DOE/EH-0171P

21

Twenty-first Annual Report

Radiation Exposures for DOE and DOE Contractor Employees - 1988

December 1990

Prepared for:

U.S. Department of Energy

Assistant Secretary for
Environment, Safety, and Health
Office of Health

DOE/EH-0171P

TWENTY-FIRST ANNUAL REPORT RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES - 1988

S. E. Merwin
W. H. Millet[a]
R. J. Traub

DOE Project Manager: R. D. Jarrett
PNL Project Managers: J. M. Selby and K. L. Swinth

December 1990

Prepared for the U.S. Department of Energy
Assistant Secretary for
Environment, Safety, and Health
Office of Health
Under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

(a) Idaho National Engineering Laboratory
Idaho Falls, Idaho 83415

FOREWORD

This is the 21st in a series of annual radiation exposure reports published by the Department of Energy (DOE) or its predecessors. This report summarizes the radiation exposures received at DOE and DOE contractor facilities in 1988. Radiation exposures to both employees and visitors are included. Trends in radiation exposures are evaluated by comparing the doses received in 1988 to those received in previous years. The significance of the doses is addressed by comparing them to the DOE limits and by correlating the doses to health risks based on risk estimates from expert groups.

This report represents a significant advancement from previous reports because it is the first for which detailed exposure data are available for each individual monitored at a DOE facility. In the past, only summarized data from each facility were available. As a result, this report contains information on different types of radiation doses, such as penetrating, shallow, and neutron doses. It also contains analysis of exposures by age, sex, and occupation of the exposed individuals. This report is the first of any federal organization that presents such detailed exposure data.

We believe this report will provide useful data to organizations or individuals involved in radiation protection activities. National and international organizations such as the National Council on Radiation Protection and Measurements, the International Commission on Radiological Protection, and the United Nations Scientific Committee on the Effects of Atomic Radiation, have used DOE radiation exposure data in the past in formulating their recommendations and analyses. The information in these reports is also used by the DOE to identify areas of needed improvement to ensure continued commitment to the As Low As Reasonably Achievable (ALARA) philosophy of radiation protection.

Paul L. Ziemer, Ph.D.
Assistant Secretary
Environment, Safety and Health

Harry J. Pettengill, Ph.D.
Deputy Assistant Secretary
for Health

PREFACE

This report is one of a series of annual reports provided by the U.S. Department of Energy (DOE) summarizing occupational radiation exposures received by DOE and DOE contractor employees. These reports provide an overview of radiation exposures received each year and identify trends in exposures being experienced over the years.

In 1968, the U.S. Atomic Energy Commission (AEC) established a program for reporting certain occupational radiation exposure information to a central radiation records repository. Annual summary reports were published from 1969 through 1973 (WASH-1350-R1 through WASH-1350-R6), which included information on AEC contractor employees and visitors, as well as employees and visitors of companies in the private sector licensed by the AEC.

In January 1975, with the separation of the AEC into the Energy Research and Development Administration (ERDA) and the U.S. Nuclear Regulatory Commission (NRC), each agency assumed responsibility for collecting and maintaining occupational radiation exposure information reported by the facilities under its jurisdiction. Former AEC licensees reported to the NRC while contractors reported to ERDA. At the same time, a contract was established with Union Carbide Corporation at Oak Ridge, Tennessee, to computerize the reporting and processing of both the ERDA and NRC radiation exposure reporting systems. On October 1, 1977, DOE was formed and assumed the responsibilities of ERDA. Processing and programming of exposure information continued at Oak Ridge until October 1978, when the management and further development of the DOE radiation exposure reporting system was assigned to the System Safety Development Center, EG&G Idaho, Inc.; the NRC system remained at Oak Ridge.

Radiation exposure data for ERDA and ERDA contractor employees and visitors for 1974 through 1976 were reported in ERDA 76/119, ERDA 77-29, and DOE/EV-0011/9. The DOE and DOE contractor radiation exposure data for 1977-1979 were presented in DOE/EV-0066/10, 11, and 12, respectively. A revised version of the 1979 report was issued as DOE/EP-0039. The data for 1980-1982 were presented in DOE/EP-0040, DOE/EP-0040/1, and DOE/EP-0040/2. The data for 1983-1987 were presented in DOE/PE-0072, DOE/EH-0011, DOE/EH-0036, DOE/EH-0069, and DOE/EH-0128, respectively. This report contains 1988 radiation exposure data for DOE and DOE contractor employees and visitors.

Previous reports for AEC/ERDA/DOE government and contractor employees and visitors may be obtained from the DOE Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830.

SUMMARY

All U.S. Department of Energy (DOE) and DOE contractors are required by DOE Order 5484.1, Chg 3, Chapter IV, to submit occupational radiation exposure records to a central repository. In 1988, data were required to be submitted for all employees who were required to be monitored in accordance with DOE Order 5480.1B, Chapter XI, and for all visitors who had a positive exposure.[a] The data required include the external penetrating whole-body dose equivalent, the shallow dose equivalent, and a summary of internal depositions of radioactive material above specified limits. Data regarding the exposed individuals include the individual's age, sex, and occupation category. This report is a summary of the external penetrating whole-body dose equivalents, the shallow dose equivalents, and the internal depositions of radioactive material reported by DOE and DOE contractors for the calendar year 1988.

A total of 81,629 DOE and DOE contractor employees were reported to have been monitored for whole-body ionizing radiation exposure in 1988. This represents 49.3% of all DOE and DOE contractor employees and is a slight increase (601) from the number of monitored employees reported for 1987. In addition to the employees, 52,529 visitors were monitored. (For more information, see Table 4.1.)

Of all monitored employees reported, 61.0% received a dose equivalent that was less than measurable, 38.3% received a dose equivalent between measurable and 1 rem, and 0.7% received a dose equivalent greater than 1 rem. No employee received a dose equivalent greater than 3 rem. The dose equivalent received by 88.1% of the visitors to DOE facilities was less than measurable. Only 11.9% of the visitors reported received a dose equivalent between measurable and 1 rem, and 0.02% of the visitors received a dose equivalent greater than 1 rem. No visitor received a dose equivalent greater than 3 rem. (These data are detailed in Table 4.1 and are illustrated in Figure 4.2.)

The collective dose equivalent for DOE and DOE contractor employees in 1988 was 3,655 person-rem, which represents a decrease of 39% from 1987. The collective dose equivalent for visitors was 245 person-rem, which represents a decrease of 34%. The average dose equivalent for all monitored employees reported was 45 mrem, and the average dose equivalent for all employees reported who received a measurable exposure was 115 mrem. The average dose equivalent for all monitored individuals (employees and visitors) reported was 29 mrem, and the average dose equivalent for all individuals reported who received a

---

(a) DOE Order 5480.11 was promulgated January 1, 1989; DOE Order 5480.1B, Chapter XI, was in effect during 1988, the calendar year covered in this report.

measurable exposure was 103 mrem. The highest average dose equivalent for all monitored individuals reported was observed at fuel processing facilities (113 mrem), and the lowest was observed at DOE offices (3 mrem). These averages are significantly less than the DOE 5 rem/year radiation protection standard for whole-body exposures. (For more information, see Tables 4.1 and 4.4.)

Of the ten occupation categories reported, production workers received both the highest collective dose equivalent (862 person-rem) and the highest average dose equivalent per individual who received a measurable exposure (220 mrem). Agricultural workers received both the lowest collective dose equivalent (1 person-rem) and the lowest average dose equivalent per individual who received a measurable exposure (20 mrem). Service workers also received a low average dose equivalent per individual who received a measurable exposure (28 mrem). (See Table 4.8 for further details.)

For both males and females, the five-year age group receiving the highest collective dose equivalent was the 30 to 34 age group. However, the highest average dose equivalent per individual who received a measurable exposure was in the 25 to 29 age group for males (130 mrem) and the 60 to 64 age group for females (135 mrem). The lowest average dose equivalent per individual who received a measurable exposure was received by the 19 and less age group for both males and females. (See Table 4.11.)

The average dose equivalent for all males who received a measurable exposure was 107 mrem; for females, the average was 96 mrem. Males received a total of 3,350 person-rem, while females received 471 person-rem. A total of 80 person-rem was received by individuals for whom sex was not specified on the report forms. (See Table 4.13.)

Of the 3,901 person-rem received by DOE and DOE contractor employees and visitors at DOE facilities, 2,997 person-rem (77%) was attributable to beta-gamma exposures and 904 person-rem (23%) was attributable to neutron exposures. Approximately 33% of the collective dose equivalent from neutrons was received at weapons fabrication and testing facilities. In addition to the penetrating dose equivalent (beta-gamma and neutron), DOE and DOE contractor employees and visitors received a collective shallow dose equivalent of 5,950 person-rem. (See Table 4.15 for further details.)

CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

The purpose of this report is to disseminate information regarding radiation exposures received at U.S. Department of Energy (DOE) and DOE contractor facilities. At these facilities, dose equivalents received by both workers and visitors are carefully monitored and recorded. The primary purpose of this practice is to ensure that the DOE occupational dose limits are not exceeded and that as low as reasonably achievable (ALARA) goals are met. A secondary purpose, however, is to provide information that can be used by other organizations and individuals who wish to collect and analyze such information. This information may be useful for estimating the effect of changing dose limits on operations at DOE facilities, determining the progress of DOE with respect to the ALARA principle, or, in combination with epidemiological information, assisting researchers in determining whether or not low doses of ionizing radiation are harmful.

This report contains eight main sections and six appendices. Section 2.0 presents relevant DOE operating requirements including dose limits, ALARA, and reporting requirements. Section 3.0 presents brief descriptions of the various categories of DOE facilities and the sources of radiation exposure at each facility category.

Section 4.0 presents a summary of the radiation doses received at DOE and DOE contractor facilities in 1988. The data are presented according to dose-equivalent interval, facility type, field organization, occupation category, age, sex, and type of exposure (external penetrating, shallow, internal, etc.). The section concludes with an evaluation of recent exposure trends at DOE and DOE contractor facilities.

Section 5.0 presents information regarding a study of cumulative exposures of workers at a single DOE and DOE contractor facility. Section 6.0 presents reporting requirements for radiation exposure incidents at DOE and DOE contractor facilities. Section 7.0 presents a comparison of the doses received at DOE and DOE contractor facilities and the consequent risks relative to other risks that occur both in the workplace and as a part of everyday life. Section 8.0 lists the references cited in this report.

Six appendices are included in the report, five of which contain raw exposure data for DOE and DOE contractor employees and visitors. Appendix A presents the 1988 distribution of whole-body dose equivalents by facility type for each DOE field organization. Appendix B presents the 1988 distribution of whole-body dose equivalents by contractor for each DOE field organization. Appendix C presents the 1988 distribution of whole-body dose equivalents for DOE government employees and visitors by DOE field organization. Appendix D presents 1988 data on penetrating (whole-body) dose equivalents, including neutron and

beta-gamma components, and shallow dose equivalents by various combinations of facility type, age, sex, and occupation. Appendix E presents 1987 data similar to the 1988 data in Appendix D. Although this report contains primarily 1988 exposure data, some of the tables and figures showing trends do include 1987 exposure data. Therefore, the 1987 data in Appendix E are provided in order to support the trend data in this and future annual reports. These data were not included in the previous annual report (DOE/EH-0128) because the data became available after the report was published. Finally, Appendix F lists the current DOE limiting values for assessed dose from occupational exposure to ionizing radiation.

This annual report is the first that presents data by exposure type, age, sex, and occupation, based on the recently revised reporting requirements. As a result, this report represents a transition from the previous annual reports. Comments or suggestions that would improve the report or make it more useful should be sent to the U.S. Department of Energy, Assistant Secretary for Environment, Safety, and Health, Washington, D.C. 20585.

2.0 DOE OPERATING REQUIREMENTS

One of the primary objectives of the DOE is to ensure that all its operations and those of DOE contractors are conducted safely. To help achieve this objective, the DOE has established radiation protection standards and program requirements to protect workers from ionizing radiation. The basic DOE standards are radiation dose limits, which establish maximum permissible doses to workers. In addition to the requirement that radiation doses to workers be maintained below the limits, it is DOE's policy that doses be maintained as far below the limits as is reasonably achievable.

2.1 DOSE LIMITS

In order to ensure that workers at DOE facilities are adequately protected from ionizing radiation, the DOE promulgates radiation protection standards for occupational workers. These standards include radiation dose limits to protect workers from both external radiation and internally deposited radionuclides. In 1988, the calendar year covered in this report, the radiation dose limits were promulgated in DOE Order 5480.1B, Chapter XI (DOE 1986). These included limits on doses both to the whole-body and to individual organs (Table 2.1). Monitoring was required by DOE Order 5480.1B, Chapter XI, when the potential existed for an individual to receive a dose or dose commitment above 10% of the quarterly or annual occupational radiation exposure standards shown in Table 2.1. Depending on the administrative policy of the field organization or contractor, monitoring may also have been provided to some or all individuals, such as clerical workers, for whom the exposure potential was extremely low.

The current DOE radiation protection standards are different from those that were in effect in 1988. In 1987, the Environmental Protection Agency (EPA) published its revised guidance to federal agencies for protection against occupational radiation exposure (FR 1987). This guidance was a result of a review by EPA of the most recent recommendations of the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP). The primary new feature of the guidance is that weighted internal doses are added to external doses to determine total effective dose equivalent. In the past, these were limited separately. The DOE became the first federal agency to implement the revised guidance when it promulgated its revised radiation protection standards for occupational workers on January 1, 1989 (see Appendix F).

TABLE 2.1. DOE Limiting Values for Assessed Dose from Exposure of Occupational Workers to Radiation (in effect before January 1, 1989)

Exposure Category	Limit
Whole body, head and trunk, gonads, lens of the eye, red bone marrow, active blood-forming organs	3 rem/quarter and 5 rem/yr
Unlimited areas of the skin (except hands and forearms), other organs, tissues, and organ systems (except bone)	5 rem/quarter and 15 rem/yr
Bone	10 rem/quarter and 30 rem/yr
Forearms	10 rem/quarter and 30 rem/yr
Hands and feet	25 rem/quarter and 75 rem/yr

2.2 ALARA PRINCIPLE

It has long been DOE's policy that radiation exposures should be maintained as far below the dose limits as is reasonably achievable. This policy is known as the ALARA principle of radiation protection, which maintains that radiation exposures should be maintained as low as reasonably achievable (ALARA), economic and social factors being taken into account (ICRP 1977).

The ALARA principle is based on the hypothesis that even very low radiation doses carry some risk. As a result, it is not enough to maintain doses at or slightly below the limits; the lower the doses, the lower the risks. Because it is not possible to reduce all doses at DOE facilities to zero, economic and social factors must be considered to determine the optimal level of radiation doses. If doses are too high according to the ALARA principle, resources would be well spent to reduce them. At some point, the resources being spent to maintain low doses are exactly balanced by the risks avoided. Reducing doses below this point results in a misallocation of resources; the resources could be spent elsewhere and have a greater impact on health and safety.

To ensure that doses are maintained ALARA at DOE facilities, the DOE has mandated that ALARA plans and procedures be implemented and documented. To help ensure that facilities meet this requirement, the DOE has developed a manual of good practices for reducing radiation exposures to ALARA levels (Munson et al. 1988). These include guidelines for administration of ALARA programs, techniques for performing ALARA calculations based on cost-benefit principles, guidelines for setting and evaluating

ALARA goals, and methods for incorporating ALARA criteria into both radiological design and operations. The establishment of ALARA as a required practice at DOE facilities demonstrates DOE's commitment to ensure minimum risk to workers from the operation of its facilities.

2.3 REPORTING REQUIREMENTS

In 1987, the DOE promulgated revised reporting requirements in DOE Order 5484.1, Chg 3 (DOE 1987). Formerly, contractors were required to report only the number of individuals who received an occupational whole-body exposure in one of 16 dose-equivalent ranges. However, contractors are required by the revised Order to report exposure data for individual employees and visitors. Data required include total effective dose equivalent, external penetrating dose equivalent (including neutron), internal effective dose equivalent, shallow dose equivalent, and extremity dose equivalent. Other data required include the individual's age, sex, employment status, and occupation, as well as the relevant organization and facility type.

The availability of these new data provided the impetus for the revised and expanded format of this report. Because the revised reporting requirements are still being implemented by individual facilities and contractors, the 1988 exposure data were not reported in a format consistent with the new requirements in all cases. In this report, data are presented based on the new reporting requirements, and explanations are provided for those cases when the data were incomplete.

3.0 FACILITY DESCRIPTIONS

DOE Order 5484.1, Chg 3, requires contractors to indicate for each reported individual the facility contributing the predominant portion of the individual's effective dose equivalent. In cases when this cannot be distinguished, the facility indicated should represent the facility wherein the greatest portion of work service was performed.

The facility indicated must be one of eleven general facility categories: accelerator, fuel/uranium enrichment, fuel fabrication, fuel processing, maintenance and support (site-wide), reactor, general research, fusion research, waste processing/management, weapons fabrication and testing, and other. Because it is not always a straightforward procedure to determine the appropriate facility type for each individual, the assignment of an individual to a particular facility type is a policy decision of each contractor.

The facility descriptions that follow indicate the types of facilities included in each category. Also included are the types of work performed at the facilities and the sources of the majority of the radiation exposures.

3.1 ACCELERATOR

The DOE administers approximately a dozen laboratories that perform significant accelerator-based research. The accelerators range in size from small single-room electrostatic devices to a four-mile circumference synchrotron, and their energies range from keV to TeV.

The differences in accelerator types, sizes and energies result in differences in the radiation types and dose rates associated with the accelerator facilities. In general, radiation doses to employees at the facilities are attributable to neutrons and x-rays, as well as muons at some of the larger facilities. Exposure rates inside the primary shielding can range up to 200 mR per hour as a result of x-ray production near some machine components. Outside of the shielding, however, x-ray exposure rates are very low, and neutron dose rates are generally less than 5 mrem per hour. Average annual doses at these facilities are slightly higher than the overall average for DOE; however, the collective dose is lower than the collective dose for most other DOE facility categories because of the relatively small number of employees at accelerator facilities. Regarding internal exposures, tritium and short-lived airborne activation products exist at some accelerator facilities, although annual internal doses are generally quite low.

3.2 FUEL/URANIUM ENRICHMENT

The DOE involvement in the nuclear fuel cycle generally begins with uranium enrichment operations and facilities (Rich et al. 1988). The current method of enrichment is isotopic separation using the gaseous diffusion process, which involves diffusing uranium through a porous membrane and using the different molecular weights of the different uranium isotopes to achieve separation.

Although current facility designs and physical controls result in low doses from internally deposited uranium, the primary radiological hazard is the potential for inhalation of airborne uranium (Rich et al. 1988). Because of the low specific activity of uranium, external dose rates are usually a few mrem per hour or less. Most of the external doses that are received are attributable to gamma exposures, although neutron exposures can occur, especially when work is performed near highly enriched uranium. Both the average and collective external doses at these facilities are among the lowest of any DOE facility category.

3.3 FUEL FABRICATION

Activities at fuel fabrication facilities involve the physical conversion of uranium compounds to usable forms, usually rod-shaped metal. Radiation exposures to personnel at these facilities are attributable almost entirely to gamma and beta radiation. However, beta radiation is considered the primary external radiation hazard because of the high beta dose rates (up to several hundred mrad per hour) at the surface of uranium rods (Rich et al. 1988). For example, physical modification of uranium metal by various metal-working operations, such as machining and lathing operations, requires protection against beta radiation exposures to the skin, eyes, and extremities. Average external doses at fuel fabrication facilities are generally higher than at other types of DOE facilities; however, collective doses are relatively low because the number of employees is low. Internal doses from inhalation of uranium are kept very low.

3.4 FUEL PROCESSING

The DOE administers several facilities that reprocess spent reactor fuel. This process separates out the plutonium produced in the reactors for use in nuclear weapons. The process also separates the fission products, which are normally designated as radioactive waste products, and unspent uranium, which can be refabricated for further use as fuel.

The very high radioactivity of spent reactor fuel (fission products) results in employees at fuel processing facilities consistently having among the highest average doses of any DOE facility type. However, the

collective dose at these facilities is less significant because of the small total number of employees. Penetrating doses are attributable primarily to gamma photons, although some neutron exposures do occur. Skin and extremity doses from handling of samples are also significant, although only a few employees typically receive skin doses greater than 5 rem per year. Strict controls are in place at fuel reprocessing facilities to prevent internal depositions; however, several measurable intakes typically occur per year. Plutonium isotopes represent the majority of the internal depositions, and annual effective equivalents from the depositions are typically less than 500 mrem.

3.5 MAINTENANCE AND SUPPORT

Most DOE sites have facilities dedicated to maintaining and supporting the site. In addition, some employees may be classified under this facility type if their main function is to provide site maintenance and support, even though they may not be located at a single facility dedicated to that purpose.

Because many maintenance and support activities at DOE sites do not involve work near sources of ionizing radiation, the average dose equivalent per monitored employee is typically among the lowest of any facility type. However, those employees who do perform work near radiation sources receive relatively high average annual doses, as is indicated by the relatively high average annual dose per employee who receives a measurable exposure. Also, collective doses are relatively high because there is a large number of these employees relative to the number classified under other facility types. The sources of ionizing radiation exposure are primarily gamma photons. However, the variations in the types of work performed and the work locations result in exposures of all types, including exposures to beta particles, x-rays, neutrons, and airborne radioactivity.

3.6 REACTOR

The DOE and its predecessors have built and operated dozens of nuclear reactors since the mid-1940s. These facilities have included plutonium or tritium production reactors, prototype reactors for energy production, research reactors, reactors designed for special purposes such as production of medical radioisotopes, and reactors designed for the propulsion of naval vessels.

In 1988, many of the DOE reactors were not operating. As a result, personnel exposures at DOE reactor facilities were attributable primarily to gamma photons and beta particles from contaminated equipment and plant areas, spent reactor fuel, activated reactor components, and other areas containing fission or activation products encountered during plant maintenance and decommissioning operations. Neutron

exposures do occur at operating reactors, although the resultant doses are a very small fraction of the collective penetrating doses. Gamma dose rates in some plant areas can be very high (up to several R per hour), requiring extensive protection measures. The average and collective external doses relative to other facility types are highly dependent on the status of reactor operations. Inhalation of airborne radioactive material is a concern in some plant areas. However, protective measures such as area ventilation or use of respiratory protection equipment result in low internal doses.

3.7 RESEARCH, GENERAL

The DOE contractors perform research at many DOE facilities including all of the national laboratories. Research is performed in general areas including biology, biochemistry, health physics, materials science, environmental science, epidemiology, and many others. Research is also performed in more specific areas such as global warming, hazardous waste disposal, energy conservation, and energy production, just to name a few.

The wide variety of research being performed at DOE facilities results in a wide variety of radiological conditions at those facilities where ionizing radiation or radioactive materials are an important part of the research. Depending on the research performed, personnel may be exposed to virtually any type of external radiation including beta particles, gamma photons, x-rays, and neutrons, as well as the potential for inhalation of radioactive material. Area dose rates and individual annual doses are also highly variable. Relative to other facility types, average annual individual doses are slightly above average at general research facilities. The collective dose equivalent is higher than at most other facility types because of the many individuals employed at general research facilities.

3.8 RESEARCH, FUSION

The DOE currently operates one major and several smaller facilities that participate in research on fusion energy. In general, both penetrating and shallow radiation doses are minimal at these facilities because the dose rates near the equipment are both low and intermittent. The external doses that do occur are attributable primarily to x-rays from energized equipment. Relative to other DOE facility types, average individual doses and collective doses are typically the lowest at fusion research facilities. Regarding internal exposures, airborne tritium is a concern at some fusion research facilities, although the current level of operation results in minimal doses.

3.9 WASTE PROCESSING/MANAGEMENT

Most DOE sites have facilities dedicated to the processing and disposal of radioactive waste. In general, the dose rates to employees when handling waste are very low because of the low specific activities or the effectiveness of shielding materials. As a result, very few employees at these facilities receive annual doses greater than 100 mrem. At two DOE sites, however, large-scale waste processing facilities exist in order to properly dispose of radioactive waste products generated during the nuclear fuel cycle. At these facilities, radiation doses to some employees can be relatively high, sometimes exceeding 1 rem per year. Penetrating doses at waste processing facilities are mostly attributable to gamma photons; however, neutron exposures are significant at the large-scale facilities. Skin doses are generally not a significant problem. Overall, average annual doses at waste processing/management facilities are among the highest of any DOE facility type, which is attributable primarily to the two large-scale facilities. The annual collective doses are closer to the average of all facility types, however, because of the relatively small number of employees at this type of facility.

3.10 WEAPONS FABRICATION AND TESTING

The primary function of a facility in this category is to fabricate weapons-grade material for the production of nuclear weapons, or the testing of nuclear weapons. At the testing facilities, radiation doses received by personnel are generally minimal because of the strict controls over personnel access to testing areas, although extremity doses can be relatively high from handling neutron-activated materials. Radiation doses are more of a concern at facilities where weapons and weapons-grade nuclear material are handled. At these facilities, neutron radiation dose rates can be significant when processing relatively small quantities of ^{238}Pu or larger quantities of mixed plutonium isotopes (Faust et al. 1988). Penetrating doses from gamma photons and plutonium x-rays can also be significant in some situations, as can skin and extremity doses from plutonium x-rays. Overall, average individual annual doses at these facilities are slightly higher than the DOE average. The collective doses received by employees at these facilities are generally higher than the collective doses at other facility types because of the large number of individuals employed.

Also of significant concern at these facilities is inhalation of plutonium, where inhalation of very small amounts could result in doses exceeding limits. To prevent plutonium intakes, strict controls are in place including process containment, contamination control procedures, and air monitoring and bioassay programs (Faust et al. 1988). As a result, significant internal exposures are very rare at these facilities.

3.11 OTHER

Individuals placed in this facility type can be generally classified under three categories: 1) those who worked in a facility that did not match one of the 10 facility types described above, 2) those who did not work for an appreciable time at any specific facility, such as transient workers, or 3) those for whom facility type was not indicated on the report forms. Examples of a facility type not included in the 10 described above include construction and irradiation facilities. In general, employees classified under this facility type receive annual doses significantly less than the annual doses averaged over all DOE facilities. However, the wide variation in the type of work performed by these individuals results in a wide variation in the types and levels of exposures. Although exposures to gamma photons are predominant, some individuals may be exposed to beta particles, x-rays, neutrons, or airborne radioactive material.

4.0 SUMMARY OF IONIZING RADIATION DOSES

Monitoring is required by DOE Order 5480.1B, Chapter XI, when the potential exists for an individual to receive a dose or dose commitment in excess of 10% of the quarterly or annual occupational radiation exposure standards shown in Table 2.1. (Effective January 1, 1989, DOE Order 5480.1B, Chapter XI, was superseded by DOE Order 5480.11. However, because this report addresses 1988 exposure data, the requirements of the former Order are presented.) Depending on the administrative policy of the contractor, monitoring may also be provided to individuals, such as clerical workers, for whom the exposure potential is extremely low.

On November 6, 1987, DOE promulgated revised reporting requirements in DOE Order 5484.1, Chg 3, which affected the reporting of occupational doses received during 1987 and beyond. Before 1987, DOE contractors were required to report only the number of individuals who received an occupational whole-body exposure in one of 16 dose-equivalent intervals ranging from "less than measurable" to "greater than 10 rem." Contractors are now required, however, to submit detailed exposure data for individual employees who were monitored and for visitors who received a measurable exposure. (Contractors are also required to provide a count of the total number of visitors monitored.) For 1988, data required to be submitted for each individual included external penetrating whole-body dose equivalent, shallow dose equivalent, and any uptake of radioactive material that resulted in a dose commitment to the critical organ in excess of 50% of the pertinent annual dose equivalent standards set forth in DOE Order 5480.1B, Chapter XI. Consequently, this report is a summary of external penetrating dose equivalents and shallow dose equivalents received by DOE and DOE contractor employees and visitors in 1988, and briefly summarizes uptakes of radioactive material that were required to be reported.

One benefit of the new reporting requirements is that calculation of collective dose equivalents received by DOE and DOE contractor employees and visitors will be more accurate than in the past. Previously, collective dose equivalents were calculated by multiplying the number of individuals who received dose equivalents in various dose-equivalent intervals by the midpoint of those intervals and then summing the products. For this report, however, this calculational method was not necessary because the actual doses received by individuals were reported by the contractors. This allowed the actual collective dose equivalents received by individuals to be determined. Analysis of the 1987 and 1988 data indicated that using the midpoints of the dose-equivalent ranges rather than the actual dose equivalents reported would have resulted in an overestimate of the collective dose equivalent received by all DOE and DOE contractor

employees and visitors by 15.5% for 1987 and 25.3% for 1988. Therefore, it is likely that the collective dose equivalents reported for previous years were overestimated by approximately 20%.

Another important change resulting from the revised reporting requirements is that the specific employees for whom the results of monitoring are required to be reported have changed. Although both the former and current reporting requirements state that annual reports shall be submitted for all monitored DOE and DOE contractor workers, the current requirements define the term "monitored worker" whereas the former requirements did not. Monitored workers are defined by the current requirements as those employees who work with or near ionizing radiation or radioactive material and who are monitored in accordance with DOE Order 5480.1B. Therefore, the term "monitored worker" is generally considered to be synonymous with the term "radiation worker." As a result, some contractors chose not to report data for individuals who were not required to be monitored, especially those who received no measurable dose. This probably accounts for the significant decrease in the number of monitored employees reported for 1987 and 1988 compared to previous years (see Figure 4.1).

4.1 DISTRIBUTION BY DOSE INTERVAL

The number of employees and visitors who received a dose equivalent in each of 16 dose-equivalent ranges is presented in Table 4.1. No DOE or DOE contractor employee received a dose equivalent greater than 3 rem, which is significantly less than the DOE radiation protection standard of 5 rem. A total of 81,629 DOE and DOE contractor employees were reported to have been monitored for whole-body ionizing radiation exposure in 1988. This represents 49.3% of all DOE and DOE contractor employees. In addition to the employees, 52,529 visitors were monitored at DOE facilities. Visitors may include radiation workers from another DOE facility present on a temporary basis.

For comparison, Table 4.1 lists both the actual collective dose equivalents reported for each dose-equivalent interval and the collective dose equivalents that would have been calculated had the midpoints of the dose-equivalent intervals been multiplied by the number of persons in those intervals. The latter calculational method was used in reports prior to the 20th annual report for calendar year 1987 (DOE/EH-0128) because individual exposure data were not submitted to the central repository. The data indicate that 73% of the overestimate of the total collective dose equivalent using this method is attributable to the "Measurable to 0.1 rem" dose-equivalent interval.

A comparison of the number of DOE and DOE contractor employees, the number of monitored employees reported, and the number of monitored employees reported who did not receive a measurable

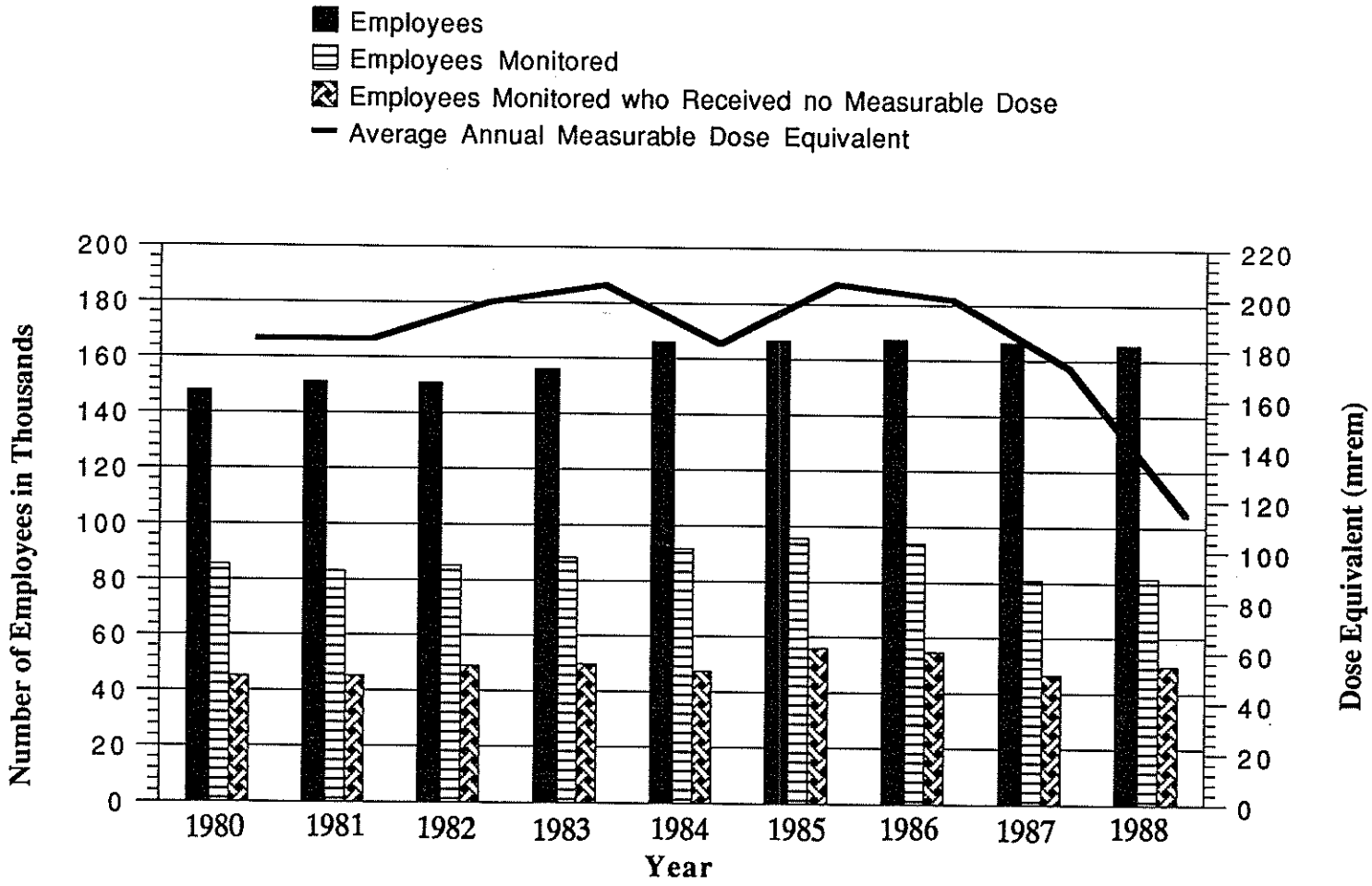

FIGURE 4.1. Comparison of Number of Employees, Number of Employees Monitored, and Number of Employees Monitored Who Received No Measurable Dose Equivalent, 1980-1988

TABLE 4.1. Distribution of Whole-Body Ionizing Radiation Doses for DOE/DOE Contractor Employees and Visitors by Dose-Equivalent Interval, 1988

Dose-Equivalent Interval (rem)[b]	Number of Persons			Collective Person-rem[a]			
	Employees	Visitors	Total	Employees	Visitors	Total	
< Measurable	49,833	46,278	96,111	0	0	0	
Measurable to 0.10	23,609	5,749	29,358	637	115	752	(1,468)[c]
0.10 to 0.25	4,299	336	4,635	679	49	728	(811)
0.25 to 0.50	2,083	110	2,193	721	37	758	(822)
0.50 to 0.75	842	38	880	515	22	537	(550)
0.75 to 1.00	427	7	434	368	6	374	(380)
1 to 2	502	10	512	658	13	672	(768)
2 to 3	34	1	35	77	2	80	(88)
3 to 4	0	0	0	0	0	0	
4 to 5	0	0	0	0	0	0	
5 to 6	0	0	0	0	0	0	
6 to 7	0	0	0	0	0	0	
7 to 8	0	0	0	0	0	0	
8 to 9	0	0	0	0	0	0	
9 to 10	0	0	0	0	0	0	
> 10	0	0	0	0	0	0	
Total	81,629	52,529	134,158	3,655	245	3,901	(4,887)

(a) Throughout this report there may be minor variations in collective dose-equivalent values because of rounding.
(b) Reported individual dose equivalents that equalled a value defining the boundary between two successive intervals were placed in the higher of the two intervals.
(c) Numbers in parentheses indicate the collective dose equivalents calculated by multiplying the midpoints of the dose-equivalent ranges by the numbers of persons in those ranges.

dose equivalent is presented for the years 1980-1988 in Figure 4.1. The figure also illustrates the average dose equivalent per employee who received a measurable exposure. The number of monitored employees reported for 1987 and 1988 decreased significantly from the number reported for previous years.[a]

Of the monitored employees reported for 1988, 61.0% received a dose equivalent that was less than measurable, 38.3% received a dose equivalent between measurable and 1 rem, and 0.7% received a dose equivalent greater than 1 rem (Figure 4.2). The dose equivalent received by 88.1% of the visitors to DOE facilities was less than measurable. Only 11.9% of the visitors received a dose equivalent between measurable and 1 rem, and 0.02% of the visitors received a dose equivalent greater than 1 rem (Figure 4.2).

