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Twenty-fourth Annual Report

Radiation Exposures for DOE and DOE Contractor Employees - 1991

November 1994

Special Topic:
New Dose Reporting Quantities II

DOE/EH-0430

TWENTY-FOURTH ANNUAL REPORT

RADIATION EXPOSURES FOR DOE AND DOE CONTRACTOR EMPLOYEES - 1991

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FOREWORD

This is the 24th in a series of annual radiation exposure reports published by the Department of Energy (DOE) and its predecessor agencies. This report summarizes the radiation exposures received by both employees and visitors at DOE and DOE contractor facilities during 1991. Trends in radiation exposures are evaluated by comparing the doses received in 1991 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 is the fourth that is based on detailed exposure data for each individual monitored at a DOE facility. Prior to 1988, only summarized data from each facility were available. This report contains information on different types of radiation doses, including total effective, internal, penetrating, shallow, neutron, and extremity doses. It also contains analysis of exposures by age, sex, and occupation of the exposed individuals. This report also continues the precedent established in the Twenty-First (1988) Annual Report by conducting a detailed, one-time review and analysis of a particular topic of interest. The special topic for this report is a comparison of occupational radiation exposure health risks for various groups of the DOE workforce to health risks for the general U.S. population and workers in other occupations.

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.

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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.

Beginning with this report, Appendix D, "Exposure Data by Dose Range, Exposure Type, Facility Type, Age, Sex, and Occupation for DOE and DOE Contractor Employees and Visitors," is no longer included. Due to additional radiation dose reporting categories required by DOE order 5484.1, and the data comparisons provided in Appendix D, the resultant size of the annual report and associated publication costs necessitated this change. A copy of Appendix D is, however, available upon request.

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 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 1983-1990 were presented in DOE/PE-0072, DOE/EH-0011, DOE/EH-0036, DOE/EH-0069,

DOE/EH-0128, DOE/EH-0171P, DOE/EH-0286P, and DOE/EH-0287P, respectively. This report contains 1991 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 Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37830.

SUMMARY

All U.S. Department of Energy and DOE contractors are required by DOE Order 5484.1, Chapter IV, to submit occupational radiation exposure records to a central depository. For 1991, data were required to be submitted for all employees who were required to be monitored in accordance with DOE Order 5480.11 and for all visitors who received a measurable dose. The data required included the total effective dose equivalent, external penetrating whole-body dose equivalent, internal dose equivalent, the shallow dose equivalent, neutron dose equivalent, and extremity dose equivalent. Data regarding the exposed individuals included the individual's age, sex, and occupation category. This report is a summary of data reported by DOE and DOE contractors for the calendar year 1991.

A total of 112,875 DOE and DOE contractor employees were reported to have been monitored for whole-body ionizing radiation exposure in 1991. This represents 61.5% of all DOE and DOE contractor employees and is an increase (13.5%) from the number of monitored employees for 1990. In addition to employees, 11,827 visitors were monitored. (For more information, see Table 4.1.)

Of all monitored employees reported, 72.9% received a total effective dose equivalent that was less than measurable, 26.9% received a dose equivalent between measurable and 1 rem (10 mSv), and 0.2% received a dose equivalent greater than 1 rem (10 mSv). Although no employee received a penetrating dose equivalent greater than 2 rem (20 mSv), 45 did receive a total effective dose equivalent greater than 2 rem (20 mSv). The total effective dose equivalent received by 62.4% of the visitors to DOE facilities was less than measurable, 36.8% received a dose equivalent between measurable and 1 rem (10 mSv), and 0.8% received a dose equivalent greater than 1 rem (10 mSv). There were eight visitors who received a total effective dose equivalent greater than 2 rem (20 mSv). (These data are detailed in Table 4.1.)

The collective dose equivalent for DOE and DOE contractor employees in 1991 was 2,491 person-rem (24.91 person-Sv), which represents a decrease of 12.7% from 1990. The collective dose equivalent for visitors was 453 person-rem (4.53 person-Sv), which represents a decrease of 45%. The average total effective dose equivalent for all monitored employees reported was 22 mrem (0.22 mSv), and the average dose equivalent for all employees reported who received a measurable exposure was 82 mrem (0.82 mSv). The average dose equivalent for all monitored individuals

(employees and visitors) reported was 24 mrem (0.24 mSv), and the average dose equivalent for all individuals reported who received a measurable exposure was 84 mrem (0.84 mSv). Activities at weapons fabrication and testing facilities resulted in the highest average dose equivalent of 50 mrem (0.50 mSv) for all monitored DOE and DOE contractor employees. The lowest average dose equivalent (1 mrem (0.01 mSv)) was received at DOE offices. These averages are significantly less than the DOE 5 rem/yr (50 mSv/yr) radiation protection standard for whole-body exposures.

Of the ten occupation categories reported (not including those classified as "unknown"), production workers received both the highest collective dose equivalent (537 person-rem (5.37 person-Sv)) and the highest average dose equivalent per individual who received a measurable exposure (115 mrem (1.15 mSv)). Agricultural workers received both the lowest collective dose (<1 person-rem (0.01 person-Sv)) and the lowest average dose equivalent (<1 mrem (<0.01 mSv)) per individual who received a measurable exposure.

The 5-year age group receiving the highest collective dose equivalent (450 person-rem (4.50 person-Sv)) was the 35-to-39 age group. The ≥ 65 age group had the highest average dose equivalent of 288 mrem (2.88 mSv) per individual who received a measurable exposure. The group receiving the lowest collective dose equivalent and average dose equivalent per individual who received a measurable exposure was the ≤ 19 age group.

The average dose for all males who received a measurable exposure was 89 mrem (0.89 mSv); for females, the average was 57 mrem (0.57 mSv). Males received a total of 2,634 person-rem (26.34 person-Sv), while females received 269 person-rem (2.69 person-Sv). A total of 41 person-rem (0.41 person-Sv) was received by individuals for whom sex was not specified on the report forms.

Of the 2,944 person-rem (29.44 person-Sv) received by DOE and DOE contractor employees and visitors at DOE facilities, 1,737 person-rem (17.37 person-Sv (59%)) was attributable to beta-gamma exposures, 343 person-rem (3.43 person-Sv (12%)) was attributable to neutron exposures and 839 person-rem (8.39 person-Sv (~29%)) was attributable to internal exposures. In addition to the penetrating dose equivalent (beta-gamma and neutron), DOE and DOE contractor employees and visitors received a collective shallow dose of 2,643 person-rem (26.43 person-Sv).

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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 other epidemiological data, assisting researchers in assessing the health-effect risks of low doses of ionizing radiation.

This report contains seven main sections and four 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 1990. 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 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 6.0 presents reporting requirements for radiation exposure incidents at DOE and DOE contractor facilities. The magnitude of the postulated health effects from radiation doses received at DOE facilities is discussed in Section 7.0 of this report. Section 8.0 lists the references cited in this report.

Three appendices are included in the report, all of which contain detailed exposure data for DOE and DOE contractor employees and visitors. Appendix A presents the 1991 distribution of total effective dose equivalents by facility type for each DOE field organization. Appendix B presents the 1991 distribution of total effective dose equivalents by contractor for each DOE field organization. Appendix C presents the 1991 distribution of total effective dose equivalents by DOE field organization for DOE government employees and visitors.

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 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 the Department'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. Radiation dose limits in effect for 1991 were promulgated January 1, 1989, in DOE Order 5480.11. This order included limits on annual dose equivalents to the whole-body and to individual organs (Table 2.1). Personnel monitoring in 1991 was required by DOE Order 5480.11 when the potential existed for an individual to receive an annual effective dose equivalent above 100 mrem (1 mSv), or an annual dose equivalent to an individual organ greater than 10% of the occupational radiation exposure limits 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 is extremely low.

The DOE radiation protection standards are based on the Environmental Protection Agency's (EPA's) revised guidance to federal agencies for protection against occupational radiation exposure (EPA 1987). This guidance was a result of a review by EPA of the 1976 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 (DOE Order 5480.11) for occupational workers on January 1, 1989.

TABLE 2.1. 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)

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, known as the ALARA principle of radiation protection, maintains that radiation exposures should be maintained as low as reasonably achievable, 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. According to the ALARA principle, if doses are too high, resources should 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 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 (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.

3.0 FACILITY DESCRIPTIONS

DOE Order 5484.1 requires contractors to indicate for each reported individual the facility contributing the predominant portion of 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 larger facilities. Dose rates inside the primary shielding can range up to 200 mrem/h as a result of x-ray production near some machine components. Outside the shielding, however, x-ray exposure rates are very low, and neutron dose rates are generally less than 5 mrem/h (0.05 mSv/h). 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 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 millirem 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 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 metalworking 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. These facilities separate the plutonium produced in reactors for use in defense programs. They also separate the fission products and uranium; the fission products are normally designated as radioactive waste products, while the uranium can be refabricated for further use as fuel.

The very high radioactivity of fission products in spent nuclear fuel 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 (50 mSv) 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 dose equivalents from the depositions are typically less than 500 mrem (5 mSv).

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, variations in the types of work performed and 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 and 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 1989, 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 rems per hour), requiring extensive protective 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 on 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 (1 mSv). 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/yr (10 mSv/yr). 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 and the shift in DOE mission from national defense production to waste management and environmental restoration. 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 or 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 a greater 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 ten facility types described above; 2) those who did not work for any 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 ten 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 in 1991 was required by DOE Order 5480.11 when the potential existed for an individual to receive an annual effective dose equivalent above 100 mrem (1 mSv), or an annual dose equivalent to individual organs above 10% of the exposure limits. Depending on the administrative policy of the contractor, monitoring may also have been 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, 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.) Data now required to be submitted for each individual include total effective dose equivalent, external penetrating dose equivalent (including neutron), shallow dose equivalent, and extremity dose equivalent. This report is a summary of the dose equivalents received by DOE and DOE contractor employees and visitors in 1991 as reported pursuant to DOE Order 5484.1.

This report is the second to contain data on total effective dose equivalent, internal dose, and extremity dose for all DOE sites. In reports previous to 1990, the primary radiation quantity analyzed was whole-body penetrating dose. In this report, the primary quantity to be analyzed will be total effective dose equivalent. Caution should be used when comparing these data to those of past annual reports since the total effective dose quantity represent the total of the penetrating and internal dose components for employees and visitors. Data shown in tables and graphs for years previous to 1990 represent only the values for whole-body penetrating dose.

4.1 DISTRIBUTION BY DOSE INTERVAL

The number of employees and visitors who received a total effective dose equivalent in each of 16 dose-equivalent ranges is presented in Table 4.1. A total of 112,875 DOE and DOE contractor employees were reported to have been monitored for whole-body ionizing radiation exposure in 1991. This represents 61.5% of all DOE and DOE contractor employees. In addition to the employees, 11,827 visitors were monitored at DOE facilities. Visitors may include radiation workers from another DOE facility present on a temporary basis.

TABLE 4.1. Distribution of Total Effective Dose Equivalent for DOE/DOE Contractor Employees and Visitors by Dose-Equivalent Interval, 1991[(a)]

	Number of Persons			Collective Person-rem		
Dose-Equivalent Interval (rem)	Employees	Visitors	Total	Employees	Visitors	Total
< Measurable	82,320	7,380	89,700	0	0	0
Measurable to 0.10	24,558	3,754	28,312	650	79	729
0.10 to 0.25	3,798	286	4,084	585	44	629
0.25 to 0.50	1,463	163	1,626	501	56	557
0.50 to 0.75	351	101	452	211	64	276
0.75 to 1.00	173	52	225	150	45	195
1 to 2	167	83	250	218	107	325
2 to 3	23	2	25	56	5	61
3 to 4	9	0	9	30	0	30
4 to 5	8	0	8	37	0	37
5 to 6	0	1	1	0	6	6
6 to 7	2	0	2	13	0	13
7 to 8	0	2	2	0	15	15
8 to 9	1	1	2	8	8	16
9 to 10	0	1	1	0	10	10
> 10	2	1	3	32	14	47
Total	112,875	11,827	124,702	2,491	453	2,944

(a) Minor variations in collective dose-equivalent values may be due to rounding.

No DOE or DOE contractor employee received a total effective dose equivalent greater than 5 rem (50 mSv) due to exposures received during 1991. There are five employees and six visitors, however, who did receive a total effective dose equivalent greater than 5 rem (50 mSv) because of past internal uptakes of radionuclides. Annual dose due to these past internal uptakes is calculated each year and is expressed in the values for total effective dose equivalent. No DOE or DOE contractor employee or visitor received a whole-body penetrating dose equivalent greater than 2 rem (20 mSv), which is significantly less than the DOE radiation protection standard of 5 rem (50 mSv) (See Table 4.2).

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 dose equivalent is presented for the years 1980-1991 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 1991 has increased from the number reported for previous years because of the greater number of DOE and DOE contractor employees involved in environmental remediation activities and because of the requirements of DOE Order 5480.11.

Of the monitored employees reported for 1991, 72.9% received a total effective dose equivalent that was less than measurable; 26.9% received a dose equivalent between measurable and 1 rem (10 mSv); and 0.2% received a dose equivalent greater than 1 rem (10 mSv) (Figure 4.2). The dose equivalent received by 62.4% of the visitors to DOE facilities was less than measurable; 36.8% received a dose equivalent between measurable and 1 rem (10 mSv); and 0.8% received a dose equivalent greater than 1 rem (10 mSv) (Figure 4.2).

TABLE 4.2. Distribution of Whole-Body Penetrating and Total Effective Dose Equivalents for DOE/DOE Contractor Employees, 1965-1991[a]

	Number of Employees Receiving Radiation Doses in Each Dose-Equivalent Range (rem)														
Year	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	Monitored
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	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	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	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
1989	57,533	32,891	437	21											90,882
1990	66,297	32,896	191	37	8	8	1	2		1			1	1	99,443
1990[c]	66,297	33,896	191	37	8	8	1	2		1			1	1	99,443
1991	86,062	26,739	74												112,875
1991[c]	82,320	30,343	167	23	8	8		2		1			1	1	112,875

(a) Throughout this report there may be minor variations in collective dose-equivalent values because of rounding.
(b) Separation of data before 1974 is unavailable.
(c) Data for total effective dose equivalent.

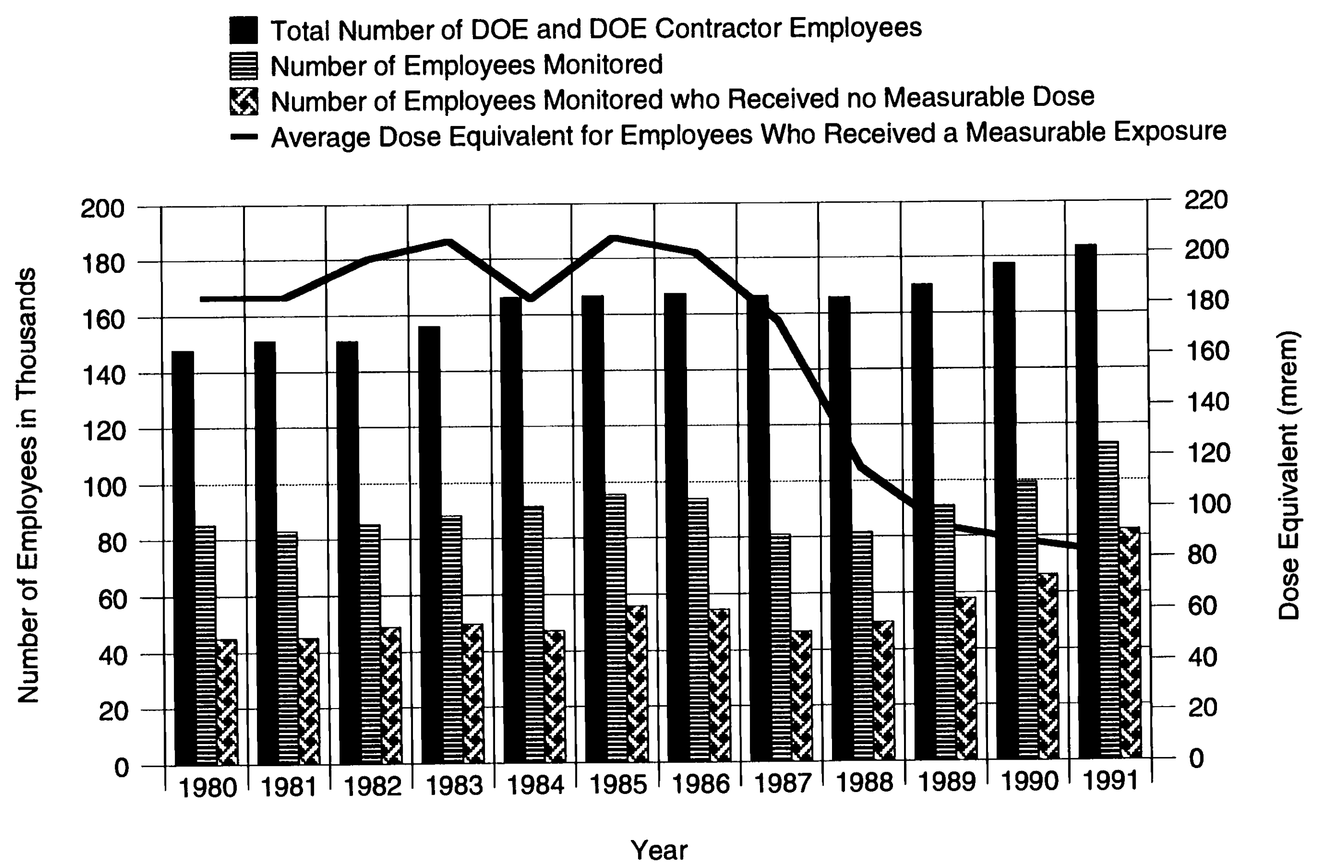

FIGURE 4.1. Comparison of Number of Employees, Number of Employees Monitored, and Number of Employees Monitored Who Received No Measurable Dose Equivalent, 1980-1991. (Data previous to 1990 is based on whole-body penetrating dose only; data since 1990 is based on total effective dose equivalent.)

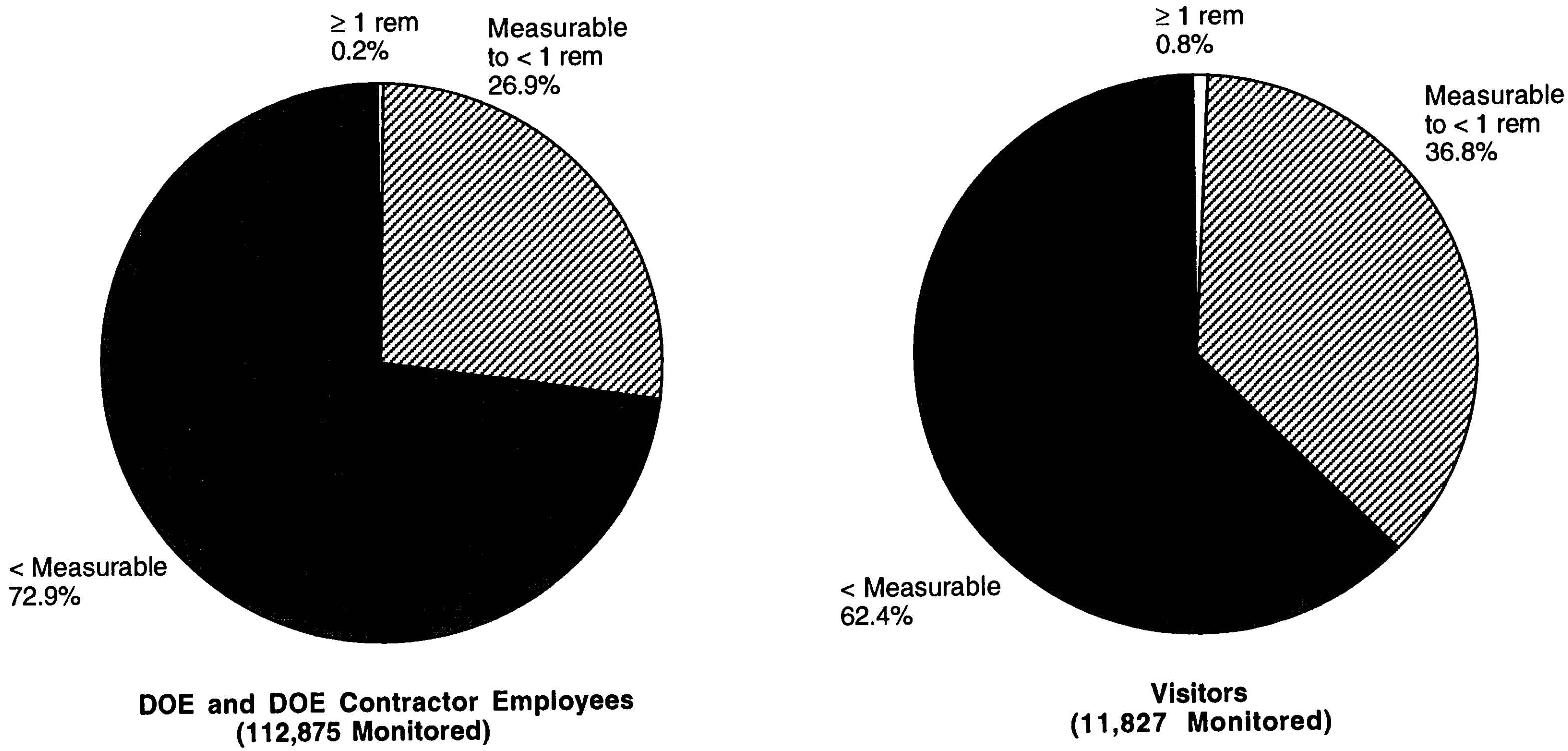

FIGURE 4.2. Percentage of Monitored Employees and Percentage of Monitored Visitors Who Received Total Effective Dose Equivalents Less than Measurable, Measurable to 1 rem, or Greater Than 1 rem, 1991

The total effective collective whole-body dose equivalent was 2,491 person-rem (24.91 person-Sv) for all DOE and DOE contractor employees, and 453 person-rem (4.53 person-Sv) for visitors to DOE facilities, for a total DOE collective dose equivalent of 2,944 person-rem (29.44 person-Sv). 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 (10 mSv) contributed the greatest portion (81.0%) of the collective dose.

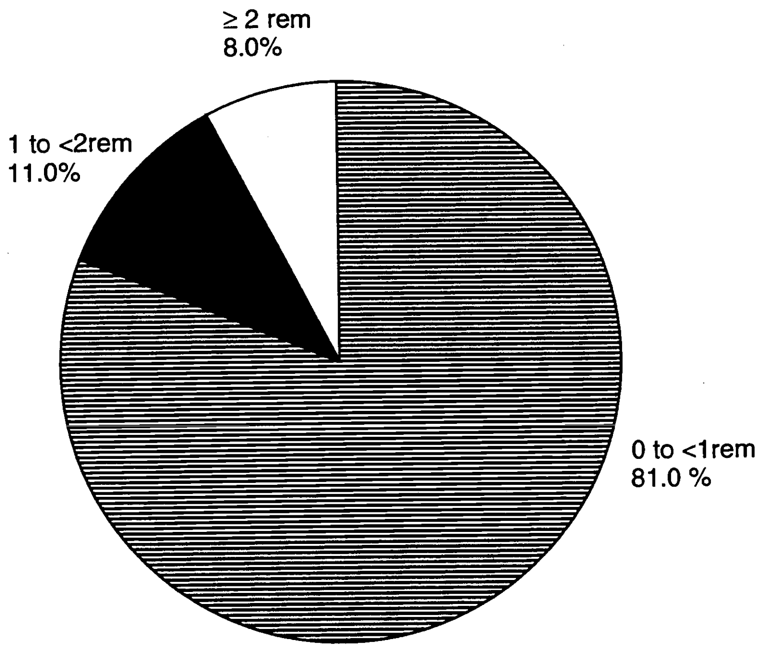

FIGURE 4.3. Contribution of Each Dose-Equivalent Interval to the Total Collective Dose Equivalent, 1991

The distribution of whole-body penetrating and total effective doses for DOE and DOE contractor employees for the years 1965-1991 is presented in Table 4.2. As indicated, the fraction of all monitored employees who received a penetrating dose equivalent greater than 1 rem (10 mSv) has declined dramatically since 1965, starting at about 5%, leveling off at about 2% from 1977 to 1987, and dropping to less than 1% for the period 1988-1991. This general downward trend in occupational radiation exposures can be observed in Figure 4.4, which shows the collective dose equivalent for employees who received a dose equivalent greater than 1 rem (10 mSv) from 1965 to 1991. The collective dose equivalent for employees who received an exposure less than 1 rem (10 mSv) was not included because, before 1974, less-than-measurable exposures were not distinguished from measurable exposures in the reporting system. The 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 and mission changes 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 1991 data for DOE and DOE contractor employees on a lognormal probability plot. This figure 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 DOE contractor employees received a dose equivalent greater than 1 rem (10 mSv), approximately 20% of the employee collective dose equivalent was attributable to individual dose equivalents greater than 1 rem (10 mSv).

