related to low-level radiation exposure in humans adds to the difficulties of analysis and interpretation of any attempted morbidity correlations with radiation measurements.

The investigators believe that the marked difficulties associated with morbidity observations make it advisable that mortality patterns rather than morbidity should receive initial attention and study.

Mortality patterns of cohorts of radiation-exposed and non-exposed populations (as well as others) may indicate the variations and differences that occur in the incidence of specific causes of death, which then may provide an indication of those systems or organs toward which more refined physiological or biochemical observations and research may be subsequently directed.

Further, it is believed that even though no positive findings of long-term mortality effects may be observed (because they do not exist, or the period of observation is not sufficiently long, or there are offsetting influences), negative findings of no discernible effects after 20 or more years of

exposure at various levels of radiation would provide valuable guidance in the subsequent consideration of radiation protection standards for humans.

The test runs for mortality would also give a by-product regarding certain types of morbidity. The method of utilizing the resources of Social Security would make it possible to divide the population of the AEC installations and the various controls into three classes: (a) individuals still in covered industry; (b) the deceased, and (c) those not in covered employment. The bulk of those in (c), if not retired, would be disabled individuals. The comparative rate of (c) in relation to (a) might be indicative of differences of frequency and types of morbidity between exposed and non-exposed groups (controls). Individuals in (c) who are drawing disability benefits under Social Security could be identified for both the exposed and control groups, and the causes of disability could be investigated. For others not receiving disability benefits a sub-sample could in principle be traced and, if possible, subjected to medical examinations regarding health status in both the exposed and control groups.

B. Proposed Initial Runs

Several AEC contractor installations have been recommended⁽³⁹⁾ for mortality study since: (a) they were the earliest facilities in operation and would have the longest periods of observation; (b) they had sufficiently large populations to expect a sufficient number of deaths with which to establish mortality patterns;

(c) sufficient personnel, employment, and radiation records exist or can be reconstructed to make an epidemiological study feasible; and (d) most (if not all) of their employees were covered by Social Security, so that separated employees may be traced regardless of place of migration or year of separation and the deceased members of each cohort may be identified. The AEC Contractor installations in which the test runs would thus be considered most feasible and representative are Hanford Operations, the Oak Ridge X-10 area, the Oak Ridge Y-12 area, and the Oak Ridge K-25 facilities.

Every effort should be made to reconstruct and include in the mortality study the roster of the academic groups who were attached to Oak Ridge in the early formative years, and who most likely had the earliest radiation exposures, namely: The University of Chicago staff that initially established the laboratories at X-10, the Oak Ridge National Laboratory; the University of California staff, who were associated with Y-12; and the staff of Columbia University associated with K-25. To exclude these early exposures that occurred before standardized procedures of recording personnel and exposure data were developed, would mean the serious loss of the longest periods of risk available anywhere for studying chronic diseases having latent periods of 20 years or more.

In addition, although the populations employed are much smaller, it is proposed that the small feed material plants be included, particularly those that began operation the earliest

and are likely to include employees exposed to the maximum levels of inhalation of internal emitters. These would include, among others, Harshaw Chemical Company and Mallinckrodt. Although Bell and Gilliland⁽²³⁾, as well as others⁽⁴⁰⁾, have not found any changes in morbidity indices definitely attributable to radiation in pilot studies of these facilities, longer-term studies should be carried out on cohorts exposed in these facilities, particularly for those workers who were exposed in the pre-1950 period. These follow-up studies should include separated as well as current or continuing employees for observations on mortality. Bell and Gilliland have found it possible to estimate general environmental air concentrations to which employees in certain feed materials plants after 1950 were exposed, although these concentrations may not reveal the actual quantities inhaled.

The study of mortality will have two (2) phases: (a) the comparison of mortality rates among the exposed with the controls, and (b) the differential causes of mortality among the study and control groups. In both of these phases, the procedures would be to divide the population into homogeneous groups in terms of age, sex, color, and similar available characteristics, and within each of these homogeneous groups, to subdivide along the gradient of exposure to radiation. The study population would also be characterized by department, craft, occupation, and exposure to various environmental factors that would be studied in addition to, and in conjunction with, radiation in the evaluation of various combinations of stresses.

This specification of the population would be done with each cohort (i.e., all persons in the installations who entered employment in each specific year) from year one to the present time. To determine the comparative mortality rates, the cohorts would be followed from year to year; and the death rates would be compared between different exposure groups to ascertain any association between mortality and levels of exposure. This will be carried out for each age, sex, and color group for each cohort. The exposure gradient will be in terms of radiation received in each year as well as the accumulated total, taking into consideration both the intensity of the dose and the time span over which exposure has continued.

This type of analysis, with appropriate tests of significance of association between exposure (taking both the time and dosage into consideration) and mortality, should reveal any measurable association, unless such associations are masked by off-setting factors such as more intensive health care for the exposed groups, which would tend to lessen the death rates and counteract any adverse effects of radiation. If there is such masking, it is unlikely that it would be equally effective in the different AEC installations. It is therefore believed that the analysis of each installation separately should be effective in demonstrating any appreciable adverse effect of radiation on life expectancy.

Secondly, since the AEC installations' high quality industrial health services were provided to all employees, the introduction of various controls outside of the installations, with which unexposed AEC populations could be compared, should assist in detecting the possible masking effect of high quality health care. A further safeguard against possible masking of higher mortality as a consequence of exposure to ionizing radiation, would be the subsequent analysis of differential causes of death between the exposed and the different outside control groups.

For each cohort and each year of observation, the various life table functions would be compared for exposed and control groups along the different paths of common characteristics and considered to determine the impact of work-associated toxic exposures on survival. Similar comparisons would be made to test possible influences of work-associated toxic exposures on the presence of different diseases found on the death certificates for different cohorts.

Various approaches to grouping employees according to common characteristics are being explored. Some of the basic approaches under consideration are as follows:

In constituting the cohorts for this study we would take all those who started work in an AEC plant in the initial year, let us say 1943. We shall follow all of these individuals from year to year for the balance of their lives. Those who started

employment in a plant in 1944 would represent a second cohort and so on. To test differences among employees of different installations the appropriate cohorts would be compared between installations in terms of life-years adjusted for age, sex, and race. The cohorts from the different plants would also be compared in terms of life-years with suitable controls of interest. Similarly, to test the influence of year of entry, the life years of different cohorts would be compared interse and with cohorts derived from controls. To test the influence of the length of exposure (years of employment in the plant) those employed 1,2,3,4... to n years will be compared with each other in each cohort, among the cohorts, and with control cohorts who by definition have 0 years of employment in an AEC installation. To appraise intensity of exposure, individuals in the same cohorts, differentiated by dosimetry and other appropriate plant-supplied criteria would be compared interse, between the different cohorts from the same and different : plants and with controls. In a similar way, cohorts may be differentiated according to the number of person-roentgen-years at risk for intercomparison.

Thus, comparisons in terms of many different charac- . .
 teristics would be possible within the cohorts, among cohorts,
 among plants, and between the experimental cohorts (those
 having worked in AEC installations) against controls

Similar comparisons would be made in terms of significant diseases as the cause of death and other diseases of the deceased that would be found on the death certificate.

The comparisons for life years lived and with respect to specified diseases associated with death would be made in terms of appropriate criteria based on controls giving the expected with which the observed would be compared, the statistical significance of the differences between the expected and the observed would be pooled statistically for different homogeneous cohorts in assessing the influence of the different exposure criteria considered in the study, in order to increase the sensitivity of this study for detecting low-level effects.

In addition to the social security 1% and 0.1% national samples that may be used as controls, certain other sub-populations would be given consideration for use as comparison groups. One such source would be the employees of the same AEC contractors working in other non-nuclear industries, selected to meet certain predetermined criteria to be developed for such a control. Other improvised sources of control populations would be covered workers from selected plants in the same geographic areas where the AEC installations are found, or -- perhaps of more interest -- cohorts of brothers or sisters who have not been employed in the atomic energy industry.

The extent and nature of such controls would be determined on the basis of the need for these additional controls, with due

consideration of the costs involved. Unless further experience justifies changes in emphasis during the initial runs, the following methods of deriving control populations will receive priority.

C. Selection of Control Groups

We visualize several controls, coming from two types of sources: (a) the 0.1% national historical sample of workers covered under Social Security, (b) the siblings of the employees of the AEC facilities who can be identified from the PSQ forms and followed through Social Security, and (c) medically-homogeneous groups.

From (a), we shall select workers from the Social Security Administration (SSA) national sample, for each cohort having the same length of covered employment (i.e., those who entered covered employment the same year) divided similarly according to age, sex, color, and any other pertinent characteristics. The expected death rates obtained for these controls would be compared with the actual death rates for the AEC contractor employees, differentiated according to exposure to radiation. Each cohort will be followed for the maximum period of observation from each year to the present, comparing the expected and the observed for the exposed group, both in terms of frequency and for specific causes.

In (b), brothers and sisters of the AEC contractor employees will be used as controls. Expected death rates would be obtained from mortality data on the siblings and would be

compared with the actual death rates experienced by the AEC workers, both those exposed and those not exposed to radiation.

If medical care lowers specifically the mortality in the AEC employee population, then the mortality of both exposed and non-exposed employees of AEC contractors should be lower than in the control groups represented by the siblings, unless radiation effects should counteract effects of medical care in the exposed groups. If the differential between the control and the "experimental" groups (AEC) appears to be associated with employment status, the control groups can be further refined by eliminating those siblings who were not in the labor force in the same years in which the cohort comparison is made, thus eliminating any dilution factors favoring the experimental (AEC) group over the controls.