(a) Much of this decrease is attributable to the revised reporting requirements discussed on page 4.2.

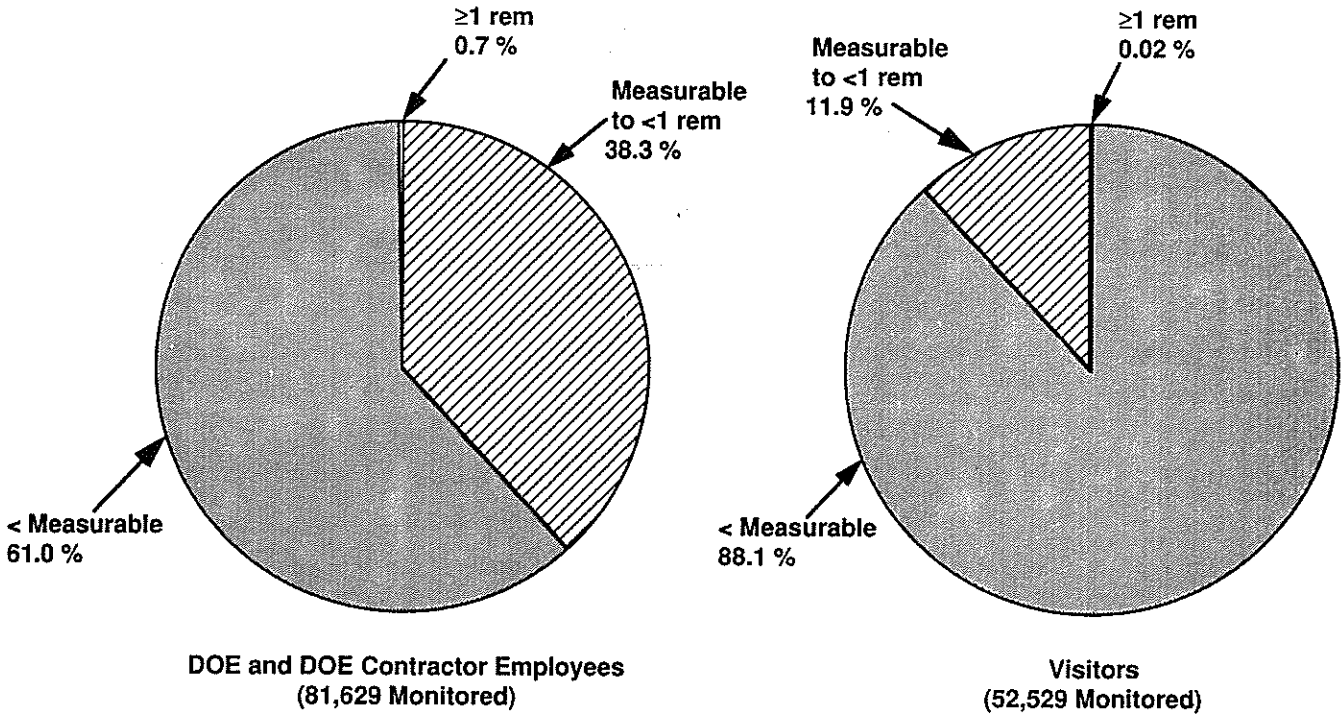

FIGURE 4.2. Percentage of Monitored Employees and Percentage of Monitored Visitors Who Received Dose Equivalents Less Than Measurable, Measurable to 1 Rem, or Greater Than 1 Rem, 1988

The collective whole-body dose equivalent was 3,655 person-rem for all DOE and DOE contractor employees, and 245 person-rem for visitors to DOE facilities, for a total DOE collective dose equivalent of 3,901 person-rem. The contribution of the individuals (employees and visitors) in each dose-equivalent interval to the collective dose equivalent is shown in Figure 4.3. Individuals whose exposure was between measurable and 1 rem contributed the greatest portion (80.7%) of the total person-rem.

The distribution of whole-body doses for DOE and DOE contractor employees for the years 1965-1988 is presented in Table 4.2. As indicated, the fraction of all monitored employees who received a dose equivalent greater than 1 rem has declined dramatically since 1965, starting at about 5%, leveling off at about 2% from about 1977 to 1987, and dropping to less than 1% in 1988. This general downward trend in occupational radiation exposures can be observed in Figure 4.4, which shows the collective dose equivalent for employees from 1965 to 1988 who received a dose equivalent greater than 1 rem. The collective dose equivalent for employees who received an exposure less than 1 rem was not included because, before 1974, less-than-measurable exposures were not distinguished from measurable exposures in the reporting system. This decrease in collective dose equivalent has been achieved even though some

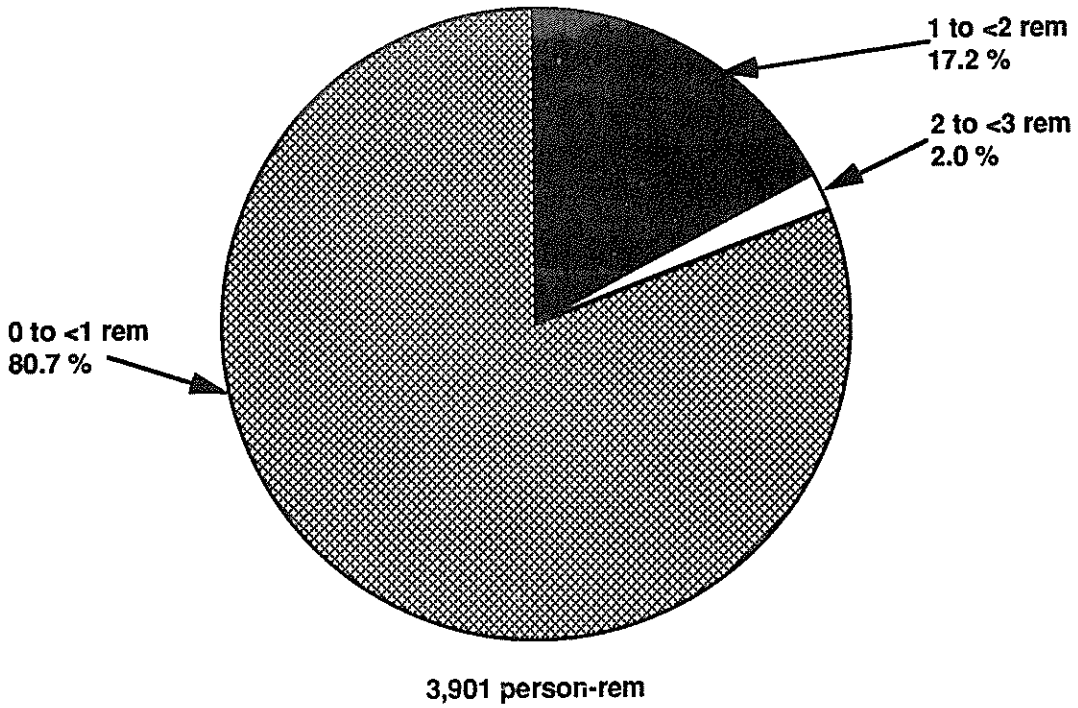

FIGURE 4.3. Contribution of Each Dose-Equivalent Interval to the Total Collective Dose Equivalent, 1988

work was performed in older facilities which were not constructed using current design criteria. This trend reflects both changes in the nature of the work performed at DOE facilities and the required application of ALARA practices throughout all DOE operations. The most recent decrease may be attributable in part to reduced operations at some DOE facilities.

Analysis of occupational doses is commonly performed by fitting the data to a lognormal distribution (Brodsky et al. 1976; Brooks 1988). Figure 4.5 presents the 1988 data for DOE and DOE contractor employees on a lognormal probability plot. If the data in Figure 4.5 were truly distributed lognormally, then the points would form a straight line. The fact that the distributions curve upward indicate that the DOE occupational dose distributions are affected significantly by dose limits. In fact, the data are more appropriately described by a hybrid lognormal distribution, which will be discussed in Section 4.7 of this report.

Figure 4.5 is useful for indicating the fraction of employees whose dose equivalents exceed various values as well as the fraction of the collective dose equivalent that is attributable to various ranges of individual dose equivalent. For example, the figure indicates that although less than 1% of monitored DOE and

TABLE 4.2. Distribution of Whole-Body Ionizing Radiation Doses for DOE/DOE Contractor Employees, 1965-1988

Year	Number of Employees Receiving Doses in Each Dose-Equivalent Interval (rem)[a]													Total Monitored
	0-1[b]													
	<Meas.	Meas.-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	>12	
1965	128,360		4,158	1,704	515	294	70	32	26	25	22	6	2		135,214
1966	131,522		3,706	1,630	593	313	88	47	24	6	2			1	137,932
1967	102,510		3,472	1,572	555	168	35	29	23	17	4	1			108,386
1968	103,206		2,799	1,408	425	144	3	1							107,986
1969	98,625		2,554	1,313	335	86	4					1			102,918
1970	92,185		2,698	1,329	279	158	5	4	2		1				96,661
1971	90,640		2,380	888	275	118	8	3				1		2	94,315
1972	86,077		2,130	929	219	95	8	2							89,460
1973	89,071		1,944	727	172	60	2	1							91,977
1974	43,184	32,500	1,667	688	149	40	4								78,232
1975	43,310	42,141	1,846	753	232	142				1					88,425
1976	40,083	47,886	1,679	475	70	6	1								90,200
1977	43,017	49,948	1,579	545	103	23			1	2				2	95,220
1978	44,898	55,296	1,323	439	53	11									102,020
1979[c]	50,003	52,235	1,286	416	33	10	1							2	104,986
1980	45,054	38,895	1,113	387	16										85,465
1981[c]	45,224	36,561	967	263	29	5									83,049
1982	48,968	34,949	1,010	313	56	28									85,324
1983	49,871	36,768	1,270	294	49	31									88,283
1984[c]	47,327	42,696	1,226	312	31	11									91,603
1985	55,939	38,085	1,366	356	51	8				1					95,806
1986	54,581	37,774	1,298	349	35	1		1					1		94,040
1987	46,512	32,939	1,258	283	36										81,028
1988	49,833	31,260	502	34											81,629

(a) Reported individual dose equivalents that equalled a value defining the boundary between two successive intervals were placed in the higher of the two intervals for the 1988 data and the lower of the two intervals for data before 1988.

(b) Separation of data before 1974 is unavailable.

(c) The data differ slightly from those listed in previous annual reports because of corrections supplied by individual contractors after publication of the reports.

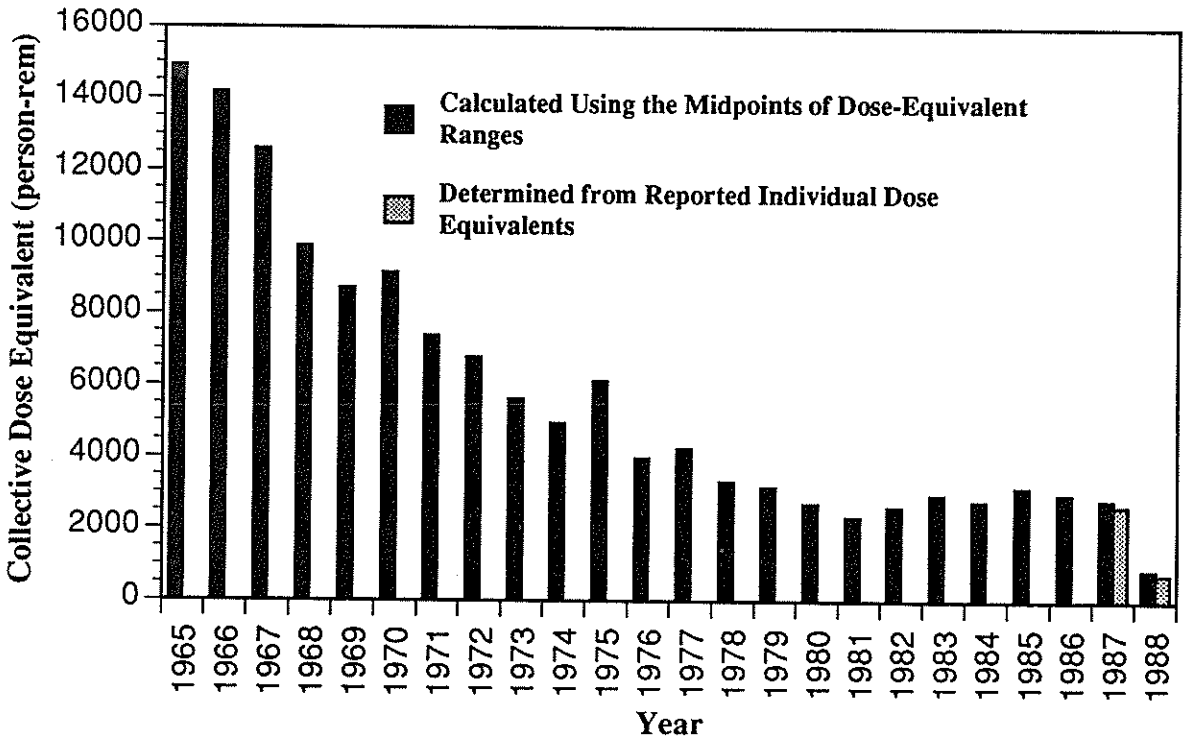

FIGURE 4.4. Total Collective Dose Equivalent for all DOE/DOE Contractor Employees Who Received a Dose Equivalent Greater Than 1 Rem, 1965-1988

DOE contractor employees received a dose equivalent greater than 1 rem, approximately 20% of the employee collective dose equivalent was attributable to individual dose equivalents greater than 1 rem.

4.2 DISTRIBUTION BY FACILITY TYPE

The number of individuals (employees and visitors) and the distribution of the annual whole-body dose equivalents in each of 11 facility categories were reported to the central repository. The assignment of exposures to one of the 11 facility types (listed in DOE Order 5484.1, Chg 3) is a policy decision of each field organization. For this section of the report, visitors and DOE offices were also considered a facility type. The contribution of each facility type to the collective dose equivalent is shown in Figure 4.6. The largest percentage of the total collective dose equivalent was in the category, "Weapons Fabrication and Testing" (19.6%). The smallest contribution was from DOE offices (0.1%). A summary of the data is presented in Table 4.3.

The average dose equivalent by facility type per individual monitored and per individual who received a measurable dose equivalent is shown in Table 4.4. The average dose equivalent per individual monitored

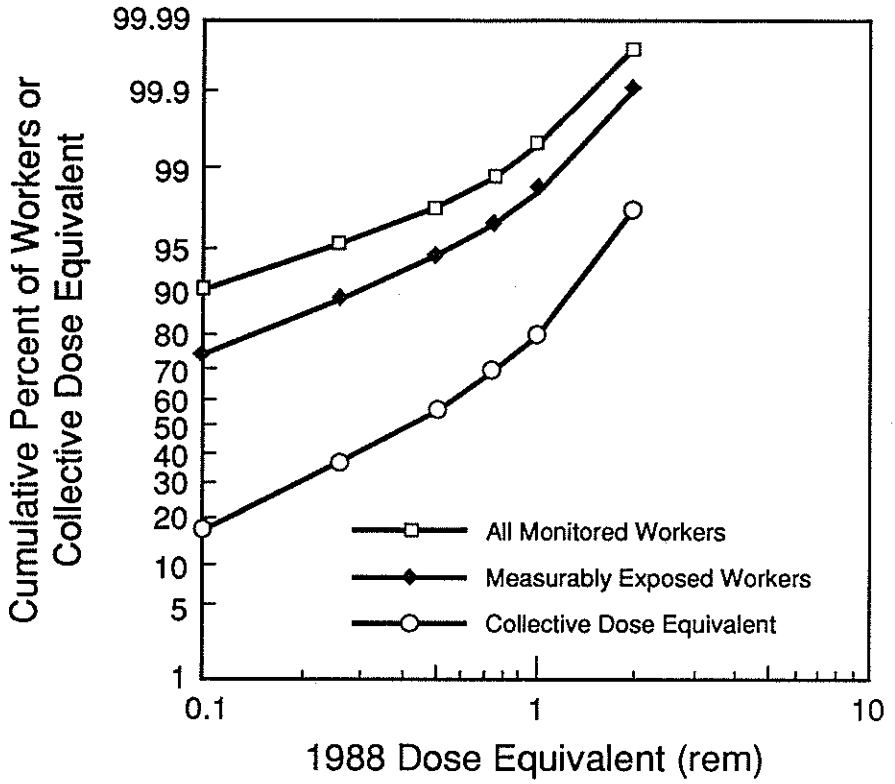

FIGURE 4.5. Log Probability Plots of Annual Exposure for Potentially Exposed and Measurably Exposed DOE and DOE Contractor Employees (Workers), 1988

for all facilities combined was 29 mrem. The highest average dose equivalent per individual monitored was observed at fuel processing facilities (113 mrem), and the lowest was observed at DOE offices (3 mrem). The average dose equivalent per individual who received a measurable dose equivalent was 103 mrem. The highest average dose equivalent per individual who received measurable dose equivalent was observed at fuel processing facilities (217 mrem), and the lowest was observed at DOE offices (19 mrem).

4.3 DISTRIBUTION BY FIELD ORGANIZATION

For each field organization, the number of monitored individuals reported, the number of individuals who received a measurable dose equivalent, and the collective dose equivalent are shown in Table 4.5.

Differences in the collective dose equivalent at each field organization reflect differences in the number of employees at the facilities, the nature of the work performed, and the administrative policy concerning whether the dose distribution is reported for all monitored employees or only for those for whom

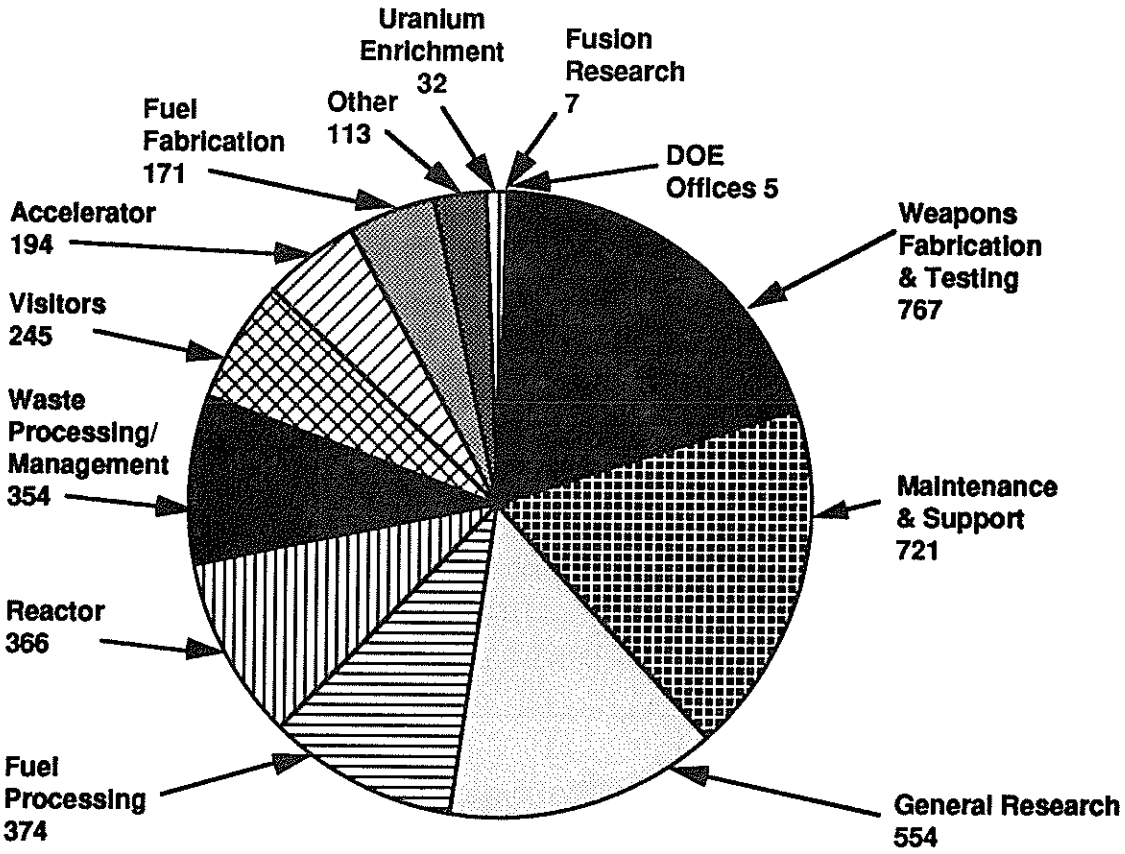

FIGURE 4.6. Contribution of Each Facility Type to the Total Collective Dose Equivalent, 1988 (numbers indicate person-rem)

monitoring is required. Table 4.6 provides an indication of the work performed at each field organization by showing the fraction of the collective dose equivalent at each field organization attributed to each facility type.

Table 4.7 presents collective dose equivalents for each field organization from 1980 to 1988. As indicated by the 1988 data, the practice of using the midpoints of dose-equivalent ranges to calculate collective dose equivalent overestimates the actual collective dose equivalent. This practice was necessary for pre-1987 data because of the lack of a requirement to report individual exposure data. For 1988, this practice would have resulted in overestimates in collective dose equivalents ranging from 13% (Nevada) to 81% (Schenectady). The collective dose equivalent for all DOE and DOE contractor employees and visitors would have been overestimated by 15.5% in 1987 and 25.3% in 1988. Therefore, it is likely that the collective dose equivalents reported for the years 1980 to 1986 were overestimated by approximately 20%. This topic will be discussed in more detail in Section 4.7.

TABLE 4.3. Distribution of Annual Whole-Body Doses for DOE/DOE Contractor Employees and Visitors by Facility Type, 1988[a]

Facility Type	Total Persons Monitored	Number of Persons Receiving Dose Equivalents in Each Dose-Equivalent Range (rem)[b]																Person-rem
		<Meas.	Meas.-0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	
Accelerator	4,590	2,882	1,292	222	94	49	20	28	3									194
Fuel/Uranium Enrichment	3,738	2,648	1,037	45	6	2												32
Fuel Fabrication	2,770	1,245	960	371	156	30	8											171
Fuel Processing	3,302	1,584	892	329	258	118	53	68										374
Maintenance and Support	20,435	12,871	5,896	924	443	158	71	61	11									721
Reactor	5,017	1,496	2,629	503	226	86	42	34	1									366
Research, General	13,369	8,886	3,332	612	270	94	66	97	12									554
Research, Fusion	1,694	1,508	178	7	1													7
Waste Processing/ Management	3,684	1,782	1,208	304	162	100	57	674										354
Weapons Fabrication and Testing	11,664	6,156	3,846	817	403	189	107	143	3									767
Other	10,061	7,711	2,103	161	64	16	2	4										113
Visitors	52,529	46,278	5,749	336	110	38	7	10	1									245
DOE Offices	1,305	1,064	239	4	1													5
Total Persons	134,158	96,111	29,358	4,635	2,193	880	434	512	35									
Total Person-rem			752	728	758	537	374	672	80									3,901

(a) Throughout this report there may be minor variations in collective dose-equivalent values because of rounding.
(b) Reported individual dose equivalents that equalled a value defining the boundary between two successive intervals were placed in the higher of the two intervals.

TABLE 4.4. Collective Dose Equivalents for DOE/DOE Contractor Employees and Visitors by Facility Type, 1988[a]

Facility Type	Number of Individuals Monitored	Number of Individuals Monitored Who Received a Measurable Exposure	Collective Dose Equivalent (Person-rem)	Average Dose Equivalent Per Individual Monitored (mrem)	Average Dose Equivalent Per Individual Monitored Who Received a Measurable Exposure (mrem)
Accelerator	4,590	1,708	194	42	114
Fuel/Uranium Enrichment	3,738	1,090	32	8	29
Fuel Fabrication	2,770	1,525	171	62	112
Fuel Processing	3,302	1,718	374	113	217
Maintenance and Support	20,435	7,564	721	35	95
Reactor	5,017	3,521	366	73	104
Research, General	13,369	4,483	554	41	124
Research, Fusion	1,694	186	7	4	38
Waste Processing/ Management	3,684	1,902	354	96	186
Weapons Fabrication and Testing	11,664	5,508	767	66	139
Other	10,061	2,350	113	11	48
Visitors	52,529	6,251	245	5	39
DOE Offices	1,305	241	5	3	19
All Facilities	134,158	38,047	3,901	29	103

(a) Throughout this report there may be minor variations in collective dose-equivalent values because of rounding.

TABLE 4.5. Collective Dose Equivalents for DOE/DOE Contractor Employees and Visitors by Field Organization, 1988

Field Organization	Number of Individuals Monitored[a]	Number of Individuals Monitored Who Received a Measurable Exposure	Collective Dose Equivalent (person-rem)	Average Dose Equivalent Per Individual Monitored (mrem)[a]	Average Dose Equivalent Per Individual Monitored Who Received a Measurable Exposure (mrem)
Albuquerque	24,415	10,193	1,210	50	119
Chicago	10,033	3,263	310	31	95
DOE-HQ	168	26	0	1	3
Idaho	5,903	2,041	253	43	124
Nevada	902	115	13	14	110
Oak Ridge	9,176	4,073	333	36	82
Pittsburgh Naval Reactor	2,053	1,693	86	42	51
Richland	9,202	4,870	654	71	134
San Francisco	10,578	998	74	7	74
Savannah River	17,198	8,700	887	52	102
Schenectady Naval Reactor	2,844	2,075	81	29	39
All Field Organizations	92,472	38,047	3,901	42	103

(a) Not including 41,686 visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied.

TABLE 4.6. Percent of Collective Dose Equivalent for Monitored DOE/DOE Contractor Employees and Visitors Attributed to a Facility Type Within Each Field Organization, 1988

Organization	Accel.	Fuel Enrich.	Fuel Fab.	Fuel Proc.	Maint.& Support	Reactor	Research, General	Research, Fusion	Waste Proc./Man.	Weapon F&T	Other	Visitors	DOE Offices
Albuquerque	4.3				10.5	1.8	17.5	0.1		56.2	4.2	5.4	
Chicago	35.5		0.2		6.6	9.6	27.4	1.6	1.7		0.4	16.8	0.1
DOE-HQ													100.0
Idaho				53.0	3.0	15.3	9.7		1.4		9.6	8.1	
Nevada					44.0					53.2		0.8	2.0
Oak Ridge		8.7	35.1	0.9			23.1		0.1	19.5	0.3	12.3	
Pittsburgh N.R.						36.0	63.0				0.6	0.3	
Richland			0.5	3.4	26.3	23.3	8.5		36.6		1.0	0.2	0.2
San Francisco	44.5	3.2			16.5		19.2	1.3		7.6	0.2	7.6	
Savannah River			5.6	24.2	42.3	6.2	2.9		11.8	1.2	3.1	2.5	0.2
Schenectady N.R.	—	—	—	—	—	45.6	8.2	—	—	—	0.1	46.1	—
All Field Organizations Combined	5.0	0.8	4.4	9.6	18.5	9.4	14.2	0.2	9.1	19.7	2.9	6.4	0.1

TABLE 4.7. Collective Dose Equivalent for Monitored DOE/DOE Contractor Employees and Visitors by Field Organization, 1980-1988 (person-rem)

Field Organization	1980	1981[a]	1982	1983	1984[a]	1985	1986	1987		1988	
Albuquerque	1,700	2,024	2,285	2,332	2,738	2,900	2,388	1,363	(1,591)[b]	1,210	(1,506)
Chicago	918	758	587	623	615	502	408	348	(438)	310	(381)
Idaho	593	302	363	353	441	420	685	318	(362)	253	(302)
Nevada	50	36	29	25	24	34	65	8	(9)	13	(15)
Oak Ridge	604	437	401	371	419	353	611	517	(610)	333	(425)
Pittsburgh Naval Reactor	186	185	194	220	180	180	143	78	(131)	86	(137)
Richland	2,256	2,093	2,272	2,458	2,399	2,548	2,321	2,477	(2,646)	654	(774)
San Francisco	240	171	289	267	195	187	108	78	(101)	74	(96)
Savannah River	1,391	1,401	1,310	1,293	1,283	1,394	1,498	945	(1,162)	887	(1,103)
Schenectady Naval Reactor	79	76	147	217	130	165	238	220	(290)	81	(147)
TOTAL	8,024[c]	7,483[c]	7,879[c]	8,158[c]	8,423[c]	8,684[c]	8,465[c]	6,353	(7,340)	3,901	(4,887)

(a) The data differ slightly from those listed in previous annual reports because of errors reported by contractors after publication of the report.

(b) Numbers in parentheses indicate the collective dose equivalents that would have been calculated by using the midpoints of the dose equivalent ranges to calculate collective dose equivalent, as was done for the 1980-1986 data. The year 1987 was the first for which actual individual dose equivalents were reported.

(c) Collective dose equivalents for the years 1980-1986 were calculated from incomplete data. Data for 1987 and 1988 suggest that the calculational method used could have overestimated the actual collective dose equivalents by approximately 20% for years before 1987.

The data in Table 4.7 are illustrated in Figure 4.7. This figure indicates the average, median, and extreme values of the collective dose equivalent per field organization for the years 1980 to 1988.

4.4 DISTRIBUTION BY OCCUPATION CATEGORY

DOE Order 5484.1, Chg. 3, requires that for each monitored individual (employee and visitor), a three-digit occupation code be included indicating the generic occupation that best fit the individual's occupation title. The 44 three-digit codes pertained to DOE occupation codes summarizing all Standard Occupational Classification (SOC) codes from the Department of Commerce's SOC Manual of 1980. The DOE is considering a revised requirement to report occupations by the full four-digit SOC code. This would eliminate the need for an intermediate code, would standardize occupational classifications, and would provide research data at a greater level of detail.

For this report, the 44 DOE occupational classifications were summarized into 11 general occupations to facilitate analysis:

- Management - managers and administrators; sales; support and clerical
- Scientists - engineers; scientists; health physicists; miscellaneous professionals; doctors and nurses
- Technicians - health technicians; engineering technicians; science technicians; radiation monitors/technicians; miscellaneous technicians
- Service - firefighters; security guards; food service employees; janitors; miscellaneous service
- Agriculture - groundskeepers; forest workers; miscellaneous agriculture
- Construction - mechanics/repairers; masons; carpenters; electricians; painters; pipe fitters; miners/drillers; miscellaneous repair/construction
- Production - machinists; sheet metal workers; operators - plant/system/utility; machine setup/operators; welders and solderers; miscellaneous precision/production
- Transport - truck drivers; bus drivers; pilots; equipment operators; miscellaneous transport
- Laborers - handlers/laborers/helpers
- Miscellaneous - military; miscellaneous
- Unknown - indicates that an occupation code was not specified on the form.

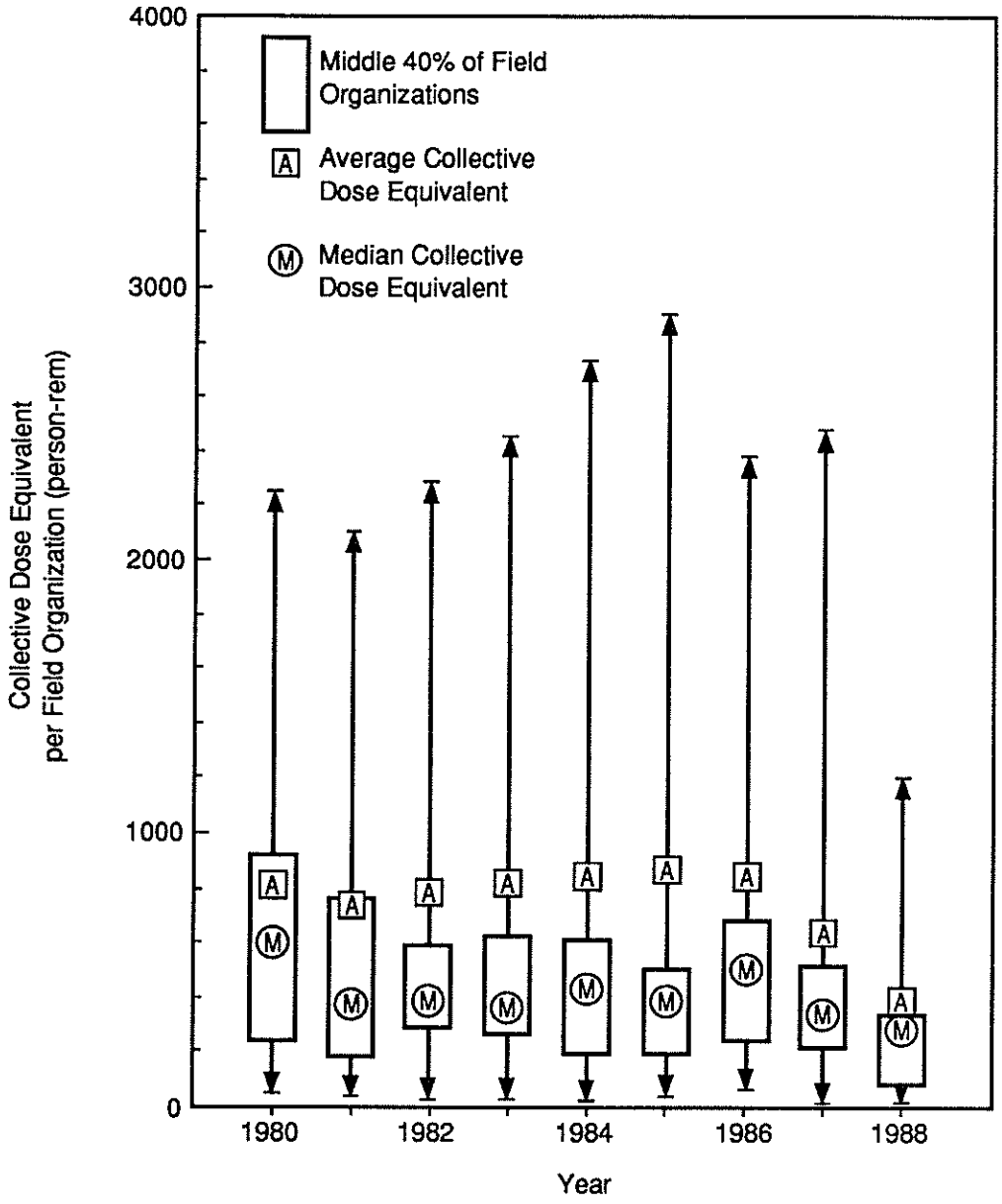

FIGURE 4.7. Average, Median and Extreme Values of the Collective Dose Equivalent per Field Organization, 1980-1988

Table 4.8 lists the number of individuals monitored, the number of individuals monitored who received a measurable dose equivalent, and the average dose equivalents for each occupation category. The "Unknown" category accounted for both the most individuals monitored and the most individuals

TABLE 4.8. Distribution of Whole-Body Ionizing Radiation Doses for DOE/DOE Contractor Employees and Visitors by Occupation, 1988

Occupation	Number of Individuals Monitored[a]	Number of Individuals Monitored Who Received A Measurable Exposure	Collective Dose Equivalent (person-rem)	Average Dose Equivalent Per Individual Monitored (mrem)[a]	Average Dose Equivalent Per Individual Monitored Who Received A Measurable Exposure (mrem)
Unknown	23,310	9,754	969	42	99
Management	9,700	2,903	173	18	60
Scientists	21,257	6,202	385	18	62
Technicians	9,069	4,183	646	71	154
Service	5,126	1,966	56	109	28
Agriculture	112	50	1	9	20
Construction	8,575	4,579	560	65	122
Production	6,159	3,924	862	140	220
Transportation	2,145	720	45	21	63
Laborers	1,615	929	82	51	88
Miscellaneous	5,404	2,837	118	22	42
All Occupations	92,472	38,047	3,901	42	103

(a) Not including 41,686 visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied.

monitored who received a measurable exposure. Individuals in the "Production" category received the highest average dose equivalent per individual monitored (140 mrem) and the highest average dose equivalent per individual monitored who received a measurable exposure (220 mrem). Figure 4.8 illustrates the data in Table 4.8 including an indication of the sex distribution of the individuals. Figure 4.9 illustrates the collective dose equivalent values in Table 4.8 as a pie chart. Table 4.9 lists the number of individuals monitored according to occupation and facility type.