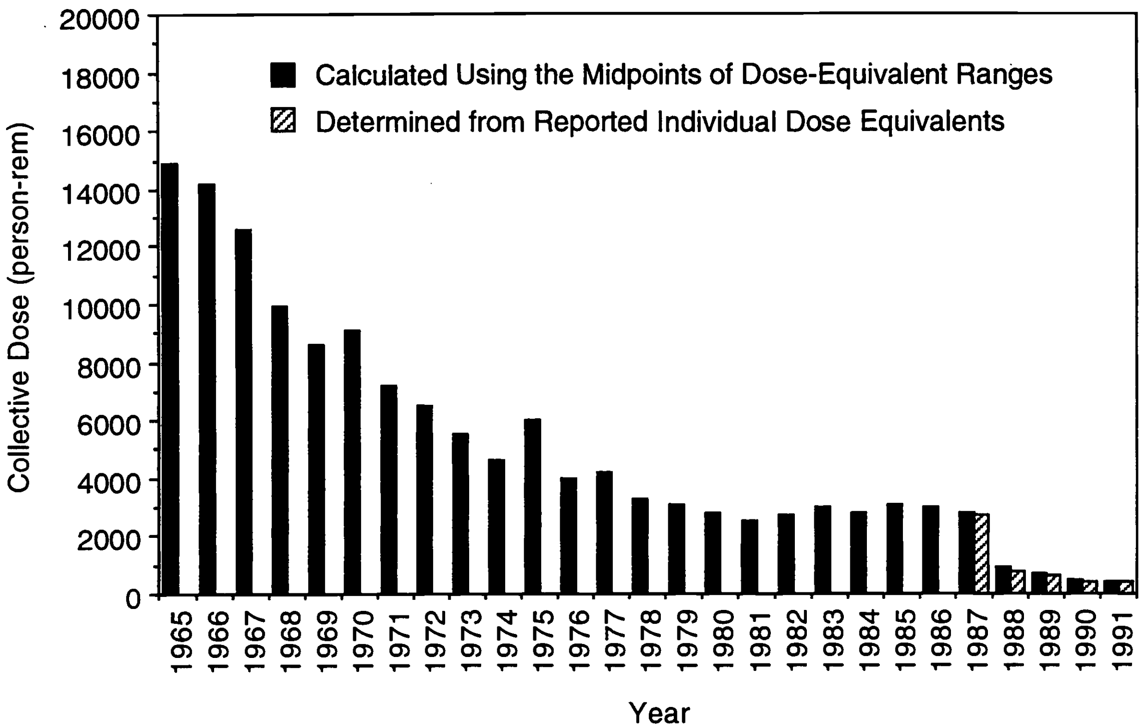

FIGURE 4.4. Total Collective Dose Equivalent for All DOE/DOE Contractor Employees Who Received a Dose Equivalent Greater Than 1 rem, 1965-1991

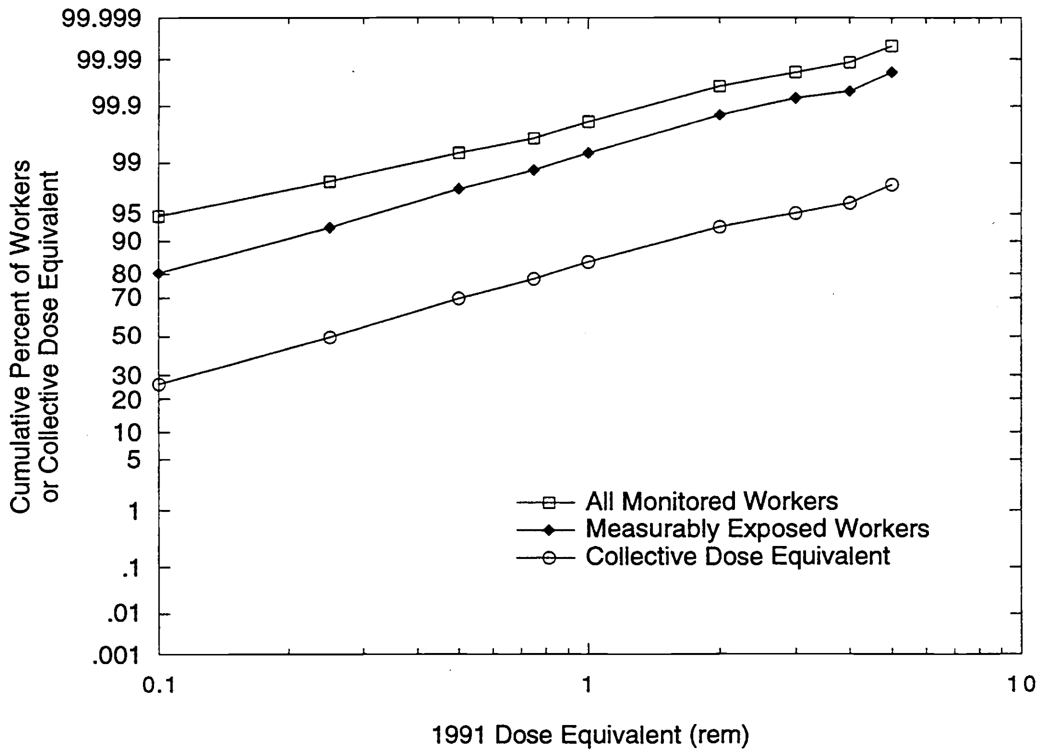

FIGURE 4.5. Lognormal Probability Plots of Annual Exposure for Potentially Exposed and Measurably Exposed DOE and DOE Contractor Employees, 1991

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) is a policy decision of each field organization. For this section of the report, the categories of "visitors" and "DOE offices" were each 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 (28.5%) was in the category "Weapons Fabrication and Testing." The smallest contribution (0.06%) was from DOE offices. A summary of the data is presented in Table 4.3.

Collective dose increased 13%, when compared with 1990 data, for the "Weapons Fabrication and Testing" category. This increase may be due to a larger penetrating dose component caused by an increased workload at weapons fabrication facilities (actually dismantling weapons). In addition,

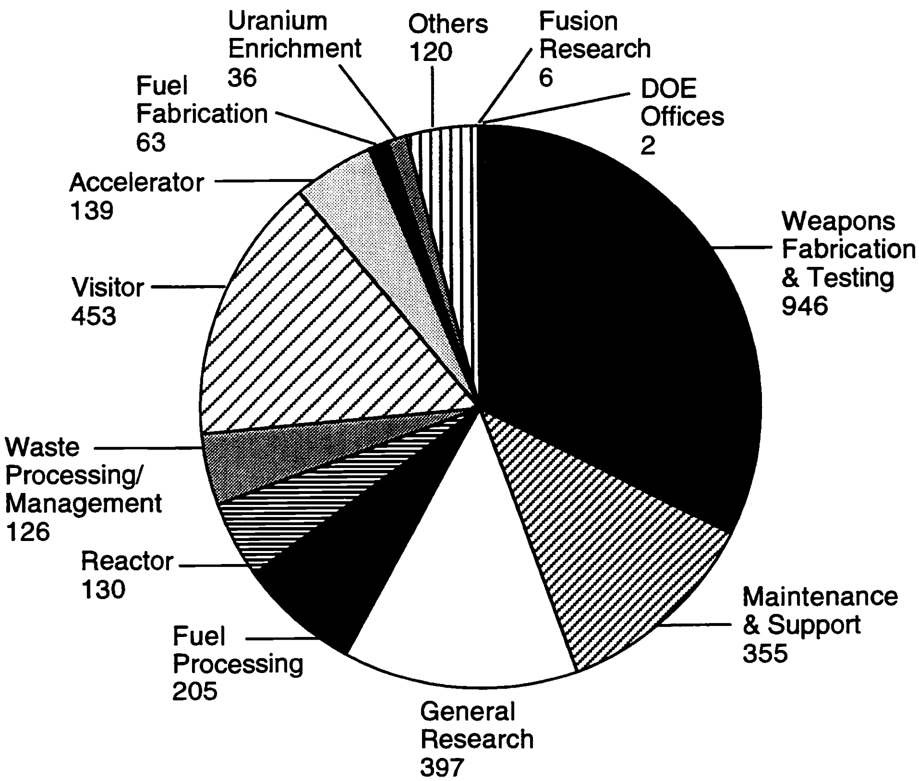

FIGURE 4.6. Contribution of Each Facility Type to the Total Collective Effective Dose Equivalent, 1991 (numbers indicate person-rem)

TABLE 4.3. Distribution of Annual Whole-Body Radiation Doses for Monitored DOE/DOE Contractor Employees and Visitors by Facility Type, 1991[(a)]

Facility Type	Number of Persons Receiving Radiation Doses in Each Dose-Equivalent Range (rem)																Total Persons	Total 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	5,294	1,063	186	84	29	9	5									1	6,671	139
Fuel/Uran. Enrichment	7,623	1,647	32	7	1		1										9,311	36
Fuel Fabrication	992	277	74	15	1	3	1										1,363	29
Fuel Processing	3,334	1,063	341	179	48	16	10										4,991	205
Maint. and Support	19,069	5,026	612	201	34	15	23	4									24,984	355
Reactor	2,473	2,201	225	71	12	7	5										4,994	130
Research, General	16,091	3,193	490	206	84	47	48	1	1	1		1					20,163	397
Research, Fusion	966	158	9														1,133	6
Waste Proc./Management	3,936	1,137	226	104	15	8	4	2									5,432	126
Weapons Fab. & Test.	10,150	6,605	1,410	511	117	61	69	16	8	6		1		1		1	18,956	946
Other	10,784	2,016	192	85	10	7	1			1							13,096	120
Visitors	7,380	3,754	286	163	101	52	83	2			1		2	1	1	1	11,827	453
DOE Offices	1,608	172	1														1,781	2
Total Persons	89,700	28,312	4,084	1,626	452	225	250	25	9	8	1	2	2		1	3	124,702	

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

a large portion of the "Weapons Fabrication and Testing" collective dose (approximately 64%) is due to internal dose caused by the uptake of internal emitters that occurred in previous reporting years.

Collective dose decreases of 29% and 41% were seen for the "Reactor" and "Fuel Processing" categories, respectively. These decreases were probably due to reduced activities in both of these production-related categories during 1991. Decreases in collective dose of 10% and 38% were also seen for the "General Research" and "Maintenance and Support" categories. These decreases, along with an overall decrease in total collective dose when compared with 1990, is likely due to ongoing efforts within the DOE community to follow the ALARA concept of radiation protection.

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 for all facilities was 24 mrem (0.24 mSv). The highest average dose equivalent per individual monitored (50 mrem) (0.50 mSv) was observed at weapons fabrication and testing facilities, and the lowest was observed at DOE offices (1 mrem) (0.01 mSv). The average dose equivalent per individual who received a measurable dose equivalent was 84 mrem (0.84 mSv). The highest average dose equivalent per individual who received a measurable dose equivalent (124 mrem) (1.24 mSv) was observed at fuel processing facilities, and the lowest (13 mrem) (0.13 mSv) was observed at DOE offices.

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 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 attributed to each facility type

TABLE 4.4. Collective Dose-Equivalent for Monitored DOE/DOE Contractor Employees and Visitors by Facility Type, 1991[a]

Facility Type	Number of Individuals	Number of Individuals with Measurable Doses	Collective Dose-Equivalent (Person-rem)	Average Dose-Equivalent (mrem) per Individual	Average Dose-Equivalent (mrem) per Individual with Measurable Doses
Accelerator	6,671	1,377	139	21	101
Fuel/Uran. Enrichment	9,311	1,688	36	4	21
Fuel Fabrication	1,363	371	29	21	78
Fuel Processing	4,991	1,657	205	41	124
Maint. and Support	24,984	5,915	355	14	60
Reactor	4,994	2,521	130	26	52
Research, General	20,163	4,072	397	20	98
Research, Fusion	1,133	167	6	5	35
Waste Proc./Management	5,432	1,496	126	23	84
Weapons Fab. & Test.	18,956	8,806	946	50	107
Other	13,096	2,312	120	9	52
Visitors	11,827	4,447	453	38	102
DOE Offices	1,781	173	2	1	13
Total	124,702	35,002	2,944	24	84

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

TABLE 4.5. Collective Dose-Equivalent for Monitored DOE/DOE Contractor Employees and Visitors by Field Organization, 1991[a]

Field Organization	Number of Monitored Individuals	Number of Individuals with Measurable Doses	Collective Dose-Equivalent (Person-rem)	Average Dose-Equivalent (mrem) per Individual	Average Dose-Equivalent (mrem) per Individual with Measurable Doses
Albuquerque Operations	21,379	2,884	389	18	135
Chicago Operations	11,493	2,648	173	15	65
DOE Headquarters	872	65	0	0	5
Idaho Operations	7,402	1,273	177	24	139
Nevada Operations	1,196	40	3	3	85
Oak Ridge Operations	26,467	4,717	172	6	36
Pittsburgh N.R. Office	2,195	1,703	84	38	50
Richland Operations	9,404	3,058	275	29	90
Rocky Flats Operations	8,358	7,643	902	108	118
San Francisco Operations	10,622	613	77	7	126
Savannah River Operations	22,583	8,391	459	20	55
Schenectady N.R. Office	2,731	1,967	233	85	118
Total DOE	124,702	35,002	2,944	24	84

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

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, 1991[(a)]

	Facility Type												
		Fuel			Maint&		Research		Waste	Weapon			DOE
Field Organization	Accel	Enrich	Fab.	Proc	Support	Reactor	Genrl	Fusion	Proc.	F&T	Other	Visit	Office
Albuquerque Operations	10.5				8.8	2.3	46.1	0.1	1.4	6.7	2.9	21.2	
Chicago Operations	45.8		0.6		6.7	5.9	14.8	3.1	0.6		0.3	22.1	
DOE Headquarters													100.0
Idaho Operations				34.5	1.1	18.7	2.5		0.4		12.7	30.2	
Nevada Operations	91.9									1.4		6.6	
Oak Ridge Operations		18.5	15.9	4.6			22.5		0.3	13.6		24.5	
Pittsburgh N.R. Office						22.3	74.3				1.2	2.2	
Richland Operations			0.2	3.0	39.2	6.8	17.3		29.3		3.5	0.4	0.2
Rocky Flats Operations										98.2		1.8	
San Francisco Operations	21.0	5.4			23.1		29.4		0.1	6.2	9.3	5.4	0.1
Savannah River Operations				27.8	39.5	4.5	2.2		8.2	1.2	14.8	1.4	0.3
Schenectady N.R. Office						8.5	2.7				0.1	88.7	
Total DOE	4.7	1.2	1.0	7.0	12.0	4.4	13.5	0.2	4.3	32.1	4.1	15.4	0.1

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

at each field organization. Table 4.7 presents collective dose equivalents for each field organization from 1982 to 1991.

4.4 DISTRIBUTION BY OCCUPATION CATEGORY

DOE Order 5484.1 requires that for each monitored individual (employee and visitor), a three-digit occupation code be included indicating the generic occupation that best fits the individual's occupation title. The 44 three-digit codes pertain 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, standardize occupational classifications, and 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 - scientists, engineers, health physicists, miscellaneous professionals, physicians, 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.

TABLE 4.7. Collective Dose-Equivalent (person-rem)[a] for Monitored DOE/DOE Contractor Employees and Visitors by Field Organization, 1982-1991[b]

Field Organization	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Albuquerque Operations[c]	1,112	1,190	1,423	1,344	979	483	556	432	363	389
Chicago Operations	587	623	615	502	408	348	310	240	214	173
Idaho Operations	363	353	441	420	620	318	253	336	366	177
Nevada Operations	29	25	24	34	65	8	13	6	7	3
Oak Ridge Operations	401	371	419	353	587	517	360	218	173	172
Pittsburgh N.R. Office	194	220	180	180	109	78	86	85	23	84
Richland Operations	2,272	2,458	2,399	2,548	2,321	2,477	654	619	353	275
Rocky Flats Operations[c]	1,173	1,142	1,315	1,556	1,407	880	654	412	769	902
San Francisco Operations	289	267	195	187	99	78	74	82	64	77
Savannah River Operations	1,310	1,293	1,283	1,394	1,498	945	887	804	753	459
Schenectady N.R. Office	147	217	130	165	167	220	81	140	240	233
Total	7,879	8,158	8,422	8,684	8,261	6,353	3,928	3,375	3,327	2,944

(a) Throughout this report there may be minor variations in collective dose-equivalent values because of rounding.
(b) The data may differ slightly from previous reports due to revisions received after publication.
(c) Effective 1/1/90, Rocky Flats Operations was designated as a separate DOE field organization. Accordingly, all current and historical radiation data associated with the Rocky Flats facilities have been extracted from Albuquerque Operations data and identified separately.

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 "Scientists" category accounted for both the most individuals monitored and the most individuals monitored who received a measurable exposure. Individuals in the "Production" category received the highest average dose equivalent per individual monitored (60 mrem (0.60 mSv)) and received the highest average dose equivalent per individual monitored who received a measurable exposure (115 mrem (1.15 mSv)). Figure 4.7 illustrates the data in Table 4.8 including an indication of the sex distribution of the individuals. Figure 4.8 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.

4.5 DISTRIBUTION BY AGE AND SEX

The 1991 exposure data submitted per DOE Order 5484.1 included information on the age and sex of the exposed individuals (employees and visitors). Unfortunately, some records were submitted without the required information. For the analysis in this report, 12 age categories were defined: 19 and less, 65 and greater, nine 5-year age groups beginning with the 20-24 age group and ending with the 60-64 age group, and unknown age. 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 was likely to be unspecified or unknown as well. For example, of the 1,286 individuals for whom sex was not specified on the report form, 1,114 (87%) also were not identified by age. Similarly, the occupation was listed as unknown or was unspecified for 1,232 (96%) of the individuals for whom sex was unspecified.

TABLE 4.8. Distribution of Total Effective Dose Equivalent for DOE/DOE Contractor Employees and Visitors by Occupation, 1991[a]

Occupation	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)
Unknown	22,909	6,212	593	26	95
Management	16,215	3,556	306	19	84
Scientists	35,946	4,847	440	12	56
Technicians	13,903	4,847	549	39	113
Service	7,350	1,684	73	10	43
Agriculture	136	27	0	0	0
Construction	11,166	4,086	311	28	76
Production	8,979	4,666	537	60	115
Transportation	2,145	545	33	15	61
Laborers	2,662	965	89	33	92
Miscellaneous	3,291	600	17	5	28

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

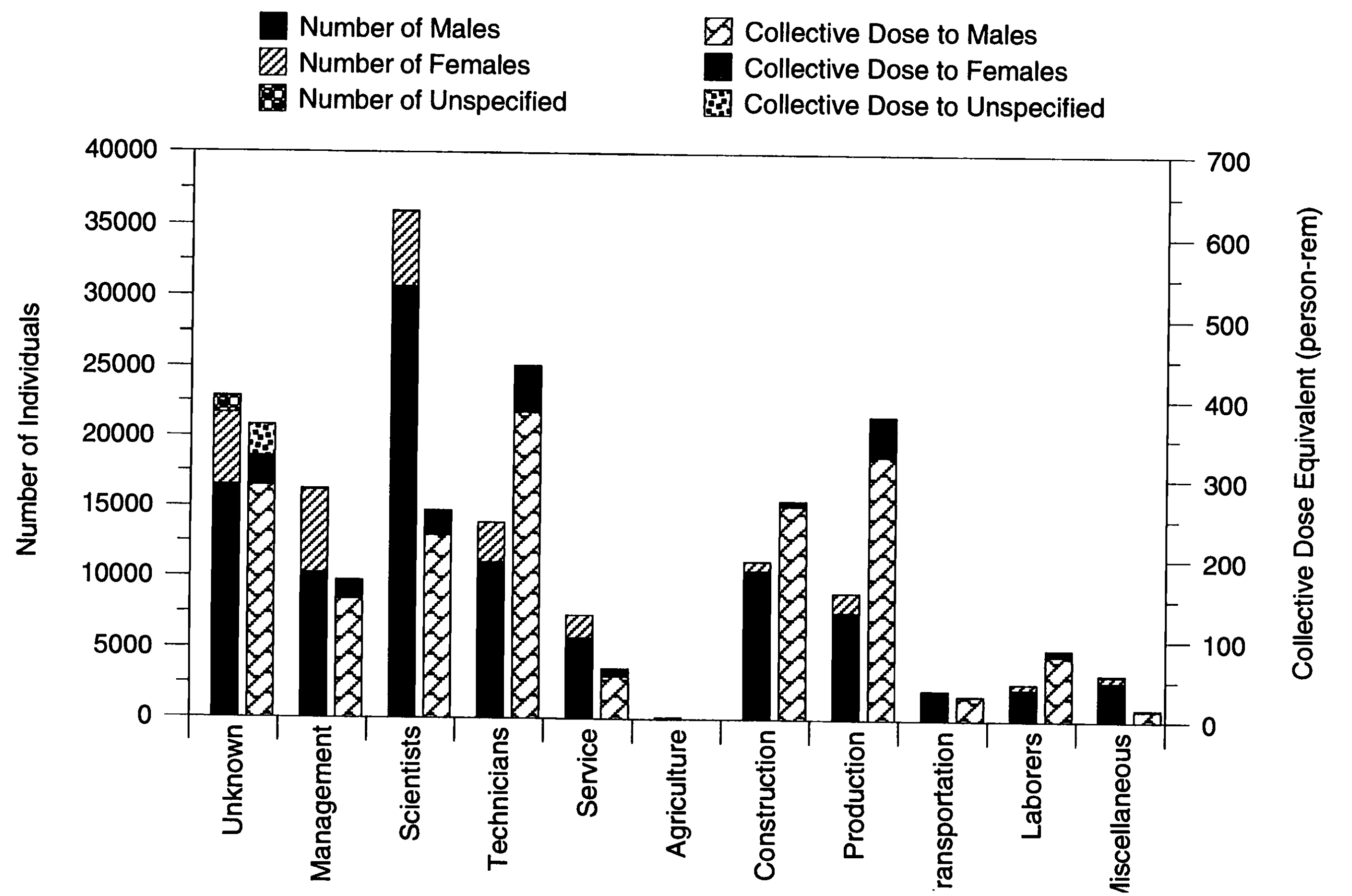

FIGURE 4.7. Penetrating Doses Received by DOE and DOE Contractor Employees and Visitors by Occupation, 1991

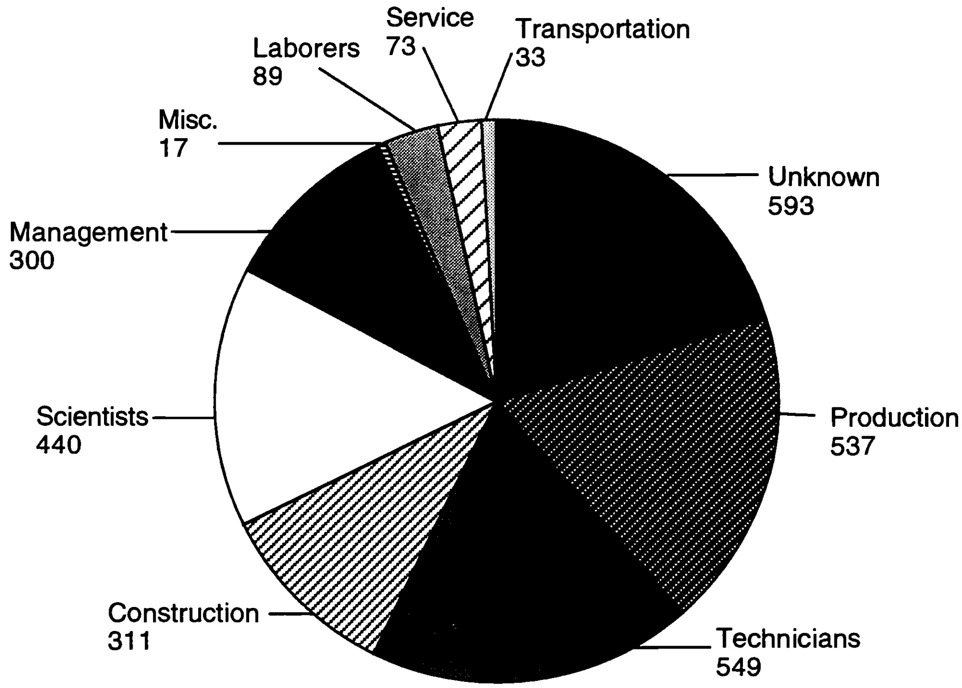

FIGURE 4.8. Contribution of Each Occupation Category to the Total Collective Dose Equivalent, 1991 (numbers indicate person-rem)

Figure 4.9 illustrates the number of individuals by sex who received total effective dose equivalents in various dose-equivalent ranges. Figure 4.10 illustrates the number of individuals by sex and age range who were monitored for ionizing radiation in 1991.

