# DOE Occupational Radiation Exposure

## 2004 Report

http://www.eh.doe.gov/rems/

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## 2004 Report

The U.S. Department of Energy
Assistant Secretary for Environment, Safety and Health
Office of Corporate Performance Assessment

# Foreword



The goal of the U.S. Department of Energy (DOE) is to conduct its operations, including radiological operations, to ensure the safety and health of all DOE employees, contractors, and subcontractors. The DOE strives to maintain radiation exposures to its workers below administrative control levels and DOE limits and to further reduce these exposures to levels that are "as low as reasonably achievable" (ALARA).

The 10 CFR 835 Subpart I requires annual individual radiation exposure records for DOE employees, contractors, and subcontractors, as well as members of the public who are required to be monitored. These are reported to the Radiation Exposure Monitoring System (REMS) Repository according to procedures provided in DOE Order 231.1A and DOE M 231.1-1A (Chapter 3 and Appendix G). The *2004 DOE Occupational Radiation Exposure Report* provides a summary and analysis of the occupational radiation exposure received by individuals associated with DOE activities and annually reported to REMS.

A brief discussion of the analysis of the occupational exposure data at DOE for 2004 is provided in the Executive Summary.

This report is intended to be a valuable tool for managing radiological safety programs and resources. The process of data collection, analysis, and report generation is streamlined to provide a current assessment of the performance of the Department with respect to radiological operations. The key to the timeliness of this report is the correct and prompt reporting of employee radiation exposure data by the sites. Your feedback and comments are important to us to make this report meet your needs.

*John Spitaleri Shaw*
*Assistant Secretary*
*Environment, Safety and Health*

*Frank E. Tooper*
*Deputy Assistant Secretary (Acting)*
*Office of Corporate Performance Assessment*

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## LIST OF EXHIBITS

## LIST OF EXHIBITS (continued)

## TABLE OF ACRONYMS

| | |
|---|---|
| 10 CFR 820 | Title 10 Code of Federal Regulation Part 820 "Procedural Rules for DOE Nuclear Activities," August 17, 1993 |
| 10 CFR 835 | Title 10 Code of Federal Regulation Part 835 "Occupational Radiation Protection," December 14, 1993 |
| 10 CFR 835, Amendment | Issued on November 4, 1998 |
| ACL | Administrative Control Level |
| AEDE | Annual Effective Dose Equivalent |
| AEC | Atomic Energy Commission |
| AHA | Automated Hazard Analysis |
| ALARA | As Low As Reasonably Achievable |
| ANL-E | Argonne National Laboratory - East |
| ANL-W | Argonne National Laboratory - West |
| BHI | Bechtel Hanford, Inc. |
| BNL | Brookhaven National Laboratory |
| BPM | Beam Positioning Monitor |
| BSRI | Bechtel Savannah River |
| CDE | Committed Dose Equivalent |
| CEDE | Committed Effective Dose Equivalent |
| CFF | Containment Fabrication Facility |
| CTS | Concentrate Transfer System |
| D&D | Decontamination and Decommissioning |
| DDE | Deep Dose Equivalent |
| DOE | Department of Energy |
| DOE  HQ | DOE Headquarters |
| DOE M 231.1-1 | Manual for Environment, Safety and Health Reporting, September 10, 1995 |
| DOE Notice 441.1 | Radiological Protection for DOE Activities, September 29, 1995 |
| DOE Order 231.1A | Environment, Safety and Health Reporting, August 19, 2003 |
| DOE Order 5480.11 | Radiation Protection for Occupational Workers, December 1988 |
| DOE Order 5484.1 | Environmental Protection, Safety and Health Protection Information Reporting Requirements, February 24, 1981, Change 7, October 17, 1990 |
| DOELAP | DOE Laboratory Accreditation Program |
| DPM | Disintegrations per Minute |
| EH-32 | DOE Office of Corporate Performance Assessment |
| EPA | Environmental Protection Agency |
| EPD | Electronic Personal Dosimeter |
| ERDA | Energy Research and Development Administration |
| ERDF | Environmental Restoration Disposal Facility |
| ES&H | Environment, Safety and Health |
| EUO | Enriched Uranium Operations |
| Fermilab | Fermi National Accelerator Laboratory |
| FHI | Fluor Hanford, Inc. |
| FRAT | Facility Radiological Action Team |
| HCA | High Contamination Area |
| ICP | Idaho Completion Project |
| ICRP | International Commission on Radiological Protection |
| IH | Industrial Hygiene |
| INEEL | Idaho National  Engineering & Environmental Laboratory |
| INL | Idaho National Laboratory |
| INPO | Institute of Nuclear Power Operations |
| INTEC | Idaho Nuclear Technology and Engineering Center |
| JSRWP | Job-specific Radiological Work Permit |
| LANL | Los Alamos National Laboratory |
| LBNL | Lawrence Berkeley National Laboratory |
| LDE | Lens (of the eye) Dose Equivalent |
| LLNL | Lawrence Livermore National Laboratory |
| MDA | Minimum Detectable Activity |
| MODS | Modifications |