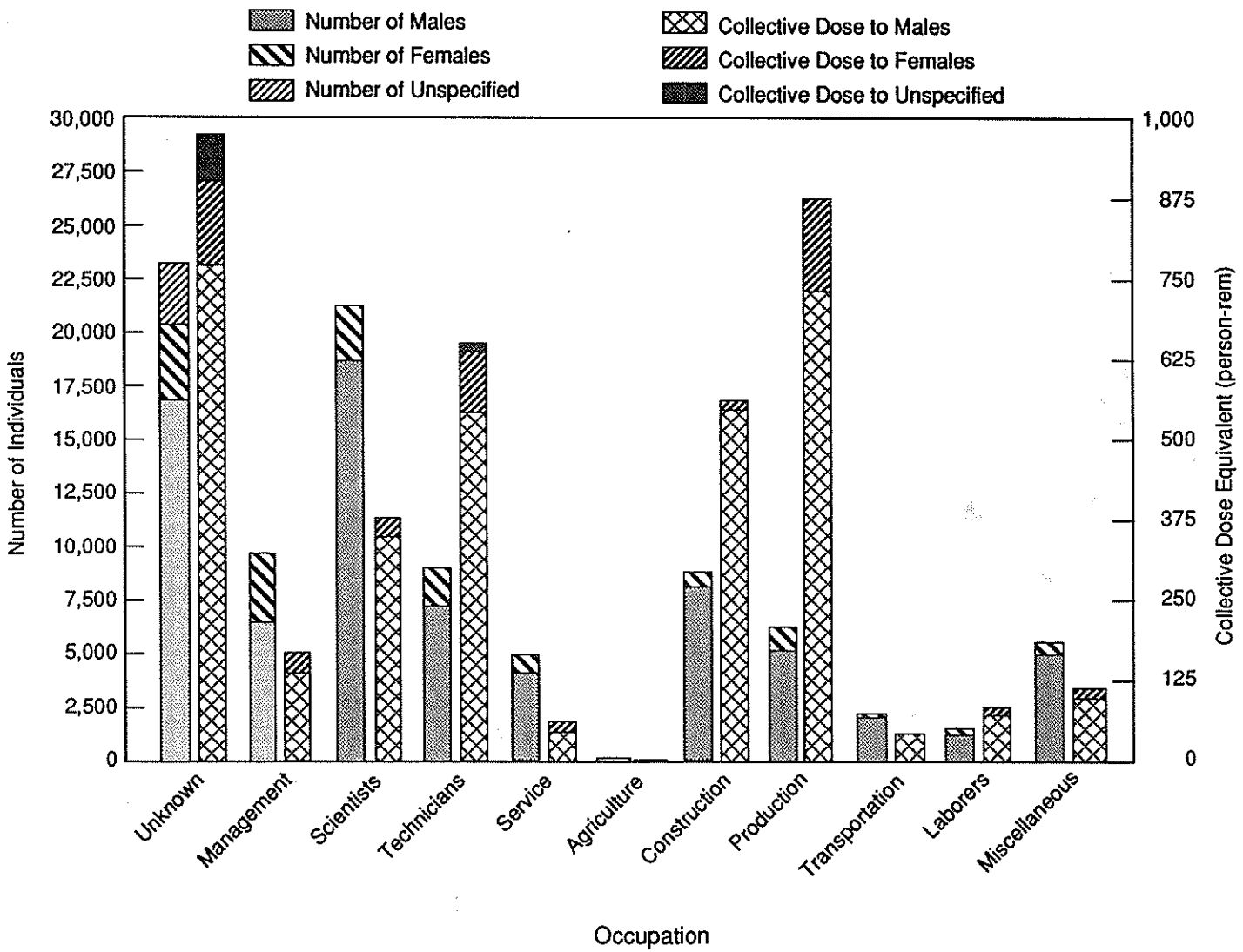

FIGURE 4.8. Penetrating Doses Received by DOE and DOE Contractor Employees and Visitors by Occupation, 1988 (not including 41,686 visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied).

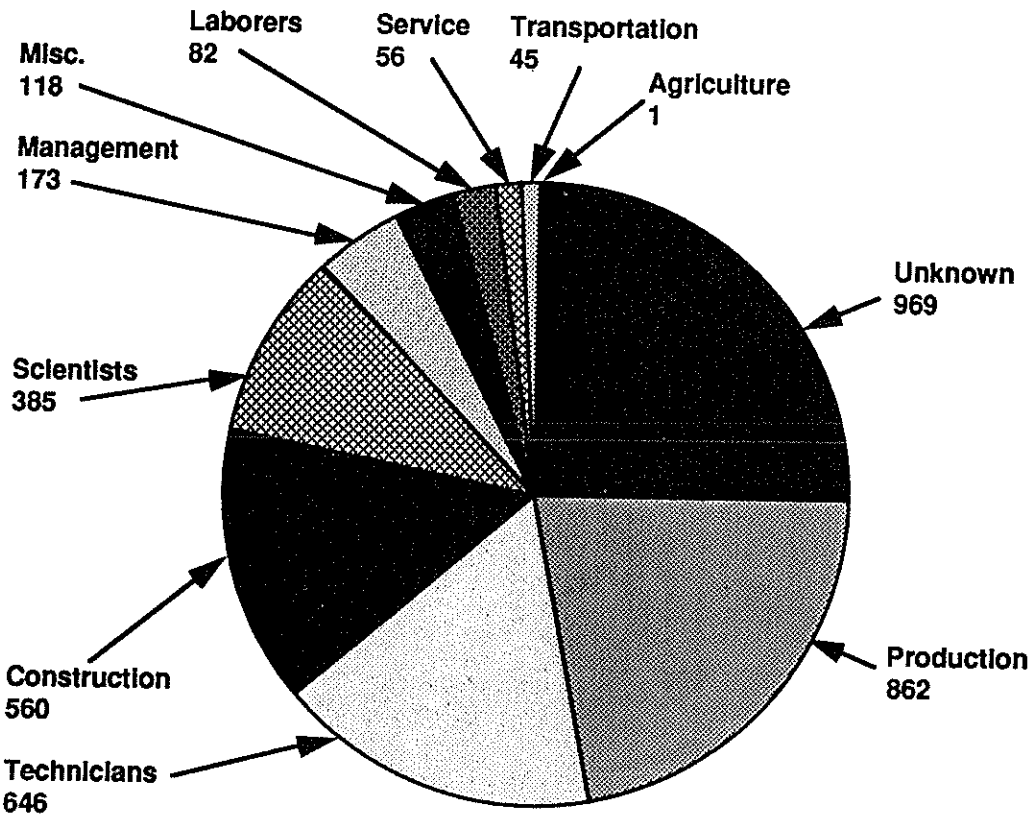

FIGURE 4.9. Contribution of Each Occupation Category to the Total Collective Dose Equivalent, 1988 (numbers indicate person-rem)

The number of individuals monitored and collective dose equivalent by occupation and dose-equivalent range are illustrated in three-dimensional format in Figure 4.10. The left half of the figure indicates the number of individuals monitored for any specified occupation and dose-equivalent range. For example, the heights of the bars indicate that most individuals monitored received either a less-than-measurable dose or a measurable dose less than 0.1 rem, and that more scientists and individuals of unknown occupation were monitored than were individuals of any other occupation. The exact number monitored is indicated by the numbers adjacent to the bars; for example, 435 technicians were monitored who received a dose equivalent between 0.25 and 0.50 rem. The right half of Figure 4.10 indicates the collective dose equivalent by occupation and dose-equivalent range. The figure demonstrates that technicians, construction workers, production workers, and individuals of unknown occupation received the majority of the collective dose equivalent received by DOE and DOE contractor employees. The numbers adjacent to the bars indicate the heights of the bars in person-rem. For example, the collective dose equivalent received by the 435 technicians who received individual dose equivalents between 0.25 and 0.50 rem was 152 person-rem.

TABLE 4.9. Number of Monitored DOE/DOE Contractor Employees and Visitors by Occupation and Facility Type, 1988[a]

Facility Type[b]	Total Persons Monitored	Unknown	Management	Scientists	Technicians	Service	Agriculture	Construction	Production	Transportation	Laborers	Miscellaneous	Total Person-rem
Accelerator	5,568	1,327	334	2,149	1,315	202	15	83	94	35	10	4	217
Fuel/Uranium Enrichment	4,269	638	512	860	400	344	1	723	512	39	184	56	38
Fuel Fabrication	4,481		550	680	216	83		315	759	92	52	1,734	193
Fuel Processing	3,477	1,953	54	585	33	10		291	512	13	19	7	385
Maintenance and Support	20,465	3,358	3,337	3,345	1,467	1,481	43	4,905	1,015	701	793	20	723
Reactor	6,061	822	679	1,678	429	128		580	610	55	23	1,057	410
Research, General	13,712	3,413	1,008	5,459	2,164	603	9	221	181	32	39	583	560
Research, Fusion	1,773	189	154	712	346	76		150	56		6	84	7
Waste Proc./ Management	4,118	161	640	1,152	550	74		729	641	98	46	27	355
Weapons Fabrication and Testing	13,419	2,279	1,775	3,217	1,680	435		392	1,636	108	104	1,793	805
Other	15,129	9,170	657	1,420	469	1,690	44	186	143	972	339	39	209
Total Persons Monitored	92,472	23,310	9,700	21,257	9,069	5,126	112	8,575	6,159	2,145	1,615	5,404	
Total Person-rem		969	173	385	646	56	1	560	862	45	82	118	3,901

(a) Not including 41,686 visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied.
(b) Visitors and DOE offices are not delineated as facility types for this table; collective doses received by visitors or at DOE offices have been incorporated into the appropriate facility type listed in the table.

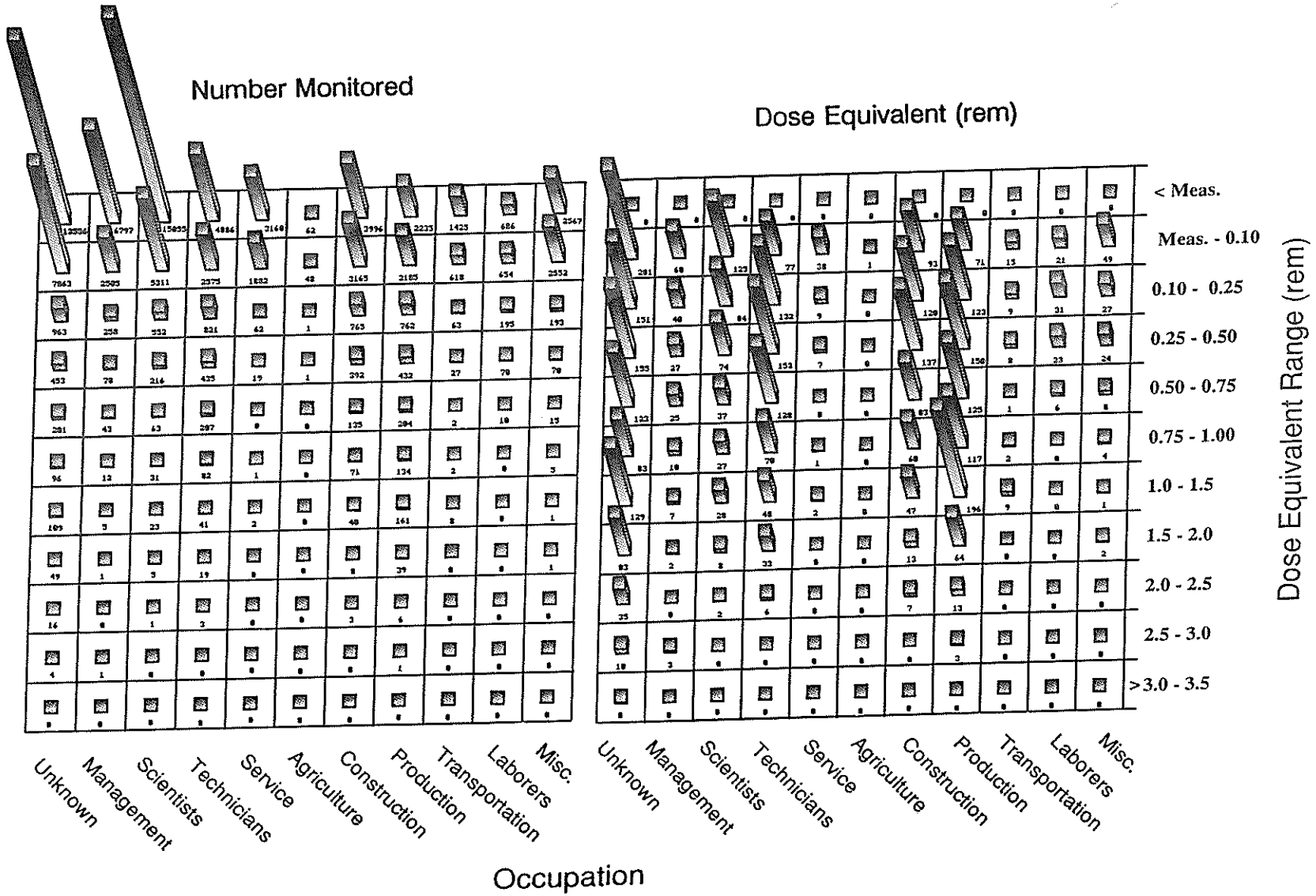

FIGURE 4.10. Three-Dimensional Representation of Number of Employees and Visitors Monitored and Collective Dose Equivalent by Occupation and Dose-Equivalent Range, 1988 (not including 41,686 visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied).

4.5 DISTRIBUTION BY AGE AND SEX

The 1988 exposure data submitted per DOE Order 5484.1, Chg. 3, included information on the age and sex of the exposed individuals (employees and visitors). Unfortunately, some forms were submitted without the required information. For the analysis in this report, 10 age categories were defined: 19-and-less, eight 5-year age groups beginning with the 20-24 age group, and ending with 65-and-greater. In addition, individuals for whom age was not specified were arbitrarily placed into the 65-and-greater age group. Regarding sex of the exposed individuals, a separate category for unspecified sex was defined. It was clear from the data that if sex was not specified on the form, other information such as age, occupation, or facility type were likely to be unspecified or unknown as well. For example, of the 3,149 monitored individuals for whom sex was not specified on the report form, 3,083 (98%) also were not identified by age. Similarly, the occupation was listed as unknown or was unspecified for 2,990 (95%) of the individuals for whom sex was unspecified.

Table 4.10 lists the number of individuals who received various penetrating dose equivalents by age and sex. The age group having the most monitored individuals was the 30-34 group; the age group having the fewest was the 19-or-less group. Table 4.11 presents similar data by collective dose equivalent rather than by number of monitored individuals. Again, the age group receiving the highest collective dose equivalent was the 30-34 group; the lowest was the 19-or-less group. Figure 4.11 illustrates the number of individuals by sex who received penetrating dose equivalents in various dose-equivalent ranges. Figure 4.12 illustrates the number of individuals by sex and age range who were monitored for ionizing radiation in 1988.

Table 4.12 lists the number of individuals monitored, the number of individuals monitored who received a measurable exposure, and the collective and average dose equivalents received by age range. The age group receiving the highest average dose equivalent per individual monitored was the 25-29 group (57 mrem); the age group receiving the lowest was the 19-and-less group (9 mrem). The age groups receiving the highest average dose equivalent per individual who received a measurable exposure were the 25-29 and 30-34 groups (124 mrem); the lowest was the 19-and-less group (40 mrem).

Table 4.13 presents similar data by sex rather than age. Males received approximately 88% of the collective dose equivalent received by individuals for whom sex was specified. Males also received higher average dose equivalents per individual monitored than did females (45 mrem versus 32 mrem) as well as higher average dose equivalents per individual monitored who received a measurable exposure (107 mrem versus 96 mrem).

TABLE 4.10. Distribution of Penetrating Doses by Age, Sex, and Exposure Range for DOE and DOE Contractor Employees and Visitors, 1988[a]

		Number of Individuals in Each Dose Equivalent Interval (rem)[b]										
Age Range	Sex[c]	<Meas.	Meas.-0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.0	1.0-2.0	2.0-3.0	3.0-4.0	>4.0	Total Monitored
≤19	M	223	72	5	1	1						302
	F	114	18	2								134
	U											
20-24	M	1,876	992	158	61	25	11	6				3,129
	F	760	273	25	11	5	2	2				1,078
	U		1									1
25-29	M	4,515	3,086	563	286	125	65	95	7			8,742
	F	1,496	683	91	50	17	7	13				2,357
	U	3	4									7
30-34	M	6,635	4,016	769	386	181	102	102	4			12,195
	F	1,866	784	144	53	32	16	15	2			2,912
	U	3	4									7
35-39	M	6,558	3,795	765	383	141	61	86	2			11,791
	F	1,608	673	90	45	26	9	10	2			2,463
	U	6	4									10
40-44	M	5,986	3,105	516	239	88	34	49	3			10,020
	F	1,270	512	61	33	15	7	6	1			1,905
	U	5	1									6
45-49	M	5,125	2,549	415	197	68	32	30	1			8,417
	F	1,006	34,530	16	7	5	6	1				1,416
	U	4	4									8
50-54	M	4,371	2,137	299	141	53	35	26	2			7,064
	F	662	256	29	6	4	2	4	2			965
	U	9	5									14
55-59	M	4,107	1,957	309	145	47	28	33	3			6,629
	F	468	155	16	3	2	2	2				648
	U	4	3									7
60-64	M	2,730	1,119	177	80	17	9	181				4,151
	F	266	73	8	1	1	2	3	1			355
	U	5	1									6
>65 or unspecified	M	1,333	921	64	26	4	3	3				2,354
	F	124	167	1	3	1						296
	U	1,287	1,643	98	27	21	3	3	1			3,083
Total	M	43,459	23,749	4,040	1,945	749	381	448	23			74,794
	F	9,640	3,939	497	221	110	50	61	11			14,529
	U	1,326	1,670	98	27	21	3	3	1			3,149

(a) Not including 41,686 visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied.

(b) Reported individual dose equivalents that equalled a value defining the boundary between two successive intervals were placed in the higher of the two intervals.

(c) M = male, F = female, U = unspecified.

TABLE 4.11. Collective Dose Equivalents by Age, Sex, and Exposure Range, 1988

Age Range	Sex[b]	Collective Dose-Equivalent in Each Dose-Equivalent Interval (rem)[a]										Total Person-rem[c]	Average Dose Equivalent Per Individual Monitored Who Received a Measurable Exposure (mrem)
		<Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.0	1.0-2.0	2.0-3.0	3.0-4.0	>4.0		
≤19	M		2	1		1						3	38
	F											1	50
	U												
20-24	M		24	24	21	16	9	9				104	83
	F		7	4	4	3	2	3				22	69
	U												
25-29	M		84	87	102	77	56	128	16			550	130
	F		17	15	18	11	6	17				83	96
	U												
30-34	M		109	120	134	110	87	133	10			704	127
	F		20	22	18	20	14	19	4			118	113
	U												
35-39	M		103	123	134	87	54	114	4			618	118
	F		16	15	16	16	8	13	5			89	104
	U												
40-44	M		79	81	82	54	29	62	1			394	98
	F		13	9	11	9	6	7	2			58	91
	U												
45-49	M		66	65	66	41	27	42	2			309	94
	F		9	5	6	4	4	8	3			38	93
	U												
50-54	M		56	47	49	32	29	31	5			249	92
	F		6	4	2	3	2	5	5			27	89
	U												
55-59	M		50	50	49	28	24	43	6			249	99
	F		4	2	1	1		3	5			17	94
	U												
60-64	M		29	27	27	10	8	22	2			124	87
	F		2	1		1	2	4	3			12	135
	U												
>65 or	M		18	9	9	2	2	5				45	44
unspecified	F		3		1	1						5	29
	U		34	15	9	12	3	4	2			79	44
Total	M		620	635	672	456	328	587	52			3,350	107
	F		97	78	77	69	44	81	26			471	96
	U		35	15	9	12	3	4	2			80	44

(a) Reported individual dose equivalents that equalled a value defining the boundary between two successive intervals were placed in the higher of the two intervals. Collective dose-equivalent values less than 1 rem are not shown.
(b) M = male, F = female, U = unspecified.
(c) May not exactly equal the sum of the numbers in the row because of rounding.

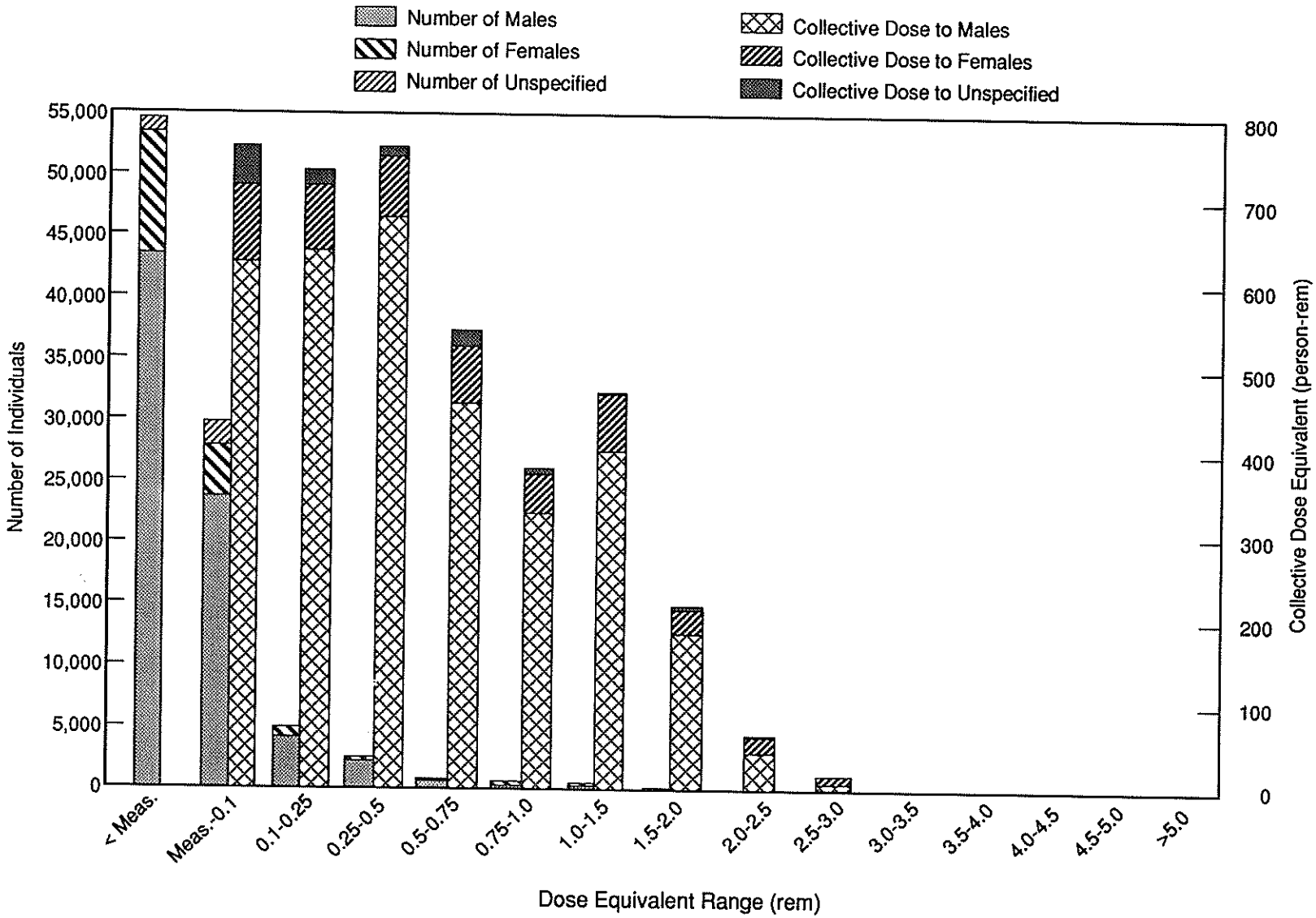

FIGURE 4.11. Distribution of Penetrating Dose Equivalents by Sex and Dose-Equivalent Range for DOE and DOE Contractor Employees and Visitors, 1988 (not including 41,686 visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied).

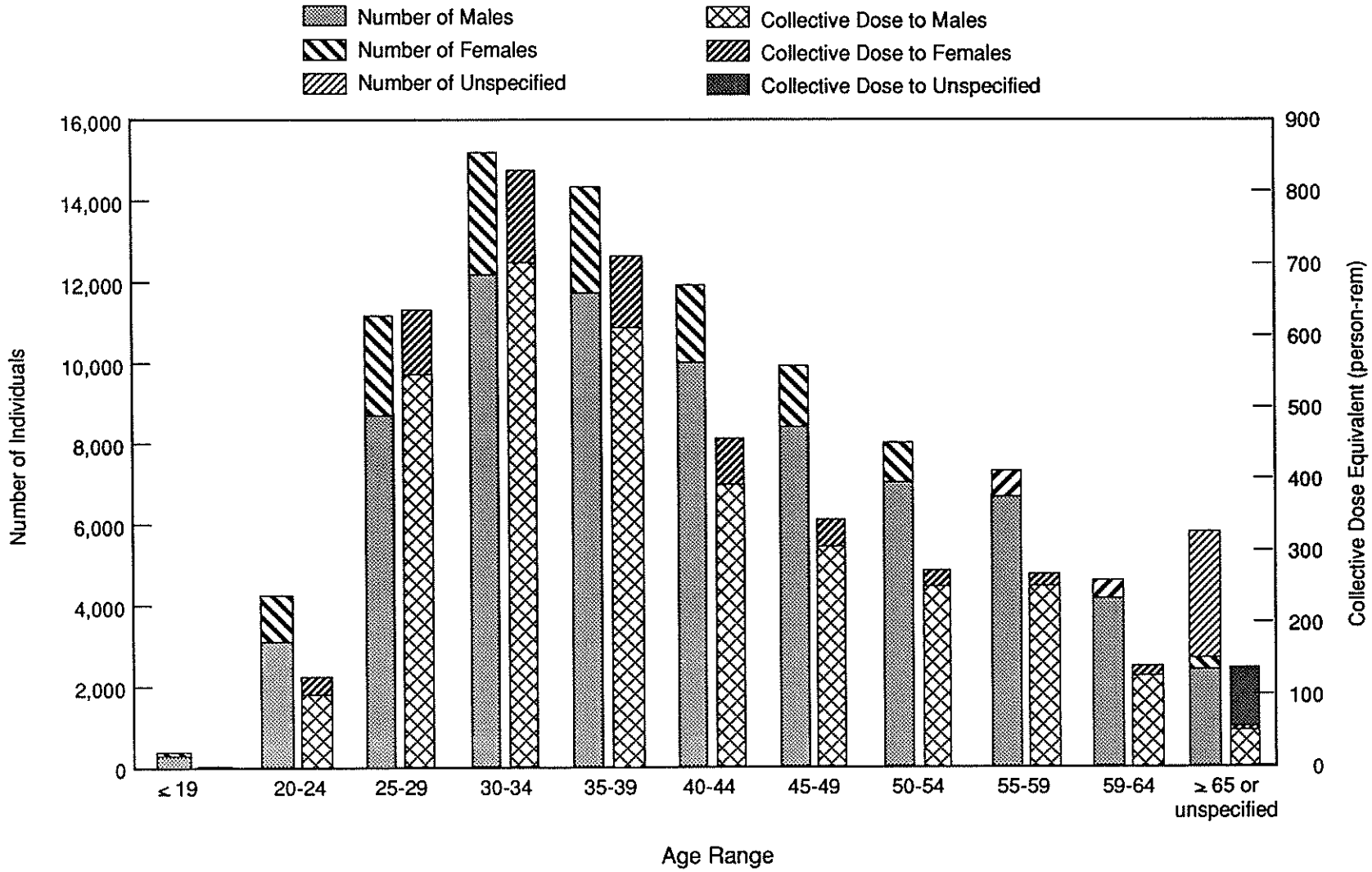

FIGURE 4.12. Number of Individuals (Employees and Visitors) Monitored and Collective Dose Equivalent by Age Range and Sex, 1988 (not including 41,686 visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied).

TABLE 4.12. Number of Individuals (Employees and Visitors) Monitored and Average Penetrating Dose Equivalents by Age, 1988

Age Range	Number of Individuals Monitored[a]	Number of Individuals Monitored Who Received A Measurable Exposure	Collective Dose Equivalent (person-rem)	Average Dose Equivalent Per Individual Monitored (mrem)[a]	Average Dose Equivalent Per Individual Monitored Who Received A Measurable Exposure (mrem)
≤19	436	99	4	9	40
20-24	4,208	1,572	126	30	80
25-29	11,106	5,092	633	57	124
30-34	15,114	6,610	822	54	124
35-39	14,264	6,092	707	50	116
40-44	11,931	4,670	452	38	97
45-49	9,841	3,706	347	35	94
50-54	8,043	3,001	276	34	92
55-59	7,284	2,705	266	37	98
60-64	4,512	1,511	136	30	90
>65 or unspecified	5,733	2,889	129	23	45
All Individuals	92,472	38,047	3,901	42	103

(a) Not including 41,686 visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied.

Because of the sensitivity of fetuses to ionizing radiation, which is greater than that of children or adults, it is important to evaluate the doses received by women of child-bearing age. Table 4.14 presents the number of women of child-bearing age (arbitrarily assumed to include women up to the age of 44) who received a measurable dose equivalent in 1988, by facility type. A total of 3,735 women of child-bearing age received a collective dose equivalent of 372 person-rem. The average individual dose equivalent for these women over all facilities was 100 mrem.

Figure 4.13 presents the number of individuals monitored and collective dose by age range and occupation in three-dimensional format. The figure indicates that many monitored individuals were either scientists or individuals for whom occupation was unspecified. Also, many monitored individuals were in the age range

TABLE 4.13. Number of Individuals Monitored and Average Penetrating Dose Equivalents by Sex, 1988

Sex	Number of Individuals Monitored[a]	Number of Individuals Monitored Who Received A Measurable Exposure	Collective Dose Equivalent (person-rem)	Average Dose Equivalent Per Individual Monitored (mrem)[a]	Average Dose Equivalent Per Individual Monitored Who Received A Measurable Exposure (mrem)
Male	74,794	31,335	3,350	45	107
Female	14,529	4,889	471	32	96
Unspecified	3,149	1,823	80	25	44
All Individuals	92,472	38,047	3,901	42	103

(a) Not including 41,686 visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied.

from 25 to 44. Production workers, construction workers, technicians, and workers of unspecified occupations in the age range 25-39 generally received the highest collective dose equivalents.

Figure 4.14 presents the age distributions of both the number of workers and collective dose equivalents for males and females. As indicated by the ages pertaining to the 50% mark on the figure, the median ages for monitored workers at DOE facilities in 1988 were approximately 37 and 42 for females and males, respectively. The median ages for collective dose equivalent were approximately 36 and 38, respectively, indicating that in general, younger workers receive slightly higher doses than do older workers.

4.6 DISTRIBUTION BY TYPE OF EXPOSURE

For calendar year 1988, DOE Order 5484.1, Chg. 3, required that specific information on the types of radiation doses received by each worker be reported. Specifically, these included the external penetrating dose equivalent (at a depth in tissue of 1.0 cm) including neutron exposure, the dose equivalent from neutron exposure only, and the shallow dose equivalent. From these data, the external penetrating beta-gamma dose equivalent can be derived by subtracting the neutron dose equivalent from the external penetrating dose equivalent including neutron exposure. That is, the two contributors to external penetrating dose equivalent are beta-gamma radiation and neutron radiation.