Table 4.10 lists the number of individuals monitored, the numbers of individuals monitored who received a measurable exposure, and the collective and average dose equivalents received by age range. The age groups receiving the highest average dose equivalent per individual monitored was the 65-and-greater age group (64 mrem) (0.64 mSv); the age group receiving the lowest was the 19-or-less group (2 mrem) (0.02 mSv). The age group receiving the highest average dose equivalent per individual who received a measurable exposure was the 65-and-greater age group (288 mrem) (2.88 mSv); the lowest was the 19-or-less group (18 mrem) (0.18 mSv). Internal dose contributions

TABLE 4.9. Number of Monitored DOE/DOE Contractor Employees and Visitors by Occupation and Facility Type, 1991[a]

Facility Type	Total Persons Monitored	Unknown	Management	Scientists	Technicians	Service	Agriculture	Construction	Production	Transportation	Laborers	Miscellaneous	Total Person-rem
Accelerator	8,283	1,313	322	3,337	1,867	238	17	410	177	99	15	488	156
Fuel/Uranium Enrichment	10,014	1,599	2,119	2,272	935	546	0	1,128	948	61	249	157	39
Fuel Fabrication	2,549	5	440	953	294	129	0	418	102	59	994	50	55
Fuel Processing	4,995	0	755	1,896	244	76	0	624	1,233	42	25	100	204
Maintenance and Support	25,247	5,754	3,720	5,020	2,977	1,792	29	3,017	1,124	724	1,046	44	423
Reactor	5,959	17	1,065	2,325	643	164	2	390	861	82	64	346	339
Research, General	21,374	4,651	2,347	7,835	2,800	463	10	737	436	86	254	1,755	411
Research, Fusion	1,282	127	91	566	264	42	0	112	33	0	1	46	7
Waste Proc./ Management	6,131	159	824	1,979	865	389	0	687	973	101	952	59	128
Weapons Fabrication and Testing	20,264	5,066	3,113	4,779	1,877	738	0	1,378	2,820	396	360	976	966
Other	18,244	4,218	1,419	4,984	1,137	2,773	78	2,265	272	495	454	14938	214
Total Persons Monitored	124,702	22,909	16,215	35,946	13,903	7,350	136	11,166	8,979	2,149	2,662	3,291	
Total Person-rem		593	300	440	549	73	0	311	537	33	89	17	2,944

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

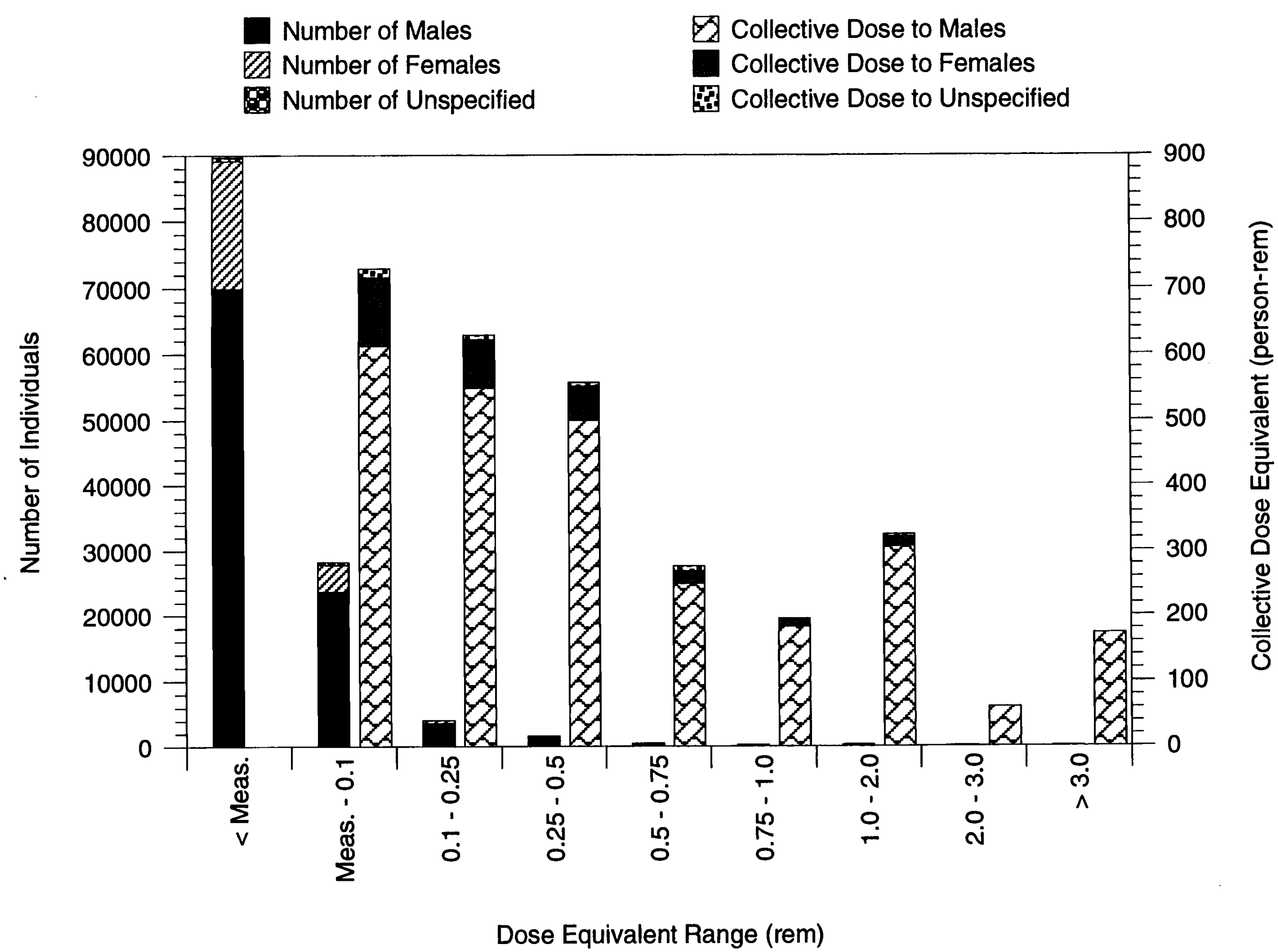

FIGURE 4.9. Distribution of Total Effective Dose Equivalents by Sex and Dose-Equivalent Range for DOE and DOE Contractor Employees and Visitors, 1991

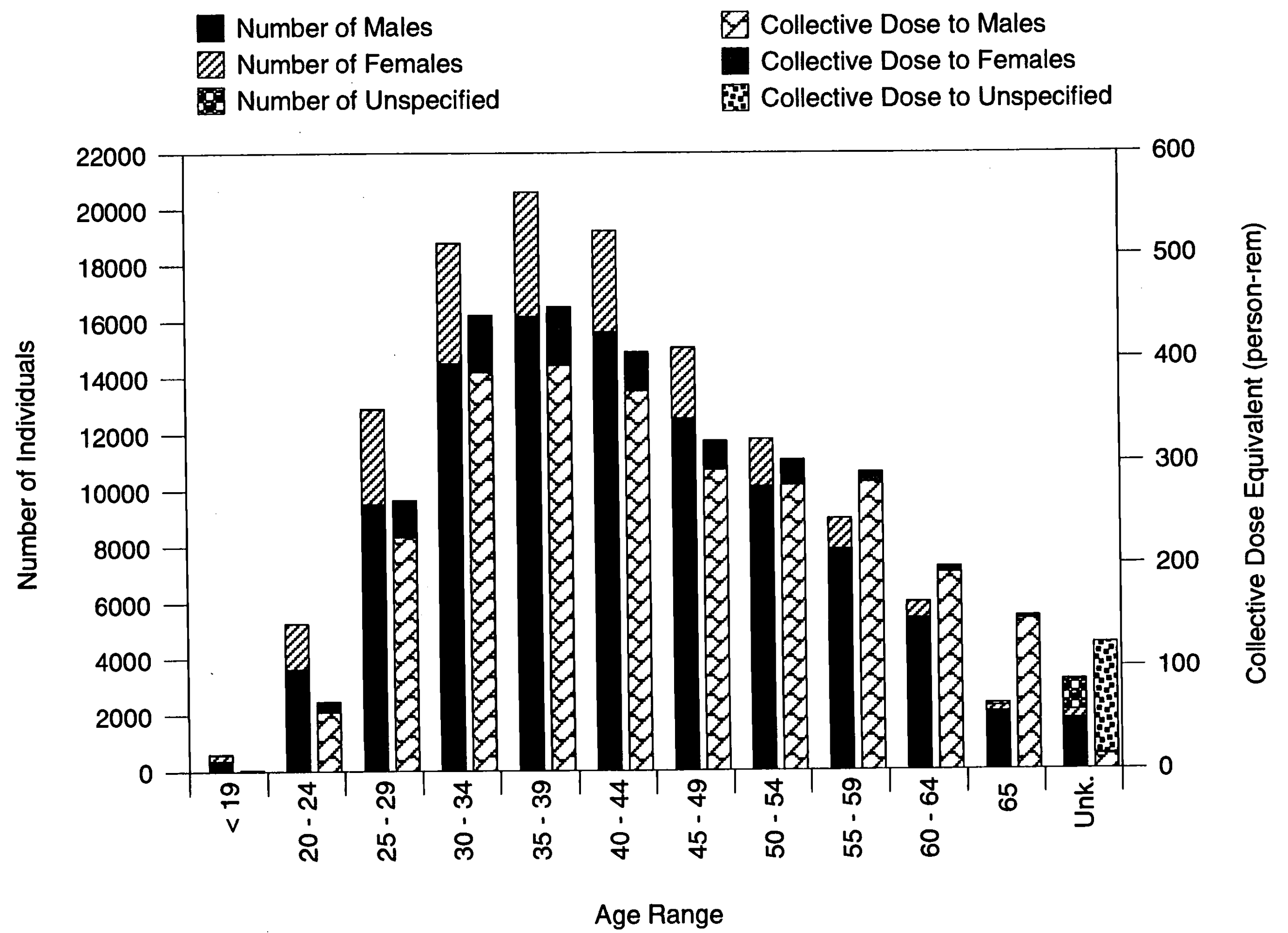

FIGURE 4.10. Number of Individuals (Employees and Visitors) Monitored and Collective Dose Equivalent by Age Range and Sex, 1991

TABLE 4.10. Number of Individuals Monitored and Average Total Effective Dose Equivalent by Age, 1991[a]

Age Range	Number of Individuals Monitored	Number of Individuals 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)
≤19	610	57	1	2	18
20-24	5,278	1,318	67	13	51
25-29	12,867	4,017	263	20	65
30-34	18,778	5,758	442	24	77
35-39	20,600	5,938	450	22	76
40-44	19,215	5,304	406	21	77
45-49	15,052	3,955	320	21	81
50-54	11,808	2,974	302	26	102
55-59	8,980	2,370	290	32	122
60-64	6,003	1,617	198	33	122
≥65	2,326	520	150	64	288
Unknown	3,185	1,174	537	17	45
All Individuals	124,702	35,002	2,944	24	84

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

(due to past uptakes) to the total effective dose equivalent quantity are the reason the 65-and-greater age group had the highest average dose equivalent per individual who received a measurable exposure.

Table 4.11 presents similar data by sex rather than age. Males received approximately 86% 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 (26 mrem versus 11 mrem) (0.26 mSv versus 0.11 mSv) as well as higher average dose equivalents per individual monitored who received a measurable exposure (89 mrem (0.89 mSv) versus 57 mrem (0.57 mSv)).

Because of the sensitivity of the fetus 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 4.12 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 1991, by facility type. A total of 3,604 women of child-bearing age received a collective dose equivalent of 197 person-rem (1.97 person-Sv). The average individual dose equivalent for these women over all facilities was 55 mrem (0.55 mSv).

Figure 4.11 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 were approximately 38 and 42 for females and males, respectively. The median ages for collective dose equivalent were approximately 38 and 43, respectively, indicating that, in general, younger workers receive slightly higher doses than do older workers.

TABLE 4.11. Number of Individuals Monitored and Average Total Effective Dose Equivalent by Sex, 1991[a]

	Number of Individuals Monitored	Number of Individuals 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)
Male	99,491	29,619	2,634	26	89
Female	23,925	4,738	269	11	57
Unspecified	1,286	64512	411	32	64
All Individuals	124,702	35,002	2,994	24	84

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

TABLE 4.12. Total Doses Received by Female Employees and Visitors of Childbearing Age, 1991[a]

Facility Type	Persons	Number of Females Receiving Measurable Doses in Each Age Group						Total Person-rem
		≤19	20-24	25-29	30-34	35-39	40-44	
Accelerator	91	2	16	21	21	19	12	5
Fuel/Uran. Enrichment	259	1	16	45	71	75	51	5
Fuel Fabrication	54	1	6	18	9	13	7	3
Fuel Processing	249	1	18	47	79	57	47	27
Maint. and Support	829	3	72	201	217	194	142	43
Reactor	170		12	40	52	36	30	12
Research, General	371	1	30	71	105	110	54	26
Research, Fusion	3			1	1		1	
Waste Proc./Management	205		22	52	56	45	30	11
Weapons Fab. & Test.	983	1	41	140	254	286	261	54
Other	390		60	113	81	83	53	13
Total Persons	3,604	10	293	749	946	918	688	
Total Person-rem		0	10	36	56	57	38	198

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

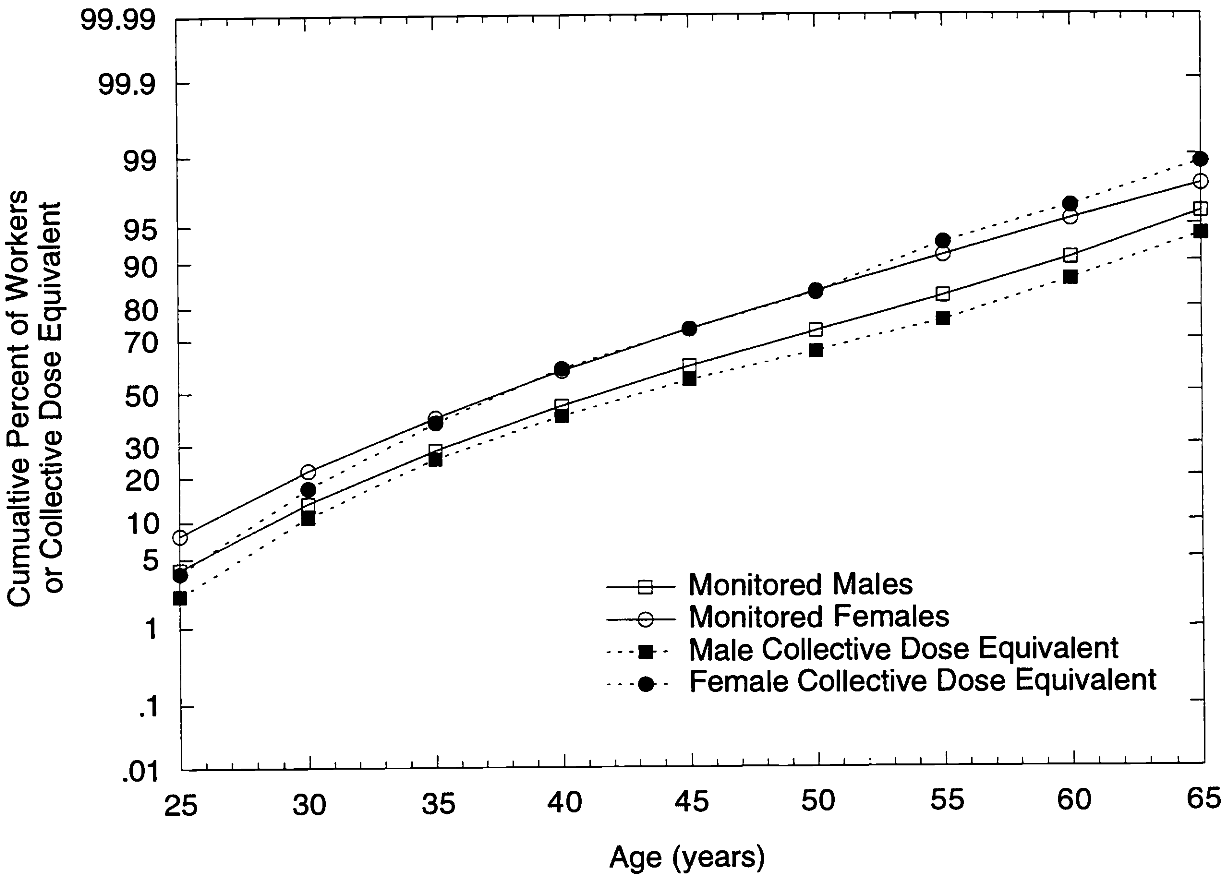

FIGURE 4.11. Number of Individuals (Employees and Visitors) Monitored and Collective Dose Equivalent by Age Range and Sex, 1991

4.6 DISTRIBUTION BY TYPE OF EXPOSURE

For calendar year 1991, DOE Order 5484.1 required that specific information on the types of radiation doses received by each worker be reported. Specifically, these included the total effective dose equivalent, the external penetrating dose equivalent (at a depth in tissue of 1.0 cm) including neutron exposure, the dose equivalent from neutron exposure only, the internal effective dose equivalent, the shallow dose equivalent, and the extremity 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. The Order does not require reports of dose to the eye.

Table 4.13 lists the various types of dose equivalents received by facility type. Of the total effective dose equivalent of 2,944 person-rem (29.44 person-Sv) received, 2,080 person-rem (20.80 person-Sv (71%)) were attributable to total penetrating radiation and 839 person-rem (8.39 person-Sv (28%)) were attributable to internally deposited radionuclides. When added, the penetrating and internal collective dose equivalent values are less than the collective dose value of total effective dose equivalent. This is due to reporting errors from some of the DOE sites. Of the total external penetrating dose equivalent of 2,080 person-rem (20.80 person-Sv), 1,737 person-rem (17.37 person-Sv (84%)) were attributable to beta-gamma radiation and 343 person-rem (3.43 person-Sv (16%)) were attributable to neutron radiation. Neutron radiation contributed the highest percentage (30%) of the total penetrating dose equivalent at general research facilities. The total shallow dose reported to have been received was 2,643 person-rem (26.43 person-Sv). Relative to the total penetrating dose equivalent, the total shallow dose equivalent was greatest at fuel/uranium enrichment and weapons fabrication and testing facilities, where the shallow dose equivalent exceeded the penetrating dose equivalent by a factors of 2.6 and 1.7, respectively. 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 1987a), the penetrating dose equivalents are of the most concern regarding health effects. Collective extremity dose equivalents were 2,252 person-rem (22.52 person-Sv) to the hand and arm and 639 person-rem (6.39 person-Sv) to the foot and leg. Exposure of the hand and arm accounted for 78% of the total extremity collective dose while foot and leg exposure accounted for 22% of the overall extremity exposure. The total extremity collective dose equivalent exceeded the total penetrating collective dose equivalent by 8% (172 person-rem (1.72 person-Sv)).

A detailed comparison of the dose equivalent quantities by sex, age range, occupation, and facility type can be found in Section 5.0 of this report. The magnitude of the postulated health effects from radiation doses received at DOE facilities is discussed in Section 7.0 of this report.

4.7 EVALUATION OF TRENDS

Doses received by DOE and DOE contractor employees and visitors have decreased dramatically over the last several years (see Table 4.7). For example, in 1985 the collective dose equivalent received by employees and visitors was 8,684 person-rem (86.84 person-Sv); in 1991, this value was

TABLE 4.13. Dose Equivalent by Dose-Equivalent Type (person-rem)[a]

Facility Type	Total Effective Dose Equivalent	Internal	Penetrating			Shallow	Extremity	
			Total	Beta-Gamma	Neutron		Arm & Hand	Leg & Foot
Accelerator	156	18	137	119	19	116	100	51
Fuel/Uran. Enrich.	39	3	36	35	1	94	48	24
Fuel Fab.	55	0	55	54	0	58	7	1
Fuel Process.	204	18	187	157	30	285	107	9
Maintenance & Support	423	99	311	250	60	405	296	127
Reactor	339	5	334	328	6	361	133	27
Research, Gen.	441	59	340	237	103	309	471	131
Research, Fusion	7	0	6	6	0	6	0	6
Waste Proc./Mgmt.	128	19	107	77	30	121	212	88
Weapons Fab. & Testing	966	607	361	308	53	621	764	148
Other	214	10	203	163	41	263	113	32
Total	2,944	839	2,080	1,737	343	2,643	2,252	639

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

2,944 person-rem (29.44 person-Sv). Some of this decrease 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. Previous to the 1987 reporting period, 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 summing the products. However, the majority of the decrease is attributable to other factors, such as the reduction of production tasks at DOE facilities and an increased emphasis on ALARA programs.

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 and visitors at Richland was 2,477 person-rem (24.77 person-Sv); in 1991, this value dropped by 89% to 275 person-rem (2.75 person-Sv). This decrease was primarily the result of both changes in the type of work performed and facility closures. Decreases also occurred from 1986 to 1991 at the Oak Ridge (-71%) and Savannah River (-69%) field organizations.

The 1991 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 4.12 illustrates the recent dramatic decrease in average annual dose equivalent per individual monitored who received a measurable exposure. Table 4.14 lists similar data for each facility type. Table 4.15 lists collective dose equivalent by facility type for the years 1980 through 1991.

One correlative effect of lower average individual dose equivalents is fewer employees who exceed various dose-equivalent levels. Figure 4.13 illustrates the number of employees who received dose equivalents greater than 0.5 rem (5 mSv), 1.0 rem (10 mSv), or 2.0 rem (20 mSv) from 1980 to 1991. As indicated in the figure, the numbers decreased significantly during the 1988-1991 time period. As a result, fewer employees are being exposed to doses that are significant fractions of the annual dose limit.

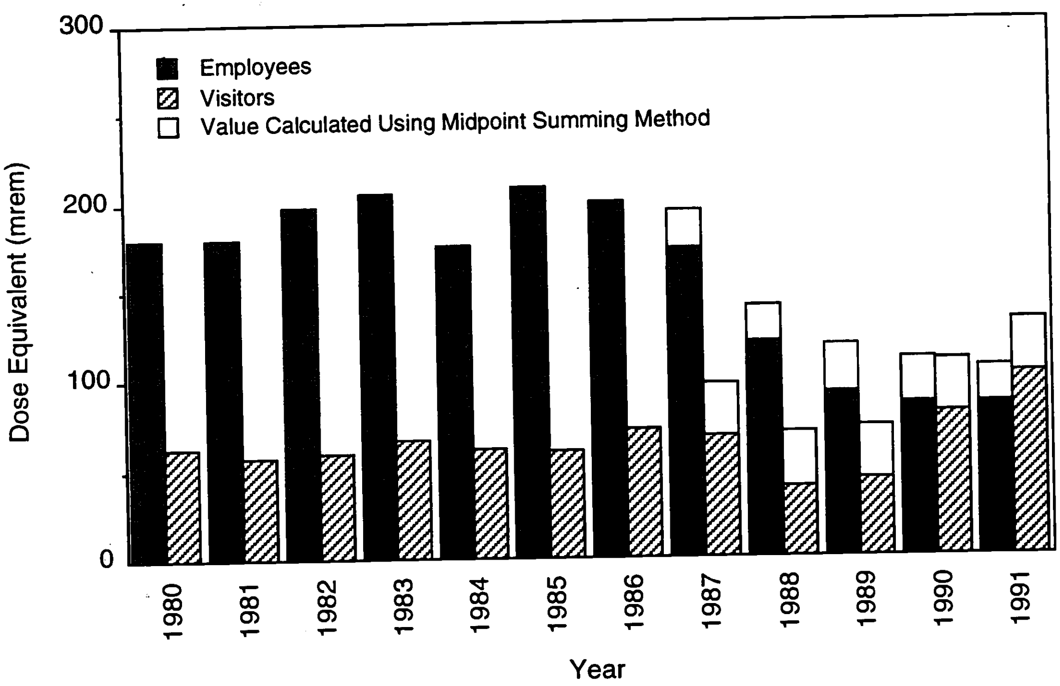

FIGURE 4.12. Average Dose Equivalent per Individual Who Received a Measurable Exposure, 1980-1991

TABLE 4.14. Average Dose Equivalent per Individual Who Received a Measurable Exposure by Facility Type,[a] 1980-1991 (mrem)

Year	Reactor	Fuel Fab.	Fuel Proc.	Uran. Enrichment	Weapons Fab. & Test.	Gen. Research	Accelerator	Other	Visitors	DOE Offices	All Facilities
1980	278	236	442	117	120	120	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
1989	92	68	259	28	105	97	116	69	43	21	84
1990	61	84	170	28	46	90	87	65	81	16	72
1990[b]	68	87	176	26	112	102	87	68	80	22	85
1991	52	79	119	27	53	85	89	59	93	12	67
1991[b]	52	78	124	21	107	97	101	64	102	12	84

(a) Throughout this report there may be minor variations in collective dose-equivalent values because of rounding. 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 1987-1989.
(b) Total effective dose equivalent for 1990. All other data in this table describe whole-body penetrating dose exposure.