In (c), a third type of control, which has certain advantages if complete rosters could be obtained, are applicants for employment at various AEC installations who were given pre-employment examinations, and were found eligible for employment, but who accepted other jobs instead and were never employed in an AEC installation. The studies of Bell and Gilliland⁽²³⁾ indicate that there have been a large number of such applicants.

D. Other Approaches under Consideration

Retrospective studies would be made of the specific causes of death, where some apparent significant differences in mortality have been found. This would require comprehensive studies of previous work exposures, assignments, and environmental agents as well as medical and radiation data within the AEC facility,

and would also require the determination of employment environmental factors prior to and subsequent to employment in an AEC installation, wherever applicable.

It is believed that in any industrial epidemiological study, information pertaining to the frequency and nature of work-connected injuries or diseases, and other compensation claims against the Commission, represents an important source of data that should be taken into consideration in grouping the health hazards and in the development of epidemiological leads pertaining to specific diseases occurring with greater frequency among certain occupational groups. It may be possible to identify other environmental factors inimical to health in this manner. It is also necessary to review all claims because of the marked variation in the scope of compensation coverage in the different states, relative to compensable injuries and diseases.

E. Specific Phases of Work to be Carried Out in the Test Runs

(1) Arrangements for the Abstracting of Pertinent Lifetime Data of AEC-Contractor Employment & Environmental Exposures

The records observed at each of the installations that would be utilized for the study are basically paper documents in a variety of forms and stages of completeness, representing data on several hundred thousand current and former employees if all the facilities were included.

For the specific facilities that would provide the basis for the test runs, it will be necessary to abstract in considerable detail the available data on employment and personnel, including all information pertaining to departments, occupations, and the dates in which the changes have occurred over the entire employment

period of the individual in the AEC installations. In addition, all the radiation measurement data for each year would have to be linked to the personnel and employment data for identification and comparison purposes. As a result of the destruction or loss of many of the early records, data recovery and processing will be the most expensive and time-consuming phase of the study.

(2) Test Runs of Feasibility of Conducting Mortality Studies Utilizing Social Security Administration and National Health Center of Health Statistics Records for Oak Ridge, Hanford, and Other Selected Facilities

Initial runs on a limited number of facilities are essential before studying the total AEC Contractor population in order to test the quality and completeness of all the recorded data as well as to determine the costs and the completeness with which individuals who have worked in these installations at any time can be identified and followed over the years. Information from previous studies indicates that the tracing of employees through the Social Security Administration (SSA) to obtain deaths would be economically and scientifically feasible for the purposes of this project.⁽³⁷⁾ A pilot study of AEC employees at Oak Ridge has also been conducted and has confirmed the feasibility of this approach.⁽²¹⁾

We shall determine with a greater degree of completeness and certainty and at what unit costs it is possible to (a) identify and follow all the employees of these contractors from year to year, (b) determine supplementary methods necessary to identify all the deceased, and (c) compare the age-sex-race

specific death rates of contractor employees with that of proper controls. The technical problems that arise in comparing the plant exposure experience of the deceased members of the different cohorts with those still alive will also be determined. The test runs will in the initial state be designed to work out and test general procedures and more accurately assess the general magnitude of the costs involved, and will be restricted to the Hanford and Oak Ridge facilities, and a series of small plants⁽³⁹⁾ in operation in the early years whose plant environmental exposures were studied extensively and recorded by the AEC Health and Safety Laboratory (HASL) in New York.

All employees of AEC contractors (with the partial exception of the universities in the early years) are covered by the SSA and have been covered since 1937. This circumstance makes it possible for us to follow almost all of the former employees of AEC installations from the beginning of their employment to the end of their lives. In fact, eventually it might be possible to consider even the types of employment in which employees were engaged before they entered AEC employment and after their leaving AEC installations, and their subsequent working life through the SSA records. Completeness of death cases obtained through SSA records would be assessed from various sources including the comparison of employer-known deaths with those derived from SSA records. It should be stressed, however, that even if the recording of deaths were somewhat incomplete,

this would not be fatal to our method of analysis, since there is no reason to believe that this deficiency would not be random with respect to all the experimental cohorts starting in a given year and even with respect to SSA control cohorts.

Arrangements would be worked out, preferably with the National Center for Health Statistics of the Department of Health, Education, and Welfare, to obtain copies of death certificates for all the deaths identified in the experimental and control cohorts. In the event this proves not feasible for any reason, then arrangements to obtain death certificates would be made with individual states and territories, even though this would be much more costly and time consuming.

(3) Analyses of Data for Determining Possible Correlations between Mortality and Environmental Exposures

The data abstracted from AEC contractor records and information furnished on death certificates will be analyzed in a number of ways, as outlined in NYO-3394-1 and discussed in more detail with some revision in other sections of this report. These multiple methods of analysis are designed to provide the optimum probability for detecting any possible correlations between radiation exposure and diseases of interest, while also investigating the possible effects of other environmental agents or demographic characteristics that might increase or counteract differences in disease incidence between the radiation exposed and non-exposed sub-cohorts under investigation. Examples of possible statistical procedures for

supplementing the qualitative analyses of the data are presented in a following section of this report.

(4) Completion of Specific Studies Already Initiated at Hanford and Other Selected Facilities

There are a number of worthwhile studies which have been initiated by some of the Medical Directors of AEC installations. Reference has been made, for instance, to Lincoln's study in Oak Ridge.⁽²¹⁾ Illustrations of these might be provided from Hanford. A study that seemed promising to us and worthy of assistance is one where the sex ratios and other information on the infants born to parents employed in Hanford is studied as related to the radiation exposure of these parents. With limited statistical guidance this study could be completed and might help in planning more extensive studies along these lines in the future.

A second illustration is a study of blood smears of all the Hanford employees at the time of entering on employment and at subsequent intervals when employed in the plant. The blood smear slides have been preserved for all the plant employees who have ever worked in Hanford. For this study it would be advisable first to test the consistency with which expert hematologists can read and interpret blood smears. It would be advisable to design the experiment so as to test the consistency of such reading and interpretation between different hematologists and for the same hematologist reading the same smears more

than once. The readings, if reasonably consistent, would then be correlated with the records of radiation exposure of the individual employees and with other toxic exposure incidental to the work of these employees in Hanford, as well as mortality and sickness experiences. Investigations of this nature have also been explored by Bell and Gilliland for samples of data from two feed materials processing centers.⁽²³⁾ Most of the feed materials processing plants have been under the surveillance of HASL since 1947. Bell and Gilliland found very wide variation in the interpretation of clinical measurements ~~of this type.~~ *For employees of these plants.*

F. Statistical Considerations

1. General

In ascertaining the most important objectives of this project, a number of questions have arisen that involve considerations of an essentially statistical as well as radiobiological nature. For example, the following types of questions have been posed:

(1) Is the atomic energy worker population "large enough" to detect chronic diseases that may be produced at very low incidence rates?

(2) Is the average occupational radiation exposure "large enough" compared to medical and other types of radiation exposure to produce an observable difference in mortality between exposed and control groups?

(3) Can radiation exposure effects be "differentiated" from effects of exposure to other toxicological materials?

(4) Can recorded radiation exposures be estimated for populations of atomic energy workers "accurately enough" for separating employees into "appropriate" exposure ranges?

(5) Are data available for enough "years at risk" after irradiation to allow detection of diseases that may have latent periods of 20 years or more?

The answers to these questions and many more are inter-related and depend on a precise formulation of project objectives and the statistical techniques to be used in interpreting results. As indicated previously, the detection of certain chronic diseases of interest or the extraction of the maximum available information regarding probable limits of low-level radiobiologic effects, requires the use of the most sensitive epidemiological and statistical methods for data collection and analysis that can be obtained or devised. The need for utilizing sensitive analytical methods will be discussed in the following paragraphs, and some proposed methods of statistical analysis will be presented in more detail in a subsequent section of this report. The development of a statistical framework for evaluating the data will aid in answering some of the questions posed in this project, or in determining the type of information required for answering these questions.

Since this project will be directed at the simultaneous investigation of many disease entities in multiple populations and sub-populations, there will be a need for computer methods of data sorting and analysis that can simultaneously embrace a number of mutually compatible statistical procedures. The purpose of this study requires a search for diseases that may occur in the following complementary ranges of incidence, and an investigation of their possible causes, all at the same time:

(a) Extremely rare diseases or health effects that may be produced at low incidence scattered over the larger populations as a result of low occupational exposures to chemically toxic agents, carcinogens, internally-deposited radionuclides, and/or external sources of radiation. These diseases include those that are already known or suspected to be possible manifestations of the identifiable sources of exposure. However, diseases not previously related to these exposures should also be searched for since there is a lack of previous human studies of the type and eventual magnitude of this project. There may also be a lack of records regarding the detection, measurement or identification of specific environmental agents to which the populations or sub-populations of interest may have been exposed.

(b) Diseases or health effects that may be produced at larger incidence in various sub-cohorts or sub-populations of

the individual atomic energy facilities. These diseases also include those that are "suspect" and those that are unknown, as well as those that can be related in advance to identifiable environmental exposures and those that can only be traced to environmental exposures--if at all--by detailed retrospective investigations of cases after they have been uncovered.