TABLE 4.14. Penetrating Doses Received by Female Employees and Visitors of Child-Bearing Age, 1988

Facility Type	Total Persons	Number of Females Receiving Measurable Doses in Each Age Range						Total Person-rem
		<19	20-24	25-29	30-34	35-39	40-44	
Accelerator	115	2	9	30	25	31	18	7
Fuel/Uranium Enrichment	133		2	27	51	28	25	5
Fuel Fabrication	246		16	65	66	55	44	26
Fuel Processing	248		26	60	82	57	23	42
Maintenance and Support	886	9	68	201	242	210	156	81
Reactor	257		26	80	73	39	39	19
Research, General	384	2	39	82	134	81	46	52
Research, Fusion	2			1		1		
Waste Processing/ Management	274	2	23	72	79	61	37	33
Weapons Fabrication and Testing	829	5	41	159	211	216	197	96
Other	361	—	68	84	83	76	50	12
Total Persons	3,735	20	318	861	1,046	855	635	
Total Person-rem		1	22	83	118	89	58	372

Table 4.15 lists the various types of dose equivalents received by facility type. Of the total external penetrating dose equivalent of 3,901 person-rem received, 2,997 person-rem (76.8%) were attributable to beta-gamma radiation and 904 person-rem (23.2%) were attributable to neutron radiation. Neutron radiation contributed the highest percentage of the total penetrating dose equivalent at weapons fabrication and testing facilities (36.6%). The total shallow dose equivalent reported to have been received was 5,950 person-rem. Relative to the total penetrating dose equivalent, the total shallow dose equivalent was greatest at fuel fabrication facilities, where the shallow dose equivalent exceeded the penetrating dose equivalent by a factor of almost 4. However, because the critical organ regarding shallow dose equivalents is the skin and because the radiation risk coefficient for induction of fatal skin cancers is low (NCRP

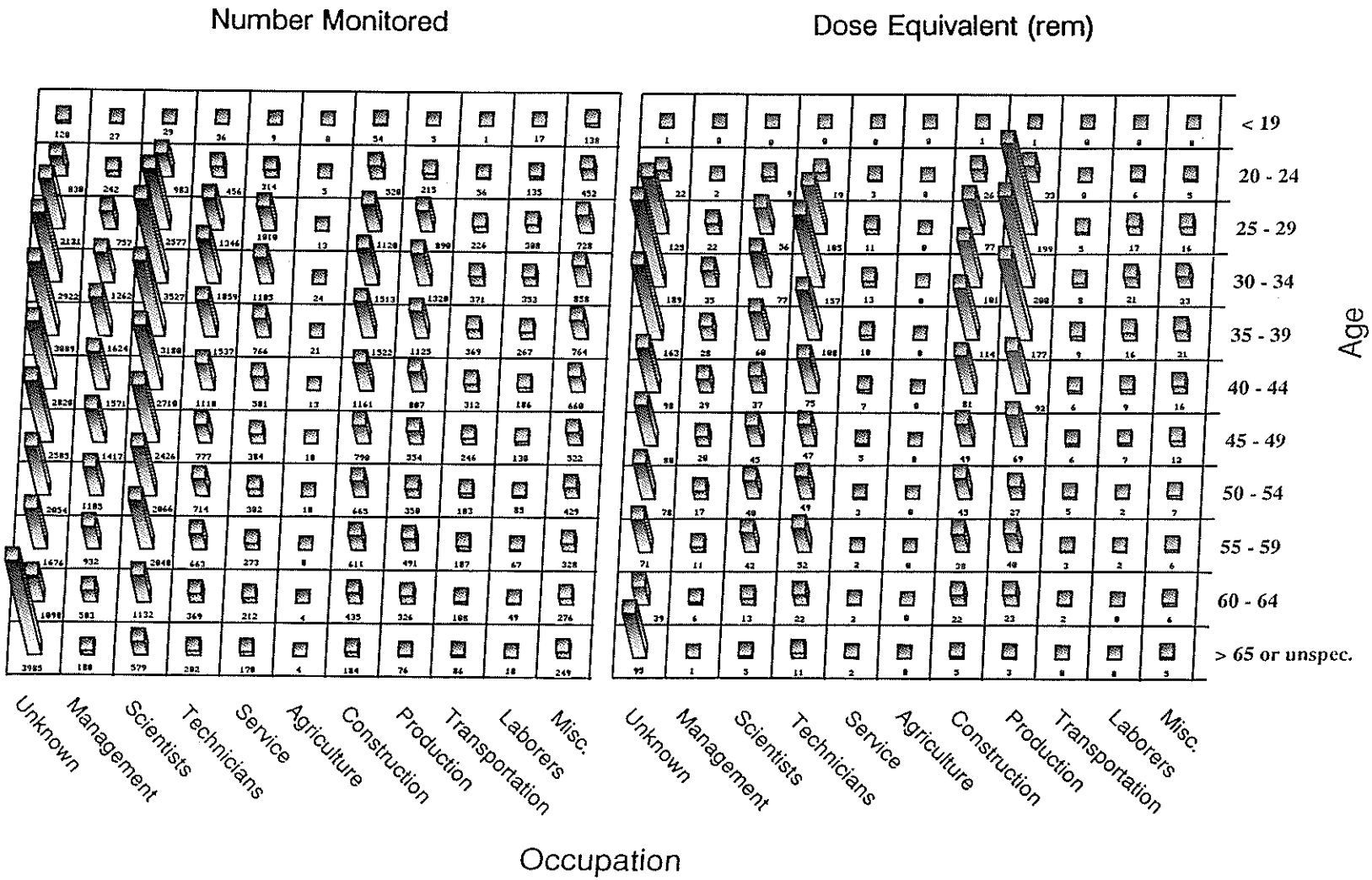

FIGURE 4.13. Three-Dimensional Representation of Number of Individuals Monitored and Collective Dose Equivalent by Age Range and Occupation, 1988 (not including 41,686 visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied).

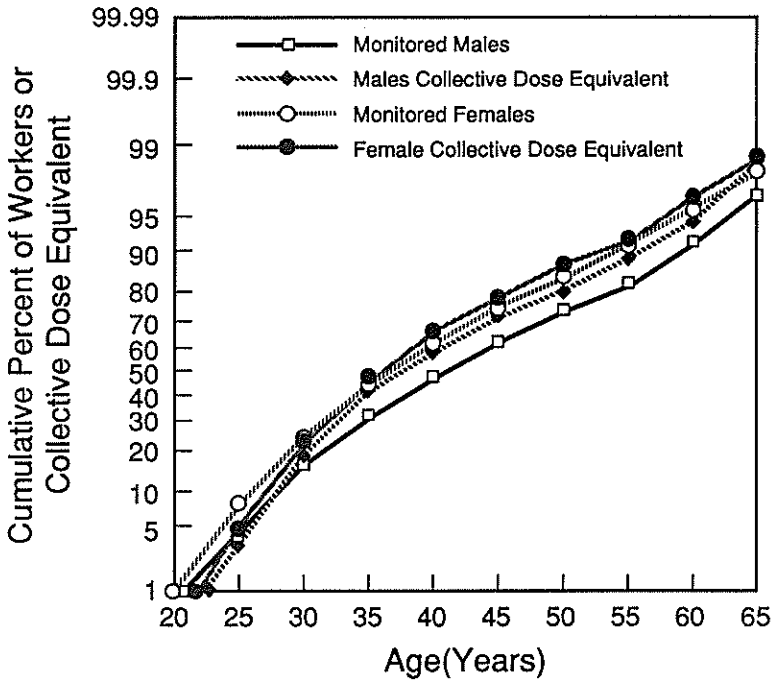

FIGURE 4.14. Age Distribution of Number of DOE and DOE Contractor Employees (workers) and Collective Dose Equivalent, 1988

1987a), the penetrating dose equivalents are of the most concern regarding health effects. The magnitude of the postulated health effects from radiation doses received at DOE facilities is discussed in Section 7 of this report.

DOE Order 5484.1, Chg. 3, also requires data to be reported on total effective dose equivalent, effective dose equivalent resulting from internally deposited radionuclides, and extremity dose equivalent. However, these requirements were deferred pending revision of DOE Order 5480.1B, Chapter XI. As discussed in Sections 2 and 4 of this report, the revision did not become effective until January 1, 1989; therefore, the 1988 exposure data did not include this information. However, subject to the previous reporting requirements, internal depositions of radioactive material were required to be reported under some circumstances.

A report of internal body deposition of radioactive materials was required when:

1. any uptake of radioactive material occurred during the reporting year that, either taken independently or added to a current burden, was estimated to result in a dose commitment to the critical organ in excess of 50% of the pertinent annual dose-equivalent standard set forth in DOE Order 5480.1B, Chapter XI; or when

TABLE 4.15. Distribution of Dose Equivalents by Facility Type for Various Types of Dose Equivalents, 1988[a]

Facility Type	Dose Equivalent by Dose-Equivalent Type (person-rem) Penetrating - Total	Penetrating - Beta-Gamma	Penetrating - Neutron	Shallow
Accelerator	217	185	31	203
Fuel/Uranium Enrichment	38	37	1	109
Fuel Fabrication	193	190	3	751
Fuel Processing	385	310	75	637
Maintenance and Support	723	580	143	882
Reactor	410	396	14	496
Research, General	560	378	183	525
Research, Fusion	7	7	0	7
Waste Processing /Management	355	240	115	367
Weapons Fabrication & Testing	805	509	296	1,619
Other	209	166	44	352
Total	3,901	2,997	904	5,950

(a) Visitors and DOE offices are not delineated as facility types for this table; collective doses received by visitors or at DOE offices have been incorporated into the appropriate facility type listed in the table.

2. any previously unreported uptake of radioactive material was determined to have been reportable according to the above criteria by reason of the most recent dose-equivalent estimates.

Only one case of internal body deposition was reported in 1988 that exceeded 50% of the pertinent annual dose-equivalent standard as set forth in DOE Order 5480.1B, Chapter XI. That exposure occurred during 1985.

Table 4.16 lists the reported cases of internal body depositions occurring since 1980 and identifies each by the first year known in which the dose equivalent exceeded 50% of the annual standard. Also listed are the radionuclide(s) involved, the organ showing the highest percent of the annual standard, and the number of individuals in each dose-equivalent range. Revisions to previously reported cases are included.

TABLE 4.16. Dose Distributions for Cases of Internal Body Depositions, 1980-1988

Year	Radionuclide	Critical Organ	Dose-Equivalent Interval (rem) 7.5-10	10-15	15-20	25-50	50-100	100-200
1980	^{238}Pu	Bone			2	2		
	^{234}U, ^{235}U, ^{238}U	Lung	1					
1981	^{238}Pu, ^{239}Pu, ^{240}Pu	Bone		1	1			
	^{238}Pu, ^{239}Pu, ^{240}Pu	Lung	1					
	^{234}U, ^{235}U, ^{238}U	Lung	3					
1982	^{238}Pu	Bone			3	1		
	^{238}Pu, ^{239}Pu, ^{240}Pu	Bone						1
1983	^{239}Pu, ^{240}Pu, ^{241}Am	Bone		1				
	^{234}U, ^{235}U	Lung	4					
1984	^{239}Pu, ^{241}Am	Lung					1	
1985	^{234}U, ^{235}U, ^{238}U	Lung	2					
	^{239}Pu, ^{241}Am	Lung	1					
1986	None							
1987	^{238}Pu	Liver	1	1				
1988	^{238}Pu, ^{239}Pu, ^{241}Am	Bone			1			

4.7 EVALUATION OF TRENDS

Doses received by DOE and DOE contractor employees have decreased dramatically over the last several years (see Table 4.7). For example, in 1985, the collective dose equivalent received by employees was 8,223 person-rem; in 1988, this value was 3,655 person-rem. Some of this decrease (~20% as indicated in Section 4.3) is attributable to the fact that the 1985 value was estimated from the numbers of individuals reported to have received doses in various dose-equivalent ranges. However, the majority of the decrease is attributable to other factors.

The most evident example of the recent dramatic decrease in collective doses is at the Richland Field Organization. In 1987, the collective dose equivalent to employees at Richland was 2,467 person-rem; in 1988, this value dropped by over 73% to 653 person-rem. This decrease was primarily the result of both changes in the type of work performed and facility closures. A dramatic decrease also occurred from 1987 to 1988 at the Oak Ridge (40%) and Idaho (26%) field organizations.

The 1988 data demonstrate that the significant decrease in collective dose equivalent is not attributable to fewer individuals being monitored, but to lower doses to those individuals who are monitored. Figure 4.15 illustrates the recent dramatic decrease in average annual dose equivalent per individual monitored who received a measurable exposure. Table 4.17 lists similar data for each facility type. Table 4.18 lists collective dose equivalent by facility type for the years 1980 through 1988.

One correlative effect of lower average individual dose equivalents is fewer employees who exceed various dose-equivalent levels. Figure 4.16 illustrates the number of employees who received dose equivalents greater than 0.5 rem, 1.0 rem or 2.0 rem from 1980 to 1988. As indicated in the figure, the numbers decreased significantly in 1988. As a result, fewer employees are being exposed to doses that are significant fractions of the annual dose limit. This may be important if the annual dose limits are eventually lowered, which is currently under consideration.

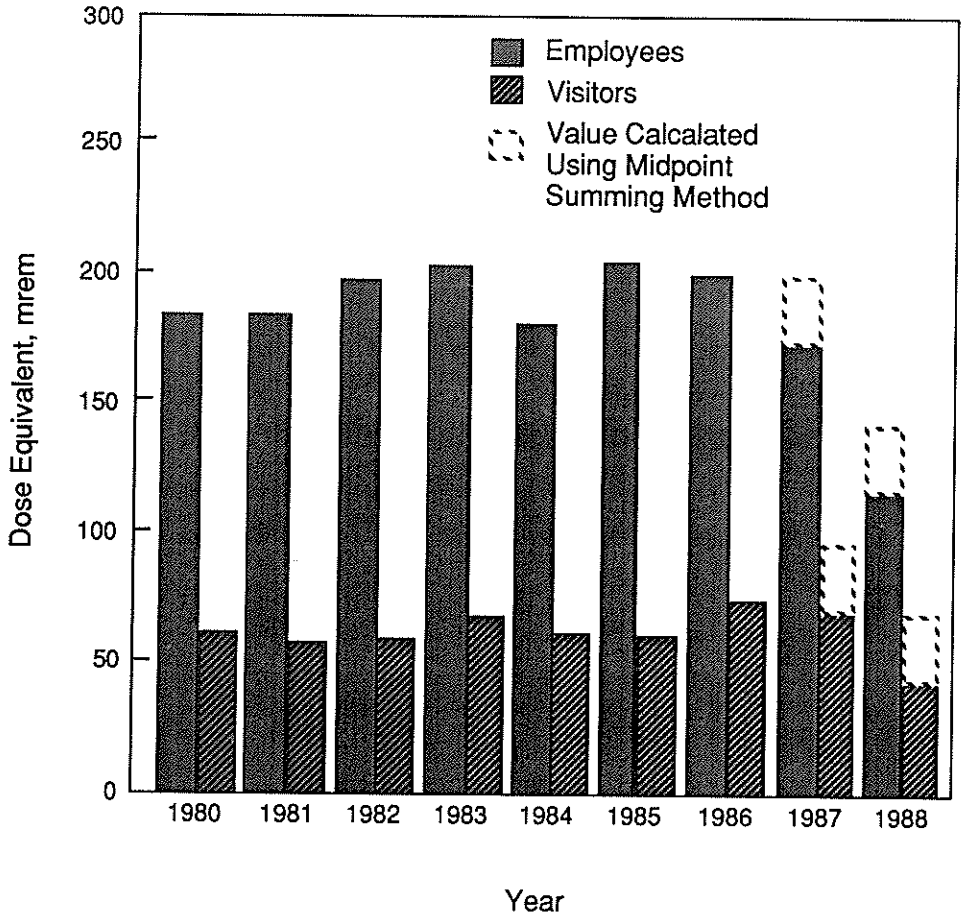

FIGURE 4.15. Average Dose Equivalent Per Individual Who Received a Measurable Exposure, 1980-1988

TABLE 4.17. Average Dose Equivalent Per Individual Who Received a Measurable Exposure by Facility Type, 1980-1988 (mrem)[a]

Year	Reactor	Fuel Fabrication	Fuel Processing	Uranium Enrichment	Weapons Fabrication and Testing	General Research	Accelerator	Other	Visitors	DOE Offices	All Facilities
1980	278	236	442	117	120	122	209	217	59	57	157
1981	270	246	412	74	129	140	228	202	57	59	156
1982	302	306	362	86	136	168	209	169	58	62	164
1983	313	322	298	79	149	169	219	202	66	57	190
1984	323	283	294	80	147	154	196	164	60	62	167
1985	323	226	318	63	170	193	175	188	59	63	182
1986	300	227	314	71	166	211	129	185	71	65	179
1987	239	155	267	37	183	150	98	173	69	30	159
1988	104	112	217	29	139	124	114	100	39	19	103

(a) Beginning in 1987, three facility categories were added to those listed in the table: maintenance and support, fusion research, and waste processing/ management. For this table, these facility categories are included in the "other" category for 1987 and 1988.

TABLE 4.18. Collective Dose Equivalent by Facility Type, 1980-1988 (person-rem)[a]

Year	Reactor	Fuel Fabrication	Fuel Processing	Uranium Enrichment	Weapons Fabrication and Testing	General Research	Accelerator	Other	Visitors	DOE Offices	All Facilities
1980	1,185	323	1,047	156	869	1,611	412	1773	619	29	8,024
1981	1,274	267	592	62	982	1,535	348	1813	571	38	7,483
1982	1,612	411	835	30	1,056	1,676	254	1293	686	26	7,879
1983	1,781	434	726	31	1,399	1,662	273	1522	300	30	8,158
1984	1,620	264	515	28	1,672	1,736	248	1944	368	30	8,423
1985	1,716	265	574	26	1,851	1,484	262	2025	461	20	8,684
1986	1,391	356	598	39	1,802	1,357	232	2117	554	20	8,465
1987	1,007	271	426	41	1,028	769	169	2260	373	8	6,353
1988	366	171	374	32	767	554	194	1195	245	5	3,901

(a) Beginning in 1987, three facility categories were added to those listed in the table: maintenance and support, fusion research, and waste processing/management. For this table, these facility categories are included in the "other" category for 1987 and 1988.

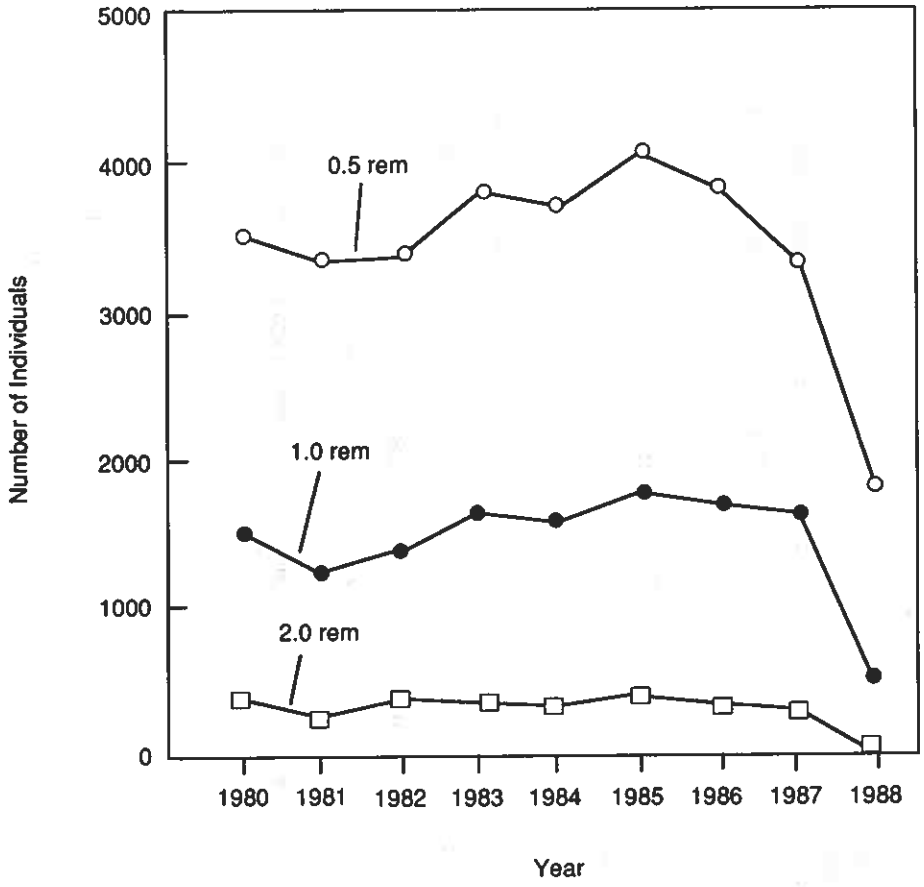

FIGURE 4.16. Number of Employees Who Received Dose Equivalents Greater than 0.5 rem, 1 rem, or 2 rem, 1980-1988

As presented previously in this report, occupational exposure data are often analyzed by fitting the data to a lognormal distribution. However, Kumazawa and coworkers have demonstrated that such data do not follow a lognormal distribution at doses near the dose limits (Kumazawa and Numakunai 1981; Kumazawa, Shimazaki and Numakunai 1982; Kumazawa, Nelson and Richardson 1984). Rather, the data follow more closely a normal distribution, and, therefore, occupational exposures are best described by a hybrid lognormal distribution. This distribution is based on the hypothesis that all occupational exposures are affected to some extent by the existence of dose limits, and that doses near the limits are affected more than are relatively low doses. Consequently, the hybrid lognormal model describes an occupational exposure distribution such that the sum of individual exposures multiplied by a constant, and its logarithm, follows the lognormal distribution. Thus, the exposures will follow the lognormal component in the lower

range, where the effect of dose limits is less pronounced, and will follow the normal distribution in the higher range, where the effect of dose limits is strong (Kumazawa and Numakunai 1981).

Kumazawa, Shimazaki and Numakunai (1982) documented a computer code that performs hybrid lognormal analysis of exposure data. This code was used in this report to describe the 1988 DOE occupational exposure distribution for DOE and DOE contractor employees (Figure 4.17). The figure indicates the fraction of workers (y-axis) whose dose equivalents were less than various values (x-axis). For example, the figure indicates that 99% of monitored DOE and DOE contractor employees received doses less than approximately 840 mrem.

One way in which hybrid lognormal analysis of occupational exposure data can be used is to provide an estimate of collective or average dose equivalent when other methods are inadequate. As presented previously in this report, before 1987, exposure data were reported simply as the numbers of individuals whose dose equivalents fell into one of 16 dose-equivalent intervals. As a result, collective and average dose equivalents were estimated by assuming that each individual received a dose equivalent equal to the midpoint of the appropriate interval. This "midpoint method" provided overestimates because a majority of individuals received a dose equivalent less than the midpoint of the appropriate interval. This method was not necessary for the 1987 and 1988 exposure data because the actual dose equivalents measured for each individual were reported. For example, Table 4.1 in this report demonstrated that 4,635 individuals received a dose equivalent in 1988 that was between 0.10 and 0.25 rem. The collective dose equivalent received by these individuals was 728 rem. Had the "midpoint method" been necessary to estimate the collective dose equivalent, the estimate would have been 4,635 multiplied by 0.175 rem, or 811 rem.

Hybrid lognormal analysis of DOE and DOE contractor employee exposures for the years 1980 through 1988 was performed to determine the error in estimating average and collective dose equivalents using the "midpoint method." Table 4.19 presents the results of this analysis. A comparison of the actual average dose equivalents for 1987 and 1988 with the averages determined using hybrid lognormal analysis indicates that the hybrid lognormal method provides a reasonably accurate estimate of average dose equivalent, unlike the "midpoint method." Comparing the estimates for the years in which the actual averages were unknown (1980 through 1986) indicates that using the "midpoint method" to determine average dose equivalents likely resulted in overestimates ranging from 15% to 27% during that period. The average overestimate during that period was approximately 18%. Therefore, it is likely that collective dose equivalents at DOE facilities determined for years before 1987 were overestimated by between 15% and 20%.

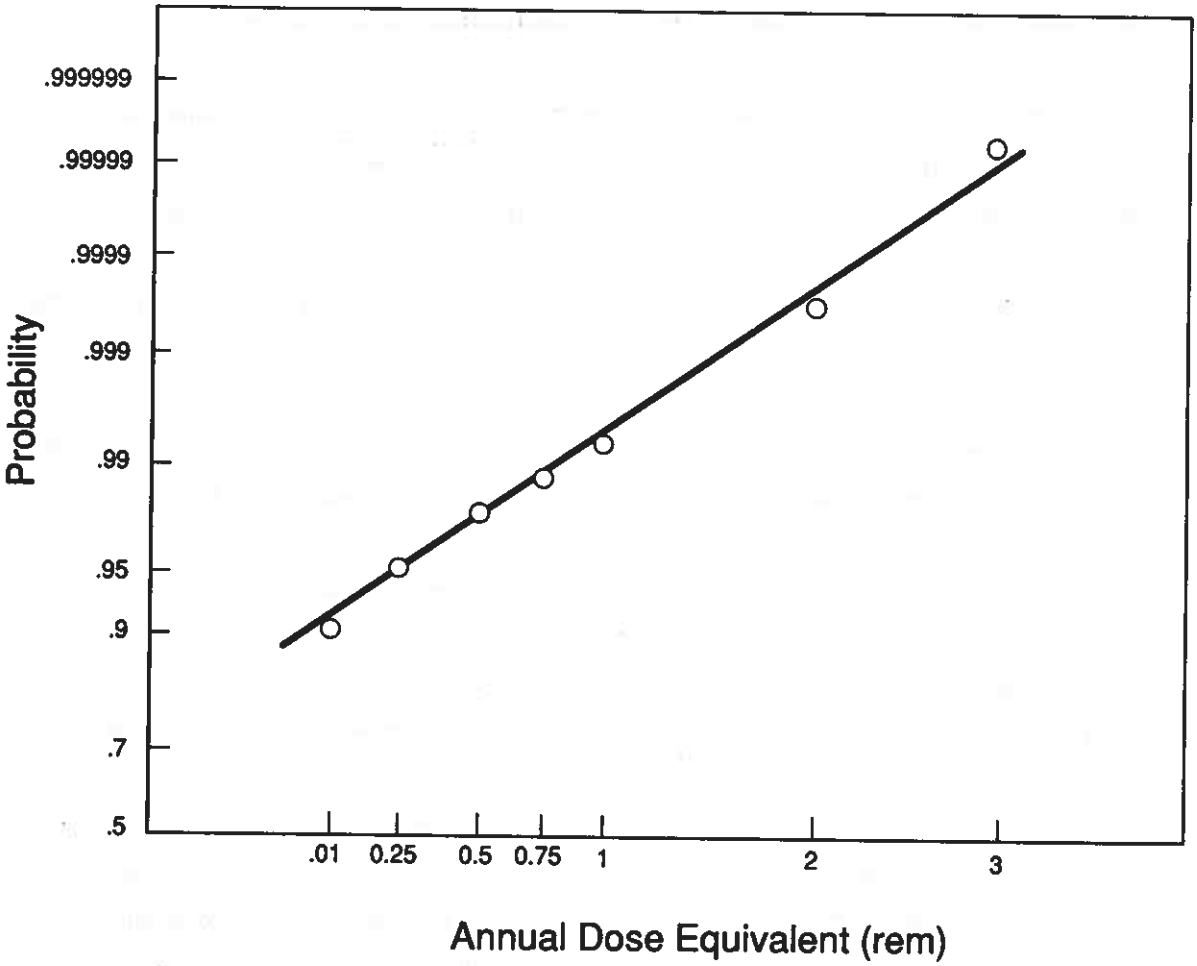

FIGURE 4.17. 1988 DOE and DOE Contractor Employee Dose Distribution Fitted to a Hybrid Lognormal Curve

TABLE 4.19. Comparison of Calculated and Actual Average Dose Equivalents for DOE Employees to Average Dose Equivalents Determined Using Hybrid Lognormal Analysis, 1980-1988

Year	Average Employee Dose Equivalent, mrem			Estimated "Midpoint Method" Overestimate[d]
	"Midpoint Method"[a]	Actual[b]	Hybrid Lognormal[c]	
1980	86.6	--	68.0	27%
1981	83.3	--	70.7	18%
1982	84.3	--	72.7	16%
1983	89.0	--	77.3	15%
1984	88.5	--	75.1	18%
1985	85.7	--	73.5	17%
1986	83.9	--	71.3	18%
1987	84.1	73.8	67.9	14%
1988	54.5	44.8	43.1	22%

(a) Determined by assuming that each individual reported to have received a dose equivalent in a given dose-equivalent interval received a dose equivalent equal to the midpoint of that interval. This method was used prior to 1987 to calculate average and collective dose equivalents. The values for 1987 and 1988 indicate the values that would have been calculated using this method.

(b) Determined from reported individual dose equivalents. This information was not available before 1987.

(c) Calculated by fitting the data to a hybrid lognormal distribution and determining average dose equivalent using the procedure described by Kumazawa, Shimazaki and Numakunai (1982).

(d) "Midpoint method" average dose equivalent divided by hybrid lognormal average dose equivalent for 1980-1986; "midpoint method" average dose equivalent divided by actual average dose equivalent for 1987 and 1988. The overestimates also apply to collective dose equivalents for the years indicated.

5.0 LIFETIME EXPOSURE STUDY

The data in Section 4.0 demonstrated that annual doses received by DOE and DOE contractor employees and visitors are significantly less than DOE limits. It is also important, however, to determine the distribution of lifetime doses of employees who have spent much of their career in the nuclear industry. For example, knowledge of the lifetime dose distribution for DOE and DOE contractor employees may provide insight into whether or not the same workers consistently receive the highest annual doses. Such information may be useful for evaluating the impact of cumulative lifetime dose limits based on a worker's age; variations of this type of dose limit have been proposed recently by the NCRP (NCRP 1987a), and a five-year cumulative exposure limit is currently being considered by the ICRP.

This section presents preliminary results of a study of lifetime doses received by radiation workers at a major DOE facility. The study involves the examination of approximately 300,000 individual dose histories on over 30,000 individuals. There are more dose histories than individuals because one dose history is available for each year an individual worked at the facility. The type of information that is recorded for each worker includes date of birth, sex, and radiation dose for each year of record (including records for penetrating radiation, non-penetrating radiation, and tritium intakes). Other information that is available includes building and job codes, which can be used to obtain information concerning the type of work performed by each worker. Analysis of these data is in progress and the findings will be presented in future reports. The results from preliminary analyses of penetrating dose are described in this section.

Figure 5.1 illustrates the distribution of cumulative lifetime doses of individual workers who were employed at a certain DOE facility at any time during the years 1944 through 1984. Only those doses received at the particular facility are included, i.e., doses received offsite prior to employment at the facility are not included. Each line on the graph represents a specified percent of workers who had lifetime doses equal to or lower than indicated for various ages. Specifically, the upper distribution line, which represents the 100th percentile distribution, indicates the highest lifetime dose by worker age for the 40-year period. For example, the highest lifetime dose that any 40-year-old worker had at any time during that period (1944 through 1984) was approximately 50 rem; the highest lifetime dose of any 55-year-old worker was approximately 77 rem. Looking at the 90th percentile distribution, the value indicated for a 45-year-old worker, for example, is approximately 8 rem. In other words, only 10% of the 45-year-old workers at the facility during the period 1944 through 1984 had cumulative doses greater than 8 rem.

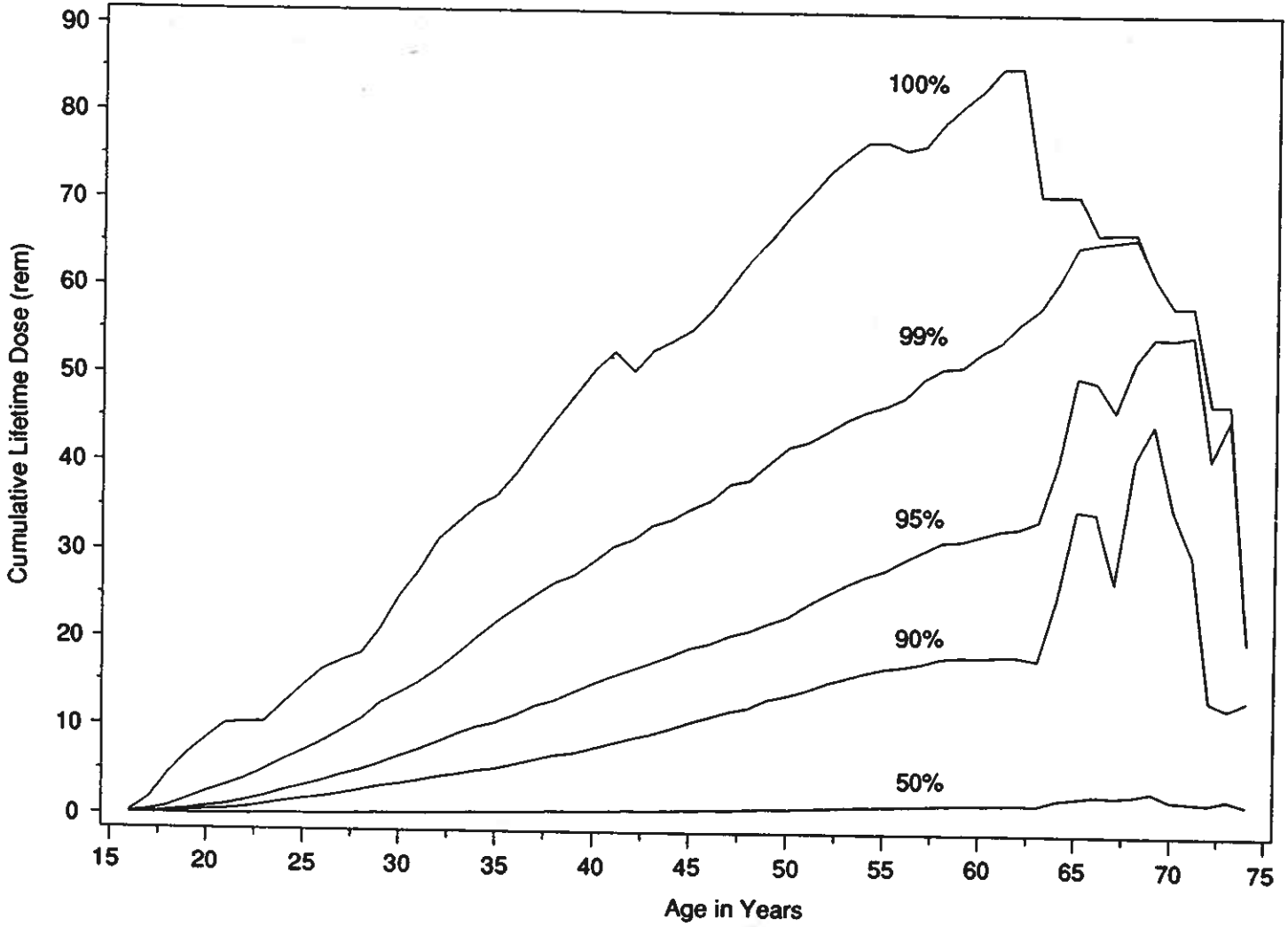

FIGURE 5.1. Lifetime Accumulation of Radiation Dose by Workers at a Major DOE Facility by Age, 1944-1984

There are several important points to consider when analyzing the data in Figure 5.1. First, even though approximately 30,000 individuals are represented, the figure was derived from over 300,000 individual annual dose histories. Accordingly, individuals who worked more than one year at the facility are represented more than once in the figure. Another important feature of the data in Figure 5.1 is that once an individual left the facility, dose histories for the individual were discontinued. For example, Figure 5.1 indicates that the maximum lifetime dose of any 41-year-old individual at the facility was approximately 52 rem, while the maximum lifetime dose of any 42 year-old was slightly lower. This indicates that the 41 year-old who had accumulated 52 rem left the facility at that age. Otherwise, the maximum lifetime dose of any 42 year-old would have to be at least 52 rem, because an individual's cumulative lifetime dose cannot decrease over time.

Figure 5.2 presents the same data distributed by maximum years of employment rather than age. In this figure, each worker is represented only once. For example, the data for individuals who worked exactly 20 years at the facility show that no worker had accumulated a dose of greater than 50 rem, and 10% of the workers had accumulated a dose of 15 rem, or 750 mrem per year worked.

Although these data are preliminary, they do indicate the magnitude of lifetime exposures received at one major DOE facility over a 40-year period. These data may be useful for determining the impact of regulations that limit lifetime exposures or cumulative exposures over several years. For example, less than 1% of the workers had a cumulative lifetime dose that exceeded their age in years, which is a limit recommended by the NCRP (NCRP 1987a). Furthermore, although not obvious from the preliminary data presented, only a small fraction of the workers received a cumulative dose greater than 10 rem over any five-year period. This limit is being considered by the ICRP.