TABLE 4.15. Collective Dose Equivalent[a] by Facility Type,[b] 1980-1991 (person-rem)

Year	Reactor	Fuel Fab.	Fuel Proc.	Uran. Enrichment	Weapons Fab. & Testing	Gen. Research	Accelerator	Other	Visitors	DOE Offices	All Facilities
1980	1,185	323	1,047	156	869	1,611	412	1,773	619	29	8,024
1981	1,270	267	592	62	982	1,535	348	1,813	571	38	7,483
1982	1,612	411	735	30	1,056	1,676	254	1,293	686	26	7,879
1983	1,781	434	726	31	1,399	1,662	273	1,522	300	30	8,158
1984	1,620	264	515	28	1,672	1,736	248	1,944	368	30	8,423
1985	1,716	265	574	26	1,851	1,484	262	2,025	461	20	8,684
1986	1,391	356	598	39	1,802	1,357	232	2,117	554	20	8,465
1987	1,007	271	426	41	1,028	769	169	2,260	373	8	6,353
1988	366	171	374	32	767	554	194	1,195	245	5	3,901
1989	329	77	491	41	512	508	184	928	303	3	3,375
1990	183	59	282	47	197	398	127	777	471	3	2,545
1990[c]	184	63	292	57	839	439	127	849	472	4	3,327
1991	125	29	187	33	341	326	121	422	383	2	2,079
1991[c]	130	29	205	36	946	397	139	487	453	2	2,944

(a) Throughout this report there may be minor variations in collective dose-equivalent values because of rounding.
(b) Beginning 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 1987-1989.
(c) Total effective dose equivalent for 1990. All other data in this table describe whole-body penetrating dose exposure.

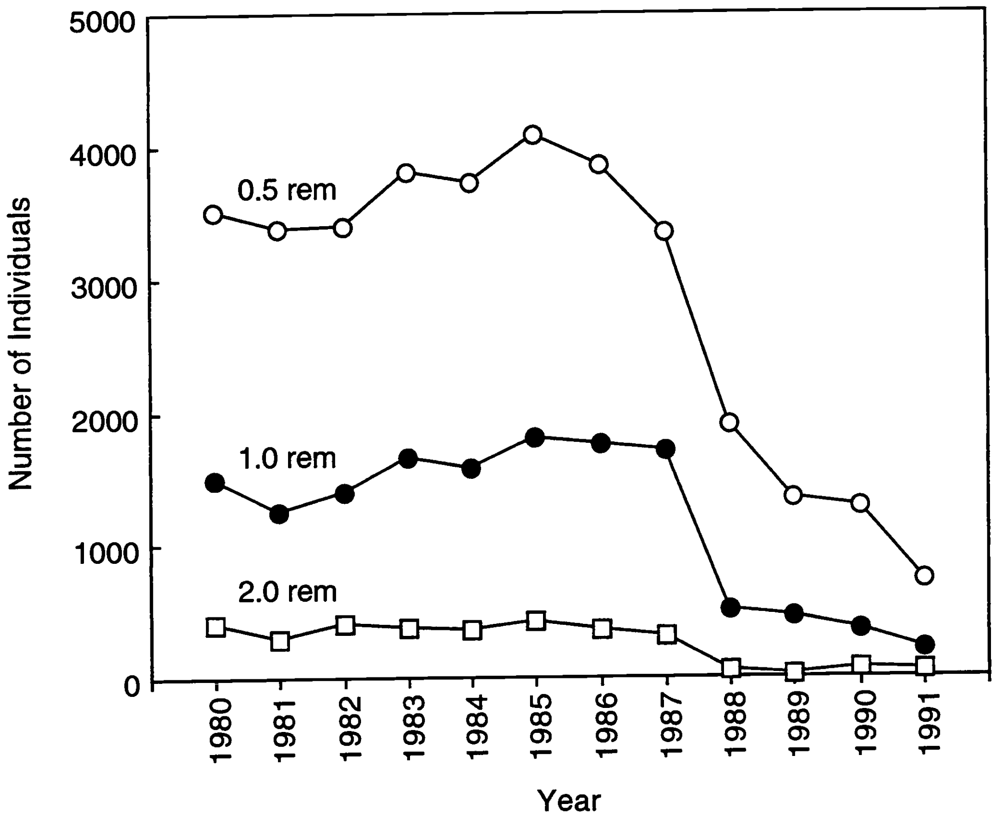

FIGURE 4.13. Number of Employees Who Received Dose Equivalents Greater Than 0.5 rem, 1 rem, and 2 rem, 1980-1991

5.0 ADDITIONAL DOSE REPORTING QUANTITIES

As mentioned earlier, this report is the second to report the complete data for all dose reporting quantities required in DOE Order 5484.1. These dose reporting quantities include total effective dose equivalent, annual internal dose equivalent, arm and hand extremity dose equivalent, and leg and foot extremity dose equivalent. This section will highlight and compare these dose quantities to the whole-body penetrating dose equivalent quantity.

The total effective dose equivalent quantity is the sum of the whole-body penetrating dose equivalent and annual internal dose equivalent. In past annual reports previous to 1990, the whole-body penetrating dose equivalent quantity was the main one reported and analyzed. Previous to 1990, only internal depositions that exceeded 50% of the annual standard were reported.

5.1 COMPARISON OF TOTAL EFFECTIVE DOSE EQUIVALENT, PENETRATING DOSE EQUIVALENT, AND INTERNAL DOSE EQUIVALENT

Figures 5.1 through 5.9 highlight the total effective dose equivalent and internal dose equivalent quantities. These quantities are compared to the penetrating dose equivalent primarily reported in the past. The average value for these quantities is shown for the age, sex, occupation, and facility categories described in Section 4.0.

5.1.1 Comparison by Age Range and Sex

Comparisons of total effective dose equivalent, penetrating dose equivalent, and internal dose equivalent by age range and sex are shown in Figures 5.1 through 5.3. Figure 5.1 illustrates the average values for the dose equivalent quantities by age range for all DOE and DOE contractor employees and visitors. The average quantities are shown in Figures 5.2 and 5.3 for male and female employees and visitors, respectively. Average total effective dose equivalent and penetrating dose equivalent values are generally highest for employees and visitors in the age ranges 30 to 40 and 50 to 65 and greater. Older male employees have much higher average internal dose equivalent values due to past internal uptakes of radioactive material. A similar trend is seen for internal dose to female employees. The higher internal dose averages for older employees accounts for the increase in

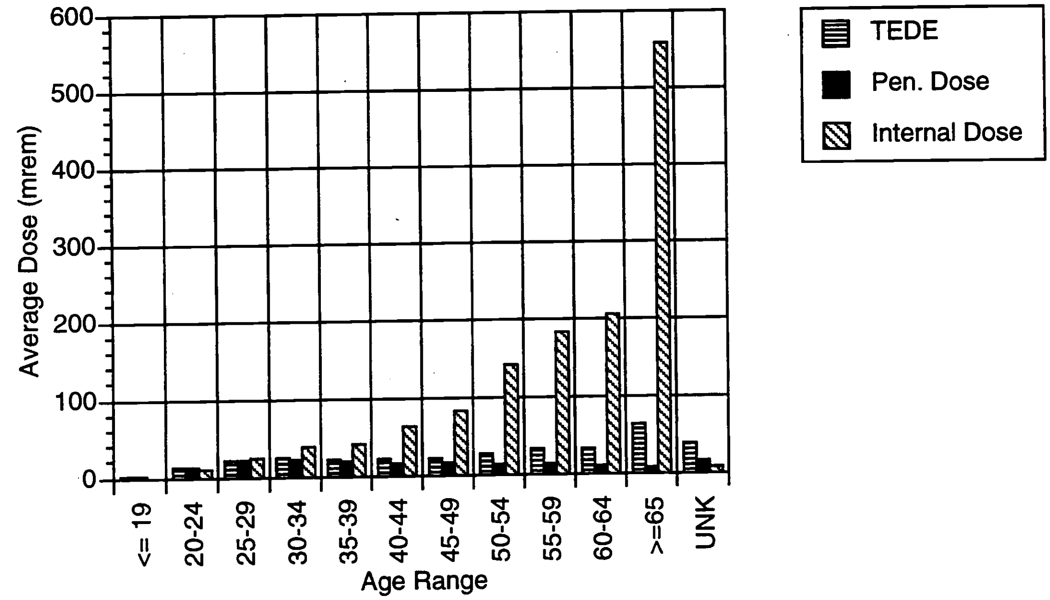

FIGURE 5.1. Comparison of Average Total Effective Dose Equivalent, Average Penetrating Dose Equivalent, and Average Internal Dose Equivalent by Age Range for All Employees and Visitors, 1991

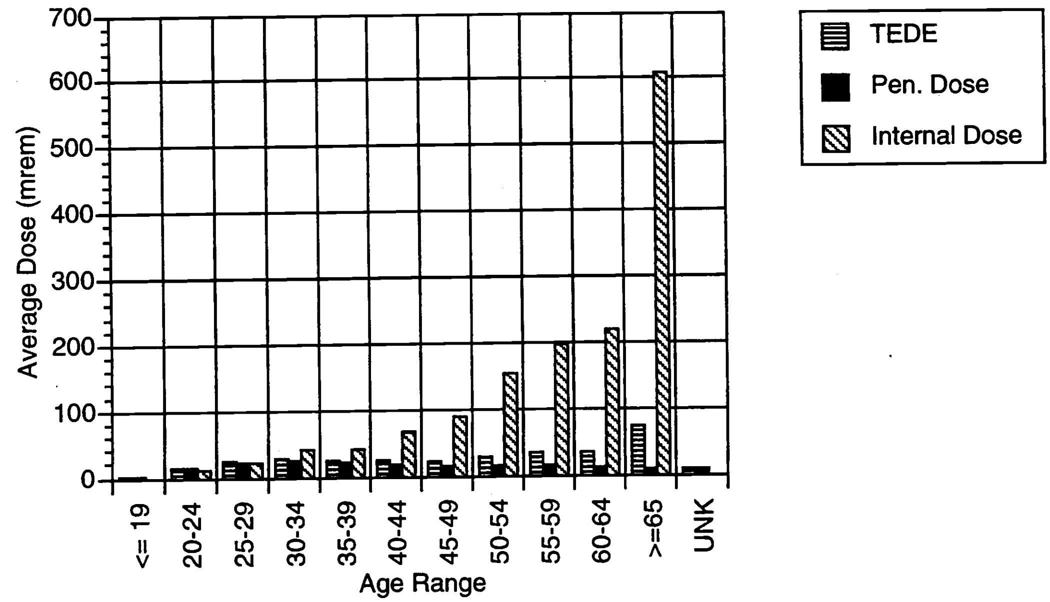

FIGURE 5.2. Comparison of Average Total Effective Dose Equivalent, Average Penetrating Dose Equivalent, and Average Internal Dose Equivalent by Age Range for Male Employees and Visitors, 1991

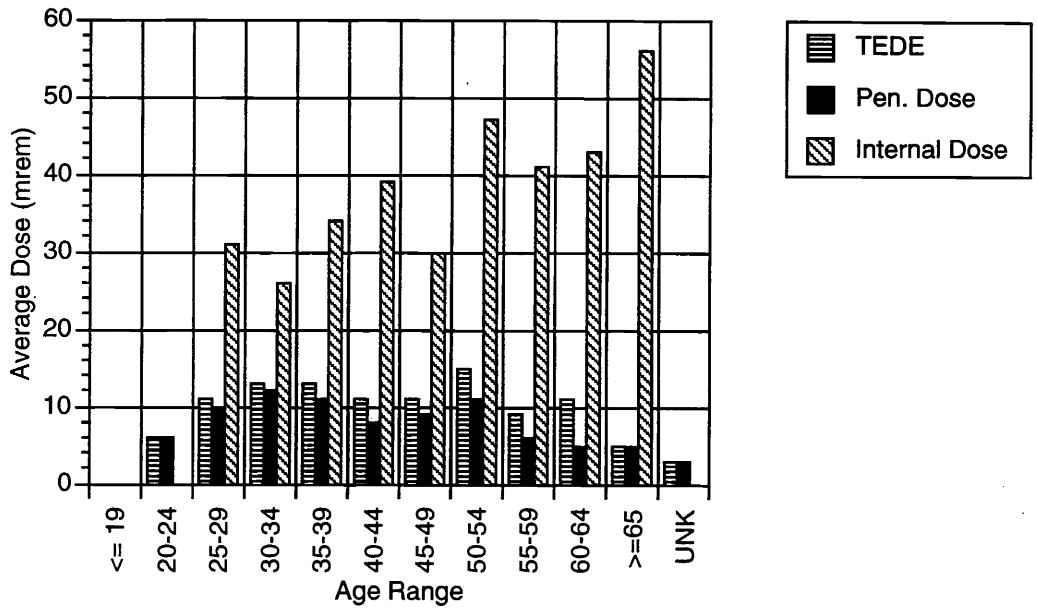

FIGURE 5.3. Comparison of Average Total Effective Dose Equivalent, Average Penetrating Dose Equivalent, and Average Internal Dose Equivalent by Age Range for Female Employees and Visitors, 1991

total effective dose equivalent for older age groups. The penetrating dose equivalent average generally decreases for all employees over the age of 40.

5.1.2 Comparison by Occupation and Sex

Figure 5.4 illustrates the average dose equivalent quantities by occupation for all employees. Production workers had the highest overall average total effective dose equivalent (60 mrem (0.60 mSv)) and penetrating dose equivalent (42 mrem (0.42 mSv)). Scientists had the highest overall average internal dose equivalent (108 mrem (1.08 mSv)) for known occupation categories. The Unknown category had the highest overall average internal dose equivalent for all cartegories (147 mrem (1.47 mSv)). Employees classified as agricultural workers had the lowest average total effective, penetrating, and internal dose equivalent values (< 1 mrem (< 0.01 mSv)). Similar data trends are shown for male and female workers in Figures 5.5 and 5.6, respectively.

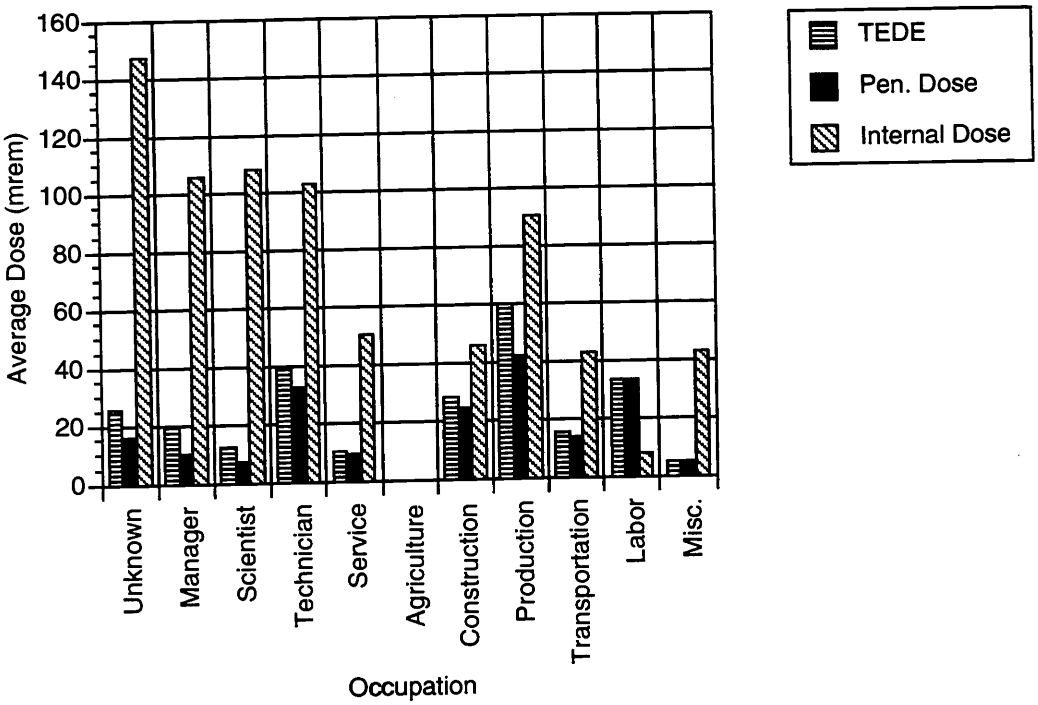

FIGURE 5.4. Comparison of Average Total Effective Dose Equivalent, Average Penetrating Dose Equivalent, and Average Internal Dose Equivalent by Occupation for All Employees and Visitors, 1991

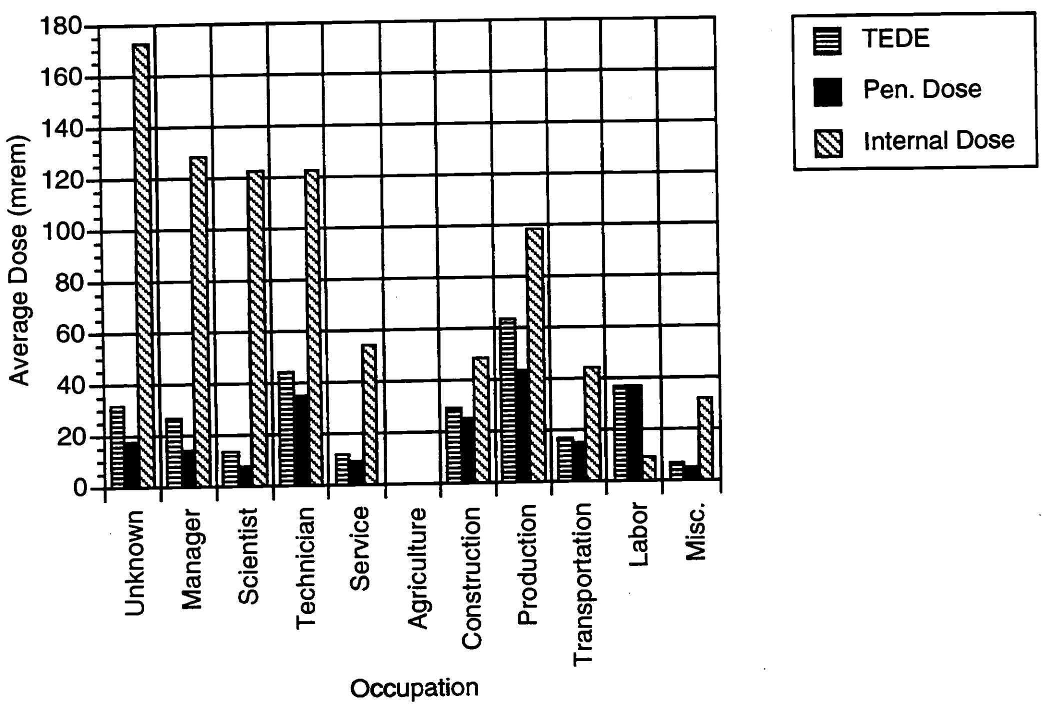

FIGURE 5.5. Comparison of Average Total Effective Dose Equivalent, Average Penetrating Dose Equivalent, and Average Internal Dose Equivalent by Occupation for Male Employees and Visitors, 1991

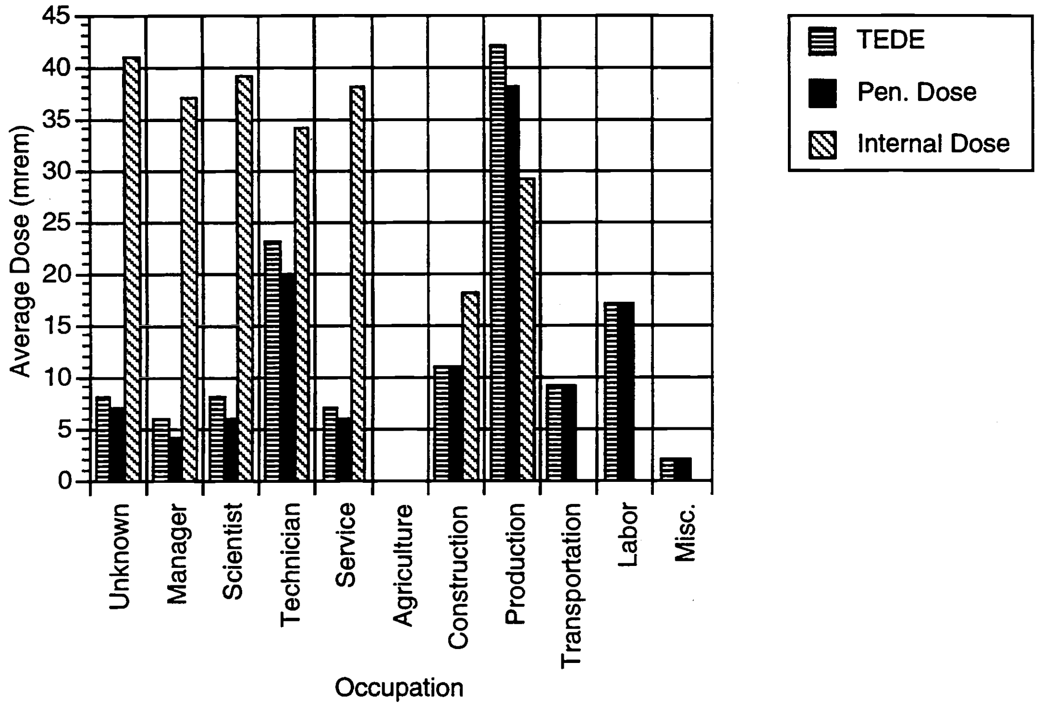

FIGURE 5.6. Comparison of Average Total Effective Dose Equivalent, Average Penetrating Dose Equivalent, and Average Internal Dose Equivalent by Occupation for Female Employees and Visitors, 1991

5.1.3 Comparison by Facility Type and Sex

Average dose equivalent values are shown for DOE facility types in Figures 5.7 through 5.9. Data shown for all employees in Figure 5.7 reveal that those working at fuel processing facilities received the highest average total effective dose equivalent (57 mrem (0.57 mSv)) and penetrating dose equivalent (56 mrem (0.56 mrem)). Employees at general research facilities received the highest average internal dose equivalent (156 mrem (1.56 mSv)). Fuel and uranium processing employees received the lowest average total effective (4 mrem (0.04 mSv)) and penetrating (4 mrem (0.04 mSv)) dose equivalent values. Fusion research and fuel fabrication employees had the lowest internal dose equivalent values (< 1 mrem (< 0.01 mSv)). Accelerator facility employees had the highest average internal dose (1636 mrem (16.36 mSv)). This high value was due to one individual (out of 11 reported) who had an internal dose equivalent exceeding 5 rem (50 mSv). The individual's exposure was due to an uptake of ^{238}Pu in 1971. The other individuals had internal dose equivalent values of

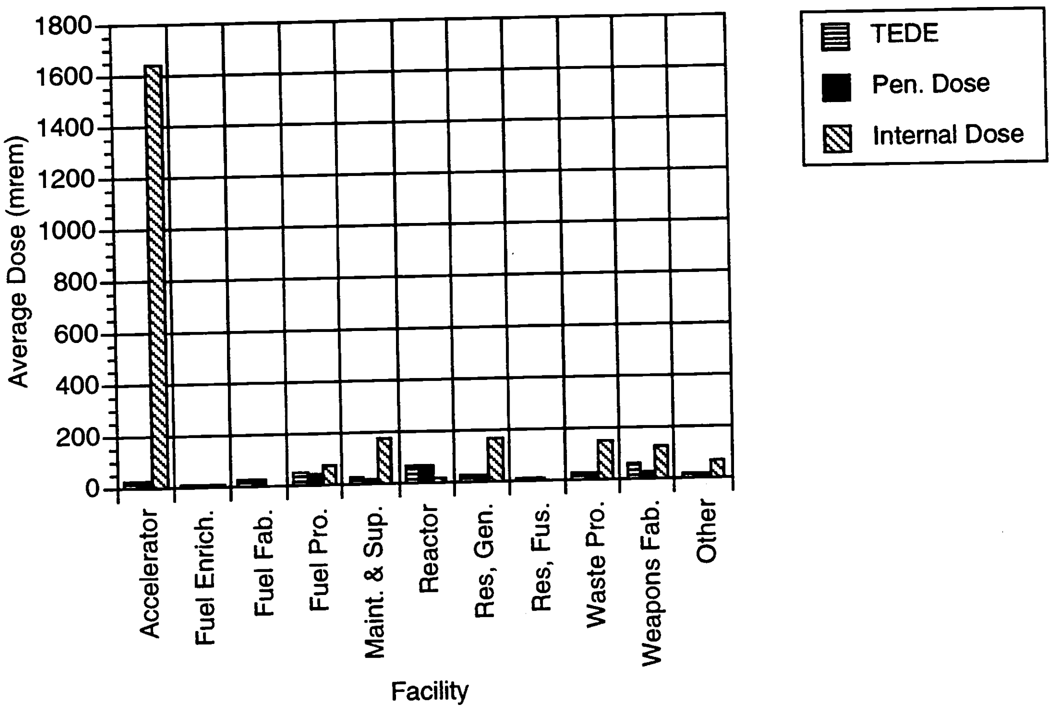

FIGURE 5.7. Comparison of Average Total Effective Dose Equivalent, Average Penetrating Dose Equivalent, and Average Internal Dose Equivalent by Facility Type for All Employees and Visitors, 1991

less than 100 mrem (1.00 mSv). Again, similar data trends were observed for the male and female components of the DOE population (Figures 5.8 and 5.9).