Thus, methods of data processing and evaluation must provide proper ways of pooling data from large populations exposed to very low average levels of environmental agents in order to detect diseases of low incidence (Type (a) above), while at the same time allowing the supplementary evaluation of diseases occurring at higher incidence within specific, more highly exposed, sub-populations (Type (b) above). The more selected highly-exposed sub-populations must be studied not only to avoid the well-known "dilution effect" that would prevent detection of occupational diseases in limited sub-populations who are exposed to larger amounts of specific environmental agents; it must also establish and define the required sub-populations that are relatively homogeneous in personal, demographic, and occupational characteristics⁽³⁷⁾ for use in proper methods of pooling data in order to detect any occupational diseases in larger populations exposed to limited amounts of specific environmental agents. These two requirements may at first seem conflicting, but they are actually complementary for the purposes of this project.

In regard to the question of whether a population is "large enough" for the detection of certain "suspect" diseases such as the types of leukemia observed in the Atomic Bomb Casualty Commission studies⁽⁴¹⁾ we must first accept the fact that there is no a priori theory or preferred model that will predict the incidence of any disease at the low-levels of continuous or fractionated occupational exposure (averaging about 0.5 R/year)⁽⁴²⁾ in the atomic energy worker populations. Bierman has recently carried out a detailed analysis of target theories in which he has also included statistical considerations of the random multiple hits on multiple targets resulting from random ionizations along the path of an ionizing particle. His comprehensive approach further supports the need for more detailed information on low-level radiobiologic effects, and shows that even linear dose-response data would not necessarily support current single-hit theories or the linear extrapolation of effects observed in one radiation dose range to other uncharted dose ranges.

Thus, questions regarding the adequacy of size⁽⁴³⁾ of a population for minimizing the probability of a Type I or Type II error (i.e., concluding that an effect exists where it does not exist, or vice versa) may not be relevant in this study, since a calculation of the probability of a Type II error requires a preferred alternative hypothesis regarding the exact amount of disease expected per unit of exposure, or per

sub-cohort classified uniquely according to exposure and years-at-risk. As pointed out below, any current estimate of the probability of disease per unit of exposure would have to be extrapolated from studies of biological effects at higher doses and dose-rates, and would thus have no singular validity for the purposes of this study.

Although the probability of developing various clinical signs or symptoms is not accurately known either as a function of the radiation exposure or time elapsed since exposure, it seems reasonable to assume that the average number of observed cases for most of the health effects inducible by chronic irradiation will generally increase within a population sub-cohort with the integrated product of roentgen exposure times person-years at risk following each increment of exposure, for a given point in time at which the sub-cohort is observed. A crude estimate has been made in Table 7 of the number of "PRY" units (person-roentgen-years at risk since exposure) as of 1964 for the main plant populations to be included in the test runs. These PRY values may be multiplied by such estimates as those for leukemia incidence after acute exposure, $\frac{(1-3)}{1.5 \times 10^{-6}}$ per person per roentgen per year-at-risk, in order to obtain average incidence rates that might be expected in the occupationally exposed populations. Such "expected rates" must currently be extrapolated from high dose and high dose-rate data such as those of the atomic bomb casualty studies under

the assumption that these effects are dose-rate independent over the range of human exposure considered. For the reasons discussed above, such an assumption cannot be accepted as the primary hypothesis of interest for calculating expected rates for purposes of studying low-level, long-term effects. At the Hanford plant, for example, if the rates believed to apply to single acute exposures are assumed not to be exceeded under conditions of long-term, low-level irradiation, the leukemia incidence might be expected on the basis of an extrapolation of high dose effects to have reached an excess of only 1.5×10^{-6} x 150,000; or perhaps up to an excess probability of less than 0.005 cases per year of operating history--an expectation of 0.011 not even 1 case in 22 years. However, although this extrapolation may be assumed for some purposes to yield reasonable upper limit estimates of expected disease incidence, the extrapolation requires further validation by large population studies if any scientific advancement in knowledge of low-level exposure risks is expected.

Obviously, if the incidence of leukemia in chronically-exposed populations were equal to or lower than that due to an acute exposure risk of the same number of PRY units, no statistical tests could be made to ascertain the significance of differences in leukemia between the exposed and control populations, even if the populations could be accurately sub-divided into (ideal) sub-groups that were homogenous^e demographically,

genetically, and characteristically with regard to all other occupational stresses or agents. However, since complete studies of occupational radiation exposure and human health experience have not yet been carried out, for our purposes the actual incidence rates under conditions of low-level occupational irradiation cannot be assumed a priori to be lower than the rates obtained from studies of acute radiation exposures. Therefore, one of the important objectives of this project is to find out whether leukemia and other specific causes of death are actually in excess in the exposed populations, compared to suitable controls of interest. If no excess, or a "negative", result is obtained, then the data would still be useful for determining upper confidence limits for certain radiation effects of interest.

If a statistically significant excess is obtained, radiation exposures are likely to be "accurate enough" to estimate the magnitude of the effect per unit of exposure; i.e., any uncertainties in population exposures would be relatively small compared to the widths of confidence bands determined by the binomial distributions in cases observed per sub-group. Within the next 10 years, the PRY exposure of the entire population of atomic energy workers may become large enough to detect or measure any radiation-induced diseases of incidence greater than about 10^{-6} /PRY. On the other hand, occupational radiation exposures as well as other sources of exposure in the

early years of the atomic energy program may be uncertain for some sub-populations. If exposures of such size and exposure level were received within specific sub-populations such that these populations would eventually exceed about 10^7 PRY units of external exposure, for example, detectable effects may eventually be observed even for such rare diseases as leukemia, particularly after some additional years at risk are accumulated. Thus, many sub-cohorts and sub-groups of employees must also be individually compared to appropriate control groups to avoid diluting the effects of larger exposures in smaller sub-groups by premature and inappropriate pooling of data to form larger populations.

In addition to ascertaining the overall health status of the atomic energy population, another important objective of this project is to locate special groups or individuals who may have sustained health impairments resulting from high external or internal exposure. Although the study of small groups of individuals may not provide enough cases for the statistical testing of incidence rates or models of disease induction as a function of whole body dose in the low-dose range, the discovery of any unsuspected cases of illness that might be attributable to environmental exposures may provide the following useful information:

- (a) New upper limit or lower limit estimates of the risk from certain modes of exposure;

- (b) Toxicity of materials or processes previously believed to be safe;
- (c) Suggested corrective measures that might be found desirable; or
- (d) Types of environmental exposure or medical records that should be maintained for future hazard assessment.

In the previous visits mentioned in this section, numerous sources of information pertaining to environmental exposure were available for some of the sub-populations that have received exposures exceeding average levels acceptable to the Commission for routine industrial operations.

The occupational radiation exposure data for most of the cohorts and sub-cohorts will probably be relatively accurate compared to the knowledge of other exposures, job classifications, and demographic characteristics required for dividing employees into corresponding exposed and control sub-groups. Previous studies ⁽⁷⁾ have shown that even with the uncertainties and errors in film dosimetry discussed in Appendix D, average annual occupational exposures of 100 man-rem or more to employee sub-populations of 200 or more persons are likely to be measured to within $\pm 30\%$ by the film badge systems employed after about 1946-48 at the Oak Ridge and Hanford facilities. Future standardization of methods of film interpretation, re-evaluation and investigation of selected previous exposures,

and records of whole body counter or bioassay measurements, may eventually allow more accurate exposure classification for individual employees or smaller population sub-groups, particularly for some of the unknown exposure situations encountered in the early years. Thus, there are possibilities for estimating low average radiation exposures to certain sub-cohorts from existing records with relative accuracy compared to other errors in determining expected and observed cases, etc.

V. CONCLUSIONS

1. Valuable records of separated employees have been destroyed pertaining to employment data, e.g., department and job titles and assignments, job descriptions, dates of job changes within the facility and in most facilities the Personnel Security Questionnaire (PSQ). In some AEC facilities the only data remaining for certain years pertaining to employment is the payroll number. This has been brought about as a result of a schedule of record disposal specified by the Federal Government, and the absence of an overall plan to utilize and develop these employment and radiation records for the determination of biological effects of radiation.

2. It is feasible to establish cohorts, according to year of employment and to trace all employees including former separated employees of AEC contractors through the Social Security Administration until their death. Comparative death rates for employees with varying degrees of exposure, duration of employment, etc., can be established and compared with similar rates obtained for controls. A number of controls, or comparative populations, should be utilized. In addition to internal controls (non-exposed employees of AEC contractors) and perhaps potential employees who were found eligible but failed to enter actual employment, external controls should also be available. The most appropriate controls would be, therefore: (1) the siblings of the employees; (2) the controls derived from the 0.1% national Social Security sample of covered employees; and (3) applicants who took and passed their pre-employment examination but were never employed in an AEC plant.

All the University groups involved with the AEC at Oak Ridge have been covered by Social Security since 1951, and can be followed in the same manner as all other employees covered under Social Security.

3. It would be advisable to initiate steps to put certain records in selected facilities on magnetic tape. As a result of the conditions that prevailed in the early years of the atomic energy program, and the nature of the operations of the AEC installations, most of the early record sources are in a variety of paper documents and, therefore, are not readily accessible or not in a form suitable for analysis. Thus, considerable abstracting and data processing would have to be undertaken to merge early record data with the later data. Much of the later data is already on IBM cards or magnetic tape in most of the larger AEC facilities. Explorations have been made, and it is possible to put some of these large bodies of data from the early years onto magnetic tape at each of the AEC installations visited.

It should be recognized that it is necessary to develop appropriate coding and classification procedures for a large variety of data. In order to plan such a system for automated record-keeping and analysis soundly and economically, persons skilled in systems development should be brought in to aid in developing the system in order to take maximum advantage of the rapid development and use of modern electronic data processing equipment.