## TABLE OF ACRONYMS (continued)

| | |
|---|---|
| NCRP | National Council on Radiation Protection and Measurements |
| NRC | Nuclear Regulatory Commission |
| NTS | Nevada Test Site |
| ORNL | Oak Ridge National Laboratory |
| ORP | Office of River Protection |
| PAG | Passive Aerosol Generator |
| PD&C | Project, Design and Construction |
| PFP | Plutonium Finishing Plant |
| PGDP | Paducah Gaseous Diffusion Plant |
| PORTS | Portsmouth Gaseous Diffusion Plant |
| PP | Pantex Plant |
| PPE | Personal Protective Equipment |
| PRF | Plutonium Reclamation Facility |
| PSEs | Planned Special Exposures |
| RCO | Radiological Control Organization |
| RCS | Radiological Control Standard |
| RCT | Radiological Control Technician |
| REMS | Radiation Exposure Monitoring System |
| RFETS | Rocky Flats Environmental Technology Site |
| RMA | Remote Mechanical A |
| RMC | Remote Mechanical C |
| ROSC | Radiological Operations Support Center |
| RTDs | Resistance Temperature Detectors |
| SDE | Shallow Dose Equivalent |
| SDE-ME | Shallow Dose Equivalent to the Maximally Exposed Extremity |
| SDE-WB | Shallow Dose Equivalent to the Skin of the Whole Body |
| SEE-IN | Significant Event Evaluation and Information Network |
| SLAC | Stanford Linear Accelerator Center |
| SNL | Sandia National Laboratory |
| SRS | Savannah River Site |
| TAN | Test Area North |
| TEDE | Total Effective Dose Equivalent |
| TODE | Total Organ Dose Equivalent |
| TRU | Transuranic |
| TVA | Tennessee Valley Authority |
| UNSCEAR | United Nations Scientific Committee on the Effects of Atomic Radiation |
| WIPP | Waste Isolation Pilot Plant |
| WSRC | Westinghouse Savannah River Company |
| Y-12 Plant | Y-12 National Security Complex |

# Executive Summary



The U.S. Department of Energy (DOE) Office of Corporate Performance Assessment (EH-3) publishes the annual *DOE Occupational Radiation Exposure Report*. This report is intended to be a valuable tool for DOE and DOE contractor managers and workers in managing radiological safety programs and to assist them in prioritizing resources. We appreciate the efforts and contributions from the various stakeholders within and outside DOE to make the report most useful.

This report includes occupational radiation exposure information for all monitored DOE employees, contractors, and subcontractors, as well as members of the public. DOE is defined to include the National Nuclear Security Administration sites. The exposure information is analyzed in terms of aggregate data, dose to individuals, and dose by site. For the purposes of examining trends, data for the past 5 years are included in the analysis.