5.2 COMPARISON OF PENETRATING DOSE EQUIVALENT, HAND AND ARM EXTREMITY DOSE EQUIVALENT, AND FOOT AND LEG EXTREMITY DOSE EQUIVALENT

Figures 5.10 through 5.18 highlight the hand and arm extremity dose equivalent and foot and leg dose equivalent quantities. These quantities are compared to the whole-body penetrating dose equivalent. Again, the average value for these quantities is shown for age, sex, occupation, and facility categories.

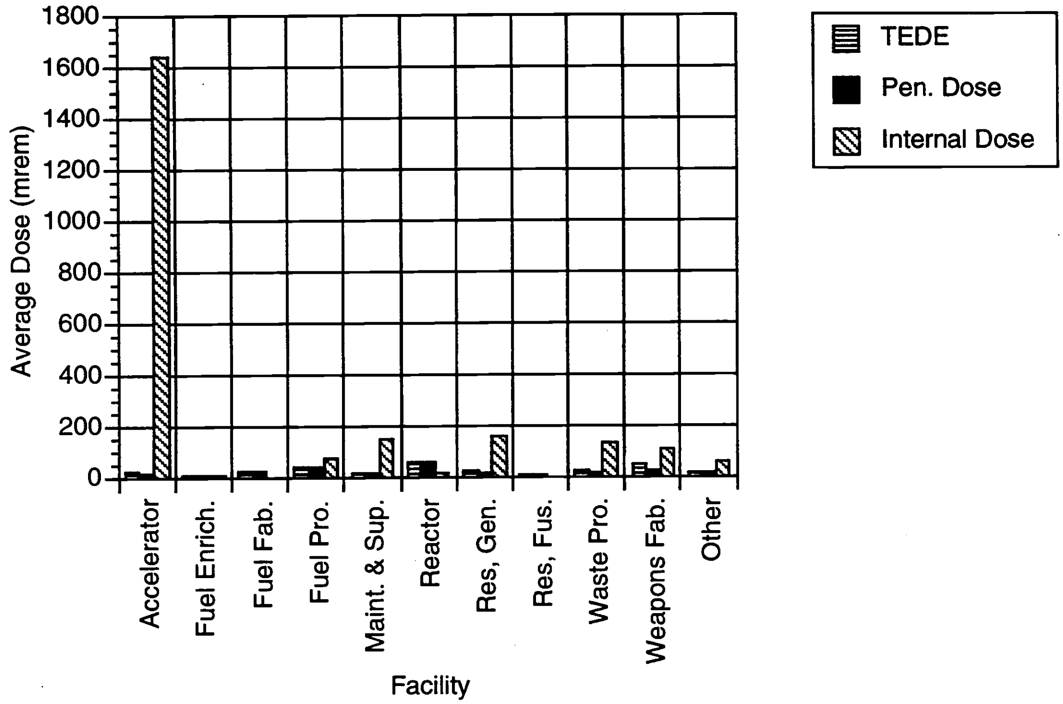

FIGURE 5.8. Comparison of Average Total Effective Dose Equivalent, Average Penetrating Dose Equivalent, and Average Internal Dose Equivalent by Facility Type for Male Employees and Visitors, 1991

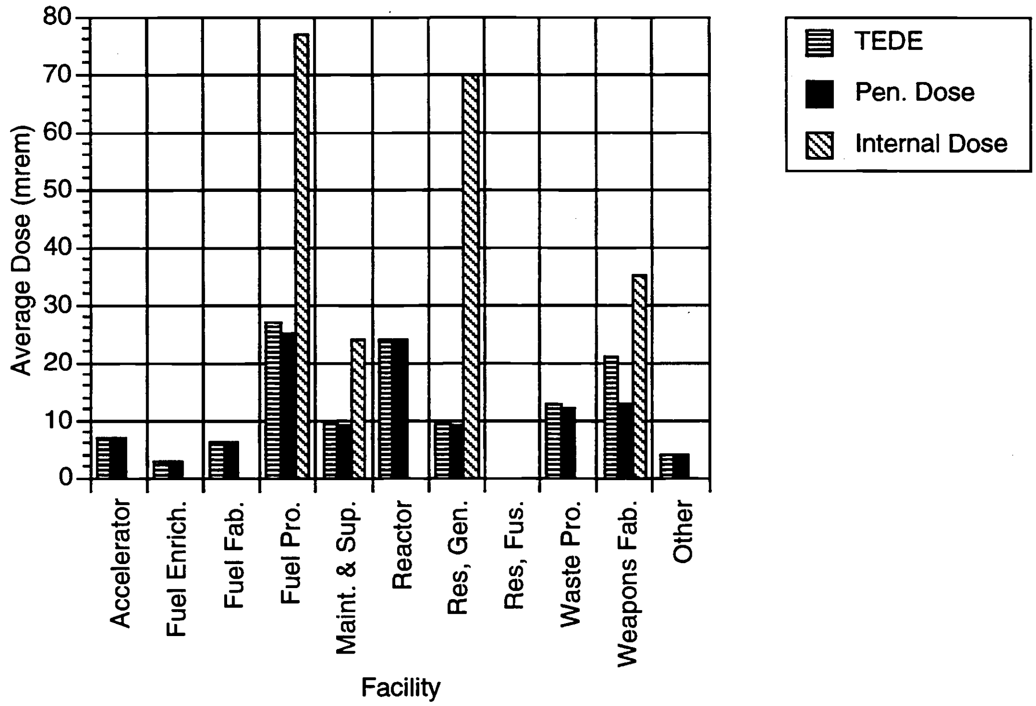

FIGURE 5.9. Comparison of Average Total Effective Dose Equivalent, Average Penetrating Dose Equivalent, and Average Internal Dose Equivalent by Facility Type for Female Employees and Visitors, 1991

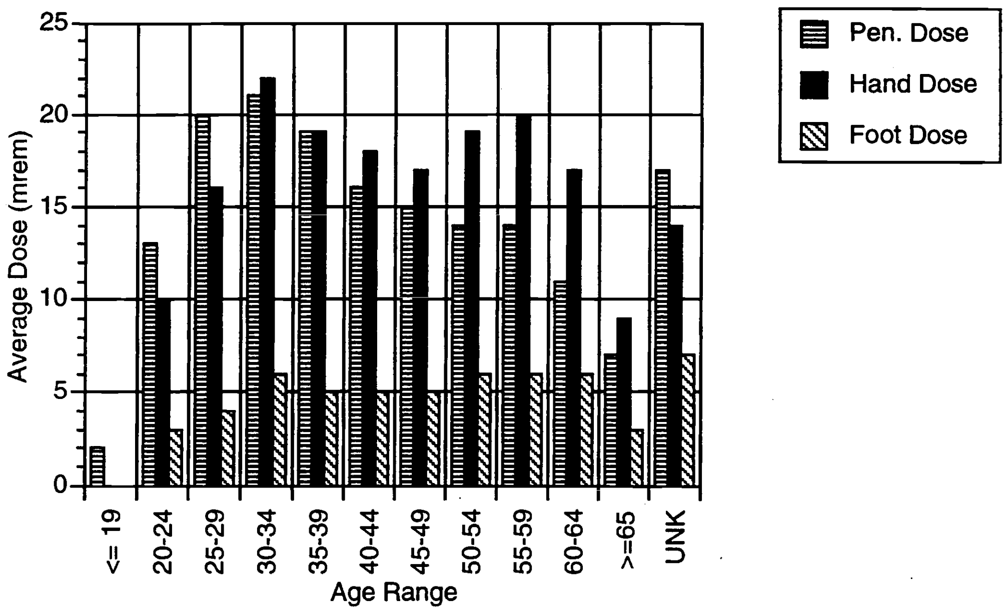

FIGURE 5.10. Comparison of Average Penetrating Dose Equivalent, Average Hand and Arm Extremity Dose Equivalent, and Average Foot and Leg Extremity Dose Equivalent by Age Range for All Employees and Visitors, 1991

5.2.1 Comparison by Age Range and Sex

Average hand and foot extremity dose equivalent values were highest for employees between the ages of 30 and 60. There is very little variation between the data shown for all employees in Figure 5.10 and male and female employees shown in Figures 5.11 and 5.12, respectively. Also, there is little variation in the extremity exposure of the maximally exposed age groups. The average hand extremity dose equivalent value was approximately 18 mrem (0.18 mSv), and the average foot extremity dose equivalent value was approximately 5 mrem (0.05 mrem).

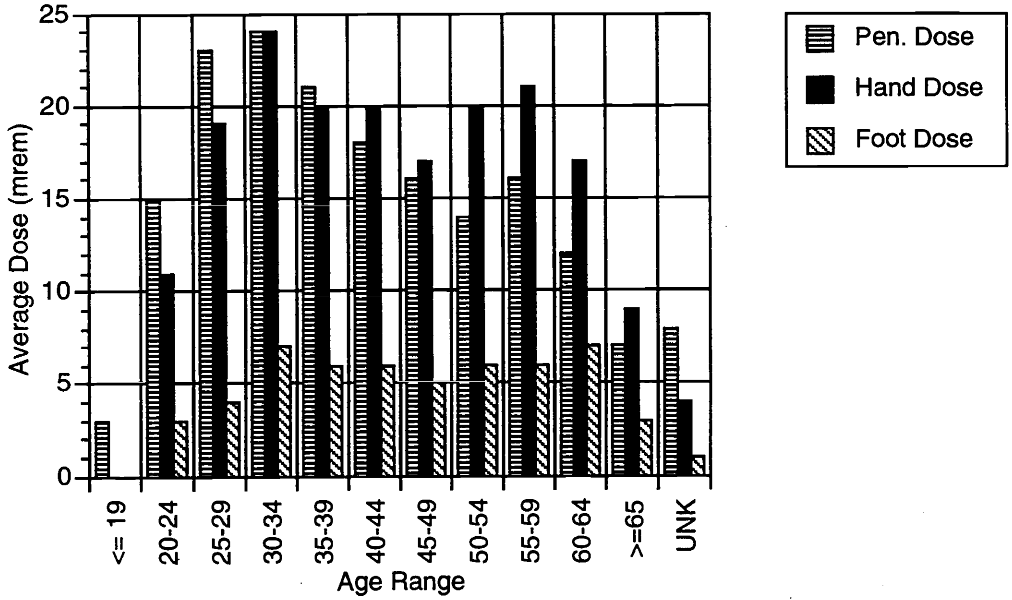

FIGURE 5.11. Comparison of Average Penetrating Dose Equivalent, Average Hand and Arm Extremity Dose Equivalent, and Average Foot and Leg Extremity Dose Equivalent by Age Range for Male Employees and Visitors, 1991

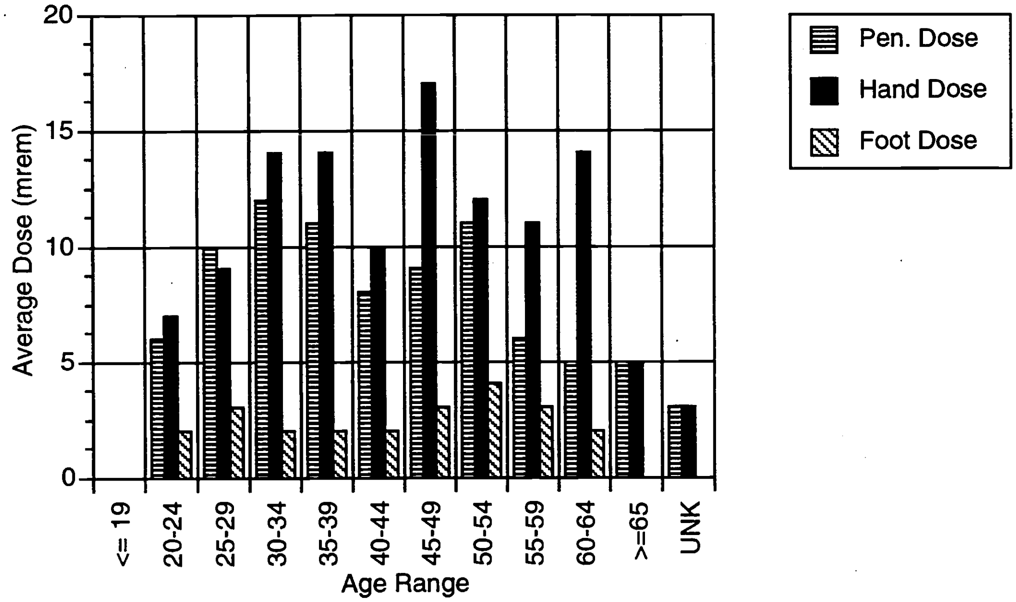

FIGURE 5.12. Comparison of Average Penetrating Dose Equivalent, Average Hand and Arm Extremity Dose Equivalent, and Average Foot and Leg Extremity Dose Equivalent by Age Range for Female Employees and Visitors, 1991

5.2.2 Comparison by Occupation and Sex

Figure 5.13 illustrates that production employees received the highest average hand extremity dose equivalent (66 mrem (0.66 mSv)) and foot extremity dose equivalent (21 mrem (0.21 mSv)). Employees in the algirulture occupation category received the lowest average hand extremity dose equivalent (< 1 mrem (< 0.01 mSv)) and foot extremity dose equivalent (< 1 mrem (< 0.01 mSv)). Figures 5.14 and 5.15 illustrate the similar trends for the male and female employees, respectively.

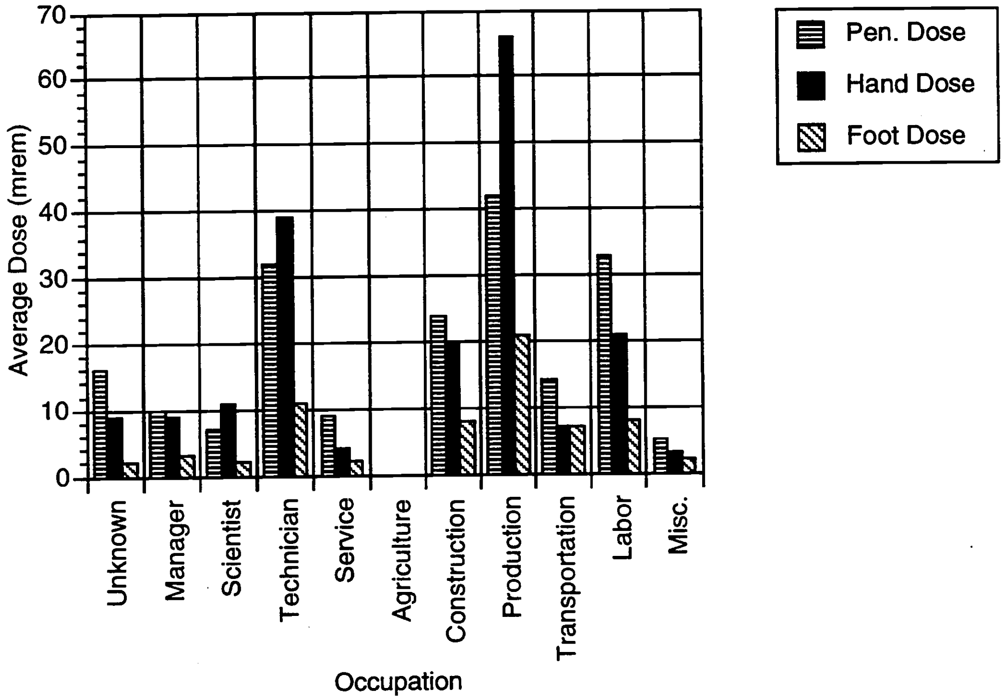

FIGURE 5.13. Comparison of Average Penetrating Dose Equivalent, Average Hand and Arm Extremity Dose Equivalent, and Average Foot and Leg Extremity Dose Equivalent by Occupation for All Employees and Visitors, 1991

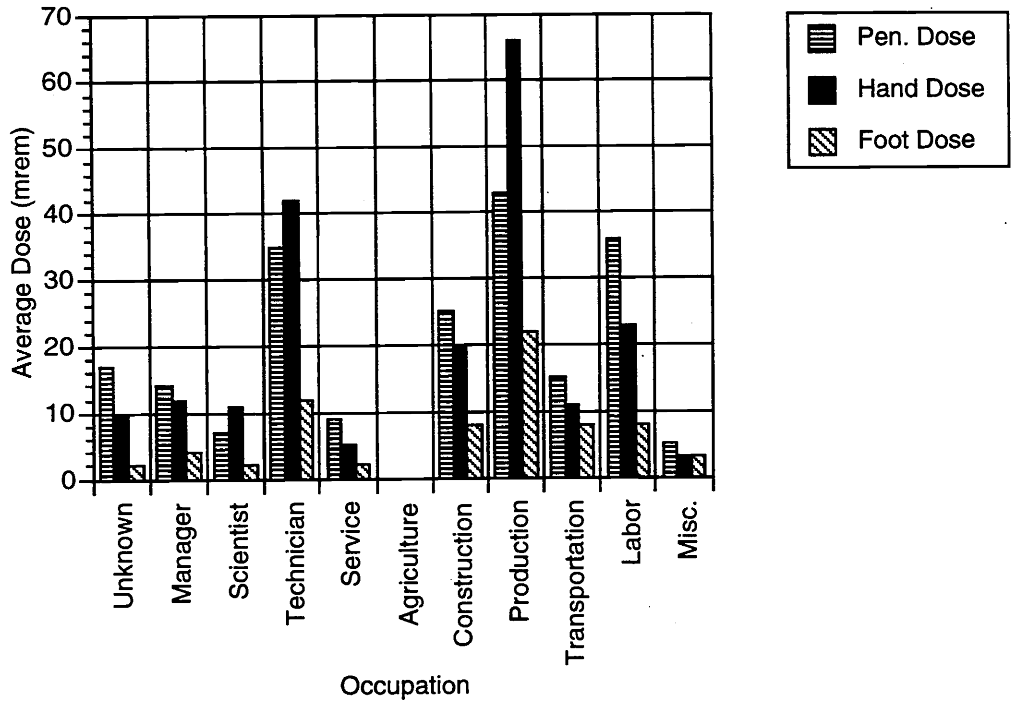

FIGURE 5.14. Comparison of Average Penetrating Dose Equivalent, Average Hand and Arm Extremity Dose Equivalent, and Average Foot and Leg Extremity Dose Equivalent by Occupation for Male Employees and Visitors, 1991

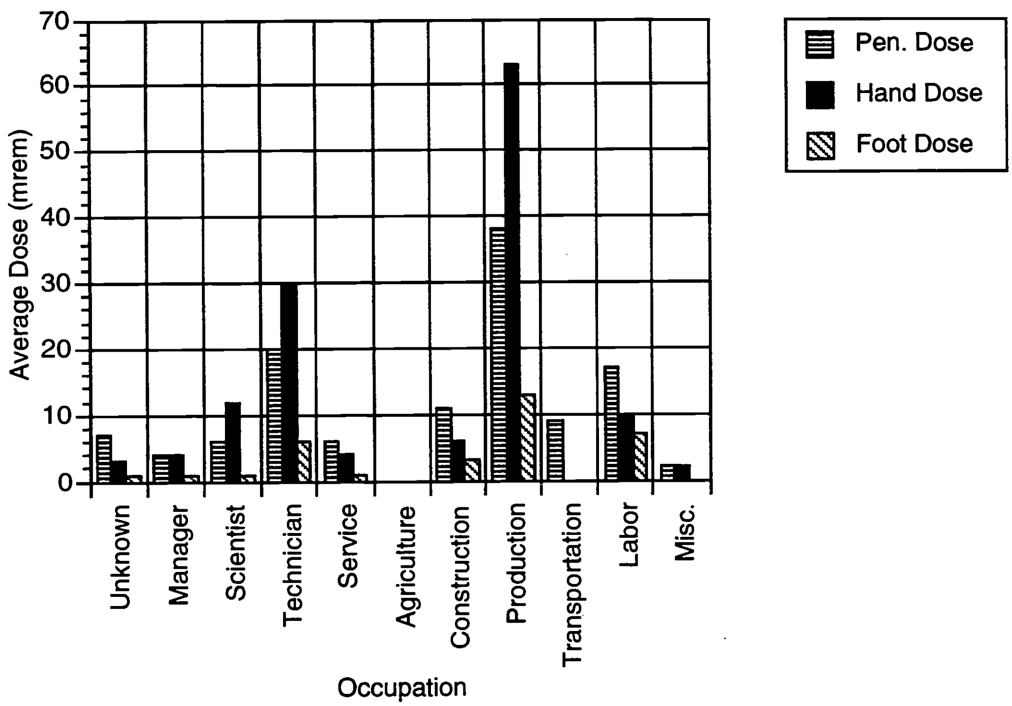

FIGURE 5.15. Comparison of Average Penetrating Dose Equivalent, Average Hand and Arm Extremity Dose Equivalent, and Average Foot and Leg Extremity Dose Equivalent by Occupation for Female Employees and Visitors, 1991

5.2.3 Comparison by Facility Type and Sex

As shown in Figure 5.16, individuals employed in weapons fabrication facilities received the highest average hand extremity dose equivalent (37 mrem (0.37 mSv)) and waste processing employees received the highest foot extremity dose equivalent (14 mrem (0.14 mSv)). Employees at fusion research facilities received the lowest average hand extremity dose equivalent (< 1 mrem (< 0.01 mSv)) and foot extremity dose equivalent (< 1 mrem (< 0.01 mSv)). Again, similar trends were seen for the male and female components of the population (Figures 5.17 and 5.18).