4. Immediate efforts should be made to establish guidelines that the AEC facilities may use to incorporate the data necessary

for mortality studies into the automatic data processing systems under development. Current efforts are underway in a number of Commission facilities to abstract data onto IBM cards and magnetic tape for purposes of current health protection requirements, and much of this same data will be needed in any epidemiological studies of the AEC contractor population. In a previous section of this report, certain items have been suggested that could immediately be included on the ADP formats incorporating radiation exposure data and other personnel or medical data that are currently processed with automatic equipment.

5. Except for the earliest years of the atomic energy program sufficiently complete radiation exposure data would be obtainable from personnel monitoring records of most AEC facilities for purposes of studying chronic radiobiologic effects. After 1947, the personnel monitoring records of a number of installations would allow annual man-rem estimates of population exposure for populations or sub-populations containing about 30 or more monitored workers exposed to average whole body exposure levels of 1 R/year or more. These estimates may be useful for estimating, or placing upper limits on, the incidence (per roentgen) of some chronic diseases that might be suspected to be inducible in low incidence by low-level irradiation of large populations. In some of the facilities, more recent dosimetry methods may allow exposure estimation at considerably lower average exposure levels. By supplementing the older film badge data with other information, it may be possible to estimate the lower average exposures received by some groups of atomic energy workers in the earlier years of the atomic energy program.

6. There are no a priori occupational exposure levels above which biological effects may be expected to suddenly increase to easily observable levels. Therefore, a thorough examination of the data accumulated in any population study of radiation effects would ideally require the classification of cohorts and sub-cohorts into a number of exposure groups including exposure to environmental agents other than radiation. Probably the most useful types of radiation exposure categories for initial comparison with the various "unexposed" or control sub-cohorts would be:

- (a) All sub-cohorts exposed to average annual exposures of more than 1 R/year during employment and perhaps more than 10 person-roentgen-years at risk. Persons with exposure exceeding this level of risk would generally have adequate assessments of annual exposure for most years of employment and may be classified relatively accurately. Also, average exposures for most individuals in such a category should be significantly higher than medical and background exposures for most years of employment.
- (b) All regular employees within each cohort who have received entries in personnel monitoring records for one or more years of employment. This category would include more than 10 times the number of persons than (a) above in most facilities and would allow a search for any rare diseases that might be produced in low incidence as a result of average occupational exposures in the monitored-employee groups of about 0.1 - 1.0 R/year.

Thus, this type of categorization would probably provide a much larger number of person-roentgen-years at risk, for which the incidence of rare diseases might be examined in cohorts that have accumulated more years at risk than the minimum latent periods for radiation-induced diseases.

7. Although AEC contractor installations differ considerably in the types and quantities of radioactive material processed and the potential for external exposure, the average annual exposure to all monitored AEC contractor employees over the period 1946-1964 has been tentatively estimated to be about 0.5 ± 0.2 rem/year for use in planning further studies. Assuming that the population of AEC contractor employees who have received occupational radiation exposure has averaged on the order of 10^5 persons, and more than 10 years at risk after the average incremental period of exposure, we would estimate that a cumulative exposure on the order of 10^5 persons $\times$ (0.5 R/year $\times$ 20 years) $\times$ 10 years at risk = 10^7 person-roentgen-years (within a factor of two) has been experienced by the AEC contractor population. This exposure level, population size, and period of observation at risk would at present be insufficient for the detection of radiation-induced diseases with incidence rates such as those estimated for leukemia produced by acute radiation exposures -- about $1-2 \times 10^{-6}$ per person-roentgen-year.⁽³⁾ However, the lack of scientific evidence of the applicability of extrapolating risks at high acute radiation exposures to predict those at low, long-term exposures, the likelihood that the atomic energy worker population will continue

in the ensuing years to receive measured low-level exposures, and the possibility that sub-cohorts of this population might receive higher exposures that may have a greater likelihood in the long run of producing observable radiation-induced effects, make it desirable to initiate long-term population studies at this time.

VI. RECOMMENDATIONS (Long Range) 6-1

1. A moratorium on the further destruction of records at the AEC contractor facilities pertaining to personnel, employment, medical examinations, hospitalization, industrial hygiene, and radiation exposure, including original dosimetry films and other related data should be strictly adhered to, until the dimensions and needs of the present and subsequent long-term projects pertaining to AEC or AEC contractor employees have been fully determined. In consideration of the millions of dollars already spent by the Federal Government to obtain much of the information related to our investigation, and the fact that some of the data once destroyed would be recoverable only at great expense or may not be recoverable at all, the costs of further storage or micro-filming of these records would be negligible.
2. Our feasibility study leads us to believe that it will be desirable to establish a permanent "National AEC Health Evaluation Center (NAECHEC)" for atomic energy workers for the surveillance and analysis of the biological effects of radiation exposure (see end of Section III). The need for such a national health evaluation center for atomic energy workers has increased greatly over the years, and the establishment of such a center is advisable if the Commission expects to make effective use of the accumulated personnel and radiation data. A central data processing facility within the NAECHEC would serve as the depository for all information and data pertinent to surveillance and research on the biological effects of radiation and related environmental influences, from all the AEC installations. The information in the National AEC Health Evaluation Center would be supplemented by employment and death information derived from the Social Security Administration and the National Center for Health Statistics.

3. The National Center for Health Statistics and the Social Security Administration have considered establishing a national registry of deaths on magnetic tape at the National Center for Health Statistics, Washington, D. C., to register all deaths in the United States alphabetically by name as well as by other characteristics. We support the staff judgment of these agencies that such a registry would be feasible and would be valuable for many types of health studies. This would provide for instantaneous identification of all former AEC and AEC contractor employees as their deaths occur each year, and would enable automatic adjustments in actuarial experiences to be obtained as well as mortality patterns. Such a death registry center would be of great use to other official agencies as well as to research investigators throughout the country. This center would also include deaths of persons not covered by Social Security. Basically, this would make it possible to obtain death certificates without delay and without querying State Departments of Health, at considerable savings in cost and time. This may further be facilitated by arrangements with the Social Security Administration to obtain death information on covered workers.
4. It was found that the PSQ forms constituted an important fundamental document, containing previous employment of the employee and names and ages of his immediate relatives, as well as other data for the development of controls. Therefore, the FBI and U.S. Civil Service Commission PSQ files in Washington should be permanently retained, as well as others not already destroyed in the various AEC installations throughout the United States.

5. Carefully selected studies of other environmental factors in AEC installations should be included in any follow-up of health effects, in order to avoid the misinterpretation of any association or lack of association between radiation and biological effects that may be produced by other toxic materials. Furthermore, this is necessary for the identification and evaluation of various stresses encountered singly and in combination in the working environment. However, primary emphasis will be placed on identifying the populations that were solely or primarily exposed to radiation. Resources and assistance should be made available to each AEC facility to more adequately measure and record individual exposures to other environmental agents.
6. Encouragement and assistance should be given to the staffs of the different AEC installations to initiate and carry out studies pertaining to their employee populations, in cooperation with Universities and other institutions. These studies could be aided and coordinated by a National AEC Health Evaluation Center for atomic energy workers, if justified by the findings of this project.
7. (39) Test runs should be conducted with employees of selected AEC contractor installations, to determine whether any biological effects in terms of mortality patterns with respect to specific causes of death have occurred many years after exposure to various levels of irradiation. The test runs would also serve to develop methodology and to further ascertain the degree to which various types of data are still available. Subsequently, the test runs would also provide the basis for further extensive effort, if warranted, or would determine whether other directions of research and

methodology are required for a further search for biological effects of long-term, low-level radiation exposure.

In the selected facilities, the destruction of important sources of data in the early years of operation and the small number of person-roentgen-years represented by the data available, makes it less probable that definitive conclusions could be derived within the immediate future. It is deemed necessary that observations be extended for many years and the investigations be ultimately enlarged to include all AEC facilities.

APPENDIX A

Outline of Items Included on Questionnaires Concerning Availability* and Accessibility* of Data in Personnel Records, Medical Records, and Radiation Exposure Records

- I. Personnel and Medical Records Data (Parts A and B)
 1. Name of Employee
 2. Social Security Number
 3. Date of Birth
 4. Place of Birth
 5. Race
 6. Sex
 7. Marital Status
 8. Veterans Status
 9. Dates When Entered Employment
 10. Separation or termination dates
 11. Personnel Security Questionnaire
 12. Reasons for Separation or Termination
 13. Pre-employment (Pre-Placement) Medical (Physical) Exam
 14. Periodic Medical Exams
 15. Medical Services
 16. Work Restrictions for Physical Handicaps or Other Medical Reasons
 17. Occupation
 18. Work Assignment
 19. Costs of Completing Records in Automatic Data Processing (ADP) Format

*The definitions of these terms and the items listed on the questionnaires are given on each questionnaire. Suggested methods of answering items and sample filled-out forms have also been provided

II. Radiation Exposure Records Data (Parts A and B)

1. Name of Employee
2. Social Security Number
3. Occupation
4. Job Assignment
5. Date(s) of Assignment to Personnel Monitoring (or
Film Badge) Service
6. Date(s) of Discontinuation of Personnel Monitoring
(or Film Badge) Service
7. Annual Whole Body (or "Penetrating", "Hard Gamma",
etc.) Dose
8. Annual Radiation Dose to Superficial Tissues
9. Previous Radiation Exposure History
10. Internal Radiation Exposures
11. Costs of Completing Records in Automatic Data
Processing (ADP) Format.