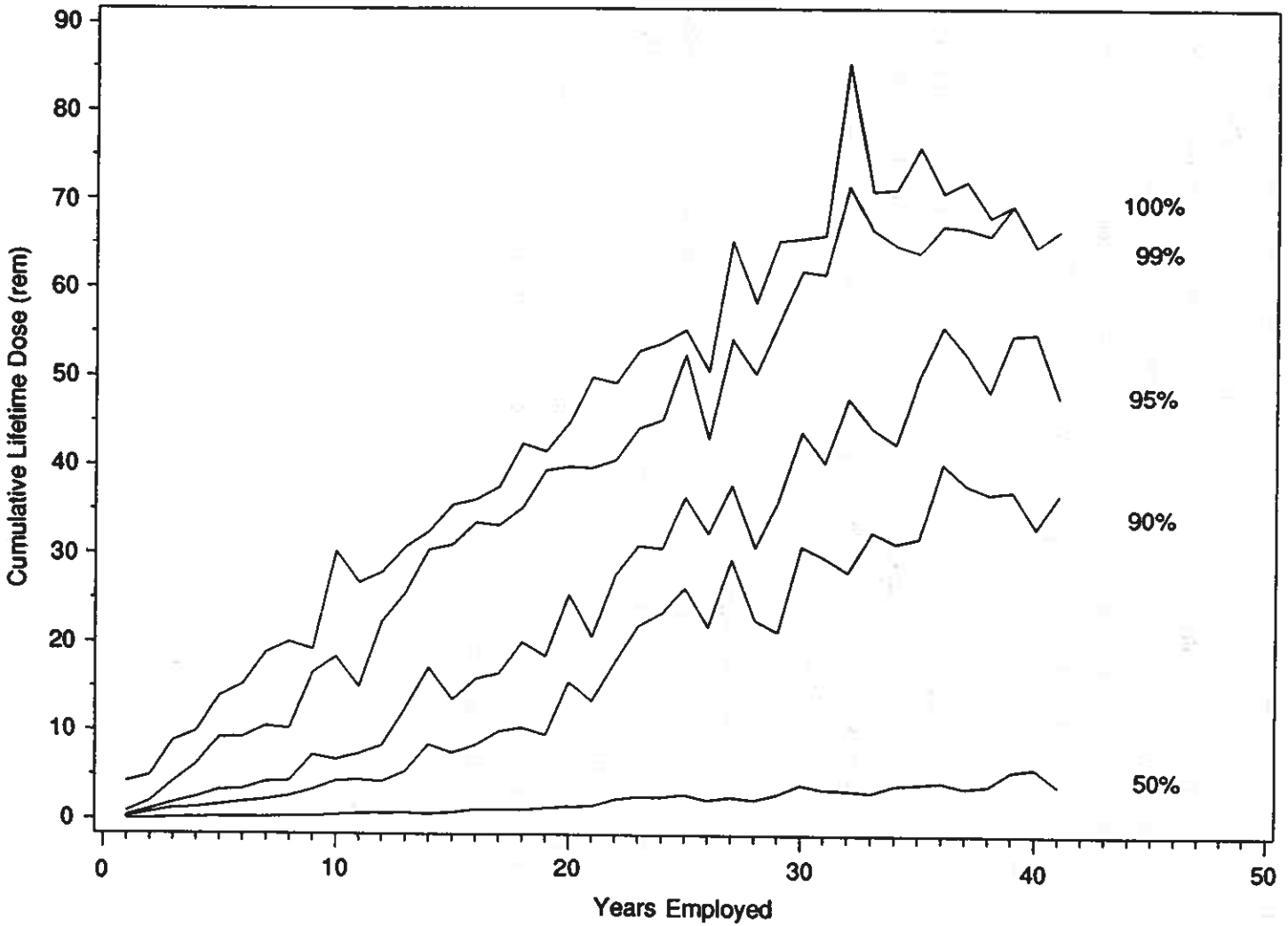

FIGURE 5.2. Lifetime Accumulation of Radiation Dose by Workers at a Major DOE Facility by Total Number of Years Employed, 1944-1984

6.0 REPORTABLE RADIATION EXPOSURE INCIDENTS

The DOE has established criteria for classifying, reporting, and investigating radiation exposure incidents in DOE Order 5484.1. Depending on the individual doses received, incidents involving exposure to radiation are classified as either Type A, Type B, or Type C occurrences. A Type A occurrence involving radiation exposure shall be reported to DOE Headquarters immediately, and an investigation of the incident shall be conducted by a DOE Headquarters or field organization board. A Type B occurrence involving radiation exposure shall be reported to DOE Headquarters within 72 hours, and an investigation of the incident shall be conducted by a DOE board appointed by the head of the field organization. A Type C incident shall be reported by memo, and an investigation shall be conducted by DOE contractor personnel, when their operations are involved, or by DOE personnel, when Federal operations are involved.

Table 6.1 list the criteria for classifying incidents involving radiation exposures at DOE facilities. Descriptions of such incidents are normally reported to the System Safety Development Center (SSDC) following submittal of the investigation report. No such incidents were reported to have occurred in calendar year 1988.

TABLE 6.1. Dose Criteria for Classification of Incidents Involving Occupational Radiation Exposures

Type of Exposure	Dose Criteria for Incident Type		
	A[a]	B[b]	C[b]
Whole-body	25 rem	5 rem	3 rem
Skin of the whole-body	75 rem	15 rem	5 rem
Thyroid	N/A	15 rem	5 rem
Forearms	150 rem	30 rem	10 rem
Hands and feet	375 rem	75 rem	25 rem
Internal dose	5 times annual standard	In excess of annual standard	N/A

(a) Rem values pertain to a single exposure except for the value for the whole-body, which pertains to a single or annual cumulated exposure.
(b) Rem values pertain to doses accumulated in one quarter.

7.0 COMPARISON OF DOSES TO RISKS

Crucial to assessing the safety of DOE operations with respect to occupational radiation exposure is an assessment of the risks from the doses received by DOE and DOE contractor employees. In Section 4 of this report, summaries of the radiation doses received by DOE and DOE contractor employees were presented. Although the average doses were much lower than the DOE limits (indicating the impact of ALARA programs), comparison of employee doses to risks is necessary for determining the magnitude of health effects, if any, that may be expected to occur. This section compares the doses received by DOE and DOE contractor employees in 1988 to risks based on published radiation risk coefficients and compares the calculated risks to other risks incurred both inside and outside the workplace.

An important consideration in assessing the relative significance of the risk of radiation doses received at DOE facilities is the doses received from sources other than working at the facilities. Everyone receives radiation doses regularly from various sources, including terrestrial radiation from naturally radioactive elements in the soil, cosmic radiation from space, radon in the air, and naturally radioactive potassium in our bodies. Other sources of radiation to which many of us are exposed include radiation from medical and dental procedures, cigarette smoke, fallout from past nuclear testing, and various food and other consumer products. Typical radiation doses received from each of these sources are listed in Table 7.1. By comparison to the values in Table 7.1, the average dose equivalent received by a DOE and DOE contractor employee who received a measurable occupational exposure during 1988 (115 mrem) was less than the average dose equivalent received by an individual from non-work-related sources. No employee received a dose equivalent greater than the DOE occupational limit of 5 rem per year.

Although low doses of radiation have not been demonstrated to increase the incidence of cancer or other diseases, risk estimates have been estimated by extrapolating from known effects at high doses to hypothetical effects at low doses. Based primarily on data from survivors of the atomic bombings at Hiroshima and Nagasaki, risk estimates have been developed that express the risk of death from cancer per unit whole-body dose equivalent of ionizing radiation. According to several sources, data published around 1980 suggest that a population distributed over all ages and both sexes would experience approximately 1×10^{-4} cancer deaths per person per rem (NCRP 1987a, ICRP 1977, NAS 1980, UNSCEAR 1977). However, as detailed in the BEIR III report (NAS 1980), risk coefficients vary considerably depending on the age and sex of the exposed individual. Furthermore, the calculated risk to an individual exposed to low levels of ionizing radiation depends highly on the models chosen to extrapolate from the Hiroshima and Nagasaki data, where excess deaths were observed only at relatively high doses delivered over a very short period of time.

TABLE 7.1. Radiation Doses Received by Individuals in the U.S. from Sources Other than Occupational Exposures (adapted from NCRP Publication 93 [NCRP 1987b])

Source	Average Annual Effective Dose Equivalent Per Member of the U.S. Population (mrem)
Natural sources	
Radon	200
Cosmic	27
Terrestrial	28
In vivo	39
Nuclear Fuel Cycle	0.0005
Consumer Products	
Domestic water supply	1 - 6
Building materials	3.6
Other	1 - 10
Medical	53
Total[a]	~360

(a) Value pertains to a nonsmoker. An additional 1300 mrem per year is estimated to be received by a typical smoker from inhalation of tobacco smoke.

More recently, both the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the Committee on the Biological Effects of Ionizing Radiations (BEIR) provided risk estimates based on a reassessment of the A-bomb dosimetry as well as extended followups of the survivor data (UNSCEAR 1988; NAS 1990). In general , the associated risk estimates range from approximately 5×10^{-4} per rem to 1×10^{-3} per rem depending on age, sex, and risk projection model used and based on acute exposures of at least 10 rem. For low doses and dose rates, both UNSCEAR and BEIR recognized the need to reduce these risk estimates by applying a dose rate effectiveness factor (DREF) of at least 2 to these values.

Figure 7.1 shows the estimated incidence of fatal cancers and the total number of person-years of life lost based on the whole-body ionizing radiation doses received at DOE facilities in 1988. These hypothetical data are based on age- and sex-specific risk equations provided in the BEIR V report (NAS 1990) and life table calculations as described by Bunger, Cook, and Barrick (1981) and Merwin, Traub, and Faust (1990).

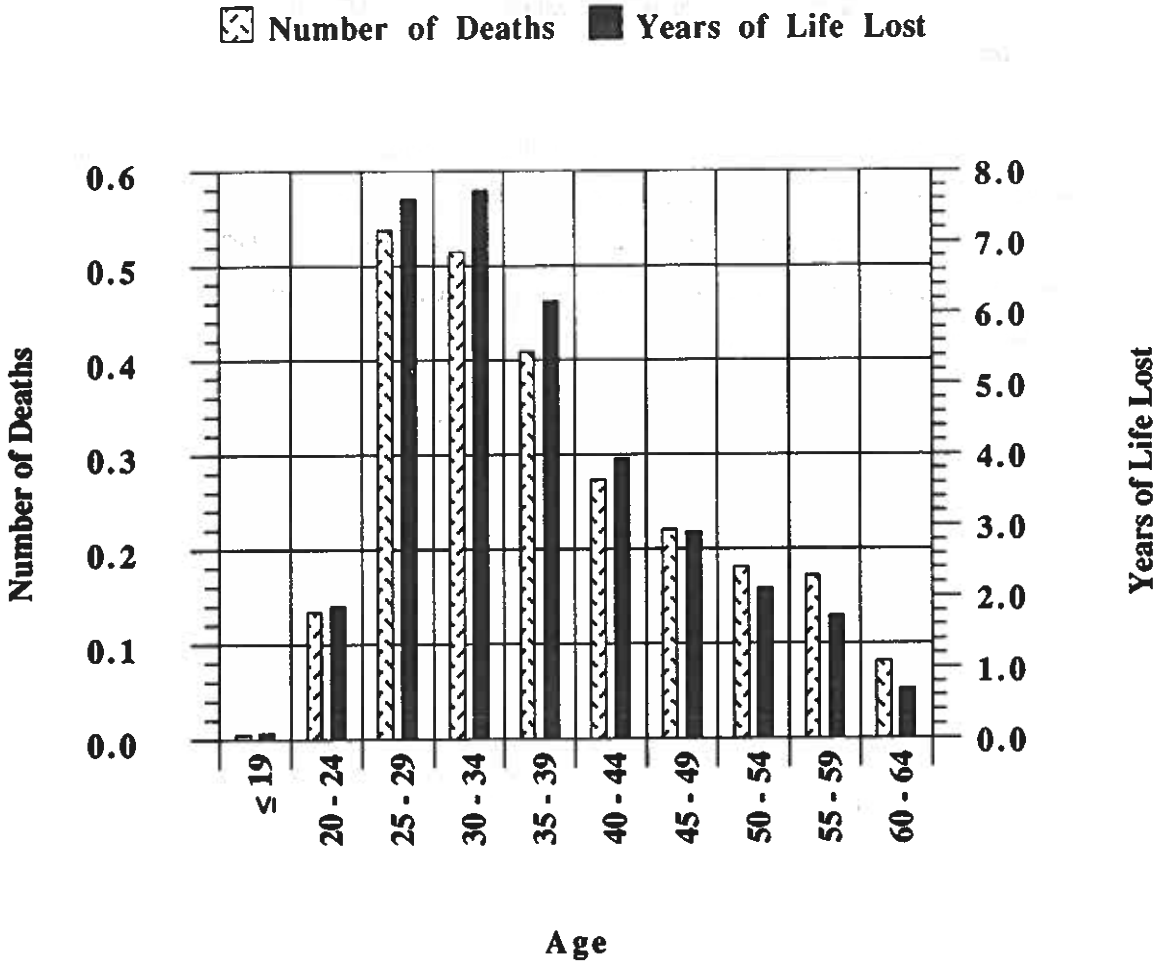

FIGURE 7.1. Estimated Maximum Number of Total Deaths and Years of Life Lost from Radiation Doses Received at DOE Facilities in 1988. (The values indicated are maximum estimates; the actual values may be zero. See text for explanation.)

The values were calculated directly from the BEIR V risk equations and the doses received by employees at DOE facilities in 1988. Applying a DREF to these values would be appropriate (NAS 1990; UNSCEAR 1988) and would reduce the values by a factor of two or more. Furthermore, the BEIR V risk estimates were based on studies of individuals who received high doses. Consequently, the actual number of deaths and years of life lost from doses received at DOE facilities may be zero.

To put into perspective the calculated risks from ionizing radiation doses received at DOE facilities, it is important to review the risks associated with other activities. The primary purpose of this review is to

indicate the effect of radiation doses received at DOE facilities on the health of workers relative to the effects of other hazards. Table 7.2 lists the estimated annual deaths per 100,000 persons in the U.S. population for various hazards.

As indicated in Table 7.2, reducing radiation doses received at DOE facilities is only one way to improve the health of workers. Other effective methods may include anti-smoking campaigns, increased safety awareness, and the promotion of safe driving practices. Radiation doses received at DOE facilities do not significantly reduce the overall health or life expectancy of workers relative to the other risks encountered both in the workplace and as a part of everyday life.

TABLE 7.2. Estimated Annual Fatality Rates in the U.S. Attributable to Various Causes[a]

Cause	Annual Number of Deaths Per 100,000 People or Workers
General Population	
All causes	874
Heart Disease	323
Cancer, All Types	193
Lung Cancer	51
Leukemia	7
Other Cancer Types	135
Accidents, All Types	39
Motor Vehicle Accidents	19
Other Accidents	20
Other Causes	319
Occupational	
Industrial injuries and illnesses	4.8[b]
Highway vehicles	1.6
Industrial vehicles or equipment	0.4
Falls	0.4
Heart attacks	0.3
Electrocutions	0.3
Caught between objects other than vehicles or equipment	0.3
Assaults	0.3
Aircraft crashes	0.2
Struck by objects other than vehicles or equipment	0.2
Explosions	0.2
Gas inhalation	0.1
Fires	0.1
Plant machinery operations	0.1
All other (including contact with carcinogenic or toxic substances, drowning, train accidents, and various occupational illnesses)	0.1
Estimated cancer fatalities from radiation doses received at DOE facilities	1.5[c]

(a) Sources: General population data for the year 1985 from NCHS (1988); occupational data (except cancer fatalities from DOE radiation doses) for the years 1986 and 1987 from DOL (1989).

(b) Ranges from a low of 1.9 per 100,000 in the services industry to a high of 24 per 100,000 in the mining industry.

(c) Based on age- and sex-specific risk equations provided in the BEIR V report (NAS 1990). These equations were based primarily on the Japanese A-bomb survivor data, which represented acute exposures. The BEIR V committee recognized the need to apply a dose rate effectiveness factor for chronic exposures, which would reduce the risk estimate provided in the table by a factor of at least two. Value indicates deaths per 100,000 DOE workers.

8.0 REFERENCES

Brodsky, A., R. P. Specht, B. G. Brooks, and W. S. Cool. 1976. "Log-Normal Distributions of Occupational Exposure in Medicine and Industry." In Proceedings of the Ninth Midyear Topical Symposium of the Health Physics Society, February 9-12, 1976, Denver, Colorado, pp. 373-379. Pergamon Press, New York.

Brooks, B. G. 1988. Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities, 1985: Eighteenth Annual Report. NUREG-0713, Vol. 7, U.S. Nuclear Regulatory Commission, Washington, D.C.

Bunger, B. M., J. R. Cook, and M. K. Barrick. 1981. "Life Table Methodology for Evaluating Radiation Risk: An Application Based on Occupational Exposures." Health Physics 40(4):439-455.

Faust, L. G., L. W. Brackenbush, K. R. Heid, W. N. Herrington, J. L. Kenoyer, L. F. Munson, L. H. Munson, J. M. Selby, K. L. Soldat, G. A. Stoetzel, and R. J. Traub. 1988. Health Physics Manual of Good Practices for Plutonium Facilities. PNL-6534, Pacific Northwest Laboratory, Richland, Washington.

Federal Register 52 FR 2822-2834. January 27, 1987. "Radiation Protection Guidance to Federal Agencies for Occupational Exposure. Recommendations Approved by the President." U.S. Environmental Protection Agency, Washington, D.C.

International Commission on Radiological Protection (ICRP). 1977. Recommendations of the International Commission on Radiological Protection. ICRP Publication 26. Pergamon Press, Oxford.

Kumazawa, S., and T. Numakunai. 1981. "A New Theoretical Analysis of Occupational Dose Distributions Indicating the Effect of Dose Limits." Health Physics 41(3):465-475.

Kumazawa, S., J. Shimazaki, and T. Numakunai. 1982. Numerical Calculation Methods Relating to Hybrid Lognormal Distributions. JAERI-M 92-035, Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken, Japan.

Kumazawa, S., D. R. Nelson, and A. C. B. Richardson. 1984. Occupational Exposure to Ionizing Radiation in the United States. EPA 520/1-84-005, U.S. Environmental Protection Agency, Washington, D.C.

Merwin, S. E., R. J. Traub, and L. G. Faust. 1990. "The Next Step in Radiation Protection: Controlling Risk Rather than Dose." In Proceedings of the Twenty-third Midyear Topical Symposium of the Health Physics Society, February 5-8, 1990, Atlantic City, New Jersey, pp. 126-135. Pergamon Press, New York.

Munson, L. H., W. N. Herrington, D. P. Higby, R. L. Kathren, S. E. Merwin, and G. A. Stoetzel. 1988. Health Physics Manual of Good Practices for Reducing Radiation Exposure to Levels that are As Low As Reasonably Achievable (ALARA). PNL-6577, Pacific Northwest Laboratory, Richland, Washington.

National Academy of Sciences (NAS), Committee on the Biological Effects of Ionizing Radiations. 1980. The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980. National Academy of Sciences, Washington, D.C.

National Academy of Sciences (NAS), Committee on the Biological Effects of Ionizing Radiations. 1990. Health Effects of Exposure to Low Levels of Ionizing Radiation. BEIR V. National Academy of Sciences, Washington, D.C.

National Center for Health Statistics (NCHS). 1988. Vital Statistics of the United States 1985. Volume II - Mortality. U.S. Department of Health and Human Services, Hyattsville, Maryland.

National Council on Radiation Protection and Measurements (NCRP). 1987a. Recommendations on Limits for Exposure to Ionizing Radiation. NCRP Publication 91, NCRP, Bethesda, Maryland.

National Council on Radiation Protection and Measurements (NCRP). 1987b. Ionizing Radiation Exposure of the Population of the United States. NCRP Publication 93, NCRP, Bethesda, Maryland.

Rich, B. L., S. L. Hinnefeld, C. R. Lagerquist, W. G. Mansfield, L. H. Munson and E. R. Wagner. 1988. Health Physics Manual of Good Practices for Uranium Facilities. EGG-2530, Idaho National Engineering Laboratory, Idaho Falls, Idaho.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). 1977. Sources and Effects of Ionizing Radiation. 1977 Report to the General Assembly. United Nations, New York.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). 1988. Sources, Effects and Risks of Ionizing Radiation. 1988 Report to the General Assembly. United Nations, New York.

U.S. Department of Energy (DOE). 1986. Environmental Protection, Safety, and Health Protection Program for DOE Operations. DOE 5480.1B, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy (DOE). 1987. Protection, Safety, and Health Protection Information Reporting System. DOE 5484.1, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy (DOE). 1988. Radiation Protection for Occupational Workers. DOE 5480.11, U.S. Department of Energy, Washington, D.C.

U.S. Department of Labor (DOL). 1989. Occupational Injuries and Illnesses in the United States by Industry, 1987. Bulletin 2328, U.S. Department of Labor, Washington, D.C.

APPENDIX A

DISTRIBUTION OF ANNUAL WHOLE-BODY DOSES BY FACILITY TYPE FOR EACH FIELD ORGANIZATION, 1988

TABLE A.1
Distribution of Annual Whole-Body Doses by Facility Type
Albuquerque Field Organization
1988

Facility Type	Total Monitored	< Meas.	Meas.- <0.10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Accelerator	828	607	127	37	21	13	7	15	1									52
Fuel/Uran. Enrich.																		
Fuel Fabrication																		
Fuel Processing																		
Maint. & Support	3,727	2,223	1,351	56	26	22	17	25	7									127
Reactor	185	123	28	14	5	5	4	5	1									22
Research, Gen.	2,685	2,035	393	72	52	20	30	71	12									211
Research, Fusion	218	211	6				1											1
Waste Proc./Mgmt.	41	28	13															
Weapons Fab. & Test.	8,394	3,574	3,446	620	339	171	101	140	3									680
Other	5,424	4,483	824	65	39	13												51
Visitors	2,493	540	1,817	103	24	5	2	1	1									65
DOE Offices	420	398	22															
TOTAL	24,415	14,222	8,027	967	506	249	162	257	25									
TOTAL PERSON-REM			192	153	173	152	141	342	57									1,210

TABLE A.2
Distribution of Annual Whole-Body Doses by Facility Type
Chicago Field Organization
1988

Facility Type	Total Monitored	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Accelerator	2,826	1,860	720	127	64	31	13	9	2									110
Fuel/Uran. Enrich.																		
Fuel Fabrication	33	23	10															1
Fuel Processing																		
Maint. & Support	707	496	168	25	9	3	2	4										21
Reactor	376	154	127	62	26	4		3										30
Research, Gen.	2,888	2,317	329	136	72	19	12	3										85
Research, Fusion	1,094	936	153	5														5
Waste Proc./Mgmt.	8			2		2	2	2										5
Weapons Fab. & Test.																		
Other	36	2	32	2														1
Visitors	1,943	871	959	83	20	8		2										52
DOE Offices	122	111	11															
TOTAL	10,033	6,770	2,509	442	191	67	29	23	2									
TOTAL PERSON-REM			73	69	66	41	25	31	4									310

TABLE A.3
Distribution of Annual Whole-Body Doses by Facility Type
Idaho Field Organization
1988

Facility Type	Total Monitored	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Accelerator																		
Fuel/Uran. Enrich.																		
Fuel Fabrication																		
Fuel Processing	1,808	1,189	306	123	104	49	15	22										134
Maint. & Support	342	195	129	15	2	1												8
Reactor	736	464	172	52	34	9	1	4										39
Research, Gen.	906	684	156	36	20	6	3	1										25
Research, Fusion																		
Waste Proc./Mgmt.	109	68	28	10	3													4
Weapons Fab. & Test.																		
Other	1,687	1,228	397	47	14	1												24
Visitors	313	33	234	24	10	9	2	1										20
DOE Offices	2	1	1															
TOTAL	5,903	3,862	1,423	307	187	75	21	28										
TOTAL PERSON REM			41	49	64	46	18	34										253

TABLE A.4
Distribution of Annual Whole-Body Doses by Facility Type
Nevada Field Organization
1988

Facility Type	Total Monitored	< Meas.	Meas.- <0.10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Accelerator																		
Fuel/Uran. Enrich.																		
Fuel Fabrication																		
Fuel Processing																		
Maint. & Support	373	334	21	8	9	1												6
Reactor																		
Research, Gen.																		
Research, Fusion																		
Waste Proc./Mgmt.																		
Weapons Fab. & Test.	514	445	46	17	6													7
Other	4	4																
Visitors	9	3	6															
DOE Offices	2	1			1													
TOTAL	902	787	73	25	16	1												
TOTAL PERSON REM			3	4	5	1												13

TABLE A.5
Distribution of Annual Whole-Body Doses by Facility Type
Oak Ridge Field Organization
1988

Facility Type	Total Monitored	< Meas.	Meas.- <0.10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Accelerator																		
Fuel/Uran. Enrich.	2,970	1,905	1,017	43	4	1												29
Fuel Fabrication	1,683	634	620	302	120	6	1											117
Fuel Processing	115	30	81	4														3
Maint. & Support																		
Reactor																		
Research. Gen.	470	96	177	117	35	24	12	9										77
Research. Fusion																		
Waste Proc./Mgmt.	135	120	15															
Weapons Fab. & Test.	770	363	182	154	50	14	5	2										65
Other	13		7	5	1													1
Visitors	3,020	1,955	1,002	39	11	9	2	2										41
DOE Offices																		
TOTAL	9,176	5,103	3,101	664	221	54	20	13										
TOTAL PERSON REM			86	107	73	32	17	17										333

TABLE A.6
Distribution of Annual Whole-Body Doses by Facility Type
Pittsburgh Naval Reactors Field Organization
1988

Facility Type	Total Monitored	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Accelerator																		
Fuel/Uran. Enrich.																		
Fuel Fabrication																		
Fuel Processing																		
Maint. & Support																		
Reactor	633	40	517	50	16	8	2											31
Research, Gen.	1,217	195	852	118	42	10												54
Research, Fusion																		
Waste Proc./Mgmt.																		
Weapons Fab. & Test.	1		1															
Other	35	21	12	1	1													1
Visitors	167	104	63															
DOE Offices																		
TOTAL	2,053	360	1,445	169	59	18	2											
TOTAL PERSON REM			27	26	21	11	2											86

TABLE A.7
Distribution of Annual Whole-Body Doses by Facility Type
Richland Field Organization
1988

Facility Type	Total Monitored	< Meas.	Meas.- ≤0.10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Accelerator	11	5	6															
Fuel/Uran. Enrich.																		
Fuel Fabrication	64	16	35	13														3
Fuel Processing	75	7	12	22	18	8	7	1										22
Maint. & Support	3,388	1,680	1,365	170	87	34	24	25	3									172
Reactor	1,018	300	388	126	100	51	32	21										152
Research, Gen.	1,362	683	569	59	26	9	7	9										56
Research, Fusion																		
Waste Proc./Mgmt.	2,493	1,094	935	222	96	66	31	45	4									239
Weapons Fab. & Test.																		
Other	613	452	145	13	2		1											7
Visitors	13		8	4	1													1
DOE Offices	165	95	68	2														2
TOTAL	9,202	4,332	3,531	631	330	168	102	101	7									
TOTAL PERSON REM			100	97	116	103	86	135	16									654

TABLE A.8
Distribution of Annual Whole-Body Doses by Facility Type
San Francisco Field Organization
1988

Facility Type	Total Monitored	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Accelerator	925	410	439	58	9	5		4										33
Fuel/Uran. Enrich.	768	743	20	2	2	1												2
Fuel Fabrication																		
Fuel Processing																		
Maint. & Support	4,322	4,219	79	11	8	1	1	3										12
Reactor																		
Research, Gen.	1,855	1,707	121	13	8	2	1	3										14
Research, Fusion	382	361	19	2														1
Waste Proc./Mgmt.	69	69																
Weapons Fab. & Test.	1,573	1,494	59	16	4													6
Other	465	460	5															
Visitors	122	22	88	9	3													6
DOE Offices	97	95	2															
TOTAL	10,578	9,580	832	111	34	9	2	10										
TOTAL PERSON REM			25	17	12	5	2	13										74

TABLE A.9
Distribution of Annual Whole-Body Doses by Facility Type
Savannah River Field Organization
1988

Facility Type	Total Monitored	< Meas.	Meas.- <0.10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Accelerator																		
Fuel/Uran. Enrich.																		
Fuel Fabrication	990	572	295	56	36	24	7											49
Fuel Processing	1,304	358	493	180	136	61	31	45										215
Maint. & Support	7,576	3,724	2,783	639	302	96	27	4	1									376
Reactor	1,155	335	655	132	25	4	3	1										55
Research, Gen.	1,108	674	368	46	14	4	1	1										25
Research, Fusion																		
Waste Proc./Mgmt.	829	403	217	70	63	32	24	20										105
Weapons Fab. & Test.	412	280	112	10	4	4	1	1										10
Other	1,754	1,036	676	28	7	2	1	4										28
Visitors	1,740	894	829	5	5	2	1	4										23
DOE Offices	330	222	106	2														2
TOTAL	17,198	8,498	6,534	1,168	592	229	96	80	1									
TOTAL PERSON REM			172	183	208	140	83	100	2									887

TABLE A.10
Distribution of Annual Whole-Body Doses by Facility Type
Schenectady Naval Reactors Field Organization
1988

Facility Type	Total Monitored	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Accelerator																		
Fuel/Uran. Enrich.																		
Fuel Fabrication																		
Fuel Processing																		
Maint. & Support																		
Reactor	914	80	742	67	20	5												37
Research, Gen.	877	494	367	15	1													7
Research, Fusion																		
Waste Proc./Mgmt.																		
Weapons Fab. & Test.																		
Other	30	25	5															
Visitors	1,023	170	743	69	36	5												37
DOE Offices																		
TOTAL	2,844	769	1,857	151	57	10												
TOTAL PERSON REM			33	23	20	6												81

TABLE A.11
Distribution of Annual Whole-Body Doses by Facility Type
DOE Headquarters
1988

Facility Type	Total Monitored	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Accelerator																		
Fuel/Uran. Enrich.																		
Fuel Fabrication																		
Fuel Processing																		
Maint. & Support																		
Reactor																		
Research, Gen.	1	1																
Research, Fusion																		
Waste Proc./Mgmt.																		
Weapons Fab. & Test.																		
Other																		
Visitors																		
DOE Offices	167	141	26															
TOTAL	168	142	26															
TOTAL PERSON REM																		

APPENDIX B

DISTRIBUTION OF ANNUAL WHOLE-BODY DOSES TO DOE CONTRACTOR EMPLOYEES AND VISITORS FOR EACH FIELD ORGANIZATION, 1988

TABLE B.1
Distribution of Annual Whole-Body Doses to Personnel
Albuquerque Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Albuquerque Office Subs																	
Employees		3	5	1													1
Visitors																	
Total		3	5	1													1
Allied Signal (Bendix Div.)																	
Employees	202	9	1														1
Visitors																	
Total	202	9	1														1
EG&G Mound																	
Employees	2	2,239	30	5	1	1											57
Visitors	3	525	1	1													8
Total	5	2,764	31	6	1	1											65
General Electric Co.-Pinellas																	
Employees	238	24	3														1
Visitors		1															
Total	238	25	3														1
Inhalation Toxicology																	
Employees	284	32	4	1			1										3
Visitors																	
Total	284	32	4	1			1										3
Jacobs-Weston Team																	
Employees	28	8															
Visitors	5																
Total	33	8															
Los Alamos National Lab.																	
Employees	4.258	501	122	98	54	55	110	20									350
Visitors	12	188	46	16	1	1	1										20
Total	4,270	689	168	114	55	56	111	20									370

TABLE B.1 (continued)
Distribution of Annual Whole-Body Doses to Personnel
Albuquerque Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
MK-Ferguson Co.-UMTRA																	
Employees	42	20															1
Visitors																	
Total	42	20															1
MK-Ferguson Subcontractors -UMTRA																	
Employees	964	275	15	1													9
Visitors																	
Total	964	275	15	1													9
Mason & Hanger (Amarillo, TX)																	
Employees	861	139	38	22	7	1	1										25
Visitors	28	21	1														1
Total	889	160	39	22	7	1	1										26
Mason & Hanger (Los Alamos, NM)																	
Employees	384	21															
Visitors																	
Total	384	21															
Pan-Am World Services, Inc.																	
Employees	1,509	108	28	20	10												20
Visitors																	
Total	1,509	108	28	20	10												20
Rockwell International																	
Employees	1,821	2,302	553	313	161	99	139	3									627
Visitors	462	887	49	5	2												26
Total	2,283	3,189	602	318	163	99	139	3									653
Ross Aviation, Inc.																	
Employees	90	5															
Visitors																	
Total	90	5															

TABLE B.1 (continued)
Distribution of Annual Whole-Body Doses to Personnel
Albuquerque Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Sandia National Lab.																	
Employees	2,289	397	62	20	9	4	5	1									46
Visitors	29	195	6	2	2	1		1									10
Total	2,318	592	68	22	11	5	5	2									56
TOTAL	13,511	7,900	964	505	247	162	257	25									1,206

TABLE B.2
Distribution of Annual Whole-Body Doses to Personnel
Chicago Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Ames Laboratory (Iowa St.)																	
Employees	83																
Visitors																	
Total	83																
Argonne National Lab.																	
Employees	2,042	367	155	70	19	10	3										88
Visitors	3	15	4	4													3
Total	2,045	382	159	74	19	10	3										91
Battelle Memorial Inst.-Columbus																	
Employees	63	21	8	3	2	2	4										11
Visitors		6															
Total	63	27	8	3	2	2	4										11
Brookhaven National Lab.																	
Employees	1,099	547	114	77	31	17	13	2									116
Visitors	285	567	56	10	8		1										33
Total	1,384	1,114	170	87	39	17	14	2									149
Chicago Office Subs.																	
Employees	59	19	13	5			1										6
Visitors		3	1														
Total	59	22	14	5			1										6
Fermilab																	
Employees	1,201	388	53	10	5												24
Visitors	502	358	22	6			1										16
Total	1,703	746	75	16	5		1										40

TABLE B.2 (continued)
Distribution of Annual Whole-Body Doses to Personnel
Chicago Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Mass. Inst. of Tech.																	
Employees	306	46	10	6	2												7
Visitors																	
Total	306	46	10	6	2												7
Princeton Plasma Physics Laboratory																	
Employees	889	145	5														5
Visitors	67	10															
Total	956	155	5														5
Solar Energy Research Institute																	
Employees	14	4	1														
Visitors																	
Total	14	4	1														
TOTAL	6,613	2,496	442	191	67	29	23	2									310

TABLE B.3
Distribution of Annual Whole-Body Doses to Personnel
Idaho Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
EG&G Idaho, Inc.																	
Employees	1,247	429	105	51	13	4	1										61
Visitors	9	59	3	2													2
Total	1,256	488	108	53	13	4	1										63
Idaho Office Subs.																	
Employees	3	3															
Visitors	2	12															
Total	5	15															
MK-Ferguson Company-ID																	
Employees	118	48	21	15	14	3	9										34
Visitors	4	50	10	4	5	2	1										11
Total	122	98	31	19	19	5	10										44
MK-Ferguson Subcontractors																	
Employees	17	13	1	5	3		3										8
Visitors	13	87	9	4	4												6
Total	30	100	10	9	7		3										14
Protection Technology-INEL																	
Employees	269	123															2
Visitor																	
Total	269	123															2
Rockwell-INEL																	
Employees	404	88	16	4													7
Visitors		1	1														
Total	404	89	17	4													7