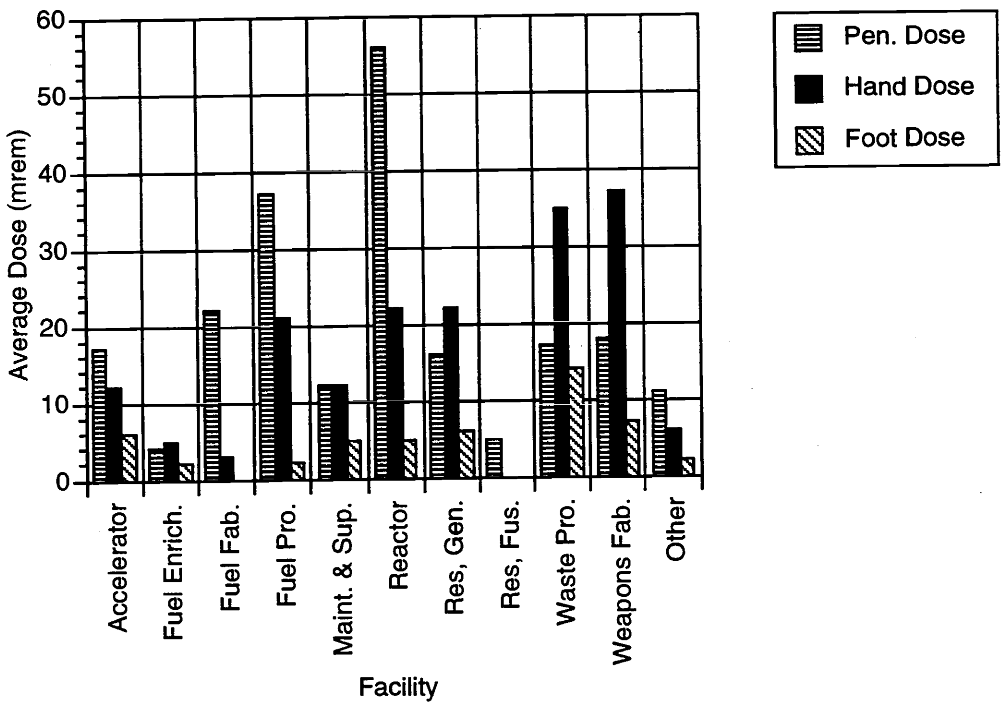

FIGURE 5.16. Comparison of Average Penetrating Dose Equivalent, Average Hand and Arm Extremity Dose Equivalent, and Average Foot and Leg Extremity Dose Equivalent by Facility Type for All Employees and Visitors, 1991

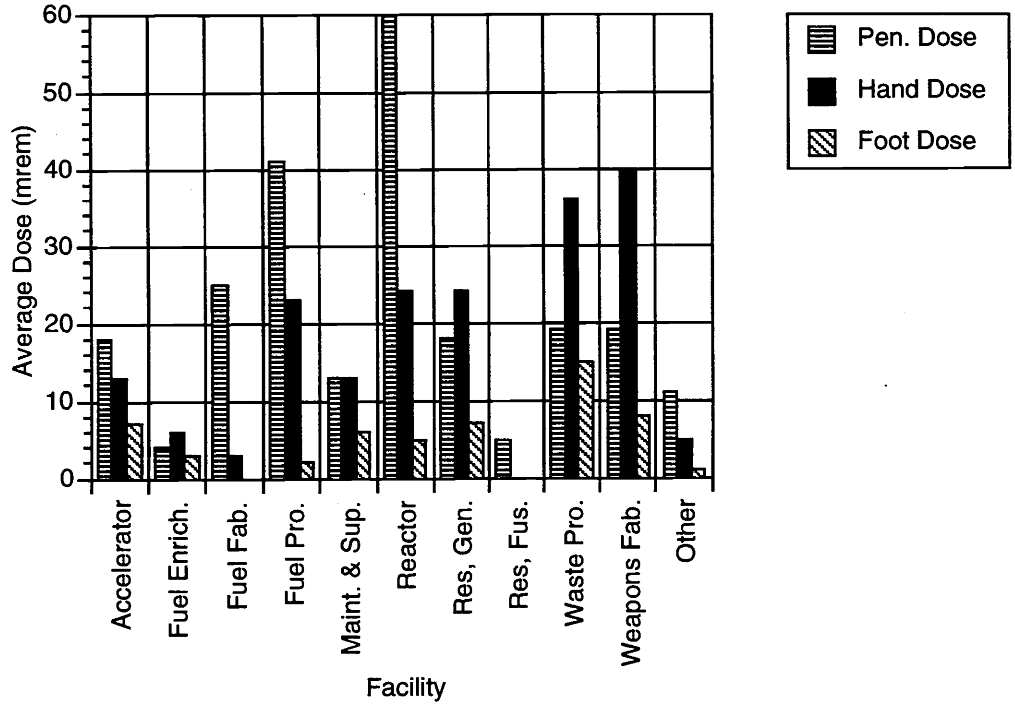

FIGURE 5.17. Comparison of Average Penetrating Dose Equivalent, Average Hand and Arm Extremity Dose Equivalent, and Average Foot and Leg Extremity Dose Equivalent by Facility Type for Male Employees and Visitors, 1991

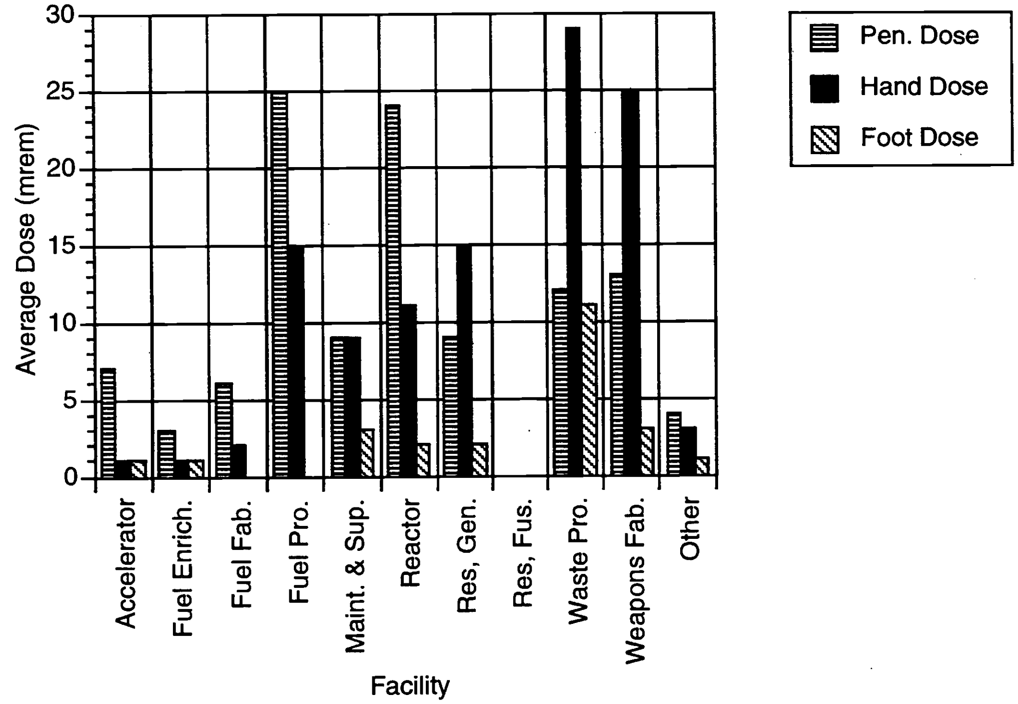

FIGURE 5.18. Comparison of Average Penetrating Dose Equivalent, Average Hand and Arm Extremity Dose Equivalent, and Average Foot and Leg Extremity Dose Equivalent by Facility Type for Female Employees and Visitors, 1991

6.0 REPORTABLE RADIATION EXPOSURE INCIDENTS

In DOE Order 5484.1, the DOE has established criteria for classifying, reporting, and investigating radiation exposure incidents. 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 must be reported to DOE Headquarters immediately, and an investigation of the incident is conducted by a DOE Headquarters or field organization board. A Type B occurrence must be reported to DOE Headquarters within 72 hours, and an investigation of the incident is conducted by a DOE board appointed by the head of the field organization. A Type C incident is required to be reported by memo, and an investigation is conducted by DOE contractor personnel when their operations are involved, or by DOE personnel when Federal operations are involved.

Table 6.1 lists the criteria for classifying incidents involving radiation exposures at DOE facilities. Descriptions of such incidents are normally reported to the System Safety Development Center following submittal of the investigation report. No such incidents were reported to have occurred in calendar year 1991.

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

	Dose Criteria for Incident Type (rem)		
Type of Exposure	A[a]	B[b]	C[b]
Whole-body	25	5	3
Skin of the whole-body	75	15	5
Thyroid	N/A	15	5
Forearms	150	30	10
Hands and feet	375	75	25
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 doses received by DOE and DOE contractor employees. Section 4.0 of this report presented summaries of the radiation doses received by DOE and DOE contractor employees. Although the average doses were much lower than the DOE limits (indicating the impact of ALARA programs and changing missions at many DOE sites), comparison of employee doses to risks is appropriate for evaluating 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 1991 to risks based on published radiation risk coefficients and compares the calculated risks to other risks incurred both inside and outside the workplace.

Important considerations in assessing the relative significance of the risk of radiation doses received at DOE facilities are 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 1991 (82 mrem (0.82 mSv)) was less than the average dose equivalent received by an individual from non-work-related sources.

Although low doses of radiation have not been demonstrated to increase the incidence of cancer or other diseases, risk estimates have been developed by extrapolating from known effects at high doses and high dose rates to hypothetical effects at low doses and low dose rates. 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 in 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

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	29
Nuclear Fuel Cycle	0.005
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.

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 data on Hiroshima and Nagasaki, where excess deaths were observed only at relatively high doses delivered over a very short period of time.

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 atomic 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 the age, sex, and risk projection model used; these estimates are based on acute exposures of at least 10 rem (100 mSv). 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 numbers of person-years of life lost based on the whole-body ionizing radiation doses received at DOE facilities in 1991. 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).

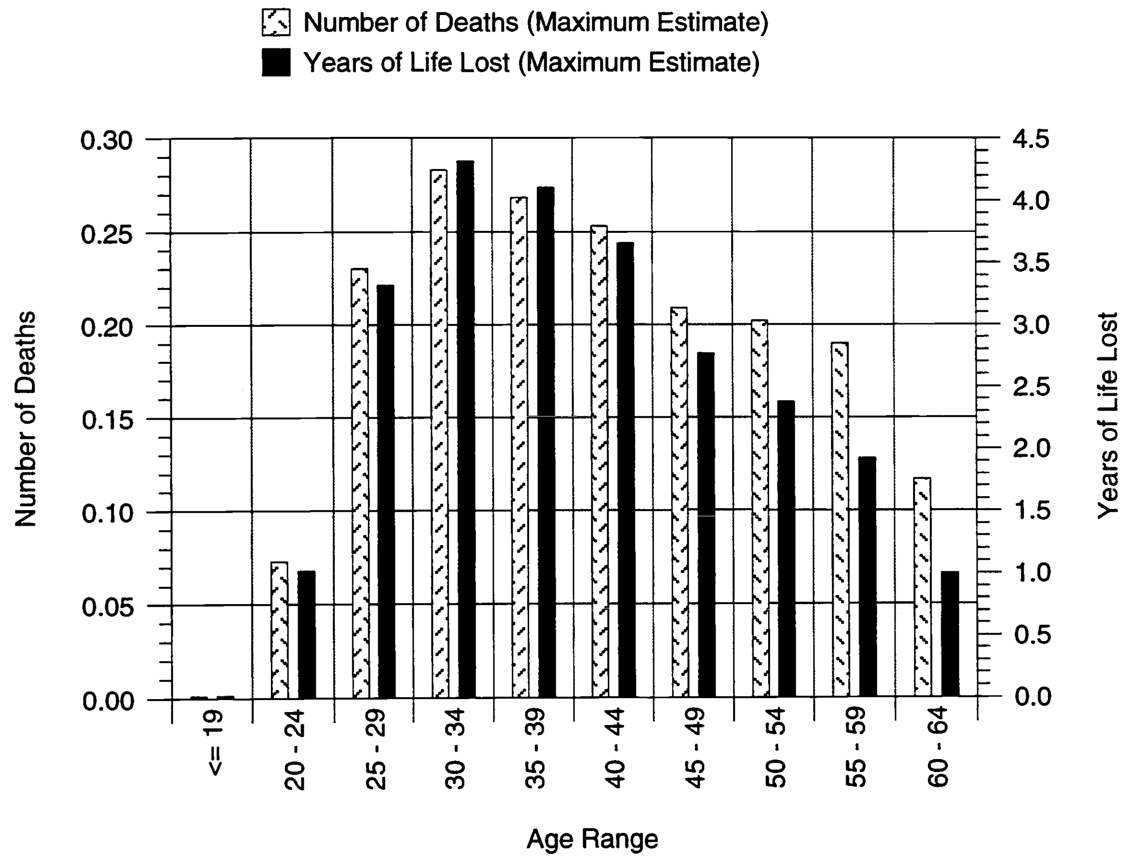

FIGURE 7.1. Estimated Maximum Number of Total Deaths and Years of Life Lost from Radiation Doses Received at DOE Facilities by Age Group in 1991—(The values indicated are maximum estimates; the actual values may be zero. See text for explanation.)

The values were calculated directly from the BEIR V risk equations and the doses received by employees and visitors at DOE facilities in 1989. 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. Figures 7.2 and 7.3 show the risk distribution by age range and sex. Because of their higher average dose, males in all age groups had higher risk values than females. Males between the ages of 30 and 44 had the highest estimated risk values.

Figures 7.4, 7.5, and 7.6 show risk values by facility type for all DOE/DOE employees, male emplyees, and female employees, respectively. The highest risk values were associated with weapons fabrication and testing facilities for male and female employees. The lowest risk values were obsrved at fusion research facilities. Similar risk trends were seen for male and female employees across all facility types.

Risk values are given by occupation type in Figures 7.7, 7.8, and 7.9. Again, the values for both sexes are shown followed by data for male and female employees. Technicians had the highest risk values for both sexes. Agriculture employees had the lowest values. Again, similar trends for both sex types were observed for all occupation types.

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 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.

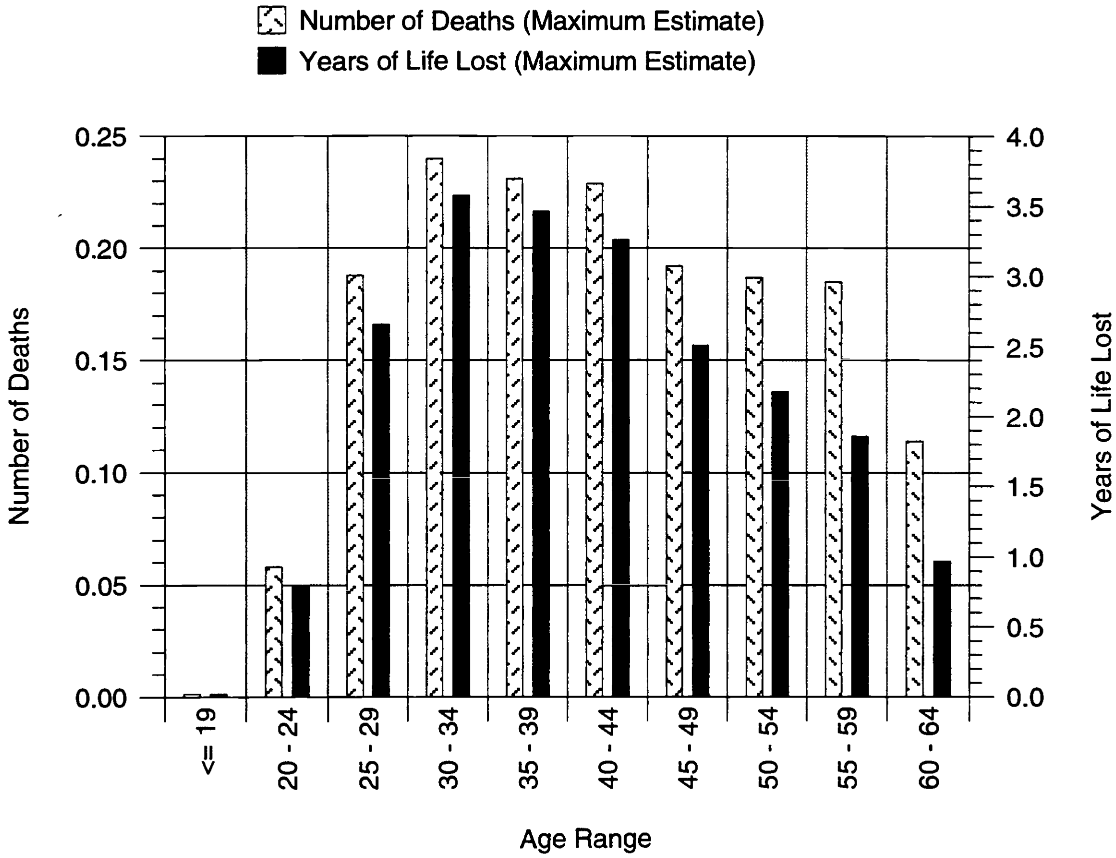

FIGURE 7.2. Estimated Maximum Number of Total Deaths and Years of Life Lost from Radiation Doses Received at DOE Facilities by Age Group for Male Employees in 1991—(The values indicated are maximum estimates; the actual values may be zero. See text for explanation.)

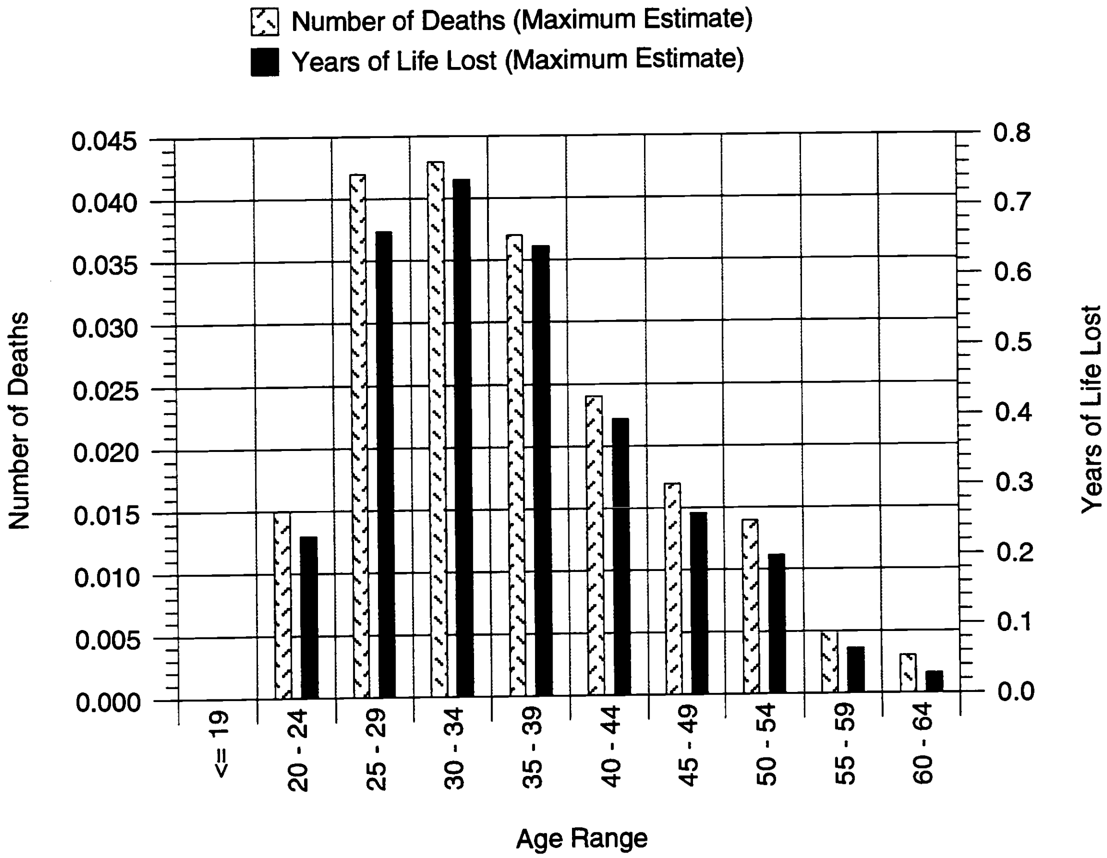

FIGURE 7.3. Estimated Maximum Number of Total Deaths and Years of Life Lost from Radiation Doses Received at DOE Facilities by Age Group for Female Employees in 1991—(The values indicated are maximum estimates; the actual values may be zero. See text for explanation.)

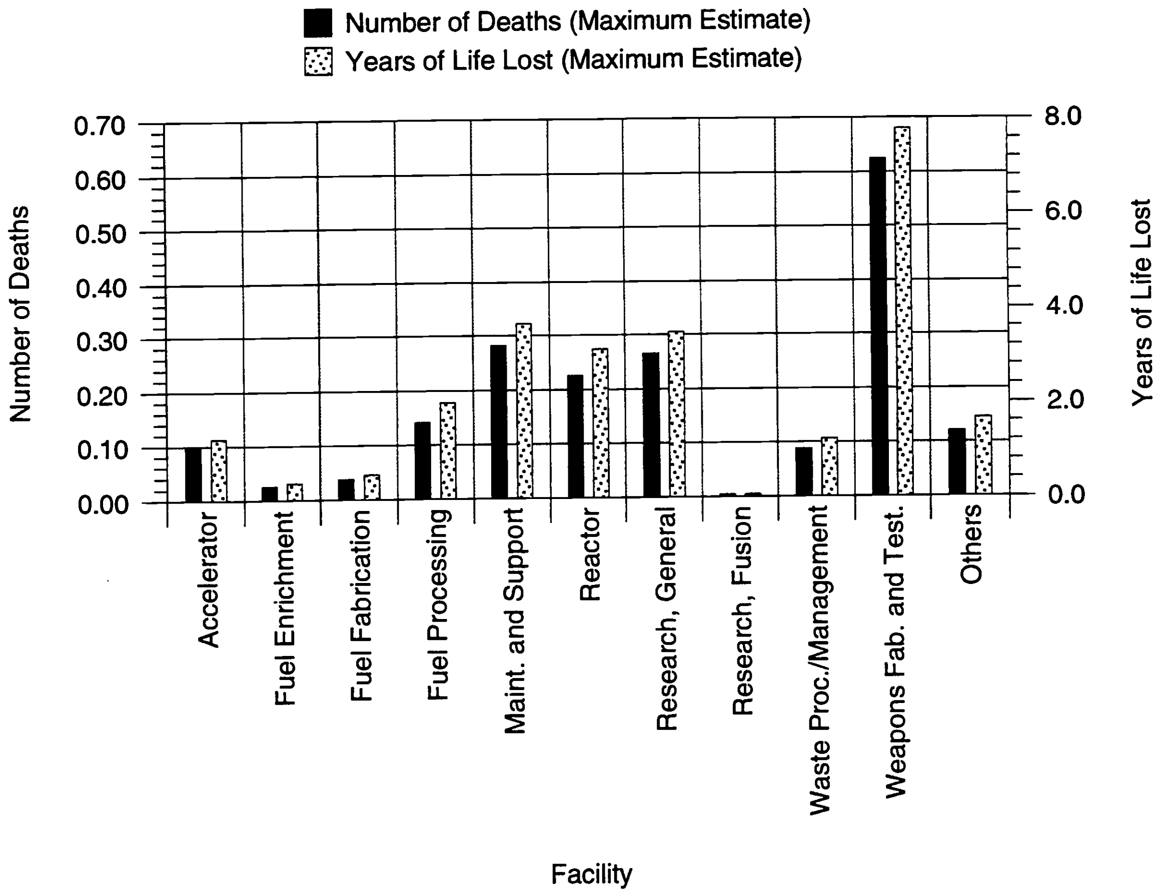

FIGURE 7.4. Estimated Maximum Number of Total Deaths and Years of Life Lost from Radiation Doses at DOE Facilities for All Employees in 1991—(The values indicated are maximum estimates; the actual values may be zero. See text for explanation.)

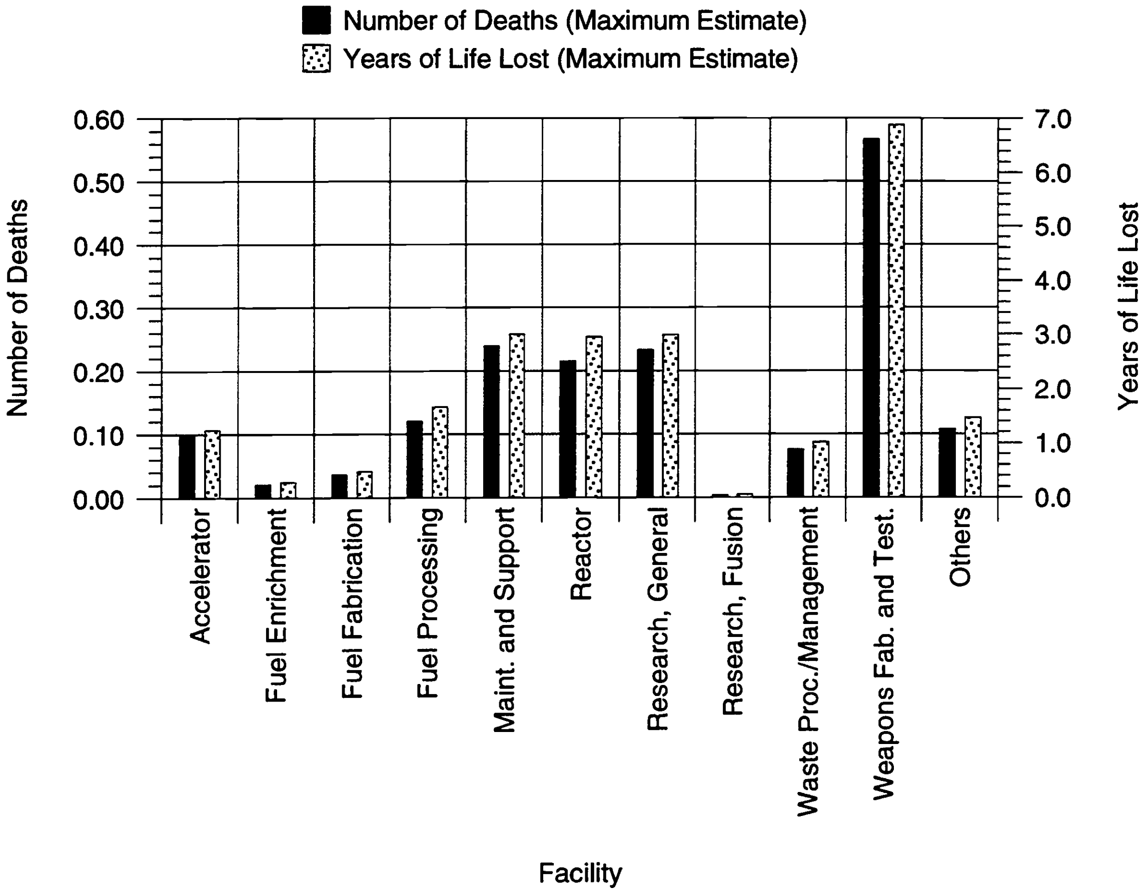

FIGURE 7.5. Estimated Maximum Number of Total Deaths and Years of Life Lost from Radiation Doses at DOE Facilities for Male Employees in 1991—(The values indicated are maximum estimates; the actual values may be zero. See text for explanation.)