APPENDIX B

AEC INSTALLATIONS VISITED BY STUDY GROUP FOR PRELIMINARY EVALUATION OF RECORDS AVAILABILITY

(June 1, 1964 - May 31, 1965)

- 1.) Hanford Laboratories, Richland, Washington
- 2.) Oak Ridge National Laboratory, X-10 Area, Oak Ridge, Tenn.
- 3.) Oak Ridge, Y-12 Area
- 4.) Oak Ridge, K-25 Area
- 5.) National Lead Company of Ohio, Fernald, Ohio
- 6.) Savannah River Plant, Augusta, Ga.
- 7.) Brookhaven National Laboratory, Upton, Long Island, N.Y.
- 8.) Lawrence Radiation Laboratory, University of California,
Berkley, Cal.
- 9.) Lawrence Radiation Laboratory, University of California,
Livermore, Cal.
- 10.) Health and Safety Laboratory, U.S.A.E.C., New York, N.Y.
- 11.) Los Alamos Scientific Laboratory, Los Alamos, N.M.
- 12.) Sandia Corporation, Albuquerque, N.M.
- 13.) National Reactor Testing Station, Idaho Falls, Idaho
- 14.) Argonne National Laboratory, Lemont, Illinois

APPENDIX C

Criteria for Abstracting Radiation Monitoring Data for Epidemiologic Study

C.1 Criteria for Abstracting Exposure Data

Since methods of film dosimetry have varied between facilities and within facilities over the years, ⁽⁴⁵⁻⁵²⁾ some uniform criteria are required for abstracting appropriate data from personnel exposure records. The criteria for abstracting exposure data should ensure:

- (a) Optimum accuracy in assessing the average whole body dose for employee population groups to be intercompared for mortality or morbidity,
- (b) Sufficient breakdown of dose by time intervals (preferably quarterly) to allow determination of any latent periods for health effects or relationships between disease incidence and years at risk following exposure.
- (c) Discrimination where possible of absorbed doses delivered, for example, only to 7-100 mg/cm² of skin from dose components penetrating 1 cm or more into soft tissue and critical internal organs.
- (d) The accomplishment of the above aims within the minimum cost to meet the requirements of an epidemiological study.

C.2 Possibilities of Achieving Sufficient Accuracy within Reasonable Cost Limits

(45-50)

The film badges used in the various atomic energy installations since the beginning of the Manhattan Project have utilized various metallic and plastic filter combinations to estimate doses to various depths in the body. The particular badge

designs employed and the dose estimates reported were determined by the needs of each individual facility, the applicable dose limits recommended for each part of the body, and the best dosimetry techniques available at the time. The various film badge procedures have generally satisfied their primary purpose through the years: the control of occupational exposure within acceptable limits.⁽⁵⁰⁾ In special cases, this primary purpose was best served by overestimating the dose in situations where accurate assessment was difficult or impossible. The freedom allowed the individual facilities to change and improve their procedures with time has been beneficial in promoting the development of better methodology, and this freedom should be continued. Therefore, the general criteria for selecting appropriate data from individual plant records for epidemiological purposes should give preference to accuracy in estimating relative doses between employees (rather than maximum doses) at several pertinent tissue depths. However, the criteria should also be flexible for adaptation to different film badge systems.

The first impression obtained from a review of the various film badge systems is that improved assessments of relative exposure might be obtained by returning to the original density readings, if not the original films, where density readings are not available, and developing individual computer programs for re-calculating, e.g., "skin dose" or "whole body dose". Procedures could be developed for using the maximum information provided on each film and uniform methods of estimating the

absorbed dose at given depths in tissue. Preliminary studies conducted as part of this project even on relatively old and poorly calibrated films have indicated that stored films may indeed be re-read to obtain revised estimates of recorded occupational exposure (see Table 9). A recent report finds no significant decrease in the density of Ilford PMZ films six years after development in Ansco-30 developer and fixation in Ansco fixer.⁽⁵³⁾ Other unpublished experiments encountered during some of the visits to AEC installations also indicate that many of the older films may still be readable.

However, since there are many types of random and fixed errors in film dosimetry,^(46-52,54-56) and often only one or two filter positions available to allow an interpretation, there would still be limits to the accuracy attainable even with a complete re-evaluation of all films available. Also, the re-reading, recording, and interpretation of an average of two filter positions required an average of at least one minute per film. For an average of about 50,000 employees monitored per year for 20 years, the cost of re-reading and re-interpreting the old films may be very large. Thus, we should consider whether existing dose records may be adequate for the epidemiologic objectives of the study.

Our review of film badge procedures for Oak Ridge, Hanford, and some of the feed materials processing centers indicates that existing dose records should provide cumulative estimates of penetrating radiation exposure for the major part of the atomic energy program. On the other hand, estimates of skin

dose may have considerably larger uncertainties in situations where soft X-rays or bremsstrahlung accompanies the beta exposure in significant amounts, or where the film may not be worn at the site of maximum tissue exposure. However, for the large number of workers exposed mainly to uranium in feed materials plants, even these exposures may be useful, perhaps in conjunction with information on work assignments, plant operations, and industrial hygiene surveys, for dividing employees into broad categories of relative exposure.

C.3 General Criteria for Abstracting Radiation Exposure Data

Thus, in order to launch this study toward its primary goals with minimum delay and expense, the following general criteria will be adopted for assigning occupational radiation exposures to atomic energy employees:

- (1) For initial longitudinal studies of mortality experience vs radiation dose, dose assignments will be made utilizing recorded evaluations of dose in rad or rem. These doses will be listed by calendar quarter when available, since this time interval is on the same order of magnitude as the minimum accuracy within which the time of initiation of certain diseases of interest such as neoplasms can be identified.⁽⁵⁹⁾ If dose evaluations are not available by calendar quarter they will be recorded on at least an annual basis. Existing computer tapes and programs should be utilized as far as possible.
- (2) In cases where obvious systematic overestimates or underestimates in radiation dose can be corrected by determinable factors to make results comparable between different time

periods or different plant populations, appropriate portions of the data as obtained from personnel exposure records may be converted to standardized form before use in the longitudinal studies of large segments of the atomic energy population.

(3) Limited investigations will be carried out in conjunction with the test runs on mortality data to verify the reliability of film badge data used in these test runs. These investigations should involve no more than about 1 man-year of effort and should include re-evaluations of dose on limited samples of films previously processed by each of the evaluation systems employed in each facility. New densities and evaluations should be compared with those obtained previously. Other methods of establishing overall dose validity may also be investigated, such as comparison with pocket chamber readings in cases where these dosimeters were worn and read on a regular basis.

(4) Detailed investigations into recorded dose evaluations over the history of each employee should not be made during the initial longitudinal studies, since most of this kind of effort would be costly and unnecessary. Except in instances when a badge was not worn during exposure (particularly in the early period of atomic industry) or when an open window film reading produced by x-rays of 20-80 kev that penetrate deeper tissues may have been interpreted as an (overestimated) dose to the skin alone, the film badge systems have been generally designed to overestimate whole body exposures to radiations in the energy region of varying film response per unit dose, or to compensate for the varying response by use of appropriate filters. The

tendency to overestimate true radiation exposures would in most cases be expected to outweigh underestimates in true exposures or reported exposures resulting from improper handling of the badge.

(4) Fast or slow neutron exposures will be accepted as evaluated since contributions from these types of radiation are not expected to appreciably affect the total man-rem penetrating dose assigned to any group. ^(57,58) Beta doses will also be accepted as read, since the film-window readings are relatively independent of energy above beta energies that are likely to ^(46,47, 50-52) penetrate to the 50-100 mg/cm² deep basal cell region of skin. However, when x-ray exposures have not been appropriately included in the skin dose, they may be added to the skin dose assignments in appropriate proportions.

(5) Within the limitations discussed above, the absorbed doses at 50 mg/cm² (about 0.050 cm) depth in skin and at about 1 cm deep in soft tissue may in some cases be estimated from appropriate data in the exposure records. For most facilities, however, the "skin" and "whole body" or "critical organ" doses will be abstracted as recorded. In special cases where there are obvious known biases in recorded exposures appropriate factors may be applied to recorded exposures to normalize them to estimated absorbed doses at these tissue depths. For example, the factor of 2.5 used to multiply the (open window-⁽⁴⁶⁾ minus-cadmium) reading of the new Oak Ridge X-10 badge, to correct for the 40% transmission of uranium beta radiation through the 80 mg/cm² of plastic and paper film wrapper in order to estimate the dose at 7 mg/cm² depth, might be removed

for the purposes of this study in order to obtain a closer approximation to the dose to the more sensitive basal cell layer. Such corrections would probably be of negligible importance for the pilot studies of mortality, however.

The depth of 50 mg/cm² was chosen as representative for determining relative amounts of skin damage since generally 400-700 rad will produce epilation if delivered to this depth (61,62) or greater. Also, while a skin erythema dose (SED) of about 800 rad may be produced by air doses of about 600 r of 70 kvp x-rays, which average about 30-40 kev in photon energy and penetrate considerable distances in tissue (see Table 4), doses only perhaps 30% greater than the SED may produce significant skin injury, and doses 2-3 times the SED might be expected to result in considerable pain and discomfort, prolonged recovery, and (61-64) possible permanent injury and possible eventual carcinogenesis. However, beta rays averaging only 100 kev, which are about 50% attenuated in only about 8 mg/cm² (the horny layer of skin), must be absorbed in surface doses of about 4,000-5,000 rad to (64) produce skin injury. Uranium betas are attenuated by a factor of about 2 in 150 mg/cm² of tissue. Beta rays from gross fission products after less than 30 days decay are made up of a spectrum having 20-50 per cent of average energy 600 kev (50% attenuated by 80 mg/cm² of tissue) with the rest averaging about 100 kev (50% absorbed in 8 mg/cm²).