TABLE B.3 (continued)
Distribution of Annual Whole-Body Doses to Personnel
Idaho Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
UNC Geotech-ID																	
Employees	189	59	2														1
Visitors		3															
Total	189	62	2														1
West Valley Nuclear Services Inc.																	
Employees	473	133	30	12	1												15
Visitors																	
Total	473	133	30	12	1												15
Westinghouse Idaho Nuclear Co.																	
Employees	971	247	108	90	35	12	14										104
Visitors	5	17	1														
Total	976	264	109	90	35	12	14										104
TOTAL	3,724	1,372	307	187	75	21	28										252

TABLE B.4
Distribution of Annual Whole-Body Doses to Personnel
Nevada Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
EG&G Kirtland																	
Employees	102	4	1														
Visitors																	
Total	102	4	1														
EG&G Los Alamos																	
Employees	67	11		4													2
Visitors	1	2															
Total	68	13		4													2
Fenix & Scisson, Inc.																	
Employees	52	9	7	6	1												4
Visitors																	
Total	52	9	7	6	1												4
Holmes & Narver, Inc., ESD																	
Employees	20	2	2														
Visitors																	
Total	20	2	2														
Reynolds Elec. & Engrg. Co.																	
Employees	498	40	14	5													5
Visitors	2	4															
Total	500	44	14	5													5
TOTAL	742	72	24	15	1												12

TABLE B.5
Distribution of Annual Whole-Body Doses to Personnel
Oak Ridge Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
M.M. Portsmouth Subcontractors																	
Employees																	
Visitors	185	344	1														6
Total	185	344	1														6
Martin Marietta (ORGDP)																	
Employees	464	65	9	1	1												5
Visitors	1																
Total	465	65	9	1	1												5
Martin Marietta (ORNL)																	
Employees	95	161	107	35	24	12	9										75
Visitors	1																
Total	96	161	107	35	24	12	9										75
Martin Marietta (Paducah)																	
Employees	69	21	6	1													2
Visitors																	
Total	69	21	6	1													2
Martin Marietta (Portsmouth)																	
Employees	1,372	931	28	2													22
Visitors																	
Total	1,372	931	28	2													22
Martin Marietta (Y-12)																	
Employees	363	182	154	50	14	5	2										65
Visitors	256	32	14	7	6		1										11
Total	619	214	168	57	20	5	3										76
Morrison-Knudsen (Decommissioning Project)																	
Employees	64	14															
Visitors	195	22															
Total	259	36															

TABLE B.5 (continued)
Distribution of Annual Whole-Body Doses to Personnel
Oak Ridge Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Oak Ridge Assoc. Universities																	
Employees	1	23	15	1													3
Visitors		23															
Total	1	46	15	1													3
Oak Ridge Office Subs.																	
Employees	56	1															
Visitors	185	6															
Total	241	7															
RMI Company																	
Employees	30	81	4														3
Visitors	7	23															
Total	37	104	4														3
Westinghouse Materials Co. of Ohio																	
Employees	634	620	304	120	6	1											117
Visitors	28	15															
Total	662	635	304	120	6	1											118
Westinghouse of Ohio Subs.																	
Employees																	
Visitors	1,097	537	24	4	3	2	1										22
Total	1,097	537	24	4	3	2	1										22
TOTAL	5,103	3,101	664	221	54	20	13										333

TABLE B.6
Distribution of Annual Whole-Body Doses to Personnel
Pittsburgh Naval Reactors Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Westinghouse Electric (BAPL)																	
Employees	182	639	21	21	10												26
Visitors	104	47															
Total	286	686	21	21	10												26
Westinghouse Electric (NRF)																	
Employees	41	718	147	37	8	2											59
Visitors		16															
Total	41	734	147	37	8	2											59
Westinghouse Plant Apparatus Div.																	
Employees	21	12	1	1													1
Visitors																	
Total	21	12	1	1													1
TOTAL	348	1,432	169	59	18	2											86

TABLE B.7
Distribution of Annual Whole-Body Doses to Personnel
Richland Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Battelle Memorial Institute (PNL)																	
Employees	613	545	59	24	9	7	9										55
Visitors		2															
Total	613	547	59	24	9	7	9										55
General Electric, Shippingport																	
Employees	165	41	6														2
Visitors																	
Total	165	41	6														2
Hanford Environmental Health Foundation																	
Employees	25	14	1														
Visitors																	
Total	25	14	1														
Kaiser Engineers Hanford-Cost Const.																	
Employees	562	489	118	72	31	19	20	3									126
Visitors		3	2														
Total	562	492	120	72	31	19	20	3									126
Westinghouse Hanford Service Subs.																	
Employees	75	53	2														1
Visitors																	
Total	75	53	2														1
Westinghouse Hanford Services																	
Employees	2,797	2,313	440	232	128	76	72	4									467
Visitors		3	2	1													1
Total	2,797	2,316	442	233	128	76	72	4									468
TOTAL	4,237	3,463	629	330	168	102	101	7									653

TABLE B.8
Distribution of Annual Whole-Body Doses to Personnel
San Francisco Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Energy Technology Engineering Center																	
Employees	6	3															
Visitors																	
Total	6	3															
LLNL Plant Services																	
Employees	419	11		1													1
Visitors																	
Total	419	11		1													1
LLNL Security																	
Employees	332	7															
Visitors																	
Total	332	7															
LLNL Subcontractors																	
Employees																	
Visitors	20	39	6	3													4
Total	20	39	6	3													4
Lawrence Berkeley Lab.																	
Employees	5	458	49	7	2		1										25
Visitors		48	3														2
Total	5	506	52	7	2		1										27
LLNL-Nevada																	
Employees	98	5	2	2													1
Visitors																	
Total	98	5	2	2													1

TABLE B.8 (continued)
Distribution of Annual Whole-Body Doses to Personnel
San Francisco Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Lawrence Livermore National Lab.																	
Employees	8,225	205	38	17	3	2	5										28
Visitors																	
Total	8,225	205	38	17	3	2	5										28
Los Angeles Lab of Biomedical & Environment																	
Employees	82	15	2				3										5
Visitors																	
Total	82	15	2				3										5
Rockwell International, Atomics International																	
Employees		1	2	1	1		1										3
Visitors		1															
Total		2	2	1	1		1										3
Stanford Linear Accelerator Center																	
Employees	216	37	9	3	3												5
Visitors																	
Total	216	37	9	3	3												5
U. of Cal./Davis, Radiobiology Lab-LEHR																	
Employees	34																
Visitors																	
Total	34																
U. of Cal./SAN-Lab of Radiobiology																	
Employees	46																
Visitors	2																
Total	48																
TOTAL	9,485	830	111	34	9	2	10										74

TABLE B.9
Distribution of Annual Whole-Body Doses to Personnel
Savannah River Field Organization
1988

Contractor	< Meas.	Meas.- <0.10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
American Telephone & Telegraph																	
Employees	6	8															
Visitors																	
Total	6	8															
Bechtel Construction-SR																	
Employees	1,913	1,974	499	220	48	16	2	1									262
Visitors																	
Total	1,913	1,974	499	220	48	16	2	1									262
Diversco																	
Employees	139	56	1														1
Visitors																	
Total	139	56	1														1
DuPont Research																	
Employees	674	368	46	14	4	1	1										25
Visitors																	
Total	674	368	46	14	4	1	1										25
Industrial Phases-SR																	
Employees	5																
Visitors																	
Total	5																
Southern Bell Tel. & Tel.																	
Employees	11	12															
Visitors																	
Total	11	12															

TABLE B.9 (continued)
Distribution of Annual Whole-Body Doses to Personnel
Savannah River Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Univ. of Georgia Ecology Lab.																	
Employees	85	20	1														
Visitors																	
Total	85	20	1														
Wackenhut Services, Inc.-SR																	
Employees	486	472	16	2													13
Visitors																	
Total	486	472	16	2													13
Westinghouse S.R. Subcontractors																	
Employees	291	100	3	2	1	1	4										10
Visitors																	
Total	291	100	3	2	1	1	4										10
Westinghouse Savannah River Co.																	
Employees	3,772	2,589	595	349	174	77	69										550
Visitors	894	829	5	5	2	1	4										23
Total	4,666	3,418	600	354	176	78	73										573
TOTAL	8,276	6,428	1,166	592	229	96	80	1									885

TABLE B.10
Distribution of Annual Whole-Body Doses to Personnel
Schenectady Naval Reactors Field Organization
1988

Contractor	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
GE-KAPL-Kesselring																	
Employees	71	614	41	13	5												26
Visitors	112	656	69	36	5												37
Total	183	1,270	110	49	10												63
GE-KAPL-Knolls																	
Employees	483	362	15	1													7
Visitors	21	38															
Total	504	400	15	1													7
GE-KAPL-Knolls Subs.																	
Employees	25	5															
Visitors																	
Total	25	5															
GE-KAPL-Windsor																	
Employees	6	125	25	7													10
Visitors	37	49															
Total	43	174	25	7													11
TOTAL	755	1,849	150	57	10												81

APPENDIX C

DISTRIBUTION OF ANNUAL WHOLE-BODY DOSES FOR DOE GOVERNMENT EMPLOYEES AND VISITORS BY DOE FIELD ORGANIZATION, 1988

TABLE C.1
Distribution of Annual Whole-Body Doses for DOE Government Employees and Visitors by DOE Field Organization 1988

Organization	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Albuquerque Operations	482	58		1													1
Amarillo Area Office	48																
Dayton Area Office		27															1
Kansas City Area Office	14	1															
Los Alamos Area Office	122	6	1		2												2
Pinellas Area Office	7																
Rocky Flats Area Office	28	32	2														1
UMTRA Project Office	10	3															
SUBTOTAL	711	127	3	1	2												4
Chicago Operations	57	3															
Environmental Meas. Lab.	34	2															
New Brunswick Lab.	66	8															
SUBTOTAL	157	13															
DOE Headquarters	142	26															
SUBTOTAL	142	26															
Idaho Operations Office	138	51															1
SUBTOTAL	138	51															1
DNA-Kirtland AFB	21	1	1	1													
U.S. Dept. of Interior	1																
EPA (NERC)	23																

TABLE C.1 (continued)
Distribution of Annual Whole-Body Doses for DOE Government Employees and Visitors by DOE Field Organization
1988

Organization	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
SUBTOTAL	45	1	1	1													
Pittsburgh Naval Reactors Office	12	13															
SUBTOTAL	12	13															
Richland Operations Office	95	68	2														2
SUBTOTAL	95	68	2														2
San Francisco Operations Office	95	2															
SUBTOTAL	95	2															
Savannah River Forest Station	12	30	1														
Savannah River Operations Office	210	76	1														1
SUBTOTAL	222	106	2														1

TABLE C.1 (continued)
Distribution of Annual Whole-Body Doses for DOE Government Employees and Visitors by DOE Field Organization
1988

Organization	< Meas.	Meas.-<0.10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total Person-rem
Schenectady Naval Reactors Office	14	8	1														
SUBTOTAL	14	8	1														
TOTAL DOE	1,631	415	9	2	2												8

APPENDIX D

1988 EXPOSURE DATA BY DOSE RANGE, EXPOSURE TYPE, FACILITY TYPE, AGE, SEX, AND OCCUPATION FOR DOE AND DOE CONTRACTOR EMPLOYEES AND VISITORS[a]

(a) Not including visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied.

TABLE D.1
Distribution of Penetrating Doses by Facility Type and Dose-Equivalent Range
1988 - Male

Facility Type	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	3,010	1,565	235	101	47	19	20	8	3							5,008	204
Fuel/Uran. Enrichment	2,319	1,203	42	5	2											3,571	33
Fuel Fabrication	1,936	1,294	344	138	27	7		1								3,747	164
Fuel Processing	1,247	748	282	235	102	46	49	11								2,720	328
Maint. and Support	10,124	5,031	807	385	131	63	39	13	5	1						16,599	612
Reactor	1,414	3,122	529	250	86	42	26	7		1						5,477	382
Research, General	7,325	3,043	567	253	86	60	47	32	7	1						11,421	488
Research, Fusion	1,416	183	7			1										1,607	7
Waste Proc./Management	1,829	996	249	138	88	55	49	12	3							3,419	309
Weapons Fab. & Test.	5,457	3,797	765	357	163	84	102	23	2							10,750	676
Other	7,382	2,767	213	83	17	4	7	2								10,475	147
Total Persons	43,459	23,749	4,040	1,945	749	381	339	109	20	3	0	0	0	0	0	74,794	
Total Person-rem	0	620	635	672	456	328	404	183	44	8	0	0	0	0	0		3,350

TABLE D.2
Distribution of Penetrating Doses by Facility Type and Dose-Equivalent Range
1988 - Female

Facility Type	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	>=5		
Accelerator	370	135	12	1	2	1	1									522	9
Fuel/Uran. Enrichment	515	178	4	1												698	5
Fuel Fabrication	415	203	51	22	6	3										700	29
Fuel Processing	345	167	47	23	16	7	8									613	46
Maint. and Support	2,749	876	118	59	27	8	6	3	3	2						3,851	110
Reactor	231	224	43	12	5			1								516	21
Research, General	1,694	410	48	21	8	6	13	5	4							2,209	69
Research, Fusion	159	5														164	
Waste Proc./Management	333	240	55	24	12	2	4	2		1						673	45
Weapons Fab. & Test.	1,255	954	105	52	32	23	17	1	1							2,440	122
Other	1,574	547	14	6	2											2,143	16
Total Persons	9,640	3,939	497	221	110	50	49	12	8	3	0	0	0	0	0	14,529	
Total Person-rem	0	97	78	77	69	44	60	21	18	8	0	0	0	0	0		471

TABLE D.3
Distribution of Penetrating Doses by Facility Type and Dose-Equivalent Range
1988 - Unknown Sex

Facility Type	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	>=5		
Accelerator	4	32			1				1							38	4
Fuel Fabrication	19	15														34	
Fuel Processing	22	101	8	6	4	2	1									144	11
Maint. and Support		13	1	1												15	1
Reactor	3	47	10	2	5	1										68	7
Research, General	3	71	5	2	1											82	3
Research, Fusion		2														2	
Waste Proc./Management	2	22	2													26	1
Weapons Fab. & Test.	163	47	10	6	2		1									229	7
Other	1,110	1,320	62	10	8			1								2,511	46
Total Persons	1,326	1,670	98	27	21	3	2	1	1	0	0	0	0	0	0	3,149	
Total Person-rem	0	35	15	9	12	3	2	2	2	0	0	0	0	0	0		80

TABLE D.4
Distribution of Collective Penetrating Doses by Facility Type and Dose-Equivalent Range
1988 - Male

Facility Type	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator		44	36	35	29	17	23	14	6							204	5,008
Fuel/Uran. Enrichment		24	6	2	1											33	3,571
Fuel Fabrication		40	55	45	16	6		2								164	3,747
Fuel Processing		23	45	83	62	39	59	17								328	2,720
Maint. and Support		139	125	133	80	53	46	22	11	3						612	16,599
Reactor		79	82	87	53	36	30	12		3						382	5,477
Research, General		75	90	89	53	52	57	55	15	3						488	11,421
Research, Fusion		5	1			1										7	1,607
Waste Proc./Management		32	39	50	53	47	60	20	7							309	3,419
Weapons Fab. & Test.		96	123	122	99	73	121	38	4							676	10,750
Other		63	32	26	10	4	9	3								147	10,475
Total Person-rem	0	620	635	672	456	328	404	183	44	8	0	0	0	0	0	3,350	
Total Persons	43,459	23,749	4,040	1,945	749	381	339	109	20	3	0	0	0	0	0		74,794

TABLE D.5
Distribution of Collective Penetrating Doses by Facility Type and Dose-Equivalent Range
1988 - Female

	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total	
Facility Type	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5	Person- rem	Total Persons
Accelerator		4	2		1	1	1									9	522
Fuel/Uran. Enrichment		4	1													5	698
Fuel Fabrication		7	9	8	3	3										29	700
Fuel Processing		5	7	8	11	6	9									46	613
Maint. and Support		22	19	20	17	7	7	5	7	5						110	3,851
Reactor		6	6	4	3			2								21	516
Research, General		10	7	7	5	5	17	8	8							69	2,209
Research, Fusion																	164
Waste Proc./Management		8	9	9	7	2	4	4		3						45	673
Weapons Fab. & Test.		21	17	18	20	20	21	2	2							122	2,440
Other		11	2	2	1											16	2,143
Total Person-rem	0	97	78	77	69	44	60	21	18	8	0	0	0	0	0	471	
Total Persons	9,640	3,939	497	221	110	50	49	12	8	3	0	0	0	0	0		14,529

TABLE D.6
Distribution of Collective Penetrating Doses by Facility Type and Dose-Equivalent Range
1988 - Unknown Sex

Facility Type	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	>=5		
Accelerator		1			1				2							4	38
Fuel Fabrication																	34
Fuel Processing		2	1	2	2	2	1									11	144
Maint. and Support																1	15
Reactor		1	2	1	3	1										7	68
Research, General		1	1	1	1											3	82
Research, Fusion																	2
Waste Proc./Management																1	26
Weapons Fab. & Test		1	2	2	1		1									7	229
Other		27	9	3	5			2								46	2,511
Total Person-rem	0	35	15	9	12	3	2	2	2	0	0	0	0	0	0	80	
Total Persons	1,326	1,670	98	27	21	3	2	1	1	0	0	0	0	0	0		3,149

TABLE D.7
Distribution of Penetrating Doses by Age and Dose-Equivalent Range
1988 - Male

Age Range	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	223	72	5	1		1										302	3
20 - 24	1,876	992	158	61	25	11	5	1								3,129	104
25 - 29	4,515	3,086	563	286	125	65	66	29	7							8,742	550
30 - 34	6,635	4,016	769	386	181	102	80	22	3	1						12,195	704
35 - 39	6,558	3,795	765	383	141	61	63	23	2							11,791	618
40 - 44	5,986	3,105	516	239	88	34	40	9	2	1						10,020	394
45 - 49	5,125	2,549	415	197	68	32	18	12	1							8,417	309
50 - 54	4,371	2,137	299	141	53	35	23	3	1	1						7,064	249
55 - 59	4,107	1,957	309	145	47	28	26	7	3							6,629	249
60 - 64	2,730	1,119	177	80	17	9	17	1	1							4,151	124
≥65 or unspecified	1,333	921	64	26	4	3	1	2								2,354	45
Total Persons	43,459	23,749	4,040	1,945	749	381	339	109	20	3	0	0	0	0	0	74,794	
Total Person-rem	0	620	635	672	456	328	404	183	44	8	0	0	0	0	0		3,350

TABLE D.8
Distribution of Penetrating Doses by Age and Dose-Equivalent Range
1988 - Female

Age Range	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	>=5		
≤19	114	18	2													134	1
20 - 24	760	273	25	11	5	2	1	1								1,078	22
25 - 29	1,496	683	91	50	17	7	12	1								2,357	83
30 - 34	1,866	784	144	53	32	16	13	2	2							2,912	118
35 - 39	1,608	673	90	45	26	9	7	3	2							2,463	89
40 - 44	1,270	512	61	33	15	7	6		1							1,905	58
45 - 49	1,006	345	30	16	7	5	5	1		1						1,416	38
50 - 54	662	256	29	6	4	2	2	2	2							965	27
55 - 59	468	155	16	3	2		1	1	1	1						648	17
60 - 64	266	73	8	1	1	2	2	1		1						355	12
≥65 or unspecified	124	167	1	3	1											296	5
Total Persons	9,640	3,939	497	221	110	50	49	12	8	3	0	0	0	0	0	14,529	
Total Person-rem	0	97	78	77	69	44	60	21	18	8	0	0	0	0	0		471

TABLE D.9
Distribution of Penetrating Doses by Age and Dose-Equivalent Range
1988 - Unknown Sex

Age Range	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
20 - 24		1														1	
25 - 29	3	4														7	
30 - 34	3	4														7	
35 - 39	6	4														10	
40 - 44	5	1														6	
45 - 49	4	4														8	
50 - 54	9	5														14	
55 - 59	4	3														7	
60 - 64	5	1														6	
≥65 or unspecified	1,287	1,643	98	27	21	3	2	1	1							3,083	79
Total Persons	1,326	1,670	98	27	21	3	2	1	1	0	0	0	0	0	0	3,149	
Total Person-rem	0	35	15	9	12	3	2	2	2	0	0	0	0	0	0		80

TABLE D.10
Distribution of Penetrating Doses by Age and Dose-Equivalent Range
1988 - Male

Age Range	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19		2	1			1										3	302
20 - 24		24	24	21	16	9	7	2								104	3,129
25 - 29		84	87	102	77	56	80	48	16							550	8,742
30 - 34		109	120	134	110	87	95	38	7	3						704	12,195
35 - 39		103	123	134	87	54	76	38	4							618	11,791
40 - 44		79	81	82	54	29	47	15	4	3						394	10,020
45 - 49		66	65	66	41	27	22	20	2							309	8,417
50 - 54		56	47	49	32	29	26	5	2	3						249	7,064
55 - 59		50	50	49	28	24	31	12	6							249	6,629
60 - 64		29	27	27	10	8	20	2	2							124	4,151
≥65 or unspecified		18	9	9	2	2	1	4								45	2,354
Total Person-rem	0	620	635	672	456	328	404	183	44	8	0	0	0	0	0	3,350	
Total Persons	43,459	23,749	4,040	1,945	749	381	339	109	20	3	0	0	0	0	0		74,794

TABLE D.11
Distribution of Penetrating Doses by Age and Dose-Equivalent Range
1988 - Female

Age Range	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19																1	134
20 - 24		7	4	4	3	2	1	2								22	1,078
25 - 29		17	15	18	11	6	15	2								83	2,357
30 - 34		20	22	18	20	14	16	3	4							118	2,912
35 - 39		16	15	16	16	8	8	5	5							89	2,463
40 - 44		13	9	11	9	6	7		2							58	1,905
45 - 49		9	5	6	4	4	6	2		3						38	1,416
50 - 54		6	4	2	3	2	2	3	5							27	965
55 - 59		4	2	1	1		1	2	2	3						17	648
60 - 64		2	1		1	2	2	2		3						12	355
≥65 or unspecified		3		1	1											5	296
Total Person-rem	0	97	78	77	69	44	60	21	18	8	0	0	0	0	0	471	
Total Persons	9,640	3,939	497	221	110	50	49	12	8	3	0	0	0	0	0		14,529

TABLE D.12
Distribution of Penetrating Doses by Age and Dose-Equivalent Range
1988 - Unknown Sex

Age Range	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
20 - 24																	1
25 - 29																	7
30 - 34																	7
35 - 39																	10
40 - 44																	6
45 - 49																	8
50 - 54																	14
55 - 59																	7
60 - 64																	6
≥65 or unspecified		34	15	9	12	3	2	2	2							79	3,083
Total Person-rem	0	35	15	9	12	3	2	2	2	0	0	0	0	0	0	80	
Total Persons	1,326	1,670	98	27	21	3	2	1	1	0	0	0	0	0	0		3,149

TABLE D.13
Distribution of Penetrating Doses by Occupation and Dose-Equivalent Range
1988 - Male

Occupation	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	10,088	5,195	794	389	162	84	90	40	9	2						16,853	771
Management	3,989	1,994	220	65	36	11	3	1		1						6,320	143
Scientists	13,101	4,699	504	195	58	28	22	5	1							18,613	350
Technicians	3,932	2,033	680	361	169	72	36	18	2							7,303	541
Service	2,431	1,543	52	17		1	1									4,045	47
Agriculture	60	43	1	1												105	1
Construction	3,756	2,958	721	380	133	71	40	8	3							8,070	542
Production	1,890	1,808	656	379	169	107	138	36	5							5,188	729
Transportation	1,355	581	60	26	2	2	8									2,034	44
Laborers	596	558	170	65	9											1,398	72
Miscellaneous	2,261	2,337	182	67	11	5	1	1								4,865	109
Total Persons	43,459	23,749	4,040	1,945	749	381	339	109	20	3	0	0	0	0	0	74,794	
Total Person-rem	0	620	635	672	456	328	404	183	44	8	0	0	0	0	0		3,350

TABLE D.14
Distribution of Penetrating Doses by Occupation and Dose-Equivalent Range
1988 - Female

Occupation	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	2,165	1,127	73	38	20	10	17	8	7	2						3,467	126
Management	2,800	507	38	13	7	1	2									3,376	30
Scientists	1,952	601	48	21	5	3	1									2,631	35
Technicians	954	479	141	73	36	9	5	1								1,698	99
Service	729	309	10	2			1									1,051	9
Agriculture	2	5														7	
Construction	238	206	42	12	2											500	18
Production	345	376	106	53	35	27	23	3	1	1						970	133
Transportation	51	22	3	1												77	1
Laborers	90	95	25	5	1											216	10
Miscellaneous	306	212	11	3	4											536	9
Total Persons	9,640	3,939	497	221	110	50	49	12	8	3	0	0	0	0	0	14,529	
Total Person-rem	0	97	78	77	69	44	60	21	18	8	0	0	0	0	0		471

TABLE D.15
Distribution of Penetrating Doses by Occupation and Dose-Equivalent Range
1988 - Unknown Sex

Occupation	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	1,303	1,541	96	26	19	2	2	1								2,990	72
Management		4														4	
Scientists	2	11														13	
Technicians		63		1	2	1			1							68	6
Service		30														30	
Construction	2	1	2													5	
Production		1														1	
Transportation	19	15														34	
Laborers		1														1	
Miscellaneous		3														3	
Total Persons	1,326	1,670	98	27	21	3	2	1	1	0	0	0	0	0	0	3,149	
Total Person-rem	0	35	15	9	12	3	2	2	2	0	0	0	0	0	0		80

TABLE D.16
Distribution of Penetrating Doses by Facility Type and Occupation
1988 - Male

Facility Type	Number of Persons Receiving Penetrating Doses in each Occupation Category											Total Persons	Total Person-rem
	Unknown	Management	Science	Technician	Service	Agriculture	Construc-tion	Production	Transpor-tation	Laborer	Miscella-neous		
Accelerator	1,174	276	1,991	1,184	157	14	78	87	35	10	2	5,008	204
Fuel/Uran. Enrichment	512	269	773	330	263	1	711	459	37	161	55	3,571	33
Fuel Fabrication		320	577	131	64		281	618	55	38	1,663	3,747	164
Fuel Processing	1,470	43	513	21	6		263	371	10	16	7	2,720	328
Maint. and Support	2,656	2,011	2,794	976	1,245	43	4,586	943	660	666	19	16,599	612
Reactor	656	607	1,558	382	114		535	519	55	21	1,030	5,477	382
Research, General	2,833	657	4,778	1,729	508	9	216	160	30	35	466	11,421	488
Research, Fusion	175	92	668	316	69		148	56		4	79	1,607	7
Waste Proc./Management	112	503	1,006	424	30		692	490	97	44	21	3,419	309
Weapons Fab. & Test.	1,663	1,120	2,796	1,428	327		375	1,363	106	84	1,488	10,750	676
Other	5,602	422	1,159	382	1,262	38	185	122	949	319	35	10,475	147
Total Persons	16,853	6,320	18,613	7,303	4,045	105	8,070	5,188	2,034	1,398	4,865	74,794	
Total Person-rem	771	143	350	541	47	1	542	729	44	72	109		3,350

TABLE D.17
Distribution of Penetrating Doses by Facility Type and Occupation
1988 - Female

Facility Type	Number of Persons Receiving Penetrating Doses in each Occupation Category											Total Persons	Total Person-rem
	Unknown	Management	Science	Technician	Service	Agriculture	Construction	Production	Transportation	Laborer	Miscellaneous		
Accelerator	153	56	151	105	45	1	3	6			2	522	9
Fuel/Uran. Enrichment	126	243	87	70	81		12	53	2	23	1	698	5
Fuel Fabrication		230	103	85	19		34	141	3	14	71	700	29
Fuel Processing	339	11	72	12	4		28	141	3	3		613	46
Maint. and Support	693	1,326	551	485	236		319	72	41	127	1	3,851	110
Reactor	107	71	119	41	14		45	91		2	26	516	21
Research, General	523	351	677	418	95		3	21	2	4	115	2,209	69
Research, Fusion	14	62	44	28	7		2			2	5	164	
Waste Proc./Management	25	137	146	125	44		37	151	1	1	6	673	45
Weapons Fab. & Test.	418	654	421	252	78		17	273	2	20	305	2,440	122
Other	1,069	235	260	77	428	6		21	23	20	4	2,143	16
Total Persons	3,467	3,376	2,631	1,698	1,051	7	500	970	77	216	536	14,529	
Total Person-rem	126	30	35	99	9	0	18	133	1	10	9		471

TABLE D.18
Distribution of Penetrating Doses by Facility Type and Occupation
1988 - Unknown Sex

Facility Type	Number of Persons Receiving Penetrating Doses in each Occupation Category											Total Persons	Total Person-rem
	Unknown	Management	Science	Technician	Service	Agriculture	Construction	Production	Transportation	Laborer	Miscellaneous		
Accelerator		2	7	26			2	1				38	4
Fuel Fabrication									34			34	
Fuel Processing	144											144	11
Maint. and Support	9			6								15	1
Reactor	59	1	1	6							1	68	7
Research, General	57		4	17			2				2	82	3
Research, Fusion				2								2	
Waste Proc./Management	24			1						1		26	1
Weapons Fab. & Test.	198	1			30							229	7
Other	2,499		1	10			1					2,511	46
Total Persons	2,990	4	13	68	30	0	5	1	34	1	3	3,149	
Total Person-rem	72	0	0	6	0	0	0	0	0	0	0		80

TABLE D.19
Distribution of (Penetrating) Neutron Doses by Facility Type and Dose-Equivalent Range
1988 - Male

Facility Type	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	4,362	583	51	12												5,008	29
Fuel/Uran. Enrichment	3,563	5	3													3,571	1
Fuel Fabrication	3,731	9	2	4	1											3,747	3
Fuel Processing	2,501	88	40	48	24	15	4									2,720	61
Maint. and Support	15,486	887	137	46	18	14	5	6								16,599	103
Reactor	5,274	172	17	10	4											5,477	13
Research, General	10,528	659	84	52	31	25	28	11	3							11,421	150
Research, Fusion	1,601	5	1													1,607	
Waste Proc./Management	2,970	246	71	66	38	15	11	2								3,419	96
Weapons Fab. & Test.	8,861	1,198	394	168	93	33	3									10,750	249
Other	9,936	424	76	32	7											10,475	37
Total Persons	68,813	4,276	876	438	216	102	51	19	3	0	0	0	0	0	0	74,794	
Total Person-rem	0	128	137	156	132	88	60	31	7	0	0	0	0	0	0		740

TABLE D.20
Distribution of (Penetrating) Neutron Doses by Facility Type and Dose-Equivalent Range
1988 - Female

Facility Type	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	467	52	3													522	2
Fuel/Uran. Enrichment	698															698	
Fuel Fabrication	698	1		1												700	
Fuel Processing	559	22	7	16	7	1	1									613	14
Maint. and Support	3,664	115	30	19	9	2	7	5								3,851	40
Reactor	504	10	1	1												516	1
Research, General	2,079	88	12	6	5	3	12	4								2,209	33
Research, Fusion	164															164	
Waste Proc./Management	575	57	14	15	9		3									673	19
Weapons Fab. & Test.	2,123	202	48	37	23	6	1									2,440	47
Other	2,078	56	6	3												2,143	4
Total Persons	13,609	603	121	98	53	12	24	9	0	0	0	0	0	0	0	14,529	
Total Person-rem	0	18	19	35	32	10	29	15	0	0	0	0	0	0	0		159

TABLE D.21
Distribution of (Penetrating) Neutron Doses by Facility Type and Dose-Equivalent Range
1988 - Unknown Sex

Facility Type	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	35	3														38	
Fuel Fabrication	34															34	
Fuel Processing	144															144	
Maint. and Support	13	1	1													15	
Reactor	64	4														68	
Research, General	81	1														82	
Research, Fusion	2															2	
Waste Proc./Management	26															26	
Weapons Fab. & Test.	229															229	
Other	2,450	51	8	2												2,511	4
Total Persons	3,078	60	9	2	0	0	0	0	0	0	0	0	0	0	0	3,149	
Total Person-rem	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0		5

TABLE D.22
Distribution of Collective Neutron Doses by Facility Type and Dose-Equivalent Range
1988 - Male

Facility Type	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator		18	8	4												29	5,808
Fuel/Uran. Enrichment			1													1	3,571
Fuel Fabrication				1	1											3	3,747
Fuel Processing		3	7	18	15	14	4									61	2,720
Maint. and Support		26	21	16	11	12	6	10								103	16,599
Reactor		4	3	4	2											13	5,477
Research, General		18	13	18	20	22	34	18	7							150	11,421
Research, Fusion																	1,607
Waste Proc./Management		9	12	24	22	13	13	3								96	3,419
Weapons Fab. & Test.		39	62	59	57	28	3									249	10,750
Other		12	11	10	4											37	10,475
Total Person-rem	0	128	137	156	132	88	60	31	7	0	0	0	0	0	0	740	
Total Persons	68,813	4,276	876	438	216	102	51	19	3	0	0	0	0	0	0		74,794

TABLE D.23
Distribution of Collective Neutron Doses by Facility Type and Dose-Equivalent Range
1988 - Female

Facility Type	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	>=5		
Accelerator		1	1													2	522
Fuel/Uran. Enrichment																	698
Fuel Fabrication																	700
Fuel Processing		1	1	6	5	1	1									14	613
Maint. and Support		3	5	7	6	2	9	9								40	3,851
Reactor																1	516
Research, General		2	2	2	3	3	14	6								33	2,209
Research, Fusion																	164
Waste Proc./Management		2	2	5	5		4									19	673
Weapons Fab. & Test.		7	7	13	14	5	1									47	2,440
Other		2	1	1												4	2,143
Total Person-rem	0	18	19	35	32	10	29	15	0	0	0	0	0	0	0	159	
Total Persons	13,609	603	121	98	53	12	24	9	0	0	0	0	0	0	0		14,529

TABLE D.24
Distribution of Collective Neutron Doses by Facility Type and Dose-Equivalent Range
1988 - Unknown Sex

Facility Type	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator																	38
Fuel Fabrication																	34
Fuel Processing																	144
Maint. and Support																	15
Reactor																	68
Research, General																	82
Research, Fusion																	2
Waste Proc./Management																	26
Weapons Fab. & Test.																	229
Other		2	1	1												4	2,511
Total Person-rem	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0	5	
Total Persons	3,078	60	9	2	0	0	0	0	0	0	0	0	0	0	0		3,149

TABLE D.25
Distribution of (Penetrating) Neutron Doses by Age and Dose-Equivalent Range
1988 - Male

Age Range	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	296	6														302	
20 - 24	2,964	110	28	16	6	4	1									3,129	22
25 - 29	7,969	475	112	88	53	23	17	4	1							8,742	144
30 - 34	11,137	680	166	114	57	26	10	4	1							12,195	167
35 - 39	10,754	732	163	68	40	19	10	5								11,791	134
40 - 44	9,266	567	106	45	21	11	2	1	1							10,020	77
45 - 49	7,693	567	97	32	18	7	1	2								8,417	65
50 - 54	6,480	461	79	30	3	6	3	2								7,064	52
55 - 59	6,121	390	70	29	10	4	5									6,629	47
60 - 64	3,877	207	45	10	8	2	2									4,151	25
≥65 or unspecified	2,256	81	10	6				1								2,354	7
Total Persons	68,813	4,276	876	438	216	102	51	19	3	0	0	0	0	0	0	74,794	
Total Person-rem	0	128	137	156	132	88	60	31	7	0	0	0	0	0	0		740