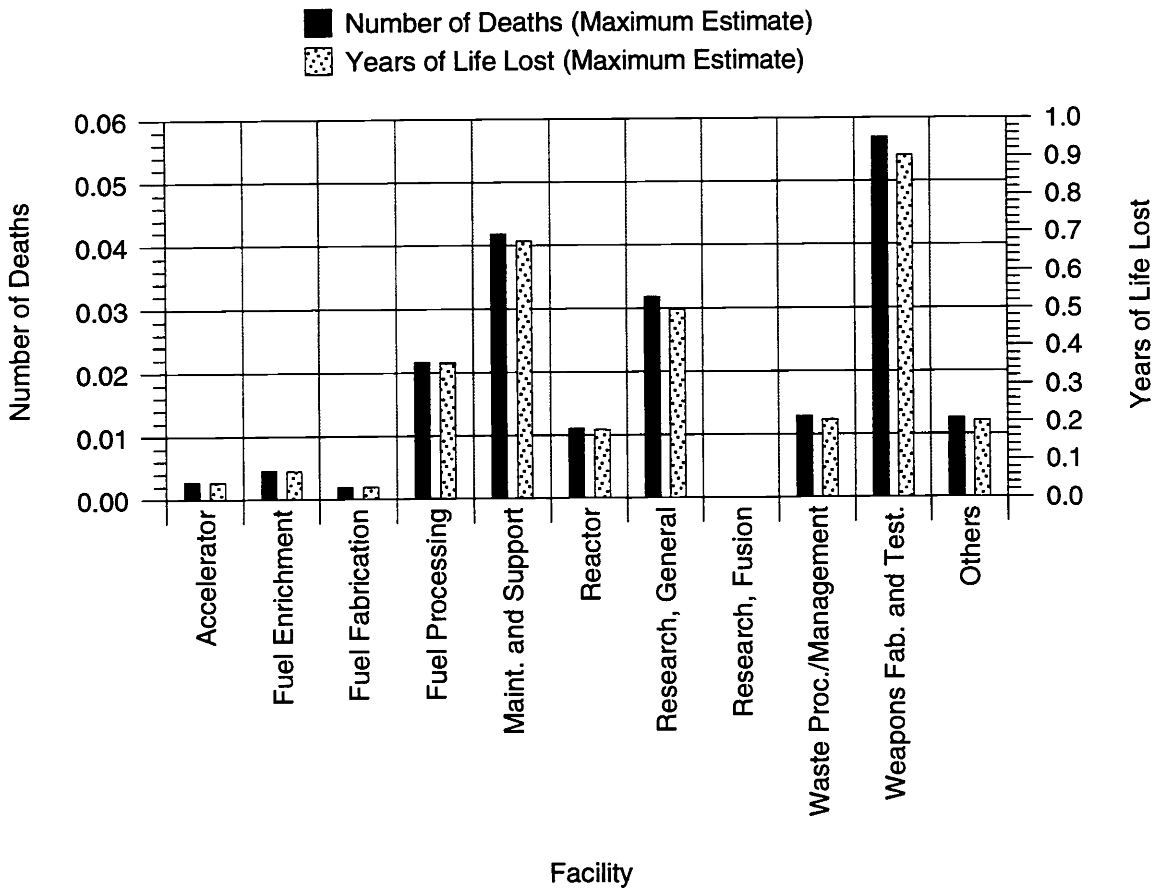

FIGURE 7.6. Estimated Maximum Number of Total Deaths and Years of Life Lost from Radiation Doses Received at DOE Facilities for Female Employees in 1991—(The values indicated are maximum estimates; the actual values may be zero. See text for explanation.)

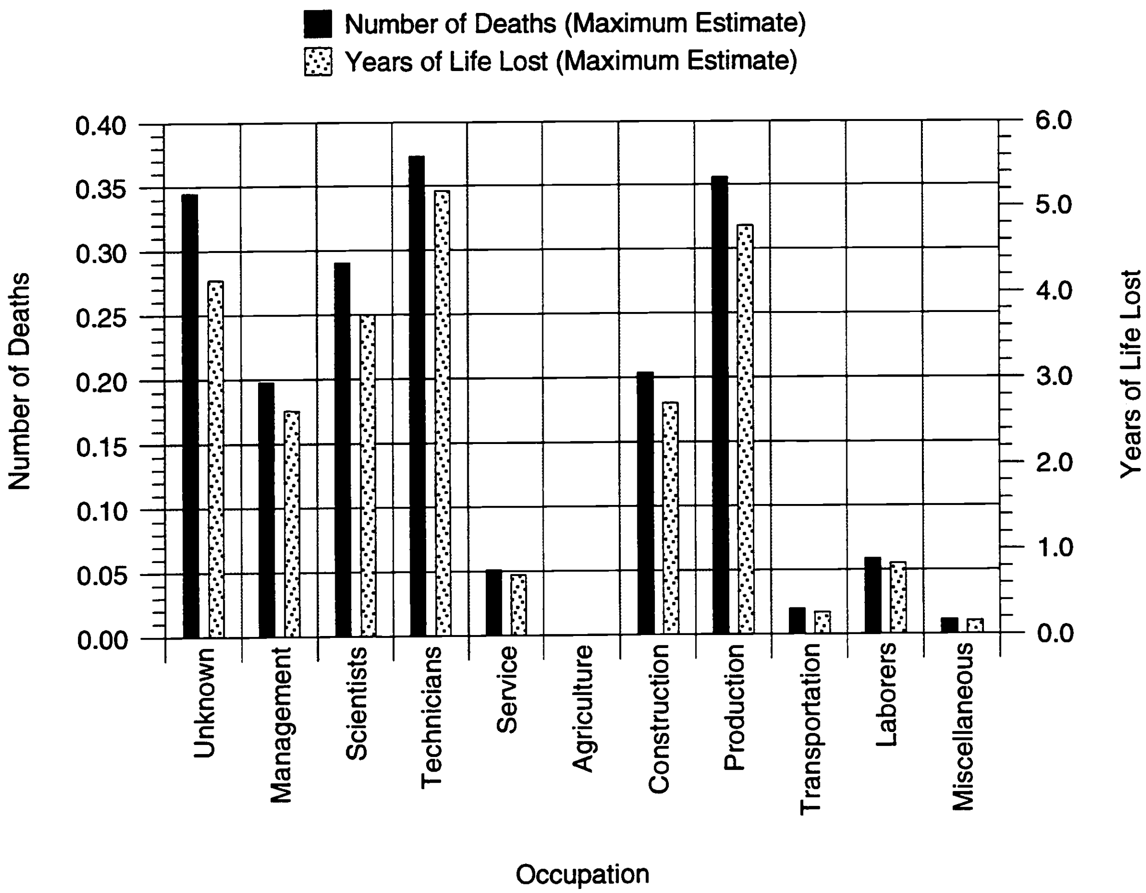

FIGURE 7.7. Estimated Maximum Number of Total Deaths and Years of Life Lost from Radiation Doses Received by Occupation Group (all employees) at DOE Facilities in 1991—(The values indicated are maximum estimates; the actual values may be zero. See text for explanation.)

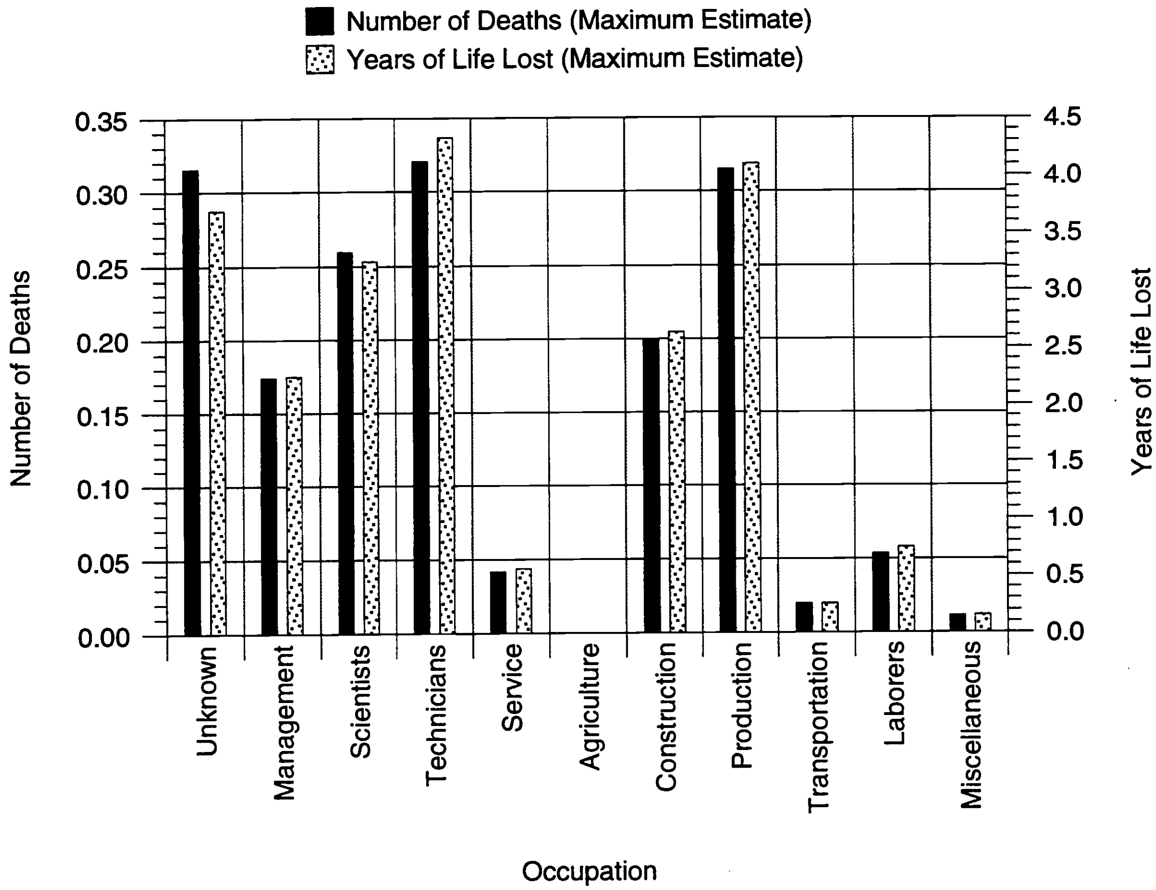

FIGURE 7.8. Estimated Maximum Number of Total Deaths and Years of Life Lost from Radiation Doses Received by Occupation Group (male employees) at DOE Facilities in 1991—(The values indicated are maximum estimates; the actual values may be zero. See text for explanation.)

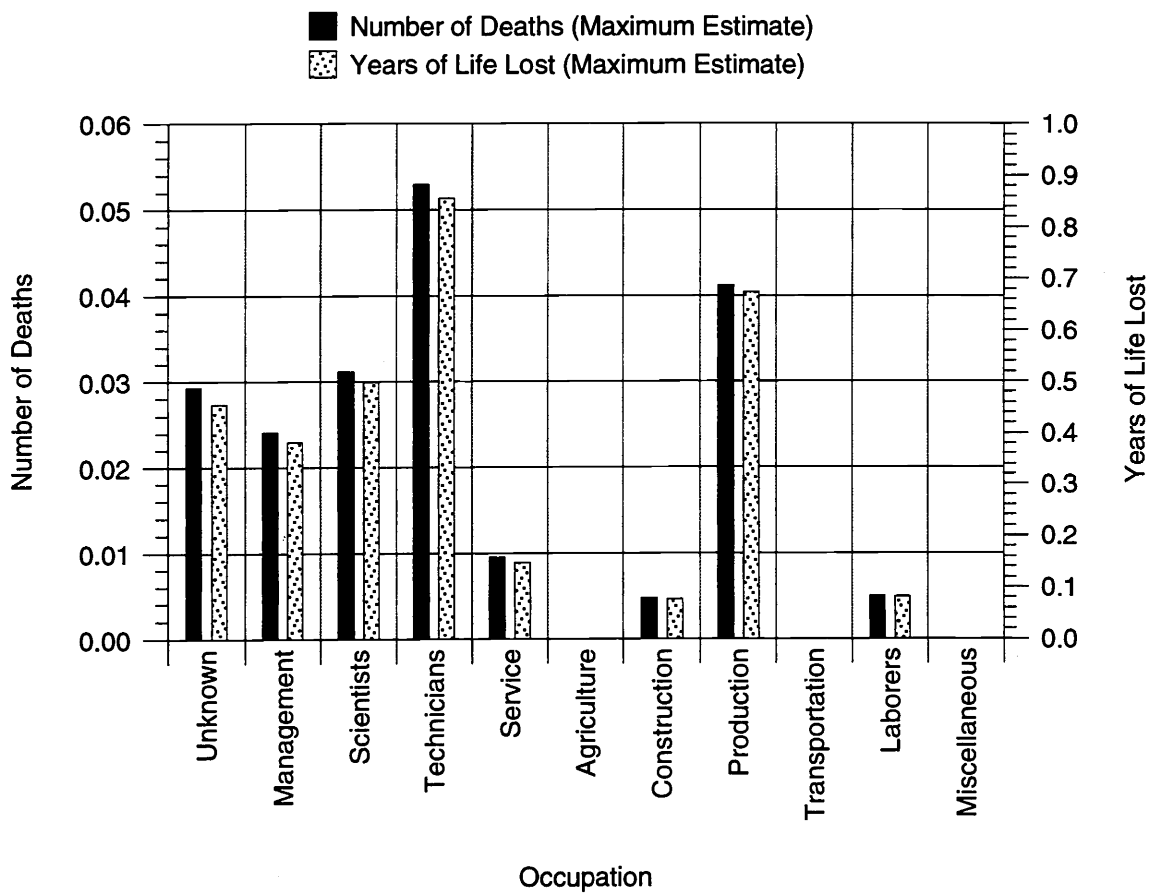

FIGURE 7.9. Estimated Maximum Number of Total Deaths and Years of Life Lost from Radiation Doses Received by Occupation Group (female employees) at DOE Facilities in 1991—(The values indicated are maximum estimates; the actual values may be zero. See text for explanation.)

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	882
Heart disease	311
Cancer, all types	197
Lung cancer	56
Leukemia	7
Other cancer types	4
Accidents, all types	40
Motor vehicle accidents	20
Other accidents	20
Human Immunodeficiency Virus Infection	7
Other causes	327
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	1.9[c]

(a) Sources: General population data for the year 1988 from National Center for Health Statistics (1992); occupational data (except cancer fatalities from DOE radiation doses) for the years 1986 and 1987 from the Department of Labor (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 atomic-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.

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APPENDIX A

DISTRIBUTION OF ANNUAL TOTAL EFFECTIVE DOSE EQUIVALENT BY FACILITY TYPE FOR EACH FIELD ORGANIZATION, 1991

TABLE A.1
Distribution of Annual Total Effective Dose Equivalent by Facility Type[a]
Albuquerque Operations
1991

Facility Type	< Meas.	Meas.- < .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 Persons	Total Person-rem
	Dose-Equivalent Ranges (rem)																	
Accelerator	814	133	32	21	4	4	1									1	1,010	41
Maint. and Support	5,230	581	55	20	2	3	2										5,893	34
Reactor	80	26	6	2	1	2	4										121	9
Research, General	3,924	542	117	67	54	31	32	1	1	1		1					4,771	179
Research, Fusion	121	15	1														137	
Waste Proc./Management	980	56	3	2	1	1	1										1,044	5
Weapons Fab. & Test.	1,884	291	48	24	2		1										2,250	26
Other	3,347	260	11	6	1												3,625	11
Visitors	2,058	370	22	4	2	2	5	2			1		2	1	1	1	2,471	82
DOE Offices	57																57	
Total Persons	18,495	2,274	295	146	67	43	46	3	1	1	1	1	2		1	2	21,379	
Total Person-rem		62	46	51	41	38	60	7	3	4	6	6	15		10	32		389

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

TABLE A.2
Distribution of Annual Total Effective Dose Equivalent by Facility Type[a]
Chicago Operations
1991

Facility Type	< Meas.	Meas.- < .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 Persons	Total Person-rem
	Dose-Equivalent Ranges (rem)																	
Accelerator	2,739	682	114	52	23	5	4										3,619	79
Fuel Fabrication	47	10	3	1													61	1
Maint. and Support	1,467	171	18	4	2	1											1,663	11
Reactor	288	121	22	6													437	10
Research, General	2,055	206	47	16	5	1	2										2,332	26
Research, Fusion	504	142	8														654	5
Waste Proc./Management	82	5	4	1													92	1
Other	3	14	1														18	1
Visitors	1,575	893	51	6	4		1										2,530	38
DOE Offices	85	2															87	
Total Persons	8,845	2,246	268	86	34	7	7										11,493	
Total Person-rem		68	40	30	20	6	8											173

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

TABLE A.3
Distribution of Annual Total Effective Dose Equivalent by Facility Type[a]
DOE Headquarters
1991

Dose-Equivalent Ranges (rem)

Facility Type	< Meas.	Meas.- < .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 Persons	Total Person-rem
Reactor	28																28	
Research, General	16																16	
Waste Proc./Management	15																15	
Weapons Fab. & Test.	12																12	
Other	23																23	
DOE Offices	713	65															778	
Total Persons	807	65															872	
Total Person-rem																		

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

TABLE A.4
Distribution of Annual Total Effective Dose Equivalent by Facility Type[(a)]
Idaho Operations
1991

Facility Type	< Meas.	Meas.- < .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 Persons	Total Person-rem
Fuel Processing	1,995	212	60	55	17	5	7										2,351	61
Maint. and Support	174	54	2														230	2
Reactor	741	146	61	26	4	4	1										983	33
Research, General	692	47	9		1	1											750	4
Waste Proc./Management	202	21	1														224	1
Other	2,308	302	50	5		2	1										2,668	22
Visitors	14	91	26	20	20	5	17										193	54
DOE Offices	3																3	
Total Persons	6,129	873	209	106	42	17	26										7,402	
Total Person-rem		30	35	38	26	15	34											177

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

TABLE A.5
Distribution of Annual Total Effective Dose Equivalent by Facility Type[a]
Nevada Operations
1991

Dose-Equivalent Ranges (rem)

Facility Type	< Meas.	Meas.- < .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 Persons	Total Person-rem
Accelerator	1,003	24	11	1													1,039	3
Weapons Fab. & Test.	99	2															101	
Visitors	7	1	1														9	
DOE Offices	47																47	
Total Persons	1,156	27	12	1													1,196	
Total Person-rem		1	2															3

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

TABLE A.6
Distribution of Annual Total Effective Dose Equivalent by Facility Type[a]
Oak Ridge Operations
1991

Dose-Equivalent Ranges (rem)

Facility Type	< Meas.	Meas.- < .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 Persons	Total Person-rem
Fuel/Uran. Enrichment	6,941	1,636	31	2													8,610	32
Fuel Fabrication	932	259	68	14	1	3	1										1,278	27
Fuel Processing	11	41	21	9													82	8
Research, General	5,549	273	78	28	5	1	2										5,936	39
Waste Proc./Management	200	12															212	
Weapons Fab. & Test.	5,803	1,374	28	2													7,207	23
Visitors	2,314	743	43	24	9	6	3										3,142	42
Total Persons	21,750	4,338	269	79	15	10	6										26,467	
Total Person-rem		77	42	27	9	9	8											172

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

TABLE A.7
Distribution of Annual Total Effective Dose Equivalent by Facility Type[a]
Pittsburgh N.R. Office
1991

Dose-Equivalent Ranges (rem)

Facility Type	< Meas.	Meas.- < .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 Persons	Total Person-rem
Reactor	101	367	21	21	3												513	19
Research, General	208	956	154	53	3												1,374	63
Other	18	30	1	2													51	1
Visitors	165	86	6														257	2
Total Persons	492	1,439	182	76	6												2,195	
Total Person-rem		25	30	27	3													84

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

TABLE A.8
Distribution of Annual Total Effective Dose Equivalent by Facility Type[(a)]
Richland Operations
1991

Facility Type	< Meas.	Meas.- < .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 Persons	Total Person-rem
	Dose-Equivalent Ranges (rem)																	
Accelerator	5	4															9	
Fuel Fabrication	13	8	3														24	1
Fuel Processing	22	13	6	4	4	2	1										52	8
Maint. and Support	2,843	924	129	74	16	8	15	1									4,010	108
Reactor	438	195	31	13	4	1											682	19
Research, General	810	433	51	25	13	8	5										1,345	47
Waste Proc./Management	1,592	662	127	73	10	5	3	2									2,474	81
Other	417	113	11	6	3	2											552	10
Visitors		12	3														15	1
DOE Offices	206	35															241	1
Total Persons	6,346	2,399	361	195	50	26	24	3									9,404	
Total Person-rem		62	57	66	30	22	30	7										275

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

TABLE A.9
Distribution of Annual Total Effective Dose Equivalent by Facility Type[a]
Rocky Flats Operations
1991

Facility Type	< Meas.	Meas.- < .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 Persons	Total Person-rem
				Dose-Equivalent Ranges (rem)														
Weapons Fab. & Test.	615	4,772	1,309	480	115	60	68	16	8	6		1		1		1	7,452	885
Visitors	100	780	20	5	1												906	16
Total Persons	715	5,552	1,329	485	116	60	68	16	8	6		1		1		1	8,358	
Total Person-rem		200	200	166	70	52	91	40	26	28		7		8		15		902

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

TABLE A.10
Distribution of Annual Total Effective Dose Equivalent by Facility Type[a]
San Francisco Operations
1991

			Dose-Equivalent Ranges (rem)															
Facility Type	< Meas.	Meas.- < .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 Persons	Total Person-rem
Accelerator	733	220	29	10	2												994	16
Fuel/Uran. Enrichment	682	11	1	5	1		1										701	4
Maint. and Support	3,917	43	12	8	5	1	4	1									3,991	18
Research, General	1,478	76	13	11	3	4	7										1,592	23
Research, Fusion	341	1															342	
Waste Proc./Management	114	1															115	
Weapons Fab. & Test.	1,289	38	12	2		1											1,342	5
Other	1,302	19	1			2				1							1,325	7
Visitors	19	51	10	2		1											83	4
DOE Offices	134	3															137	
Total Persons	10,009	463	78	38	11	9	12	1		1							10,622	
Total Person-rem		14	13	13	7	8	16	2		5								77

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

TABLE A.11
Distribution of Annual Total Effective Dose Equivalent by Facility Type[a]
Savannah River Operations
1991

	Dose-Equivalent Ranges (rem)																	
Facility Type	< Meas.	Meas.- < .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 Persons	Total Person-rem
Fuel Processing	1,306	797	254	111	27	9	2										2,506	128
Maint. and Support	5,438	3,253	396	95	9	2	2	2									9,197	182
Reactor	709	653	38														1,400	21
Research, General	888	264	16	6		1											1,175	10
Waste Proc./Management	751	380	91	28	4	2											1,256	38
Weapons Fab. & Test.	448	128	13	3													592	6
Other	3,359	1,264	117	66	6	1											4,813	68
Visitors	930	276	5	2													1,213	6
DOE Offices	363	67	1														431	1
Total Persons	14,192	7,082	931	311	46	15	4	2									22,583	
Total Person-rem		165	141	104	27	13	6	5										459