The depth of tissue at which the penetrating dose will be normalized was chosen as 1 cm since this is the average depth of germinal tissue in the male gonads, which has as low a (46,60) permissible exposure level as any other part of the body.

Also, the absorbed dose at 1 cm depth will not be much different from the absorbed dose at 5 cm, the average depth of the blood-forming organs, ⁽⁶⁵⁾ for gamma radiation exceeding about 50 kev (see Table 4). Most of the absorbed dose from gamma radiation in production or processing operations involving mixed fission products or induced activities will be produced by photons in the higher energy range in which the film badge reading per unit dose is relatively energy independent behind the thicker high-Z shield. ^(46,47) In situations where the 17 kev radiation from plutonium is important, ^(47,48) the "air-dose" of 17 kev radiation interpreted using thin metallic and plastic shields may be reduced by an appropriate factor in estimating absorbed doses 1 cm or more deep in tissue. However, these types of corrections can be expected to play only a minor role at most in the initial longitudinal studies of mortality.

For cases in which very low-energy bremsstrahlung may contribute appreciably to the skin dose, appropriate corrections may or may not have been incorporated in the recorded exposures. At 10 kev, an energy absorption coefficient of 4.96 ² cm /gm in muscle ⁽⁶⁶⁻⁷⁰⁾ is equivalent to a half-thickness of only about 140 mg/cm². For 3 kev x-rays, the half-thickness in tissue may be calculated to be about 3.4 mg/cm² --about half the minimum thickness of the dead corny layer of skin. Only a very small fraction of 3 kev x-rays would penetrate the approximately 30 mg/cm² paper wrappers of most film packets. Thus the inclusion of some error in skin dose measurements when

bremsstrahlung of 3-10 kev is present together with beta radiation would have to be accepted. However, these errors should not be important and should be on the safe side insofar as the estimation of dose at the basal layer of the epidermis is concerned, since the absorption per gm/cm² of silver remains high relative⁽⁶⁸⁾ to tissue or air for radiation that penetrates the paper wrapper or the epidermis. Further, since photons of 11.3 kev are 95 percent absorbed within 1 cm of tissue, it has been suggested that photons having energies lower than 11.3 kev be considered as part of the beta-ray dose in therapeutic exposures.⁽⁷¹⁾

Although during the past 10 years film badge services have been developing methods of estimating the penetrating dose from photons in the 20-200 kev region, where the film response per unit tissue dose varies strongly with energy,^(46,52) some of the earlier recorded exposures may require re-interpretation in the event that x or gamma rays in the low-energy region are known to have produced large errors in interpretation. As an aid and guide in determining the need for such special adjustment in recorded dose values, data on the x-ray absorption characteristics of the various filter materials, and the approximate photographic response behind such filters, have been compiled in Tables 1-6 and Figures 1-3 using absorption data from References 46 and 66-70.

APPENDIX D

Budget Expenditures, AEC Project No. AT(30-1) 3394
(June 1, 1964 through May 31, 1965)

Item	Budget Allotment 6/1/64-5/31/65	Budget Expenditures (projected to May 31, 1965)	Balance (projected as of May 31, 1965)
Salaries	31,400	27,944	3,456
Fringe Benefits (6% of salaries)	1,884	1,677	207
Supplies	700	2,000	200*
Travel	17,500	11,193	3,907*
Communications	700	700	0
Equipment	1,754	2,500	154*
Consultants' Fees	2,500	1,500	1,000
Indirect Costs (49.9% of Salaries)	15,669	13,944	1,725
TOTALS	\$ 72,107	\$ 61,458	\$ 10,649

* Unexpended funds were transferred as approved from other categories to make up deficits.

TABLE 1

Physical Parameters Useful in Estimating Film Badge Response

MATERIAL - Z	Atomic Wt	Spec. Gravity	K Critical Absorption Edge		LI Edge	LII Edge (kev)	LIII Edge
			λ	KeV = 12.398 λ			
Lead 82	207.21	11.34	0.14049	88.2	15.86	15.2	13.05
Gold 79	197.0	19.3 (cont.) (19.25 - 19.35)	0.15320	80.9	14.36	13.75	11.9
Tantalum 73	180.95	16.6	0.1836	67.5	11.7	11.16	9.9
Th 90	118.70	7.30 (single xr) (7.2 - 7.5)	0.12394	29.2	4.47	4.17	3.94
Indium 49	114.76	7.28	0.44298	28.0	4.25	3.95	3.74
Cadmium 48	112.41	8.65	0.46313	26.8	4.02	3.74	3.55
Silver 47	107.880	10.49 (10.4 - 10.6)	0.48448 (shorter than cd. kd. X-Rays)	25.6	3.82	3.54	3.36
Bromine 35	79.916		0.91809	13.5			
Zinc 30	65.38	6.92 (6.9 - 7.2)	1.2805	9.76			
Brass (cast-rolled)	Copper & Zinc	8.4 - 8.7					
Copper 29	63.54	8.93	1.3774	9.00		0.961	0.943
Iron (Pure) 26		7.86					
Iron 26	55.85	(7.03 - 7.90)	1.7394	7.12			
Steel (machine)		(7.70 - 7.83)					
Aluminum 13	26.98	2.70 (2.55 - 2.80)	7.9356	1.56			
Gelatin		1.27					
Paper		0.70 - 1.15					
Tissue	13% C 87% H ₂ O						
Plastic 6 - 15		1.16 - 1.20 (Acrylic) 1.27 - 1.60 (Acetate) 1.20 (Phenolic) 1.054 - 1.070 (Styrene)					

TABLE 2 - X - Ray Absorption Coefficients of Filters

MATERIAL	Density	Thickness of Material Having Same Absorption as 1 cm Tissue				
		for 20 Kev	40 Kev	80 Kev	100 Kev	600 Kev
82 Lead	11.34	137 cm ² /g	14.3 cm ² /gm	2.1 cm ² /g	5.9 cm ² /g	0.086
79 Gold	19.3					
73 Tantalum	16.6					
50 Tin	7.3	20 cm ² /g	18.9 cm ² /g (K - 29.3 Kev)	2.87	1.58 cm ² /g	0.036
49 Indium	7.28					
48 Cadmium	8.65	Min = 9.2 cm ² /gm at 26.8 Kev	21 cm ² /g	3 cm ² /g	1.4 cm ² /g	0.034
47 Silver	10.49	Min = 9.8 cm ² /gm at 25.6 Kev	20 cm ² /g	2.8	1.35 cm ² /g	0.0335
35 Bromine		80 cm ² /g	8.1 cm ² /gm	1.15	0.61 cm ² /g	0.031
30 Zinc	6.92					
Brass	8.5					
29 Copper	8.93	43 cm ² /g	4.6 cm ² /g	0.64	0.35	0.026
26 Steel	7.8	30	3.3	0.48	0.265	0.0275
13 Aluminum	2.7	3.16	0.351	0.0536	0.0372	0.0286
Gelatin	1.27					
Paper	1.0					
Tissue (wet)	1.0	0.5 cm ² /g	0.077	0.0255	0.023	0.029
Tissue (bone)	1.1 - 1.85	2.51	0.305	0.0520	0.0386	0.0315
Plastic Poleptyrene		0.188	0.0300	0.0213	0.0228	0.0318
Lucite		0.311	0.0426	0.0226	0.0235	0.0319
Polyethylene		0.176	0.0295	0.0224	0.0241	0.0338
Bakelite		0.257	0.0368	0.0217	0.0227	0.0283
Water	1.0	0.56 cm ² /gm	0.075 cm ² /g	0.0245 cm ² /g	0.029 cm ² /gm	0.0185

TABLE 3
Comparative X-Ray Absorption of Materials Encountered in Film Dosimetry

Atomic No. and Material	Density ₂ gm/cm ²	20 Kev		40 Kev	
		Half- Thickness ₂ gm/cm ² cm	Thickness Equivalent to 1 cm Tissue	Half- Thickness ₂ gm/cm ² cm	Thickness Equivalent to 1 cm Tissue
82 - Lead	11.34	0.00506 0.000446 cm	0.00032 cm	0.0485 0.00427 cm	0.000475
50 - Tin	7.3	0.0346 0.00474 cm	0.00339 cm	0.0367 0.00502	0.00056
48 - Cadmium	8.65	Max $\mu = 0.0753 \text{ g/cm}^2$ = 0.0087 cm at 26.8 ke		0.0330 0.00382	0.000425
47 - Silver	10.49	Max $\mu = 0.0707 \text{ g/cm}^2$ = 0.00674 cm at 25.6 Kev		0.0347 0.00330	0.000367
35 - Bromine		0.00866		0.0856	
29 - Copper	8.93	0.0161 0.00180	0.00129 cm	0.151 0.0169	0.00188
26 - Steel	7.8	0.0231 0.00296	0.00211 cm	0.210 0.0269	0.00299
13 - Aluminum	2.7	0.219 0.0811	0.0579 cm	1.97 0.730	0.0811
Tissue (soft)	1	1.39 1.4 cm	1 cm	9.00 9.0 cm	1 cm
Tissue (bone)	1.1-1.85	0.276		2.27	
Polyethylene	1.06	3.69 3.48 cm		23.1 21.8 cm	
Lucite	1.18	2.22		16.3	
Polyethylene		2.94		23.5	
Bakelite	1.20	2.70		18.8	
Water	1.0	1.24 1.24 cm	0.886 cm	9.25 9.25 cm	1.03 cm
Transmission through 1 cm tissue		-0.69/1.4 e = 0.61		-0.69/90 e = 0.926	