TABLE D.26
Distribution of (Penetrating) Neutron Doses by Age and Dose-Equivalent Range
1988 - Female

Age Range	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	131	3														134	
20 - 24	1,034	33	2	6	2	1										1,078	6
25 - 29	2,207	95	16	23	10	3	3									2,357	26
30 - 34	2,699	120	42	28	12	2	7	2								2,912	41
35 - 39	2,284	116	29	15	13	1	3	2								2,463	29
40 - 44	1,781	82	16	16	6	2	1	1								1,905	18
45 - 49	1,339	51	11	6	6	1	2									1,416	12
50 - 54	899	54	2	2	3	1	3	1								965	11
55 - 59	615	28	1				2	2								648	7
60 - 64	337	12		1		1	3	1								355	7
≥65 or unspecified	283	9	2	1	1											296	1
Total Persons	13,609	603	121	98	53	12	24	9	0	0	0	0	0	0	0	14,529	
Total Person-rem	0	18	19	35	32	10	29	15	0	0	0	0	0	0	0		159

TABLE D.27
Distribution of (Penetrating) Neutron Doses by Age and Dose-Equivalent Range
1988 - Unknown Sex

Age Range	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
20 - 24	1															1	
25 - 29	7															7	
30 - 34	7															7	
35 - 39	8	2														10	
40 - 44	5	1														6	
45 - 49	5	3														8	
50 - 54	13	1														14	
55 - 59	7															7	
60 - 64	6															6	
≥65 or unspecified	3,019	53	9	2												3,083	4
Total Persons	3,078	60	9	2	0	0	0	0	0	0	0	0	0	0	0	3,149	
Total Person-rem	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0		5

TABLE D.28
Distribution of Collective Neutron Doses by Age and Dose-Equivalent Range
1988 - Male

Age Range	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19																	302
20 - 24		3	4	6	4	3	1									22	3,129
25 - 29		14	18	31	32	20	20	6	2							144	8,742
30 - 34		21	26	42	34	22	12	6	2							167	12,195
35 - 39		22	26	25	26	17	11	8								134	11,791
40 - 44		16	16	15	13	9	3	2	2							77	10,020
45 - 49		18	15	11	11	6	1	3								65	8,417
50 - 54		14	13	11	2	5	3	4								52	7,064
55 - 59		11	11	10	6	3	6									47	6,629
60 - 64		6	7	4	5	2	2									25	4,151
≥65 or unspecified		2	1	2				2								7	2,354
Total Person-rem	0	128	137	156	132	88	60	31	7	0	0	0	0	0	0	740	
Total Persons	68,813	4,276	876	438	216	102	51	19	3	0	0	0	0	0	0		74,794

TABLE D.29
Distribution of Collective Neutron Doses by Age and Dose-Equivalent Range
1988 - Female

Age Category	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19																	134
20 - 24		1		2	1	1										6	1,078
25 - 29		3	3	8	6	2	3									26	2,357
30 - 34		4	6	11	8	2	8	3								41	2,912
35 - 39		3	5	6	8	1	4	3								29	2,463
40 - 44		2	2	5	4	2	1	2								18	1,905
45 - 49		2	2	2	4	1	2									12	1,416
50 - 54		2		1	2	1	4	2								11	965
55 - 59		1					2	3								7	648
60 - 64						1	4	2								7	355
≥65 or unspecified					1											1	296
Total Person-rem	0	18	19	35	32	10	29	15	0	0	0	0	0	0	0	159	
Total Persons	13,609	603	121	98	53	12	24	9	0	0	0	0	0	0	0		14,529

TABLE D.30
Distribution of Collective Neutron Doses by Age and Dose-Equivalent Range
1988 - Unknown Sex

Age Category	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
20 - 24																	1
25 - 29																	7
30 - 34																	7
35 - 39																	10
40 - 44																	6
45 - 49																	8
50 - 54																	14
55 - 59																	7
60 - 64																	6
≥65 or unspecified		2	1	1												4	3,083
Total Person-rem	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0	5	
Total Persons	3,078	60	9	2	0	0	0	0	0	0	0	0	0	0	0		3,149

TABLE D.31
Distribution of (Penetrating) Neutron Doses by Occupation and Dose-Equivalent Range
1988 - Male

Occupation	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	15,167	1,273	186	91	46	39	33	15	3							16,853	230
Management	5,728	479	64	37	8	3	1									6,320	44
Scientists	17,836	635	96	33	10	1	2									18,613	52
Technicians	6,442	549	195	86	26	3		2								7,303	103
Service	3,837	201	6	1												4,045	6
Agriculture	104		1													105	
Construction	7,532	379	107	37	15											8,070	52
Production	4,246	418	190	150	111	56	15	2								5,188	239
Transportation	1,990	41	3													2,034	2
Laborers	1,329	51	16	2												1,398	5
Miscellaneous	4,602	250	12	1												4,865	7
Total Persons	68,813	4,276	876	438	216	102	51	19	3	0	0	0	0	0	0	74,794	
Total Person-rem	0	128	137	156	132	88	60	31	7	0	0	0	0	0	0		740

TABLE D.32
Distribution of (Penetrating) Neutron Doses by Occupation and Dose-Equivalent Range
1988 - Female

Occupation	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	3,239	154	22	10	11	6	16	9								3,467	58
Management	3,272	75	18	9	1	1										3,376	10
Scientists	2,526	87	9	6	3											2,631	8
Technicians	1,509	112	44	24	6		3									1,698	26
Service	1,003	46	2													1,051	1
Agriculture	7															7	
Construction	474	22	3	1												500	2
Production	811	56	18	43	32	5	5									970	51
Transportation	77															77	
Laborers	198	12	4	2												216	2
Miscellaneous	493	39	1	3												536	2
Total Persons	13,609	603	121	98	53	12	24	9	0	0	0	0	0	0	0	14,529	
Total Person-rem	0	18	19	35	32	10	29	15	0	0	0	0	0	0	0		159

TABLE D.33
Distribution of (Penetrating) Neutron Doses by Occupation and Dose-Equivalent Range
1988 - Unknown Sex

Occupation	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	2,928	51	9	2												2,990	4
Management	4															4	
Scientists	10	3														13	
Technicians	62	6														68	
Service	30															30	
Construction	5															5	
Production	1															1	
Transportation	34															34	
Laborers	1															1	
Miscellaneous	3															3	
Total Persons	3,078	60	9	2	0	0	0	0	0	0	0	0	0	0	0	3,149	
Total Person-rem	0	3	1	1	0	0	0	0	0	0	0	0	0	0	0		5

TABLE D.34
Distribution of (Penetrating) Beta-Gamma Doses by Facility Type and Dose-Equivalent Range
1988 - Male

Facility Type	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	3,398	1,227	213	85	41	20	14	8	2							5,008	174
Fuel/Uran. Enrichment	2,322	1,201	42	5	1											3,571	32
Fuel Fabrication	1,936	1,296	347	137	23	7		1								3,747	162
Fuel Processing	1,251	759	310	265	84	28	19	4								2,720	267
Maint. and Support	10,631	4,683	780	327	102	42	24	6	4							16,599	509
Reactor	1,481	3,076	523	247	81	36	25	7		1						5,477	369
Research, General	7,667	2,842	544	234	81	33	15	5								11,421	339
Research, Fusion	1,419	180	7			1										1,607	7
Waste Proc./Management	1,975	960	233	121	67	39	22	2								3,419	213
Weapons Fab. & Test.	5,622	3,985	673	315	109	29	15	1	1							10,750	427
Other	7,738	2,526	148	45	6	4	6	2								10,475	111
Total Persons	45,440	22,735	3,820	1,781	595	239	140	36	7	1	0	0	0	0	0	74,794	
Total Person-rem	0	588	598	619	359	205	164	59	15	3	0	0	0	0	0		2,610

TABLE D.35
Distribution of (Penetrating) Beta-Gamma Doses by Facility Type and Dose-Equivalent Range
1988 - Female

Facility Type	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	>=5		
Accelerator	405	105	8		3		1									522	7
Fuel/Uran. Enrichment	515	178	4	1												698	5
Fuel Fabrication	415	203	52	22	5	3										700	28
Fuel Processing	347	172	48	36	5	3	2									613	32
Maint. and Support	2,800	856	131	47	14	3										3,851	70
Reactor	236	221	42	12	4			1								516	20
Research, General	1,747	376	40	34	7	3	2									2,209	36
Research, Fusion	159	5														164	
Waste Proc./Management	368	230	53	16	4		2									673	26
Weapons Fab. & Test.	1,279	968	113	56	20	1	3									2,440	75
Other	1,620	507	14	2												2,143	13
Total Persons	9,891	3,821	505	226	62	13	10	1	0	0	0	0	0	0	0	14,529	
Total Person-rem	0	93	80	78	38	11	11	2	0	0	0	0	0	0	0		312

TABLE D.36
Distribution of (Penetrating) Beta-Gamma Doses by Facility Type and Dose-Equivalent Range
1988 - Unknown Sex

Facility Type	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	7	29			1				1							38	3
Fuel Fabrication	19	15														34	
Fuel Processing	22	101	8	6	4	2	1									144	11
Maint. and Support	1	13		1												15	1
Reactor	3	47	10	3	4	1										68	7
Research, General	4	70	5	2	1											82	3
Research, Fusion		2														2	
Waste Proc./Management	2	22	2													26	1
Weapons Fab. & Test.	163	47	10	6	2		1									229	7
Other	1,126	1,320	49	9	6			1								2,511	42
Total Persons	1,347	1,666	84	27	18	3	2	1	1	0	0	0	0	0	0	3,149	
Total Person-rem	0	34	13	10	10	3	2	2	2	0	0	0	0	0	0		75

TABLE D.37
Distribution of Collective Beta-Gamma Doses by Facility Type and Dose-Equivalent Range
1988 - Male

Facility Type	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator		34	33	30	26	18	16	13	4							174	5,000
Fuel/Uran. Enrichment		24	6	2	1											32	3,571
Fuel Fabrication		40	55	45	13	6		2								162	3,747
Fuel Processing		24	49	93	50	24	21	6								267	2,720
Maint. and Support		130	121	113	62	35	29	10	9							509	16,599
Reactor		78	81	86	49	31	29	12		3						369	5,477
Research, General		68	85	82	50	29	17	8								339	11,421
Research, Fusion		5	1			1										7	1,607
Waste Proc./Management		30	37	43	40	34	25	3								213	3,419
Weapons Fab. & Test.		100	106	111	65	25	17	2	2							427	10,750
Other		55	22	14	4	4	8	3								111	10,475
Total Person-rem	0	588	598	619	359	205	164	59	15	3	0	0	0	0	0	2,610	
Total Persons	45,440	22,735	3,820	1,781	595	239	140	36	7	1	0	0	0	0	0		74,794

TABLE D.38
Distribution of Collective Beta-Gamma Doses by Facility Type and Dose-Equivalent Range
1988 - Female

Facility Type	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator		3	1		2		1									7	522
Fuel/Uran. Enrichment		4	1													5	698
Fuel Fabrication		7	9	8	3	3										28	700
Fuel Processing		5	7	12	3	2	2									32	613
Maint. and Support		22	21	15	8	3										70	3,851
Reactor		6	6	4	2			2								20	516
Research, General		9	6	12	4	2	2									36	2,200
Research, Fusion																	164
Waste Proc./Management		8	9	6	2		2									26	673
Weapons Fab. & Test.		20	18	20	12	1	4									75	2,440
Other		10	2	1												13	2,143
Total Person-rem	0	93	80	78	38	11	11	2	0	0	0	0	0	0	0	312	
Total Persons	9,891	3,821	505	226	62	13	10	1	0	0	0	0	0	0	0		14,529

TABLE D.39
Distribution of Collective Beta-Gamma Doses by Facility Type and Dose-Equivalent Range
1988 - Unknown Sex

Facility Type	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator		1			1				2							3	38
Fuel Fabrication																	34
Fuel Processing		2	1	2	2	2	1									11	144
Maint. and Support																1	15
Reactor		1	2	1	2	1										7	68
Research, General		1	1	1	1											3	82
Research, Fusion																	2
Waste Proc./Management																1	26
Weapons Fab. & Test.		1	2	2	1		1									7	229
Other		26	7	3	3			2								42	2,511
Total Person-rem	0	34	13	10	10	3	2	2	2	0	0	0	0	0	0	75	
Total Persons	1,347	1,666	84	27	18	3	2	1	1	0	0	0	0	0	0		3,149

TABLE D.40
Distribution of (Penetrating) Beta-Gamma Doses by Age and Dose-Equivalent Range
1988 - Male

Age Range	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	227	68	6			1										302	3
20 - 24	1,931	963	152	63	15	5										3,129	82
25 - 29	4,734	2,975	576	283	103	42	21	7	1							8,742	406
30 - 34	6,935	3,901	752	368	140	61	30	7	1							12,195	537
35 - 39	6,898	3,637	699	368	127	27	26	9								11,791	484
40 - 44	6,266	2,931	502	208	64	23	21	4		1						10,020	317
45 - 49	5,383	2,419	359	171	55	16	9	4	1							8,417	244
50 - 54	4,583	2,011	269	121	40	27	11	1	1							7,064	197
55 - 59	4,279	1,865	290	113	34	30	14	2	2							6,629	203
60 - 64	2,829	1,072	159	62	13	7	7	1	1							4,151	98
≥65 or unspecified	1,375	893	56	24	4		1	1								2,354	38
Total Persons	45,440	22,735	3,820	1,781	595	239	140	36	7	1	0	0	0	0	0	74,794	
Total Person-rem	0	588	598	619	359	205	164	59	15	3	0	0	0	0	0		2,610

TABLE D.41
Distribution of (Penetrating) Beta-Gamma Doses by Age and Dose-Equivalent Range
1988 - Female

Age Range	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	114	19	1													134	1
20 - 24	777	259	30	9	2			1								1,078	17
25 - 29	1,534	663	104	45	7	1	3									2,357	57
30 - 34	1,918	777	129	67	17	3	1									2,912	77
35 - 39	1,650	655	92	46	17	2	1									2,463	60
40 - 44	1,306	493	61	38	4	1	2									1,905	40
45 - 49	1,025	335	34	9	7	4	2									1,416	27
50 - 54	688	239	26	8	3		1									965	16
55 - 59	479	146	15	3	3	2										648	10
60 - 64	272	70	10	1	2											355	5
≥65 or unspecified	128	165	3													296	3
Total Persons	9,891	3,821	505	226	62	13	10	1	0	0	0	0	0	0	0	14,529	
Total Person-rem	0	93	80	78	38	11	11	2	0	0	0	0	0	0	0		312

TABLE D.42
Distribution of (Penetrating) Beta-Gamma Doses by Age and Dose-Equivalent Range
1988 - Unknown Sex

Age Range	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
20 - 24		1														1	
25 - 29	3	4														7	
30 - 34	3	4														7	
35 - 39	8	2														10	
40 - 44	6															6	
45 - 49	7	1														8	
50 - 54	10	4														14	
55 - 59	4	3														7	
60 - 64	5	1														6	
≥65 or unspecified	1,301	1,646	84	27	18	3	2	1	1							3,083	75
Total Persons	1,347	1,666	84	27	18	3	2	1	1	0	0	0	0	0	0	3,149	
Total Person-rem	0	34	13	10	10	3	2	2	2	0	0	0	0	0	0		75

TABLE D.43
Distribution of Collective Beta-Gamma Doses by Age and Dose-Equivalent Range
1988 - Male

Age Range	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19		1	1			1										3	302
20 - 24		24	23	22	9	4										82	3,129
25 - 29		80	89	100	62	36	25	11	2							406	8,742
30 - 34		106	118	128	84	52	35	12	2							537	12,195
35 - 39		98	111	129	78	24	30	14								484	11,791
40 - 44		74	79	72	40	20	24	7		3						317	10,020
45 - 49		63	56	59	33	14	11	6	2							244	8,417
50 - 54		51	42	42	24	23	12	2	2							197	7,064
55 - 59		47	46	39	20	26	17	3	4							203	6,629
60 - 64		27	24	21	8	6	9	2	2							98	4,151
≥65 or unspecified		17	8	8	3		1	2								38	2,354
Total Person-rem	0	588	598	619	359	205	164	59	15	3	0	0	0	0	0	2,610	
Total Persons	45,440	22,735	3,820	1,781	595	239	140	36	7	1	0	0	0	0	0		74,794

TABLE D.44
Distribution of Collective Beta-Gamma Doses by Age and Dose-Equivalent Range
1988 - Female

Age Range	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19																1	134
20 - 24		6	5	3	1			2								17	1,078
25 - 29		16	17	15	4	1	3									57	2,357
30 - 34		20	20	23	10	2	1									77	2,912
35 - 39		15	15	16	11	2	1									60	2,463
40 - 44		12	9	13	2	1	2									40	1,905
45 - 49		9	5	3	4	3	2									27	1,416
50 - 54		6	4	3	2		1									16	965
55 - 59		4	2	1	2	2										10	648
60 - 64		2	2		1											5	355
≥65 or unspecified		3	1													3	296
Total Person-rem	0	93	80	78	38	11	11	2	0	0	0	0	0	0	0	312	
Total Persons	9,891	3,821	505	226	62	13	10	1	0	0	0	0	0	0	0		14,529

TABLE D.45
Distribution of Collective Beta-Gamma Doses by Age and Dose-Equivalent Range
1988 - Unknown Sex

Age Category	Collective Dose Equivalent in each Dose-Equivalent Range (rem)															Total Person-rem	Total Persons
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
20 - 24																	1
25 - 29																	7
30 - 34																	7
35 - 39																	10
40 - 44																	6
45 - 49																	8
50 - 54																	14
55 - 59																	7
60 - 64																	6
≥65 or unspecified		33	13	10	10	3	2	2	2							75	3,083
Total Person-rem	0	34	13	10	10	3	2	2	2	0	0	0	0	0	0	75	
Total Persons	1,347	1,666	84	27	18	3	2	1	1	0	0	0	0	0	0		3,149

TABLE D.46
Distribution of (Penetrating) Beta-Gamma Doses by Occupation and Dose-Equivalent Range
1988 - Male

Occupation	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	11,002	4,599	676	330	141	56	40	9								16,853	541
Management	4,285	1,768	210	45	8	3				1						6,320	100
Scientists	13,420	4,487	460	167	37	22	14	5	1							18,613	298
Technicians	4,058	2,063	666	326	111	43	23	11	2							7,303	438
Service	2,581	1,402	44	17			1									4,045	41
Agriculture	60	43	2													105	1
Construction	3,820	3,016	705	306	117	58	38	7	3							8,070	490
Production	1,939	1,905	657	455	162	50	16	3	1							5,188	490
Transportation	1,365	574	53	20	2	2	8									2,034	42
Laborers	603	563	172	53	7											1,398	68
Miscellaneous	2,307	2,315	165	62	10	5		1								4,865	101
Total Persons	45,440	22,735	3,820	1,781	595	239	140	36	7	1	0	0	0	0	0	74,794	
Total Person-rem	0	588	598	619	359	205	164	59	15	3	0	0	0	0	0		2,610

TABLE D.47
Distribution of (Penetrating) Beta-Gamma Doses by Occupation and Dose-Equivalent Range
1988 - Female

Occupation	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	2,258	1,072	68	44	16	5	3	1								3,467	69
Management	2,851	479	34	10	1		1									3,376	21
Scientists	1,992	574	46	14	5											2,631	27
Technicians	979	484	154	60	19	1	1									1,698	73
Service	760	282	6	2			1									1,051	8
Agriculture	2	5														7	
Construction	240	212	37	9	2											500	16
Production	353	387	123	78	18	7	4									970	82
Transportation	51	22	3	1												77	1
Laborers	91	97	25	3												216	8
Miscellaneous	314	207	9	5	1											536	7
Total Persons	9,891	3,821	505	226	62	13	10	1	0	0	0	0	0	0	0	14,529	
Total Person-rem	0	93	80	78	38	11	11	2	0	0	0	0	0	0	0		312

TABLE D.48
Distribution of (Penetrating) Beta-Gamma Doses by Occupation and Dose-Equivalent Range
1988 - Unknown Sex

Occupation	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	1,319	1,542	82	25	17	2	2	1								2,990	68
Management		4														4	
Scientists	5	8														13	
Technicians	2	61		2	1	1			1							68	6
Service		30														30	
Construction	2	1	2													5	
Production		1														1	
Transportation	19	15														34	
Laborers		1														1	
Miscellaneous		3														3	
Total Persons	1,347	1,666	84	27	18	3	2	1	1	0	0	0	0	0	0	3,149	
Total Person-rem	0	34	13	10	10	3	2	2	2	0	0	0	0	0	0		75

TABLE D.49
Distribution of Shallow Doses by Facility Type and Dose-Equivalent Range
1988 - Male

Facility Type	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	3,148	1,464	225	82	41	18	18	7	4		1					5,008	190
Fuel/Uran. Enrichment	1,894	1,491	119	47	14	2	2				1				1	3,571	97
Fuel Fabrication	1,582	1,368	275	156	93	73	88	33	25	16	15	11	6	3	3	3,747	672
Fuel Processing	1,009	801	313	255	124	74	75	33	12	8	5	5	2	2	2	2,720	568
Maint. and Support	8,658	6,107	1,122	451	138	65	30	16	6	4	1		1			16,599	760
Reactor	1,157	3,183	671	272	101	45	32	8	5		2				1	5,477	460
Research, General	6,796	3,549	587	273	108	52	39	14	2			1				11,421	471
Research, Fusion	1,420	179	7			1										1,607	7
Waste Proc./Management	1,616	1,160	307	146	69	58	40	10	7	2	1	1	1	1		3,419	327
Weapons Fab. & Test.	4,496	3,847	994	642	256	142	219	78	38	15	11	7	2		3	10,750	1,399
Other	6,917	3,134	280	75	17	13	20	12	1	4	1			1		10,475	240
Total Persons	38,693	26,283	4,900	2,399	961	543	563	211	100	49	38	25	12	7	10	74,794	
Total Person-rem	0	783	759	837	584	468	682	363	222	134	122	93	51	33	62		5,192

TABLE D.50
Distribution of Shallow Doses by Facility Type and Dose-Equivalent Range
1988 - Female

Facility Type	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	378	127	12		3	1	1									522	9
Fuel/Uran. Enrichment	418	255	20	5												698	12
Fuel Fabrication	314	258	54	30	17	10	8	3	3	2		1				700	78
Fuel Processing	293	183	66	45	13	8	4	1								613	55
Maint. and Support	2,417	1,154	159	79	22	13	6	1								3,851	121
Reactor	183	246	62	20	3	1		1								516	28
Research, General	1,605	493	55	40	9	3	4									2,209	49
Research, Fusion	160	4														164	
Waste Proc./Management	304	256	77	24	7	3	1	1								673	39
Weapons Fab. & Test.	1,056	1,022	160	84	46	30	30	5	5	1	1					2,440	198
Other	1,378	710	34	10	2	5	2		1						1	2,143	42
Total Persons	8,506	4,708	699	337	122	74	56	12	9	3	1	1	0	0	1	14,529	
Total Person-rem	0	139	108	116	75	64	68	21	20	8	3	4	0	0	5		631

TABLE D.51
Distribution of Shallow Doses by Facility Type and Dose-Equivalent Range
1988 - Unknown Sex

Facility Type	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	4	32			1				1							38	4
Fuel Fabrication		32	2													34	1
Fuel Processing		120	10	5	4	1	4									144	14
Maint. and Support		13		2												15	1
Reactor		47	12	3	3	2	1									68	8
Research, General		72	5	3	1		1									82	5
Research, Fusion		2														2	
Waste Proc./Management		24	1	1												26	1
Weapons Fab. & Test.	1	173	40	10	3		1	1								229	22
Other	302	2,137	51	7	5	1	4	4								2,511	70
Total Persons	307	2,652	121	31	17	4	11	5	1	0	0	0	0	0	0	3,149	
Total Person-rem	0	61	17	11	10	4	13	8	2	0	0	0	0	0	0		127

TABLE D.52
Distribution of Shallow Doses by Age and Dose-Equivalent Range
1988 - Male

Age Range	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	210	82	8	1		1										302	4
20 - 24	1,550	1,222	221	76	33	18	3	3		2					1	3,129	148
25 - 29	3,893	3,414	704	343	141	83	89	40	18	13	1	1		1	1	8,742	760
30 - 34	5,809	4,475	898	464	197	128	138	39	18	5	14	5	2	1	2	12,195	1,050
35 - 39	5,819	4,132	901	456	194	100	106	33	17	10	11	4	2	4	2	11,791	975
40 - 44	5,413	3,369	634	287	131	60	72	26	13	3	6	4	1		1	10,020	638
45 - 49	4,732	2,740	453	265	88	45	40	25	16	4	2	4	3			8,417	507
50 - 54	4,055	2,277	383	169	80	38	38	10	5	5		3			1	7,064	372
55 - 59	3,585	2,296	375	181	64	43	43	21	8	4	2	1	3	1	2	6,629	425
60 - 64	2,377	1,321	233	118	25	23	30	12	3	3	2	3	1			4,151	244
≥65 or unspecified	1,250	955	90	39	8	4	4	2	2							2,354	69
Total Persons	38,693	26,283	4,900	2,399	961	543	563	211	100	49	38	25	12	7	10	74,794	
Total Person-rem	0	783	759	837	584	468	682	363	222	134	122	93	51	33	62		5,192

TABLE D.53
Distribution of Shallow Doses by Age and Dose-Equivalent Range
1988 - Female

Age Range	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	107	25	2													134	1
20 - 24	644	375	38	11	4	2	2	1							1	1,078	35
25 - 29	1,286	820	134	75	17	13	10	1				1				2,357	110
30 - 34	1,609	956	184	88	36	18	15	4	1	1						2,912	155
35 - 39	1,392	818	127	70	26	16	7	2	4	1						2,463	120
40 - 44	1,146	586	84	42	17	13	11	3	2	1						1,905	94
45 - 49	915	403	56	19	10	5	5	1	2							1,416	50
50 - 54	622	278	40	12	7	3	3									965	29
55 - 59	427	185	18	10	3	2	2				1					648	21
60 - 64	242	90	11	8	2	2										355	9
≥65 or unspecified	116	172	5	2			1									296	6
Total Persons	8,506	4,708	699	337	122	74	56	12	9	3	1	1	0	0	1	14,529	
Total Person-rem	0	139	108	116	75	64	68	21	20	8	3	4	0	0	5		631

TABLE D.54
Distribution of Shallow Doses by Age and Dose-Equivalent Range
1988 - Unknown Sex

Age Range	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
20 - 24		1														1	
25 - 29		7														7	
30 - 34		7														7	
35 - 39	2	8														10	
40 - 44	1	5														6	
45 - 49	4	4														8	
50 - 54	1	12	1													14	1
55 - 59	1	6														7	
60 - 64		6														6	
≥65 or unspecified	298	2,596	120	31	17	4	11	5	1							3,083	125
Total Persons	307	2,652	121	31	17	4	11	5	1	0	0	0	0	0	0	3,149	
Total Person-rem	0	61	17	11	10	4	13	8	2	0	0	0	0	0	0		127

TABLE D.55
Distribution of Shallow Doses by Occupation and Dose-Equivalent Range
1988 - Male

Occupation	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10-0.25	0.25-0.50	0.50-0.75	0.75-1.00	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	4.0-4.5	4.5-5.0	>=5		
Unknown	9,839	5,204	824	435	200	104	121	58	27	15	13	6	3	1	3	16,853	1,100
Management	3,882	1,996	254	116	32	22	14	2	1		1					6,320	196
Scientists	11,342	6,178	659	245	75	38	43	13	9	5	4		1	1		18,613	558
Technicians	3,622	2,156	748	425	179	86	58	17	8	1	3					7,303	650
Service	2,029	1,855	117	29	5	2	3	2	2			1				4,045	98
Agriculture	51	51	1	2												105	2
Construction	2,707	3,524	991	475	162	99	57	23	12	6	1	7	1	2	3	8,070	831
Production	1,389	1,806	706	441	261	164	246	84	35	20	15	10	5	3	3	5,188	1,357
Transportation	1,235	644	90	34	9	6	7	7	2							2,034	81
Laborers	527	525	216	96	16	9	3		1	2	1		1		1	1,398	126
Miscellaneous	2,070	2,344	294	101	22	13	11	5	3			1	1			4,865	195
Total Persons	38,693	26,283	4,900	2,399	961	543	563	211	100	49	38	25	12	7	10	74,794	
Total Person-rem	0	783	759	837	584	468	682	363	222	134	122	93	51	33	62		5,192

TABLE D.56
Distribution of Shallow Doses by Age and Dose-Equivalent Range
1988 - Female

Occupation 4X	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	2,079	1,178	88	65	28	14	6	3	3	1	1				1	3,467	127
Management	2,681	599	49	25	11	6	3	2								3,376	50
Scientists	1,684	831	82	24	7	2	1									2,631	51
Technicians	790	579	160	107	35	17	7	3								1,698	132
Service	557	458	29	4	1	1	1									1,051	21
Agriculture	2	5														7	
Construction	113	306	61	15	3	2										500	29
Production	209	405	161	84	32	29	38	4	6	1		1				970	188
Transportation	38	33	5	1												77	2
Laborers	75	91	38	7	2	2				1						216	17
Miscellaneous	278	223	26	5	3	1										536	13
Total Persons	8,506	4,708	699	337	122	74	56	12	9	3	1	1	0	0	1	14,529	
Total Person-rem	0	139	108	116	75	64	68	21	20	8	3	4	0	0	5		631

TABLE D.57
Distribution of Shallow Doses by Age and Dose-Equivalent Range
1988 - Unknown Sex

Occupation	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	303	2,508	115	30	15	3	11	5								2,990	118
Management		4														4	
Scientists	2	11														13	
Technicians		61	2	1	2	1			1							68	7
Service		30														30	
Construction	2	1	2													5	
Production		1														1	
Transportation		32	2													34	1
Laborers		1														1	
Miscellaneous		3														3	
Total Persons	307	2,652	121	31	17	4	11	5	1	0	0	0	0	0	0	3,149	
Total Person-rem	0	61	17	11	10	4	13	8	2	0	0	0	0	0	0		127

APPENDIX E

1987 EXPOSURE DATA BY DOSE RANGE, EXPOSURE TYPE, FACILITY TYPE, AGE, SEX, AND OCCUPATION FOR DOE AND DOE CONTRACTOR EMPLOYEES AND VISITORS[a]

(a) Not including visitors who were reported to have been monitored and received no measurable dose, but for whom no further information was supplied.