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

TABLE A.12
Distribution of Annual Total Effective Dose Equivalent by Facility Type[a]
Schenectady N.R. Office
1991

Facility Type	< Meas.	Meas.- < .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 Persons	Total Person-rem
	Dose-Equivalent Ranges (rem)																	
Reactor	88	693	46	3													830	20
Research, General	471	396	5														872	6
Other	7	14															21	
Visitors	198	451	99	100	65	38	57										1,008	207
Total Persons	764	1,554	150	103	65	38	57										2,731	
Total Person-rem		26	25	36	42	33	72											233

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

APPENDIX B

DISTRIBUTION OF ANNUAL TOTAL EFFECTIVE DOSE EQUIVALENT BY CONTRACTOR, 1991

TABLE B.1
Distribution of Annual Total Effective Dose Equivalent by Contractor[a]
Albuquerque Operations
1991

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
						Dose-Equivalent Ranges (rem)												
Albuquerque Office Subs																		
Employees	1	2	4	2													9	2
Visitors																		
Total	1	2	4	2													9	2
Albuquerque Transportation Division																		
Employees	23	1															24	
Visitors																		
Total	23	1															24	
Allied-Signal, Inc. (Bendix Div.)																		
Employees	196	11															207	
Visitors	1																1	
Total	197	11															208	
EG&G Mound Applied Technologies																		
Employees	1,837	306	13	2			2										2,160	8
Visitors	42	2															44	
Total	1,879	308	13	2			2										2,204	8
G.E. - Pinellas																		
Employees	241	41	1														283	1
Visitors																		
Total	241	41	1														283	1
Inhalation Toxicology Research Inst.																		
Employees	253	22	5	1	1												282	2
Visitors		2															2	
Total	253	24	5	1	1												284	2

TABLE B.1 (continued)
Distribution of Annual Total Effective Dose Equivalent by Contractor[a]
Albuquerque Operations
1991

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
			Dose-Equivalent Ranges (rem)															
Jacobs-Weston Team																		
Employees	45	2															47	
Visitors																		
Total	45	2															47	
Johnson Controls, Inc.																		
Employees	1,395	172	32	12	1	1											1,613	16
Visitors																		
Total	1,395	172	32	12	1	1											1,613	16
Los Alamos National Laboratory																		
Employees	5,145	683	165	95	60	38	35	1	1	1		1				1	6,226	232
Visitors	495	155	15	2	2	1	5	2			1		2	1	1	1	683	74
Total	5,640	838	180	97	62	39	40	3	1	1	1	1	2		1	2	6,909	306
MK-Ferguson Co. - UMTRA																		
Employees	39	14															53	
Visitors																		
Total	39	14															53	
MK-Ferguson Subs - UMTRA																		
Employees	548	135	2	1													686	4
Visitors																		
Total	548	135	2	1													686	4
Mason & Hanger - Amarillo																		
Employees	2,034	154	39	26	2												2,255	22
Visitors	111																111	
Total	2,145	154	39	26	2												2,366	22

TABLE B.1 (continued)
Distribution of Annual Total Effective Dose Equivalent by Contractor[a]
Albuquerque Operations
1991

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
	Dose-Equivalent Ranges (rem)																	
Mason & Hanger - Los Alamos																		
Employees	412	31															443	1
Visitors	1																1	
Total	413	31															444	1
Ross Aviation, Inc.																		
Employees	78	10															88	
Visitors																		
Total	78	10															88	
Sandia National Laboratory																		
Employees	3,033	291	12	3	1	2	4										3,346	17
Visitors	1,201	207	7	2		1											1,418	8
Total	4,234	498	19	5	1	3	4										4,764	26
Westinghouse (WIPP)																		
Employees	803	17															820	
Visitors	165	4															169	
Total	968	21															989	
Albuquerque Operations Total	18,099	2,262	295	146	67	43	46	3	1	1	1	1	2	1	1	2	20,971	388

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

TABLE B.2
Distribution of Annual Total Effective Dose Equivalent by Contractor[(a)]
Chicago Operations
1991

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
	Dose-Equivalent Ranges (rem)																	
Ames Laboratory (Iowa State)																		
Employees	87	18	1														106	1
Visitors	1																1	
Total	88	18	1														107	1
Argonne National Laboratory																		
Employees	3,343	266	59	15	5	1	1										3,690	30
Visitors		29	3														32	1
Total	3,343	295	62	15	5	1	1										3,722	31
Battelle Memorial Institute - Columbus																		
Employees	121	37	5	3	1	1											168	4
Visitors	24	23	3	1													51	1
Total	145	60	8	4	1	1											219	6
Brookhaven National Laboratory																		
Employees	1,453	434	101	56	21	4	5										2,074	70
Visitors	522	360	28	5	4		1										920	19
Total	1,975	794	129	61	25	4	6										2,994	89
Chicago Office Subs																		
Employees	39	26	4	2	1	1											73	4
Visitors																		
Total	39	26	4	2	1	1											73	4
Fermilab																		
Employees	1,436	390	37	4	2												1,869	19
Visitors	826	448	16														1,290	15
Total	2,262	838	53	4	2												3,159	34

TABLE B.2 (continued)
Distribution of Total Effective Dose Equivalent by Contractor[a]
Chicago Operations
1991

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
							Dose-Equivalent Ranges (rem)											
Mass. Inst. of Tech.																		
Employees	240	47	4														291	2
Visitors	125	11															136	
Total	365	58	4														427	2
National Renewable Energy Lab (NREL)- CH																		
Employees	13	5															18	
Visitors																		
Total	13	5															18	
Princeton Plasma Physics Laboratory																		
Employees	373	124	6														503	5
Visitors	67	22	1														90	1
Total	440	146	7														593	6
Chicago Operations Total	8,670	2,240	268	86	34	7	7										11,312	172

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

TABLE B.3
Distribution of Annual Total Effective Dose Equivalent by Contractor[a]
DOE Headquarters
1991

Dose-Equivalent Ranges (rem)

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
DOE Office Subs																		
Employees	94																94	
Visitors																		
Total	94																94	
DOE Headquarters Total	94																94	

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

TABLE B.4
Distribution of Annual Total Effetive Dose Equivalent by Contractor[a]
Idaho Operations
1991

Dose-Equivalent Ranges (rem)

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
Babcock & Wilcox Idaho, Inc.																		
Employees	466	30	1														497	1
Visitors		2															2	
Total	466	32	1														499	1
Chem-Nuclear Geotech																		
Employees	693	24	1	1													719	1
Visitors		5															5	
Total	693	29	1	1													724	1
EG&G Idaho, Inc.																		
Employees	1,831	249	72	26	4	4	1										2,187	38
Visitors	3	25	3														31	1
Total	1,834	274	75	26	4	4	1										2,218	39
Idaho Office Subs																		
Employees	18	1				1											20	1
Visitors	1																1	
Total	19	1				1											21	1
MK-Ferguson Company - ID																		
Employees	180	20	6	3		2	2										213	7
Visitors		17	12	9	6	2	6										52	19
Total	180	37	18	12	6	4	8										265	26
MK-Ferguson Subcontractors -ID																		
Employees	52	7	2	1			1										63	2
Visitors	7	34	11	11	14	3	11										91	33
Total	59	41	13	12	14	3	12										154	35

TABLE B.4 (continued)
Distribution of Annual Total Effective Dose Equivalent by Contractor[a]
Idaho Operations
1991

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
Protection Technology - INEL																		
Employees	391	44															435	1
Visitors																		
Total	391	44															435	1
West Valley Nuclear Services, Inc.																		
Employees	720	198	44	3													965	15
Visitors																		
Total	720	198	44	3													965	15
Westinghouse Idaho Nuclear Co.																		
Employees	1,555	176	56	52	18	5	5										1,867	57
Visitors	3	8															11	
Total	1,558	184	56	52	18	5	5										1,878	57
Idaho Operations Total	5,920	840	208	106	42	17	26										7,159	176

TABLE B.5
Distribution of Annual Total Effective Dose Equivalent by Contractor[(a)]
Nevada Operations
1991

Dose-Equivalent Ranges (rem)

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
EG&G Amador Valley Operations																		
Employees	2																2	
Visitors																		
Total	2																2	
EG&G Las Vegas																		
Employees	142																142	
Visitors																		
Total	142																142	
EG&G Los Alamos																		
Employees	2																2	
Visitors																		
Total	2																2	
EG&G Santa Barbara																		
Employees	51																51	
Visitors																		
Total	51																51	
EG&G Special Technologies Laboratories																		
Employees	13																13	
Visitors																		
Total	13																13	
EG&G Washington D.C.																		
Employees	9																9	
Visitors																		
Total	9																9	

TABLE B.5 (continued)
Distribution of Annual Total Effective Dose Equivalent by Contractor[(a)]
Nevada Operations
1991

Dose-Equivalent Ranges (rem)

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
Fenix & Scisson, Inc.																		
Employees	63	5	9	1													78	2
Visitors																		
Total	63	5	9	1													78	2
Holmes & Narver, Inc., ESD																		
Employees	32	1															33	
Visitors																		
Total	32	1															33	
Nevada Miscellaneous Contractors																		
Employees	53																53	
Visitors	1																1	
Total	54																54	
Raytheon Services - Nevada																		
Employees	30	1															31	
Visitors																		
Total	30	1															31	
Reynolds Elec. & Engr. Co.																		
Employees	635	18	2														655	1
Visitors	6		1														7	
Total	641	18	3														662	1

TABLE B.5 (continued)
Distribution of Annual Total Effective Dose Equivalent by Contractor[a]
Nevada Operations
1991

Dose-Equivalent Ranges (rem)

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
Science Applications Internt'l Corp. - NV																		
Employees	22	1															23	
Visitors																		
Total	22	1															23	
Nevada Operations Total	1,061	26	12	1													1,100	3

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

TABLE B.6
Distribution of Annual Total Effective Dose Equivalent by Contractor[(a)]
Oak Ridge Operations
1991

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
	Dose-Equivalent Ranges (rem)																	
Bechtel National, Inc. - (FUSRAP)																		
Employees	68	8															76	
Visitors	211	26	1														238	1
Total	279	34	1														314	2
M.M. Portsmouth Subcontractors																		
Employees																		
Visitors	404	81	3														488	2
Total	404	81	3														488	2
Martin Marietta (K-25)																		
Employees	3,511	341															3,852	1
Visitors	117	69															186	
Total	3,628	410															4,038	2
Martin Marietta (ORNL)																		
Employees	5,410	267	77	28	5	1	2										5,790	39
Visitors	278	39	6	8	1	1											333	6
Total	5,688	306	83	36	6	2	2										6,123	45
Martin Marietta (Paducah)																		
Employees	1,780	215	8														2,003	5
Visitors	2	25															27	
Total	1,782	240	8														2,030	5
Martin Marietta (Portsmouth)																		
Employees	1,650	1,080	23	2													2,755	25
Visitors	2																2	
Total	1,652	1,080	23	2													2,757	25

TABLE B.6 (continued)
Distribution of Annual Total Effective Dose Equivalent by Contractor[a]
Oak Ridge Operations
1991

Dose-Equivalent Ranges (rem)

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
Martin Marietta (Y-12)																		
Employees	5,803	1,374	28	2													7,207	23
Visitors	57	293	4	1													355	4
Total	5,860	1,667	32	3													7,562	28
Morrison-Knudsen (WSSRAP)																		
Employees	132	4															136	
Visitors	257																257	
Total	389	4															393	
Oak Ridge Inst. for Sci. & Educ. (ORISE)																		
Employees	139	6	1														146	
Visitors	4	62															66	1
Total	143	68	1														212	1
RMI Company																		
Employees	11	41	21	9													82	8
Visitors	3	1															4	
Total	14	42	21	9													86	8
Westinghouse Environ. Mgmt. Co. of Ohio																		
Employees	932	259	68	14	1	3	1										1,278	27
Visitors	979	147	29	15	8	5	3										1,186	26
Total	1,911	406	97	29	9	8	4										2,464	54
Oak Ridge Operations																		
Total	21,750	4,338	269	79	15	10	6										26,467	172

TABLE B.7
Distribution of Annual Total Effective Dose Equivalent by Contractor[a]
Pittsburgh N.R. Office
1991

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
	Dose-Equivalent Ranges (rem)																	
Westinghouse Electric (BAPL)																		
Employees	196	758	26	14													994	20
Visitors	164	86	6														256	2
Total	360	844	32	14													1,250	22
Westinghouse Electric (NRF)																		
Employees	104	537	145	60	6												852	61
Visitors																		
Total	104	537	145	60	6												852	61
Westinghouse Plant Apparatus Division																		
Employees	18	30	1	2													51	1
Visitors	1																1	
Total	19	30	1	2													52	1
Pittsburgh N.R. Office Total	483	1,411	178	76	6												2,154	83

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

TABLE B.8
Distribution of Annual Total Effective Dose Equivalent by Contractor[(a)]
Richland Operations
1991

Dose-Equivalent Ranges (rem)

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
Battelle Memorial Institute (PNL)																		
Employees	916	478	58	27	15	9	5										1,508	53
Visitors		5															5	
Total	916	483	58	27	15	9	5										1,513	53
Hanford Environmental Health Foundation																		
Employees	44	14															58	
Visitors																		
Total	44	14															58	
Kaiser Engineers Hanford - Cost Const																		
Employees	759	279	44	21	12	8	12										1,135	52
Visitors		2															2	
Total	759	281	44	21	12	8	12										1,137	52
Westinghouse Hanford Service Subs																		
Employees	127	23	1														151	1
Visitors																		
Total	127	23	1														151	1
Westinghouse Hanford Services																		
Employees	4,294	1,558	255	147	23	9	7	3									6,296	168
Visitors		5	3														8	1
Total	4,294	1,563	258	147	23	9	7	3									6,304	168
Richland Operations																		
Total	6,140	2,364	361	195	50	26	24	3									9,163	274

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

TABLE B.9
Distribution of Annual Total Effective Dose Equivalent by Contractor(a)
Rocky Flats Operations
1991

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
	Dose-Equivalent Ranges (rem)																	
EG&G Rocky FLats Services																		
Employees	117	120															237	1
Visitors																		
Total	117	120															237	1
EG&G Rocky Flats																		
Employees	242	3,621	1,143	449	112	57	67	15	8	6		1		1		1	5,723	803
Visitors	100	780	20	5	1												906	16
Total	342	4,401	1,163	454	113	57	67	15	8	6		1		1		1	6,629	820
EG&G Rocky Flats Subcontractors																		
Employees	20	8	1														29	
Visitors																		
Total	20	8	1														29	
J. A. Jones - Rocky Flats																		
Employees	98	489	134	30	3	2	1	1									758	55
Visitors																		
Total	98	489	134	30	3	2	1	1									758	55
Wackenhut Services - Rocky Flats																		
Employees	53	452	28	1		1											535	24
Visitors																		
Total	53	452	28	1		1											535	24
Rocky Flats Operations Total	630	5,470	1,326	485	116	60	68	16	8	6		1		1		1	8,188	900

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

TABLE B.10
Distribution of Annual Total Effective Dose Equivalent by Contractor[a]
San Francisco Operations
1991

Dose-Equivalent Ranges (rem)

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
Energy Technology Engineering Center																		
Employees	1	3	3	3		2	5										17	10
Visitors		2				1											3	1
Total	1	5	3	3		3	5										20	11
LLNL Plant Services																		
Employees	427	5															432	
Visitors																		
Total	427	5															432	
LLNL Security																		
Employees	317																317	
Visitors																		
Total	317																317	
LLNL Subcontractors																		
Employees																		
Visitors	16	22	9	2													49	3
Total	16	22	9	2													49	3
Lawrence Berkeley Laboratory																		
Employees		145	6	1		1											153	5
Visitors		27	1														28	1
Total		172	7	1		1											181	6
Lawrence Livermore Nat'l Lab. - Nevada																		
Employees	74	2	3														79	1
Visitors	1																1	
Total	75	2	3														80	1

TABLE B.10 (continued)
Distribution of Annual Total Effective Dose Equivalent by Contractor
San Francisco Operations
1991

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
	Dose-Equivalent Ranges (rem)																	
Lawrence Livermore National Laboratory																		
Employees	8,385	143	28	23	9	5	7	1		1							8,602	43
Visitors																		
Total	8,385	143	28	23	9	5	7	1		1							8,602	43
Stanford Linear Accelerator Center																		
Employees	603	110	27	9	2												751	13
Visitors																		
Total	603	110	27	9	2												751	13
U. of Cal./Davis, Radiobiology Lab -LEHR																		
Employees	20		1														21	
Visitors	2																2	
Total	22		1														23	
U. of Cal./SF - Lab of Radiobiology																		
Employees	29	1															30	
Visitors																		
Total	29	1															30	
San Francisco Operations Total	9,875	460	78	38	11	9	12	1		1							10,485	77

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

TABLE B.11
Distribution of Annual Total Effective Dose Equivalent by Contractor[a]
Savannah River Operations
1991

Dose-Equivalent Ranges (rem)

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
American Telephone & Telegraph																		
Employees	25	1															26	
Visitors																		
Total	25	1															26	
Bechtel Construction - SR																		
Employees	2,653	1,946	208	45	4	1											4,857	94
Visitors																		
Total	2,653	1,946	208	45	4	1											4,857	94
Diversco																		
Employees	216	77															293	1
Visitors																		
Total	216	77															293	1
Industrial Phases - SR																		
Employees	17	5															22	
Visitors																		
Total	17	5															22	
Miscellaneous DOE Contractors - SR																		
Employees	158	72	2														232	2
Visitors																		
Total	158	72	2														232	2
Service America																		
Employees	773	486	58	22	6	1											1,346	32
Visitors																		
Total	773	486	58	22	6	1											1,346	32

TABLE B.11
Distribution of Annual Total Effective Dose Equivalent by Contractor[a]
Savannah River Operations
1991

Dose-Equivalent Ranges (rem)

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
Southern Bell Tel. & Tel.																		
Employees	18	4															22	
Visitors																		
Total	18	4															22	
Univ. of Georgia Ecology Laboratory																		
Employees	88	14															102	
Visitors																		
Total	88	14															102	
Wackenhut Services, Inc. - SR																		
Employees	727	271	48	43													1,089	26
Visitors																		
Total	727	271	48	43													1,089	26
Westinghouse S.R. Subcontractors																		
Employees	69	26															95	
Visitors	925	261	5	2													1,193	6
Total	994	287	5	2													1,288	7
Westinghouse Savannah River Co.																		
Employees	8,155	3,837	609	199	36	13	4	2									12,855	296
Visitors	5	15															20	
Total	8,160	3,852	609	199	36	13	4	2									12,875	297
Savannah River Operations																		
Total	13,829	7,015	930	311	46	15	4	2									22,152	458

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

TABLE B.12
Distribution of Annual Total Effective Dose Equivalent by Contractor[a]
Schenectady N.R. Office
1991

Dose-Equivalent Ranges (rem)

Contractor	< Meas.	Meas.- < .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 Persons	Total Person-rem
GE-KAPL - Kesselring																		
Employees	81	546	38	2													667	15
Visitors	25	83															108	
Total	106	629	38	2													775	15
GE-KAPL - Kesselring - Electric Boat																		
Employees																		
Visitors	53	299	99	100	65	38	57										711	206
Total	53	299	99	100	65	38	57										711	206
GE-KAPL - Knolls																		
Employees	460	388	5														853	6
Visitors	26	36															62	
Total	486	424	5														915	6
GE-KAPL - Knolls Subs																		
Employees	7	14															21	
Visitors	15	5															20	
Total	22	19															41	
GE-KAPL - Windsor																		
Employees	1	144	7	1													153	5
Visitors	79	28															107	
Total	80	172	7	1													260	5
Schenectady N.R. Office Total	747	1,543	149	103	65	38	57										2,702	233

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

APPENDIX C

DISTRIBUTION OF ANNUAL TOTAL EFFECTIVE DOSE EQUIVALENT FOR DOE EMPLOYEES AND VISITORS BY DOE ORGANIZATION, 1991

TABLE C.1
Distribution of Annual Total Effective Dose Equivalent for DOE Employees and Visitors by DOE Organization[(a)]
1991

		Dose-Equivalent Ranges (rem)																
Organization	< Meas.	Meas.- < .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 Persons	Total Person-rem
Albuquerque Field Office																		
Employees	196	8															204	
Visitors																		
Total	196	8															204	
Dayton Area Office																		
Employees																		
Visitors	40																40	
Total	40																40	
Kansas City Area Office																		
Employees	12																12	
Visitors																		
Total	12																12	
Los Alamos Area Office																		
Employees	81	3															84	
Visitors	2																2	
Total	83	3															86	
Pinellas Area Office																		
Employees	1																1	
Visitors																		
Total	1																1	
Kirtland Area Office																		
Employees	16																16	
Visitors																		
Total	16																16	

TABLE C.1 (continued)
Distribution of Annual Total Effective Dose Equivalent for DOE Employees and Visitors by DOE Organization[a]
1991

Organization	< Meas.	Meas.- < .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 Persons	Total Person-rem
	Dose-Equivalent Ranges (rem)																	
UMTRA Project Office																		
Employees	9																9	
Visitors																		
Total	9																9	
WIPP Project Office																		
Employees	39	1															40	
Visitors																		
Total	39	1															40	
Albuquerque Operations																		
Total	396	12															408	
Chicago Field Office																		
Employees	85	2															87	
Visitors																		
Total	85	2															87	
Environmental Meas. Lab.																		
Employees	32	2															34	
Visitors																		
Total	32	2															34	

TABLE C.1 (continued)
Distribution of Annual Total Effective Dose Equivalent for DOE Employees and Visitors by DOE Organization[(a)]
1991

Dose-Equivalent Ranges (rem)

Organization	< Meas.	Meas.- < .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 Persons	Total Person-rem
New Brunswick Laboratory																		
Employees	48	2															50	
Visitors	10																10	
Total	58	2															60	
Chicago Operations																		
Total	175	6															181	
DOE Headquarters																		
Employees	713	65															778	
Visitors																		
Total	713	65															778	
DOE Headquarters																		
Total	713	65															778	
Idaho Field Office																		
Employees	209	33	1														243	1
Visitors																		
Total	209	33	1														243	1
Idaho Operations																		
Total	209	33	1														243	1

TABLE C.1 (continued)
Distribution of Annual Total Effective Dose Equivalent for DOE Employees and Visitors by DOE Organization[a]
1991

Organization	< Meas.	Meas.- < .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 Persons	Total Person-rem
	Dose-Equivalent Ranges (rem)																	
Nevada Field Office																	47	
Employees	47																1	
Visitors		1																
Total	47	1															48	
Defense Nuclear Agency - Kirtland AFB																	7	
Employees	7																	
Visitors																		
Total	7																7	
Environmental Protection Agency (NERC)																	41	
Employees	41																	
Visitors																		
Total	41																41	
Nevada Operations Total	95	1															96	
Pittsburgh N.R. Office																	41	1
Employees	9	28	4															
Visitors																		
Total	9	28	4														41	1
Pittsburgh N.R. Office Total	9	28	4														41	1

TABLE C.1 (continued)
Distribution of Annual Total Effective Dose Equivalent for DOE Employees and Visitors by DOE Organization[a]
1991

Organization	< Meas.	Meas.- < .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 Persons	Total Person-rem
						Dose-Equivalent Ranges (rem)												
Richland Field Office																		
Employees	206	35															241	1
Visitors																		
Total	206	35															241	1
Richland Operations																		
Total	206	35															241	1
Rocky Flats Office																		
Employees	85	82	3														170	2
Visitors																		
Total	85	82	3														170	2
Rocky Flats Operations																		
Total	85	82	3														170	2
San Francisco Field Office																		
Employees	134	3															137	
Visitors																		
Total	134	3															137	
San Francisco Operations																		
Total	134	3															137	

TABLE C.1 (continued)
Distribution of Annual Total Effective Dose Equivalent for DOE Employees and Visitors by DOE Organization[a]
1991

Organization	< Meas.	Meas.- < .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 Persons	Total Person-rem
					Dose-Equivalent Ranges (rem)													
S.R. Forest Station																	77	
Employees	62	15																
Visitors																		
Total	62	15															77	
Savannah River Field Office																	354	1
Employees	301	52	1															
Visitors																		
Total	301	52	1														354	1
Savannah River Operations																	431	1
Total	363	67	1															
Schenectady N.R. Office																	29	
Employees	17	11	1															
Visitors																		
Total	17	11	1														29	
Schenectady N.R. Office																	29	
Total	17	11	1															

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