TABLE 3 CONTINUED

Comparative X-Ray Absorption of Materials Encountered in Film Dosimetry

Half-Thickness gm/cm ² cm	Thickness Equiv. to 1 cm tissue	Half-Thickness gm/cm ² cm	Thickness Equiv. to 1 cm tissue	Thickness gm/cm ² cm	Thickness Equiv. to 1 cm tissue
0.330 0.0291 cm	0.00108	0.118 0.0104	0.00035	0.710	0.0296
0.241 0.0330	0.00122	0.439 0.0602	0.0020	2.64 cm	0.11
0.231 0.0267	0.00099	0.495 0.0572	0.0019	20.4 2.36	0.0983
0.247 0.0235	0.00087	0.514 0.0489	0.00163	20.7 1.97	0.082
0.602		1.14		22.4	
1.08 0.121	0.0045	1.98 0.222	0.0074	26.7 2.99	0.125
1.44 0.184	0.00682	2.62 0.336	0.0113	25.2 3.23	0.135
12.9 4.78	0.177	18.6 6.89	0.230	24.2 8.96	0.373
27.2 27 cm	1 cm	30.1 30 cm	1 cm	23.9 24 cm	1 cm
13.3		18.0		22.0	
32.5 30.6 cm		30.4 28.7 cm		21.8 20.5 cm	
30.7		29.5		21.7	
31.0		28.8		20.5	
32.0		30.5		24.5	
28.3 28.3 cm	1.05 cm	24.0 24.0 cm	0.80 cm	37.5 37.5 cm	1.56 cm
$\mu = 0.69/27$ e = 0.975		$\mu = 0.69/30$ e = 0.977		$\mu = 0.69/24$ e = 0.972	

TABLE 4 - X-Ray Transmission of Several Filter Materials
Compared to 1 cm Tissue

Material	Fraction of X-Ray Energy Transmitted for a Photon Energy of:				
	20 Kev	40 kev	80 Kev	100 Kev	600 Kev
1 cm Soft Tissue	0.61	0.926	0.975	0.977	0.972
0.1 cm Lead	-0.693/0.00446 $e = 1/c \cdot 155.4$ 10^{-67}	-0.693/0.0427 $e = 1/(33.0)^2$ 9.2×10^{-8}	-0.693/0.291 e 0.0926 Below K Edge	-0.693/0.104 e 0.00128	-0.693/7.10 e 0.907
0.1 cm Cadmium	(Max. of 3.5×10^{-4} at K Edge = 26.8 Kev)	-0.693/0.0382 e 1.4×10^{-8}	-0.693/0.267 e 0.0746	-0.693/0.572 e 0.298	-0.693/23.6 e 0.97
0.1 cm Silver	(Max. of 2.8×10^{-5} at K Edge = 25.6 Kev)	-0.693/0.033 e 7.5×10^{-10}	-0.693/0.235 e 0.0524	-0.693/0.489 e 0.242	-0.693/19.7 e 0.966
0.1 cm Copper	-0.693/0.018 e 2×10^{-17}	-0.693/0.169 e 0.0164	-0.693/1.21 e 0.564	-0.693/2.22 e 0.732	-0.693/29.9 e 0.977
0.1 cm Steel	-0.693/0.0296 e 7.04×10^{-11}	-0.693/0.269 e 0.076	-0.693/1.84 e 0.686	-0.693/3.36 e 0.814	-0.693/32.3 e 0.979
0.1 Aluminum cm	-0.693/0.811 e 0.425	-0.693/7.30 e 0.910	-0.693/47.8 e 0.985	-0.693/68.9 e 0.990	-0.693/89.6 e 0.992
0.1 cm Polystyrene	-0.693/34.8 e 0.980	-0.693/218 e 0.997	-0.693/306 e 0.998	-0.693/287 e 0.998	-0.693/205 e 0.997

TABLE 5 - Relative Response of Kodak Type 3 Film
Behind Various Filters

Filter Material	Relative Responses at Effective Energies* of:				
	20 Kev	40 Kev	80 Kev	100 Kev	600 Kev
Kodak Type 3 Packet behind 52 mg/cm ² plastic*	~ 8	20.5	13	9.5	1
0.1 cm Lead	$< 8 \times 10^{-67}$	1.9×10^{-6}	1.2	0.0122	0.907
0.1 cm Cadmium	$< 3 \times 10^{-3}$	3×10^{-7}	0.97	2.83	0.97
0.1 cm Silver	$< 2 \times 10^{-4}$	1.5×10^{-8}	0.68	2.30	0.966
0.1 cm Copper	$< 1.6 \times 10^{-16}$	0.336	7.3	6.95	0.977
0.1 cm Steel	$< 5 \times 10^{-10}$	1.56	8.9	7.73	0.979
0.1 cm Aluminum	~ 3.4	18.6	12.8	9.40	0.992
0.1 cm Polystyrene	~ 7.8	20.4	13	9.5	1

- * Calculated by multiplying the relative responses of the bare Type 3 Packet (behind 52 mg/cm² of Plastic) as read from Fig. 21, ORNL - 3126, by the transmissions of the previous table. Somewhat different responses curves would be obtained using data in Refs 5 or 6.

TABLE 6

Composition and Relative Mass Stopping Power of
Air, Water, Tissue, and Bone for Beta Radiation*

Relative Mass Stopping Power for
Electrons Having an Energy of:

Substance	Composition	0.01 Mev	0.1 Mev	2.0 Mev
Air	75.5% N	0.996	0.995	0.997
	23.2% O			
	1.3% A			
	11.2% H			
Water	88.8% O	1.17	1.15	1.14
Wet Tissue	10% H	1.16	1.14	1.13
	12% C			
	4% N			
	73% O			
	0.1% Na			
	0.04% Mg			
	0.2% P			
	0.2% S			
	0.1% Cl			
	0.37% K			
	0.01% Ca			
	5.02% H			
Bone	18.76% C	1.04	1.04	1.04
	3.35% N			
	47.76% O			
	0.2% Na			
	0.41% Mg			
	7.15% P			
	0.30% Cl			
	17.05% Ca			

* K.Z.Morgan, unpublished data.

TABLE 7-A - CRUDE ESTIMATES OF MAGNITUDES OF RADIATION-EXPOSURE-YEARS AT RISK(1964)

PLANT	TOTAL NO. EMPLOYEES (1964)	PEAK NO. EMPLOYEES	ESTIMATED FRACTION EXPOSED TO MORE THAN 10% EXTERNAL MPD CUMULATIVE	NO. EMPLOYEES WITH MORE THAN 10% of M.P. BODY BURDEN	MAJOR SOURCES OF EXPOSURE	ESTIMATED RANGE OF "PRY" UNITS (PERSON-ROENTGEN-YEARS) (WHOLE-BODY RADIATION)
HANFORD PLANT Pu-production reactors; chem. separations plants; research & development	1800-labs 7000-prod. & reactor op. (construction workers not included-presently about 1700)	25,000?	8% (highest whole body dose = 110 Rem)	18 (Pu-239) highest = 215% of an MPBB by inhalation, MPBB 0.64uc)	Pu inhalation; 16Kev x-rays to skin, mostly >50 Kev x-rays to whole body from reactors & fission prod.	1000 persons x 0.5 r per yr. x (avg. exposure time of 20 yr.) x (avg. years at risk of 15 yr.) = <u>150,000</u> ($\times \frac{10}{2}$) -
NATIONAL LEAD CO. of Ohio	3,000	6,000?	3% (recent annual reports show extremely small ext. whole body dose; skin doses are 10-20 times higher, however.	Difficult to assess by urinalysis; estimated at no more than 100 persons. Some air conc. up to 527 "NCG"	U inhalation-low enrichment, or natural; Th daughters Beta exp. to hands; Low whole body Y.	100 persons x 1 r per yr. x 10 yr. x 15 yr. = <u>15,000</u> ($\div 3$) $\times 2$

TABLE 7-B - CRUDE ESTIMATES OF MAGNITUDES OF RADIATION-EXPOSURE-YEARS AT RISK

PLANT	TOTAL NO. EMPLOYEES (1964)	PEAK NO. EMPLOYEES	ESTIMATED FRACTION EXPOSED TO MORE THAN 10% EXTERNAL MPD CUMULATIVE	NO. EMPLOYEES WITH MORE THAN 10% OF M.P. BODY BURDEN	MAJOR SOURCES OF EXPOSURE	ESTIMATED RANGE OF "PRY" UNITS (PERSON-ROENTGEN-YEARS) (WHOLE-BODY RADIATION)
OAK RIDGE X-10 Isotope Sep. Res. & Dev.	4,300 (about 1/3 for more than 15 yrs)	12,000	<10%	3 persons > 1/4, but less than 1/2 of perm. body burden Pu; 1 Sr 90- small	External whole- body gamma from isotope separa- tion facilities & isotope packaging	$500 \times 0.5 \times$ 10×20 $= 50,000$ $\frac{(\times 10)}{(\div 2)}$
Y-12 Uranium purif. & fabrication	5,000	25,000 (1946)	<3%	Currently being measured in whole body counter (sensitivity 100 μ g U235 at 95% conf.= 30% of MPBB)	U235-various enrichments; Beta exposure to hands. Low whole body doses. Very low Th.	$500 \times 0.5 \times$ 10×20 $= 50,000$ $\frac{(\times 2)}{(\div 10)}$