TABLE E.1
Distribution of Penetrating Doses by Facility Type and Dose-Equivalent Range
1987 - Male

Facility Type	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	2,052	1,686	239	83	28	16	19	9	1							4,133	184
Fuel/Uran. Enrichment	2,027	1,072	61	17	2	1	1									3,181	39
Fuel Fabrication	1,743	1,089	313	254	80	13	3	1	1	2						3,499	245
Fuel Processing	1,690	773	273	182	89	75	72	16	4							3,174	375
Maint. and Support	7,997	5,021	826	387	181	109	164	141	69	48	14	11				14,968	1,428
Reactor	1,690	3,218	654	284	170	126	168	107	61	26	9	3				6,516	1,131
Research, General	13,035	3,562	629	348	118	101	92	46	14	1	1					17,947	686
Research, Fusion	1,189	194	19	1	1											1,404	9
Waste Proc./Management	1,240	992	284	168	91	67	77	44	9	3						2,975	440
Weapons Fab. & Test.	4,442	3,149	928	409	162	83	123	85	17	2						9,400	892
Other	4,285	3,121	270	140	37	23	9	11	3	1						7,900	249
Total Persons	41,390	23,877	4,496	2,273	959	614	728	460	179	83	24	14	0	0	0	75,097	
Total Person-rem	0	642	702	797	579	530	892	787	397	223	77	51	0	0	0		5,678

TABLE E.2
Distribution of Penetrating Doses by Facility Type and Dose-Equivalent Range
1987 - Female

Facility Type	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	259	146	18	5	1											429	9
Fuel/Uran. Enrichment	371	205	8													584	5
Fuel Fabrication	389	219	48	47	10	2	2									717	39
Fuel Processing	361	138	36	19	14	7	17	1								593	55
Maint. and Support	2,211	971	128	79	24	5	6	1	4	2						3,431	113
Reactor	328	266	51	24	11	4	12	5	2							703	61
Research, General	3,726	504	47	32	9	11	20	8	6	5						4,368	110
Research, Fusion	138	5														143	
Waste Proc./Management	239	206	58	12	12	4	12	3								546	49
Weapons Fab. & Test.	1,143	839	132	63	33	15	26	13	3							2,267	157
Other	871	482	20	8	3											1,384	18
Total Persons	10,036	3,981	546	289	117	48	95	31	15	7	0	0	0	0	0	15,165	
Total Person-rem	0	99	84	101	72	41	115	53	33	19	0	0	0	0	0		617

TABLE E.3
Distribution of Penetrating Doses by Facility Type and Dose-Equivalent Range
1987 - Unknown Sex

Facility Type	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	2	1														3	
Fuel Fabrication	76	5														81	
Fuel Processing	42	2														44	
Research, General	155	47	10	1												213	4
Waste Proc./Management	1	1														2	
Weapons Fab. & Test.			15	4	2	1		1		1						24	11
Other	517	946	55	8	5	3	5									1,539	44
Total Persons	793	1,002	80	13	7	4	5	1	0	1	0	0	0	0	0	1,906	
Total Person-rem	0	24	12	4	4	4	6	2	0	3	0	0	0	0	0		59

TABLE E.4
Distribution of Penetrating Doses by Age and Dose-Equivalent Range
1987 - Male

Age Range	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	160	68	4	1	1		1									235	5
20 - 24	1,693	1,103	180	96	35	32	26	16	6	3						3,190	221
25 - 29	4,168	3,154	630	343	159	123	134	91	25	11	6					8,844	933
30 - 34	5,965	3,874	837	459	210	124	173	112	46	17	7	3				11,827	1,222
35 - 39	6,152	3,679	816	415	173	100	138	77	39	15	3	5				11,612	1,023
40 - 44	5,427	2,918	571	262	113	80	86	52	14	16	1	1				9,541	673
45 - 49	4,712	2,434	427	201	70	47	55	34	21	5	5	1				8,012	492
50 - 54	4,122	2,074	352	166	77	38	46	40	10	7	2	3				6,937	428
55 - 59	4,045	2,046	391	182	84	46	42	28	13	7		1				6,885	419
60 - 64	2,654	1,197	213	106	30	20	19	10	4	2						4,255	191
≥65 or unspecified	2,292	1,330	75	42	7	4	8		1							3,759	71
Total Persons	41,390	23,877	4,496	2,273	959	614	728	460	179	83	24	14	0	0	0	75,097	
Total Person-rem	0	642	702	797	579	530	892	787	397	223	77	51	0	0	0		5,678

TABLE E.5
Distribution of Penetrating Doses by Age and Dose-Equivalent Range
1987 - Female

Age Range	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	77	23	1													101	1
20 - 24	810	306	35	17	5	1	2	3	2	1						1,182	37
25 - 29	1,584	724	128	71	26	5	21	8	2	2						2,571	133
30 - 34	1,905	793	138	66	34	11	27	7	1	2						2,984	147
35 - 39	1,643	667	99	57	25	13	16	4	2	1						2,527	113
40 - 44	1,305	456	55	36	15	10	13	4	1							1,895	76
45 - 49	1,015	335	41	16	7	4	6	2	1	1						1,428	44
50 - 54	705	261	20	12	1	1	4	1	1							1,006	23
55 - 59	488	155	16	8	3		3		4							677	24
60 - 64	263	77	11	4	1	1	3	2	1							363	15
≥65 or unspecified	241	184	2	2		2										431	6
Total Persons	10,036	3,981	546	289	117	48	95	31	15	7	0	0	0	0	0	15,165	
Total Person-rem	0	99	84	101	72	41	115	53	33	19	0	0	0	0	0		617

TABLE E.6
Distribution of Penetrating Doses by Age and Dose-Equivalent Range
1987 - Unknown Sex

Age Range	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
20 - 24	1															1	
25 - 29	6	1														7	
30 - 34	5															5	
35 - 39	9	1	1													11	
40 - 44	2															2	
45 - 49	12	1														13	
50 - 54	5	1														6	
55 - 59	6	1														7	
60 - 64	3															3	
≥65 or unspecified	744	997	79	13	7	4	5	1		1						1,851	58
Total Persons	793	1,002	80	13	7	4	5	1	0	1	0	0	0	0	0	1,906	
Total Person-rem	0	24	12	4	4	4	6	2	0	3	0	0	0	0	0		59

TABLE E.7
Distribution of Penetrating Doses by Occupation and Dose-Equivalent Range
1987 - Male

Occupation	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	≤ Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	12,960	5,528	1,092	520	160	121	111	45	14		1					20,552	941
Management	3,436	2,145	251	107	55	34	23	9	4	3						6,067	249
Scientists	11,128	5,278	534	184	73	48	49	13	4	4						17,315	458
Technicians	3,309	2,057	650	377	164	99	80	63	26	11	9	3				6,848	818
Service	1,976	1,663	97	22	8	4	2	4	3							3,779	82
Agriculture	83	25	1													109	1
Construction	3,143	3,043	793	369	190	125	204	168	102	58	14	11				8,220	1,585
Production	1,659	1,660	650	520	226	136	218	130	26	7						5,232	1,167
Transportation	1,376	563	79	35	6	5	6	7								2,077	66
Laborers	701	469	159	65	13	5	5	4								1,421	89
Miscellaneous	1,619	1,446	190	74	64	37	30	17								3,477	220
Total Persons	41,390	23,877	4,496	2,273	959	614	728	460	179	83	24	14	0	0	0	75,097	
Total Person-rem	0	642	702	797	579	530	892	787	397	223	77	51	0	0	0		5,678

TABLE E.8
Distribution of Penetrating Doses by Occupation and Dose-Equivalent Range
1987 - Female

Occupation	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	3,586	1,164	102	47	16	11	22	8	6	5						4,967	143
Management	2,616	555	48	10	2	3	1	1	1							3,237	32
Scientists	1,587	639	45	27	4	3	5									2,310	41
Technicians	798	463	146	102	37	9	14	2	4							1,575	133
Service	587	350	20	3	1											961	12
Agriculture	5	2														7	
Construction	207	216	39	10	7	3	3	1		2						488	33
Production	264	345	109	77	45	19	50	18	4							931	201
Transportation	100	35	1	2												138	2
Laborers	67	84	26	8												185	9
Miscellaneous	219	128	10	3	5			1								366	10
Total Persons	10,036	3,981	546	289	117	48	95	31	15	7	0	0	0	0	0	15,165	
Total Person-rem	0	99	84	101	72	41	115	53	33	19	0	0	0	0	0		617

TABLE E.9
Distribution of Penetrating Doses by Occupation and Dose-Equivalent Range
1987 - Unknown Sex

Occupation	Number of Persons Receiving Penetrating Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	668	950	71	13	7	4	5	1		1						1,720	56
Scientists	5															5	
Technicians	3															3	
Construction	6	1														7	
Transportation	76	5														81	
Miscellaneous	35	46	9													90	3
Total Persons	793	1,002	80	13	7	4	5	1	0	1	0	0	0	0	0	1,906	
Total Person-rem	0	24	12	4	4	4	6	2	0	3	0	0	0	0	0		59

TABLE E.10
Distribution of Penetrating Doses by Facility Type and Occupation
1987 - Male

Facility Type	Number of Persons Receiving Penetrating Doses in each Occupation Category											Total Persons	Total Person-rem
	Unknown	Management	Science	Technician	Service	Agriculture	Construction	Production	Transportation	Laborer	Miscellaneous		
Accelerator	669	241	1,799	1,057	156	16	65	75	33	21	1	4,133	184
Fuel/Uran. Enrichment	409	248	723	313	232	1	626	416	28	171	14	3,181	39
Fuel Fabrication	28	403	583	125	56		384	710	687	32	491	3,499	245
Fuel Processing	1,536	42	427	33	16	2	413	317	10	5	373	3,174	375
Maint. and Support	1,376	2,054	2,597	935	1,024	34	4,742	1,070	627	506	3	14,968	1,428
Reactor	1,348	667	1,587	544	97		627	379	46	17	1,204	6,516	1,131
Research, General	9,924	641	4,541	1,649	532	10	265	171	18	31	165	17,947	686
Research, Fusion	7	102	616	311	61		156	60		7	84	1,404	9
Waste Proc./Management	99	484	864	399	24		536	480	81	8		2,975	440
Weapons Fab. & Test.	1,177	915	2,583	1,225	310		331	1,498	110	110	1,141	9,400	892
Other	3,979	270	995	257	1,271	46	75	56	437	513	1	7,900	249
Total Persons	20,552	6,067	17,315	6,848	3,779	109	8,220	5,232	2,077	1,421	3,477	75,097	
Total Person-rem	941	249	458	818	82	1	1,585	1,167	66	89	220		5,678

TABLE E.11
Distribution of Penetrating Doses by Facility Type and Occupation
1987 - Female

Facility Type	Number of Persons Receiving Penetrating Doses in each Occupation Category											Total Persons	Total Person-rem
	Unknown	Management	Science	Technician	Service	Agriculture	Construc-tion	Production	Transpor-tation	Laborer	Miscella-neous		
Accelerator	90	52	133	106	37	1	4	4		2		429	9
Fuel/Uran. Enrichment	77	254	70	58	50		9	41		25		584	5
Fuel Fabrication		242	101	78	18		32	142	75	13	16	717	39
Fuel Processing	347	12	44	9	7		30	128			16	593	55
Maint. and Support	413	1,347	472	417	212	1	322	101	44	102		3,431	113
Reactor	267	82	115	77	15		43	65			39	703	61
Research, General	2,797	323	666	443	88	1	7	21	3	5	14	4,368	110
Research, Fusion	1	65	39	27	8		1				2	143	
Waste Proc./Management	15	120	110	104	48		25	123	1			546	49
Weapons Fab. & Test.	358	614	391	222	76		12	295	2	19	278	2,267	157
Other	602	126	169	34	402	4	3	11	13	19	1	1,384	18
Total Persons	4,967	3,237	2,310	1,575	961	7	488	931	138	185	366	15,165	
Total Person-rem	143	32	41	133	12	0	33	201	2	9	10		617

TABLE E.12
Distribution of Penetrating Doses by Facility Type and Occupation
1987 - Unknown Sex

Facility Type	Number of Persons Receiving Penetrating Doses in each Occupation Category											Total Persons	Total Person-rem
	Unknown	Management	Science	Technician	Service	Agriculture	Construction	Production	Transportation	Laborer	Miscellaneous		
Accelerator			2				1					3	
Fuel Fabrication									81			81	
Fuel Processing			2				5				37	44	
Research, General	157			3							53	213	4
Waste Proc./Management	1						1					2	
Weapons Fab. & Test.	24											24	11
Other	1,538		1									1,539	44
Total Persons	1,720	0	5	3	0	0	7	0	81	0	90	1,906	
Total Person-rem	56	0	0	0	0	0	0	0	0	0	3		59

TABLE E.13
Distribution of (Penetrating) Neutron Doses by Facility Type and Dose-Equivalent Range
1987 - Male

Facility Type	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	3,638	441	34	17	2		1									4,133	25
Fuel/Uran. Enrichment	3,178	1	2													3,181	
Fuel Fabrication	3,471	17	4	3	3	1										3,499	5
Fuel Processing	2,953	62	43	47	37	25	7									3,174	79
Maint. and Support	14,053	654	145	70	28	9	6	2	1							14,968	104
Reactor	6,365	116	19	14	2											6,516	12
Research, General	16,780	774	170	85	46	39	41	11	1							17,947	210
Research, Fusion	1,400	4														1,404	
Waste Proc./Management	2,623	182	80	56	26	4	4									2,975	63
Weapons Fab. & Test.	7,374	1,350	335	156	92	64	28	1								9,400	294
Other	7,733	141	26													7,900	8
Total Persons	69,568	3,742	858	448	236	142	87	14	2	0	0	0	0	0	0	75,097	
Total Person-rem	0	111	134	158	145	122	101	23	5	0	0	0	0	0	0		799

TABLE E.14
Distribution of (Penetrating) Neutron Doses by Facility Type and Dose-Equivalent Range
1987 - Female

Facility Type	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	398	30	1													429	1
Fuel/Uran. Enrichment	584															584	
Fuel Fabrication	715	1		1												717	
Fuel Processing	535	9	17	14	8	6	4									593	23
Maint. and Support	3,278	98	32	12	7		2	1	1							3,431	24
Reactor	693	8	1	1												703	1
Research, General	4,210	93	13	11	9	12	9	9	2							4,368	56
Research, Fusion	143															143	
Waste Proc./Management	491	35	6	8	4	1	1									546	9
Weapons Fab. & Test.	1,921	227	53	28	21	13	4									2,267	54
Other	1,361	22	1													1,384	1
Total Persons	14,329	523	124	75	49	32	20	10	3	0	0	0	0	0	0	15,165	
Total Person-rem	0	16	20	27	31	28	23	17	7	0	0	0	0	0	0		169

TABLE E.15
Distribution of (Penetrating) Neutron Doses by Facility Type and Dose-Equivalent Range
1987 - Unknown Sex

Facility Type	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	3															3	
Fuel Fabrication	81															81	
Fuel Processing	44															44	
Research, General	179	32	2													213	1
Waste Proc./Management	2															2	
Weapons Fab. & Test.	24															24	
Other	1,483	50	5	1												1,539	3
Total Persons	1,816	82	7	1	0	0	0	0	0	0	0	0	0	0	0	1,906	
Total Person-rem	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0		4

TABLE E.16
Distribution of (Penetrating) Neutron Doses by Age and Dose-Equivalent Range
1987 - Male

Age Range	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	230	5														235	
20 - 24	2,978	135	28	22	16	6	4	1								3,190	38
25 - 29	8,028	486	130	78	51	45	23	3								8,844	163
30 - 34	10,866	592	152	102	60	35	17	2	1							11,827	173
35 - 39	10,680	638	126	79	48	23	15	3								11,612	138
40 - 44	8,851	490	111	46	21	12	8	2								9,541	83
45 - 49	7,425	427	86	43	13	9	7	2								8,012	68
50 - 54	6,424	376	89	32	9	2	4		1							6,937	51
55 - 59	6,444	309	86	26	9	7	4									6,885	46
60 - 64	4,022	177	31	12	8	2	2	1								4,255	25
≥65 or unspecified	3,620	107	19	8	1	1	3									3,759	13
Total Persons	69,568	3,742	858	448	236	142	87	14	2	0	0	0	0	0	0	75,097	
Total Person-rem	0	111	134	158	145	122	101	23	5	0	0	0	0	0	0		799

TABLE E.17
Distribution of (Penetrating) Neutron Doses by Age and Dose-Equivalent Range
1987 - Female

Age Range	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	99	1	1													101	
20 - 24	1,144	25	4	3	2	1	1	1	1							1,182	10
25 - 29	2,407	100	26	17	11	7	2	1								2,571	31
30 - 34	2,802	99	29	27	11	10	5		1							2,984	41
35 - 39	2,351	113	29	14	12	5	2	1								2,527	29
40 - 44	1,789	68	17	4	10	3	4									1,895	21
45 - 49	1,358	46	11	4	2	4	2	1								1,428	13
50 - 54	964	32	1	5			3	1								1,006	8
55 - 59	647	24	2					3	1							677	8
60 - 64	346	8	4	1		1	1	2								363	6
≥65 or unspecified	422	7			1	1										431	2
Total Persons	14,329	523	124	75	49	32	20	10	3	0	0	0	0	0	0	15,165	
Total Person-rem	0	16	20	27	31	28	23	17	7	0	0	0	0	0	0		169

TABLE E.18
Distribution of (Penetrating) Neutron Doses by Age and Dose-Equivalent Range
1987 - Unknown Sex

Age Range	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
20 - 24	1															1	
25 - 29	7															7	
30 - 34	5															5	
35 - 39	10	1														11	
40 - 44	2															2	
45 - 49	13															13	
50 - 54	6															6	
55 - 59	7															7	
60 - 64	3															3	
≥65 or unspecified	1,762	81	7	1												1,851	4
Total Persons	1,816	82	7	1	0	0	0	0	0	0	0	0	0	0	0	1,906	
Total Person-rem	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0		4

TABLE E.19
Distribution of (Penetrating) Neutron Doses by Occupation and Dose-Equivalent Range
1987 - Male

Occupation	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	19,083	1,079	175	85	40	37	41	11	1							20,552	210
Management	5,702	270	47	29	16	2	1									6,067	38
Scientists	16,620	545	99	42	8	1										17,315	52
Technicians	6,036	544	164	55	36	7	4	1	1							6,848	98
Service	3,603	167	9													3,779	7
Agriculture	109															109	
Construction	7,584	396	146	70	17	7										8,220	78
Production	4,234	419	176	153	119	88	41	2								5,232	296
Transportation	2,044	16	10	7												2,077	4
Laborers	1,348	51	18	4												1,421	5
Miscellaneous	3,205	255	14	3												3,477	9
Total Persons	69,568	3,742	858	448	236	142	87	14	2	0	0	0	0	0	0	75,097	
Total Person-rem	0	111	134	158	145	122	101	23	5	0	0	0	0	0	0		799

TABLE E.20
Distribution of (Penetrating) Neutron Doses by Occupation and Dose-Equivalent Range
1987 - Female

Occupation	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	4,767	134	13	12	10	11	9	9	2							4,967	57
Management	3,151	72	8	5	1											3,237	5
Scientists	2,238	53	11	5	2	1										2,310	7
Technicians	1,385	118	44	19	5	1	1	1	1							1,575	27
Service	914	46	1													961	1
Agriculture	7															7	
Construction	463	20	4	1												488	2
Production	757	47	35	32	31	19	10									931	67
Transportation	138															138	
Laborers	171	6	8													185	2
Miscellaneous	338	27		1												366	1
Total Persons	14,329	523	124	75	49	32	20	10	3	0	0	0	0	0	0	15,165	
Total Person-rem	0	16	20	27	31	28	23	17	7	0	0	0	0	0	0		169

TABLE E.21
Distribution of (Penetrating) Neutron Doses by Occupation and Dose-Equivalent Range
1987 - Unknown Sex

Occupation	Number of Persons Receiving Neutron Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	1,663	51	5	1												1,720	3
Scientists	5															5	
Technicians	3															3	
Construction	7															7	
Transportation	81															81	
Miscellaneous	57	31	2													90	1
Total Persons	1,816	82	7	1	0	0	0	0	0	0	0	0	0	0	0	1,906	
Total Person-rem	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0		4

TABLE E.22
Distribution of (Penetrating) Beta-Gamma Doses by Facility Type and Dose-Equivalent Range
1987 - Male

Facility Type	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	2,275	1,501	228	67	23	15	15	8	1							4,133	159
Fuel/Uran. Enrichment	2,028	1,072	61	17	1	1	1									3,181	39
Fuel Fabrication	1,747	1,088	317	253	77	10	3	1	1	2						3,499	240
Fuel Processing	1,692	792	306	215	89	39	28	9	4							3,174	296
Maint. and Support	8,181	4,993	774	371	141	92	143	134	67	47	14	11				14,968	1,323
Reactor	1,700	3,217	651	286	172	122	162	108	60	26	9	3				6,516	1,119
Research, General	13,581	3,272	538	323	101	73	36	18	4	1						17,947	476
Research, Fusion	1,190	193	19	1	1											1,404	9
Waste Proc./Management	1,317	1,028	252	144	67	48	66	41	9	3						2,975	377
Weapons Fab. & Test.	4,483	3,374	877	391	147	61	55	10	2							9,400	598
Other	4,323	3,111	254	129	36	23	9	11	3	1						7,900	241
Total Persons	42,517	23,641	4,277	2,197	855	484	518	340	151	80	23	14	0	0	0	75,097	
Total Person-rem	0	623	666	772	512	417	632	580	336	215	74	51	0	0	0		4,879

TABLE E.23
Distribution of (Penetrating) Beta-Gamma Doses by Facility Type and Dose-Equivalent Range
1987 - Female

Facility Type	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	268	141	15	4	1											429	7
Fuel/Uran. Enrichment	371	205	8													584	5
Fuel Fabrication	389	220	48	46	10	2	2									717	39
Fuel Processing	362	142	44	32	8	3	2									593	32
Maint. and Support	2,231	982	133	63	13	2	4		1	2						3,431	89
Reactor	330	265	50	24	11	6	10	5	2							703	60
Research, General	3,797	461	49	34	12	8	5	1		1						4,368	54
Research, Fusion	138	5														143	
Waste Proc./Management	254	207	49	13	9	2	9	3								546	40
Weapons Fab. & Test.	1,149	868	130	64	37	11	6	2								2,267	104
Other	880	473	21	7	3											1,384	17
Total Persons	10,169	3,969	547	287	104	34	38	11	3	3	0	0	0	0	0	15,165	
Total Person-rem	0	96	85	98	62	29	45	18	6	8	0	0	0	0	0		448

TABLE E.24
Distribution of (Penetrating) Beta-Gamma Doses by Facility Type and Dose-Equivalent Range
1987 - Unknown Sex

Facility Type	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	2	1														3	
Fuel Fabrication	76	5														81	
Fuel Processing	42	2														44	
Research, General	164	45	3	1												213	2
Waste Proc./Management	1	1														2	
Weapons Fab. & Test.			15	4	2	1		1		1						24	11
Other	529	940	51	7	4	3	5									1,539	42
Total Persons	814	994	69	12	6	4	5	1	0	1	0	0	0	0	0	1,986	
Total Person-rem	0	22	10	4	4	4	6	2	0	3	0	0	0	0	0		55

TABLE E.25
Distribution of (Penetrating) Beta-Gamma Doses by Age and Dose-Equivalent Range
1987 - Male

Age Range	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	165	63	4	1	1		1									235	4
20 - 24	1,741	1,089	174	102	32	17	15	13	4	3						3,190	184
25 - 29	4,310	3,136	622	358	158	83	80	58	22	11	6					8,844	770
30 - 34	6,139	3,855	822	448	194	102	119	83	39	17	6	3				11,827	1,049
35 - 39	6,342	3,643	782	396	149	87	102	57	31	15	3	5				11,612	885
40 - 44	5,566	2,877	539	253	103	68	68	39	12	14	1	1				9,541	590
45 - 49	4,829	2,416	389	189	53	37	43	29	16	5	5	1				8,012	424
50 - 54	4,235	2,035	331	149	61	37	37	31	10	6	2	3				6,937	377
55 - 59	4,132	2,050	347	169	74	36	33	23	13	7		1				6,885	373
60 - 64	2,707	1,180	202	99	25	13	17	7	3	2						4,255	166
≥65 or unspecified	2,351	1,297	65	33	5	4	3		1							3,759	57
Total Persons	42,517	23,641	4,277	2,197	855	484	518	340	151	80	23	14	0	0	0	75,097	
Total Person-rem	0	623	666	772	512	417	632	580	336	215	74	51	0	0	0		4,879

TABLE E.26
Distribution of (Penetrating) Beta-Gamma Doses by Age and Dose-Equivalent Range
1987 - Female

Age Range	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	77	24														101	
20 - 24	820	300	39	14	5	1	1	1	1							1,182	27
25 - 29	1,600	722	131	60	22	7	6	4	1	2						2,571	101
30 - 34	1,935	798	134	70	25	8	11	1	1	1						2,984	106
35 - 39	1,671	665	100	53	21	7	8	2								2,527	84
40 - 44	1,319	453	55	42	16	4	4	2								1,895	55
45 - 49	1,026	338	34	15	7	4	4									1,428	31
50 - 54	712	258	21	11	2	1	1									1,006	15
55 - 59	494	151	15	9	4	2	2									677	15
60 - 64	265	76	15	3	2		1	1								363	9
≥65 or unspecified	242	104	3	2												431	4
Total Persons	10,169	3,969	547	287	104	34	38	11	3	3	0	0	0	0	0	15,165	
Total Person-rem	0	96	85	98	62	29	45	18	6	8	0	0	0	0	0		448

TABLE E.27
Distribution of (Penetrating) Beta-Gamma Doses by Age and Dose-Equivalent Range
1987 - Unknown Sex

Age Range	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
20 - 24	1															1	
25 - 29	6	1														7	
30 - 34	5															5	
35 - 39	10		1													11	
40 - 44	2															2	
45 - 49	12	1														13	
50 - 54	5	1														6	
55 - 59	6	1														7	
60 - 64	3															3	
≥65 or unspecified	764	990	68	12	6	4	5	1		1						1,851	54
Total Persons	814	994	69	12	6	4	5	1	0	1	0	0	0	0	0	1,906	
Total Person-rem	0	22	10	4	4	4	6	2	0	3	0	0	0	0	0		55

TABLE E.28
Distribution of (Penetrating) Beta-Gamma Doses by Occupation and Dose-Equivalent Range
1987 - Male

Occupation	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	≤ Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	13,621	5,113	1,007	492	142	103	53	17	4							20,552	731
Management	3,507	2,131	248	93	32	23	17	9	4	3						6,067	211
Scientists	11,299	5,234	467	155	62	36	41	13	4	4						17,315	405
Technicians	3,370	2,104	652	370	125	61	63	58	24	9	9	3				6,848	720
Service	2,059	1,591	90	21	5	4	2	4	3							3,779	75
Agriculture	83	25	1													109	1
Construction	3,183	3,170	758	302	156	105	194	167	102	58	14	11				8,220	1,507
Production	1,680	1,756	662	599	257	109	109	44	10	6						5,232	871
Transportation	1,379	562	81	38	4	2	4	7								2,077	62
Laborers	703	477	162	53	12	5	5	4								1,421	84
Miscellaneous	1,633	1,478	149	74	60	36	30	17								3,477	212
Total Persons	42,517	23,641	4,277	2,197	855	484	518	340	151	80	23	14	0	0	0	75,097	
Total Person-rem	0	623	666	772	512	417	632	580	336	215	74	51	0	0	0		4,879

TABLE E.29
Distribution of (Penetrating) Beta-Gamma Doses by Occupation and Dose-Equivalent Range
1987 - Female

Occupation	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	3,654	1,125	102	50	18	10	6	1		1						4,967	86
Management	2,635	553	39	4	1	2	1	1	1							3,237	27
Scientists	1,597	643	43	17	5	2	3									2,310	34
Technicians	810	482	152	92	22	3	10	2	2							1,575	106
Service	604	336	19	1	1											961	11
Agriculture	5	2														7	
Construction	212	221	30	10	6	3	3	1		2						488	31
Production	266	353	126	105	47	14	15	5								931	134
Transportation	100	35	1	2												138	2
Laborers	67	91	24	3												185	8
Miscellaneous	219	128	11	3	4			1								366	9
Total Persons	10,169	3,969	547	287	104	34	38	11	3	3	0	0	0	0	0	15,165	
Total Person-rem	0	96	85	98	62	29	45	18	6	8	0	0	0	0	0		448

TABLE E.30
Distribution of (Penetrating) Beta-Gamma Doses by Occupation and Dose-Equivalent Range
1987 - Unknown Sex

Occupation	Number of Persons Receiving Beta-Gamma Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	681	943	67	12	6	4	5	1		1						1,720	53
Scientists	5															5	
Technicians	3															3	
Construction	6	1														7	
Transportation	76	5														81	
Miscellaneous	43	45	2													90	2
Total Persons	814	994	69	12	6	4	5	1	0	1	0	0	0	0	0	1,906	
Total Person-rem	0	22	10	4	4	4	6	2	0	3	0	0	0	0	0		55

TABLE E.31
Distribution of Shallow Doses by Facility Type and Dose-Equivalent Range
1987 - Male

Facility Type	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	2,163	1,607	237	70	21	13	14	7	1							4,133	160
Fuel/Uran. Enrichment	1,648	1,341	117	30	16	8	7	2	7		2		1		2	3,181	132
Fuel Fabrication	1,386	1,146	261	172	100	67	89	52	40	38	25	26	18	10	69	3,499	1,436
Fuel Processing	1,292	957	280	262	141	72	68	33	25	15	10	5	2	4	8	3,174	695
Maint. and Support	6,802	5,802	1,133	455	201	112	158	140	89	47	14	12	3			14,968	1,591
Reactor	1,980	2,863	686	304	174	110	171	119	68	28	10	3				6,516	1,178
Research, General	13,524	3,654	340	235	89	54	24	12	4	8	3					17,947	409
Research, Fusion	1,184	199	19	1	1											1,404	9
Waste Proc./Management	1,218	1,016	283	160	83	57	73	44	21	9	1	2	1	2	5	2,975	528
Weapons Fab. & Test.	3,667	3,096	982	616	279	172	250	168	75	35	29	7	8	9	7	9,400	1,896
Other	3,568	3,691	340	148	60	30	26	23	11	3						7,900	373
Total Persons	38,432	25,372	4,678	2,453	1,165	695	880	600	341	183	94	55	33	25	91	75,097	
Total Person-rem	0	735	732	861	711	599	1,082	1,031	757	499	304	203	140	117	637		8,409

TABLE E.32
Distribution of Shallow Doses by Facility Type and Dose-Equivalent Range
1987 - Female

Facility Type	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	268	137	18	5	1											429	8
Fuel/Uran. Enrichment	315	248	16	3	1	1										584	13
Fuel Fabrication	305	263	47	31	15	14	18	5	2	3	1	2	3		8	717	170
Fuel Processing	301	165	50	43	18	8	5	1	1		1					593	60
Maint. and Support	1,980	1,131	179	74	21	18	19	5	2	2						3,431	154
Reactor	340	241	55	29	12	7	12	5	2							703	66
Research, General	3,731	524	51	36	11	9	1	4							1	4,368	65
Research, Fusion	138	5														143	
Waste Proc./Management	232	212	55	20	9	4	7	6	1							546	51
Weapons Fab. & Test.	932	927	163	91	55	24	37	24	10	3		1				2,267	259
Other	675	645	37	16	5	3	3									1,384	36
Total Persons	9,217	4,498	671	348	148	88	102	50	18	8	2	3	3	0	9	15,165	
Total Person-rem	0	125	105	123	89	76	125	86	40	22	6	11	12	0	64		883

TABLE E.33
Distribution of Shallow Doses by Facility Type and Dose-Equivalent Range
1987 - Unknown Sex

Facility Type	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Accelerator	2	1														3	
Fuel Fabrication	67	12	2													81	1
Fuel Processing	22	21		1												44	1
Research, General	168	43	2													213	2
Waste Proc./Management	1	1														2	
Weapons Fab. & Test.			15	2	1	1		3		1	1					24	16
Other	306	1,144	59	15	5	2	6	2								1,539	54
Total Persons	566	1,222	78	18	6	3	6	5	0	1	1	0	0	0	0	1,906	
Total Person-rem	0	27	12	6	4	3	7	8	0	3	3	0	0	0	0		73

TABLE E.34
Distribution of Shallow Doses by Age and Dose-Equivalent Range
1987 - Male

Age Range	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	146	77	9		1		1	1								235	7
20 - 24	1,563	1,160	209	112	42	24	29	22	15	6	1	3	1	2	1	3,190	307
25 - 29	3,818	3,323	640	374	197	115	150	112	46	30	20	5	3	3	8	8,844	1,271
30 - 34	5,529	3,981	899	499	243	150	204	132	86	42	21	16	4	2	19	11,827	1,795
35 - 39	5,723	3,885	820	432	203	115	166	102	74	29	17	10	10	4	22	11,612	1,557
40 - 44	5,099	3,051	586	293	136	99	109	73	37	25	7	4	5	4	13	9,541	1,026
45 - 49	4,467	2,515	440	230	107	55	74	53	28	16	9	3	3	3	9	8,012	751
50 - 54	3,920	2,163	395	167	80	56	63	38	19	14	9	5	2	1	5	6,937	600
55 - 59	3,688	2,311	388	198	93	46	54	44	21	16	4	7	3	3	9	6,885	650
60 - 64	2,490	1,299	200	104	55	30	25	21	11	5	5	1	2	2	5	4,255	342
≥65 or unspecified	1,989	1,607	92	44	8	5	5	2	4		1	1		1		3,759	103
Total Persons	38,432	25,372	4,678	2,453	1,165	695	880	600	341	183	94	55	33	25	91	75,097	
Total Person-rem	0	735	732	861	711	599	1,082	1,031	757	499	304	203	140	117	637		8,409

TABLE E.35
Distribution of Shallow Doses by Age and Dose-Equivalent Range
1987 - Female

Age Range	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
≤19	74	26	1													101	1
20 - 24	750	343	49	22	5	3	5	2	2	1						1,182	48
25 - 29	1,431	807	159	76	30	18	24	15	2	3	1	1			4	2,571	214
30 - 34	1,695	934	159	92	34	21	30	11	4	1		1			2	2,984	206
35 - 39	1,508	746	119	72	30	17	16	8	6	1	1	1			2	2,527	170
40 - 44	1,226	501	68	37	20	14	16	8	2	1			2			1,895	109
45 - 49	958	366	49	27	12	9	4	1	1				1			1,428	56
50 - 54	671	284	27	11	4	3	2	2	1						1	1,006	34
55 - 59	452	181	19	10	7	2	4	1		1						677	27
60 - 64	249	91	14		6	1	1	1								363	12
≥65 or unspecified	203	219	7	1				1								431	7
Total Persons	9,217	4,498	671	348	148	88	102	50	18	8	2	3	3	0	9	15,165	
Total Person-rem	0	125	105	123	89	76	125	86	40	22	6	11	12	0	64		883

TABLE E.36
Distribution of Shallow Doses by Age and Dose-Equivalent Range
1987 - Unknown Sex

Age Range	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
20 - 24	1															1	
25 - 29	4	3														7	
30 - 34	2	3														5	
35 - 39	8	3														11	
40 - 44	1	1														2	
45 - 49	6	7														13	
50 - 54	3	3														6	
55 - 59	5	2														7	
60 - 64	1	1		1												3	
≥65 or unspecified	535	1,199	78	17	6	3	6	5		1	1					1,851	72
Total Persons	566	1,222	78	18	6	3	6	5	0	1	1	0	0	0	0	1,906	
Total Person-rem	0	27	12	6	4	3	7	8	0	3	3	0	0	0	0		73

TABLE E.37
Distribution of Shallow Doses by Occupation and Dose-Equivalent Range
1987 - Male

Occupation	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	13,099	5,498	810	491	201	139	141	83	50	13	12	1	4	4	6	20,552	1,277
Management	3,454	2,049	275	120	66	43	32	12	10	5		1				6,067	313
Scientists	10,242	5,976	646	206	92	43	58	20	10	9	6	2		2	3	17,315	639
Technicians	3,176	2,120	640	404	186	102	97	60	27	17	14	4			1	6,848	906
Service	1,653	1,909	143	30	15	7	7	9	5	1						3,779	134
Agriculture	60	47	1	1												109	2
Construction	2,336	3,378	998	498	228	145	210	187	129	64	15	18	6	4	4	8,220	1,941
Production	1,239	1,574	684	471	276	160	276	195	101	69	44	29	23	15	76	5,232	2,680
Transportation	1,225	670	97	38	8	9	10	9	5	4	1				1	2,077	118
Laborers	659	474	157	76	24	9	12	5	3	1	1					1,421	125
Miscellaneous	1,289	1,677	227	118	69	38	37	20	1		1					3,477	275
Total Persons	38,432	25,372	4,678	2,453	1,165	695	880	600	341	183	94	55	33	25	91	75,097	
Total Person-rem	0	735	732	861	711	599	1,082	1,031	757	499	304	203	140	117	637		8,409

TABLE E.38
Distribution of Shallow Doses by Occupation and Dose-Equivalent Range
1987 - Female

Occupation	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	3,535	1,201	95	69	28	21	9	4	3		1				1	4,967	139
Management	2,521	623	61	18	4	2	5	1	1				1			3,237	50
Scientists	1,455	740	72	26	9	3	3	1	1							2,310	54
Technicians	673	541	147	104	44	26	29	8	3							1,575	181
Service	466	447	36	7	2	1	1			1						961	26
Agriculture	3	4														7	
Construction	106	284	62	16	5	7	5	1		2						488	46
Production	152	359	144	92	48	26	48	33	10	5	1	3	2		8	931	351
Transportation	80	53	3	1		1										138	3
Laborers	55	81	35	7	4	1	2									185	17
Miscellaneous	171	165	16	8	4			2								366	15
Total Persons	9,217	4,498	671	348	148	88	102	50	18	8	2	3	3	0	9	15,165	
Total Person-rem	0	125	105	123	89	76	125	86	40	22	6	11	12	0	64		883

TABLE E.39
Distribution of Shallow Doses by Occupation and Dose-Equivalent Range
1987 - Unknown Sex

Occupation	Number of Persons Receiving Shallow Doses in each Dose-Equivalent Range															Total Persons	Total Person-rem
	< Meas.	Meas.- < .10	0.10- 0.25	0.25- 0.50	0.50- 0.75	0.75- 1.00	1.0- 1.5	1.5- 2.0	2.0- 2.5	2.5- 3.0	3.0- 3.5	3.5- 4.0	4.0- 4.5	4.5- 5.0	>=5		
Unknown	462	1,145	74	17	6	3	6	5		1	1					1,720	70
Scientists	3	2														5	
Technicians	3															3	
Construction	4	3														7	
Transportation	67	12	2													81	1
Miscellaneous	27	60	2	1												90	2
Total Persons	566	1,222	78	18	6	3	6	5	0	1	1	0	0	0	0	1,906	
Total Person-rem	0	27	12	6	4	3	7	8	0	3	3	0	0	0	0		73

APPENDIX F

OCCUPATIONAL DOSE LIMITS IN DOE ORDER 5480.11

Table F.1. DOE Limiting Values for Assessed Dose from Exposure of Occupational Workers to Radiation (effective January 1, 1989)

Exposure Category	Limit
Total effective dose equivalent	5 rem/yr (effective dose equivalent)
Lens of eye	15 rem/yr (dose equivalent)
Extremity	50 rem/yr (dose equivalent)
Skin of the whole body	50 rem/yr (dose equivalent)
Other organ or tissue	50 rem/yr (dose equivalent)
Unborn child	0.5 rem/gestation period (dose equivalent)

* U.S. G.P.O.:1991-281-714:40038

UNITED STATES
DEPARTMENT OF ENERGY
WASHINGTON, D.C. 20545

EH-411