TABLE 7-B-CRUDE ESTIMATES OF MAGNITUDES OF RADIATION-EXPOSURE-YEARS AT RISK (CONT'D)

PLANT	TOTAL NO. EMPLOYEES (1964)	PEAK NO. EMPLOYEES	ESTIMATED FRACTION EXPOSED TO MORE THAN 10% EXTERN- AL MPD CUMU- LATIVE	NO.EMPLOYEES WITH MORE THAN 10% OF M.P. BODY BURDEN	MAJOR SOURCES OF EXPOSURE	ESTIMATED RANGE OF "PRY" UNITS (PERSON-ROENTGEN- YEARS) (WHOLE BODY RADIATION)
K-25 Uranium Isotope by gaseous diffusion; some chem. processing	2,600	12,700 (70% man- ual; 20% clerical, 10% admin. not incl. early con- struction workers)	< 3% (e.g.in 1963, 119 out of 2,519 were ex- posed to 0-1r, none greater than 1 r)	3 by whole body counter, urine data obtained since 1944 could be used to help select ex- posed group.	UF ₆ , UF. Other uranium salts-mostly low enrich- ment. Low whole body gamma.	200 x 0.5 r per yr. x 10 x 20 <u>20,000</u> (X 2) (÷ 10)

Table 8

Comparison of Film Badge and Pocket Chamber Records in an
Atomic Energy Facility for Fourteen Years of Operation

Year	Median Dose (R)	Total Man-rem*	No. of Employees Badged	Avg. Film Badge Annual Total (R)	Total Man Rem*	No. of Employees Wearing Pocket Chambers	Avg. Pocket Chamber Annual Total (R)
1950	0.163	19	64	0.295	19	67	0.213
1951	0.180	51	123	0.267	36	118	0.305
1952	0.320	63	141	0.449	58	143	0.409
1953	0.270	39	152	0.350	52	150	0.503
1954	0.230	101	249	0.406	130	271	0.481
1955	0.300	411	517	0.795	158	46	3.456
1956	0.370	672	753	0.893	667	413	1.593
1957	0.530	331	926	0.352	1,040	601	1.744
1958	0.430	361	735	0.809	677	449	1.508
1959	0.380	407	845	0.552	426	306	1.073
1960	0.360	430	830	0.518	397	395	1.006
1961	0.290	451	852	0.530	361	314	1.150
1962	0.056	211	980	0.216	150	100	1.445
1963	0.068	271	787	0.345	240	145	1.662
Total/Average		4,794	—	0.555	4,470	—	1.183

*Penetrating whole body radiation only, where recorded separately.
There were over 2,000 individual names encountered over this time period, indicating that less than 1 out of 10 individuals ever exposed to radiation at the plant is currently (1963) receiving film service.

TABLE 9

Comparison of Recorded Radiation Exposures
with those Re-evaluated from Stored Films

Employee	Total Recorded Cumulative Exposure for 1951-1954 (rem)	Total of Re-evaluated Monthly Gamma Expo- sures (MILLI REM) (Read in 1965 from stored Films, using Typical duPont type 502 Response to Ra.)
1	1540	784
2	1342	548
3	2122	2979
4	3350	2509
5	1482	516
6	1435	1294
7	1182	1993
8	1477	728
9	982	825
10	967	613
11	4632 (including an assumed reading)	9465
12	1617	1686
13	1200	-20
14	1352	140
15	312	0
16	1317	453
17	1222	368
18	6247	4506
19	1252	16
20	4255	6893
21	1212	123
TOTAL	40,497 man-rem	36,419 MAN-REM

*All original calibration films were not available.

TABLE 10
SUMMARY OF RECORDS AVAILABILITY
AT HANFORD & OAK RIDGE

<u>ITEM OF INFORMATION</u> (for employees on the site in the years indicated)	YEARS FOR WHICH INFORMATION IS AVAILABLE IN SOME FORM* (either at site, in Washington, and elsewhere)			
	HANFORD	OAK RIDGE		
		X-10	Y-12	K-25
A. <u>Personnel & Medical Records Data</u>				
Name (and at least one initial)	1944-present (100%)	1943-present (99%)	1947-present (100%)	1944 (90%) 1945-present (100%)
Social Security Number	1944-present (100%)	1943-present (95%)	1947-present (100%)	1942-present (90%)
Other Identification Number		1943-present (99%)	1947-present (100%)	
Date of Birth or Age	1944-present (100%)	1943-present (99%)	1948-present (100%)	1944-present (100%) 1942-present (90%)
Place of Birth	1944-present (100%)	1943-present (95%)	1943-present (15%)	1942-present (90%)

*Numbers in parentheses give estimated degree of completeness or the percentage of employees for whom the item of information is retained.

TABLE 10 (continued)

ITEM OF INFORMATION	HANFORD	OAK RIDGE		
		X-10	Y-12	K-25
Color	1944-present (100%)	1943-present (95%)	1963-present (100%) 1943-present (19%)	1942-present (90%)
Sex	1944-present (100%)	1943-present (99+%)	1943-present (19%)	1944-present (100%)
Marital Status	1944-present (100%)	1943-present (99+%)	-	1944-present (those receiving physicals)
Veterans Status	1946-present (on all currently employed per- sonnel)	1943-present (95%)	1943-present (19%)	1942-present (90%)
Dates When Entered Employment	1944-present (100%)	1943-present (99%)	1943-present (19%) 1947-present (100%)	1944-present (100%)
Separation or Termination Dates	1944-present (100%)	1943-present (99%)	1943-present (19%) 1947-present (100%)	1944-present (100%)
Copies of Personnel Security Questionnaires	Records Destroyed 5 yrs. following term. Sept. 1946-present, in Washington, D.C.	1943-present (99%)	Terminates since 1955 (15%)	1943-present (100%-supplemented by Washington)

TABLE 10 (continued)

ITEM OF INFORMATION	HANFORD	OAK RIDGE		
		X-10	Y-12	K-25
Reasons for Separation or Termination	1944-present (100%)	1943-present (99%)	1947-present (100%)	1950-present (100%)
Dates of Pre-employment Medical Examination	1944-present (100%)	1950-present (100%)	1947-present (100%)	1944-present ?
Results of Pre-employment Medical Exams	1944-present (100%)	1950-present (100%)	1947-present (100%)	1949-present ?
Dates of Periodic Medical Exams	1944-present (100%)	1950-present (100%)	1947-present (100%)	1944-present ?
Results of Periodic Medical Exams	1944-present (100%)	1950-present (100%)	1947-present (100%)	1947-present ?
Records of Visits to Medical Department	1944-present (100%)	1950-present	1947-present (100%)	1944-present
Work Restrictions for Physical Handicaps or other Medical Reasons	1944-present (100%)	-	1947-present (100%)	1945-present
Occupation of Persons Employed at the Site	1944-present (100%)	1943-present (99+%)	1947-present (100%)	1944 thru 1949 (99%)
Occupational History of Separated Employees	1944-present (100%)	1943-present (99%)	-	1950 to present
Work Assignment				
Beginning Date	1944-present (100%)	1943-present (99%)	1947-present (100%)	1961-present

TABLE 10 (continued)

ITEM OF INFORMATION	HANFORD	OAK RIDGE		
		X-10	Y-12	K-25
Termination Date	1944-present (100%)	1943-present (99%)	1947-present (100%)	-
Division or Department	1944-present (100%)	1943-present (99+%)	1947-present (100%)	-
Job Assignment	1957-present (~100%)	1943-present (99+%)	None	-
Work Location			1947-present (100%)	-

Continued.....

TABLE 10 (continued)

ITEM OF INFORMATION	HANFORD	OAK RIDGE		
		X-10	Y-12	K-25
B. <u>Radiation Exposure</u> <u>Records Data</u>				
Annual Whole Body Dose (or "Penetrating", "Hard Gamma", etc. Dose)				
(a) Whole Body dose in r, rep, rad, or rem	1944-present (~100%)	1947-present (99%+)	1950-present (100%)	1945-present (100%)
(b) Years for which correct- ion was made for low- energy x-rays and beta-rays	1944-present (~100%)	None-not applicable	1952-1956 (100%)	1945-present (100%)
(c) Years for which annual whole body dose of sepa- rated employees has been retained	1944-present (~100%)	1948-present (99%+) (1948-55 must be computed)	1950-present (100%)	1945-present (100%)
Annual Radiation Dose to Superficial Tissues	1946-present (~100%)	1947-present (99%+)	1950-present (100%)	1945-present (100%)
External Radiation Exposure History from Previous Employ- ments Requested for New Employees	1957-present (~100%)	1962-present (99%+)	1962-present	-
Records of bioassay sample data identifying employees possibly exposed to inhalation or ingestion or radioactive materials	1947-present (~100%)	1951-present (90%)	1950-present	1950-present (100%)

FIGURE 1

CRITICAL X-RAY K-ABSORPTION EDGE VS. Z

Energy Absorption Coeff. (cm²/gm) ($\mu - \sigma_s$)/ ρ

FIGURE 2

FIGURE 3
ABSORPTION COEFF. VS. ATOMIC NO.
 (ABOVE K EDGE)

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