As shown in *Exhibit ES-1*, the DOE collective total effective dose equivalent (TEDE) decreased by 24% from 1,445 person-rem (14,450 person-mSv) to 1,094 person-rem (10,940 person-mSv) between years 2003 and 2004. This is the largest decrease in the collective dose in the past 15 years. The decrease in 2004 is due primarily to decreased doses at five of the six DOE sites with the highest radiation doses. Seventy-seven percent of the collective TEDE for the DOE complex was accrued at six DOE sites in 2004. These six sites are (in descending order of collective dose for 2004) Hanford, Savannah River, Los Alamos, Oak Ridge, Idaho, and Rocky Flats. The sites attributed decreases in collective dose to:

- Rocky Flats radioactive source material being shipped off site for disposal.
- completion of thermal stabilization and repackaging of plutonium-bearing materials at Hanford.
- deactivation and decontamination activities at the Plutonium Finishing Plant at Hanford.
- decreased number of tank farm entries at Hanford.
- completion of work, including de-inventory of a number of facilities at Savannah River.
- suspension of nonessential operations at Los Alamos National Laboratory (LANL) during the second half of 2004.
- decrease in the isotope production work at Oak Ridge National Laboratory (ORNL) during 2004.

***Exhibit ES-1:***
***Collective TEDE (person-rem), 2000-2004.***

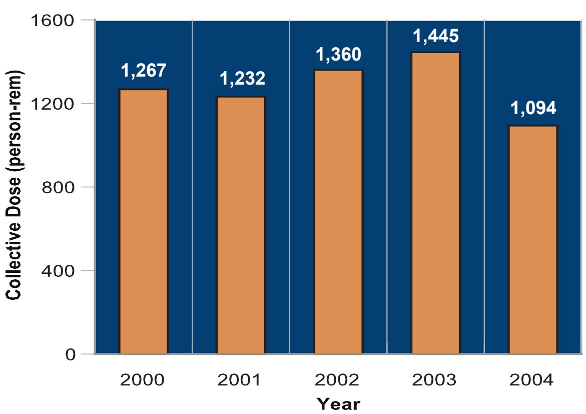
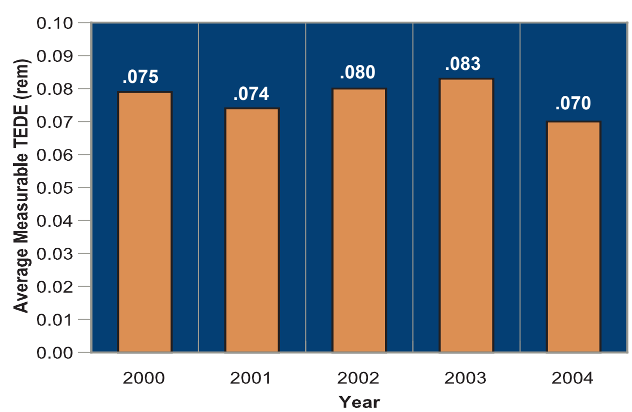



***Exhibit ES-2:***
***Average Measurable TEDE (rem), 2000-2004.***



The average dose to workers with measurable dose decreased by 16% from 0.083 rem (0.83 mSv) in 2003 to 0.070 rem (0.70 mSv) in 2004, as shown in *Exhibit ES-2*. The decrease is due to the 24% decrease in the collective dose and a 10% decrease in the number of workers with measurable dose. The number of individuals with measurable dose decreased from 17,484 in 2003 to 15,740 in 2004. The percentage of monitored individuals receiving measurable dose decreased to 16% in 2004 from 17% in 2003.

As shown in *Exhibits ES-3* and *ES-4*, there were no exposures in excess of the DOE 5 rem (50 mSv) annual TEDE limit and two exposures in excess of the DOE administrative control level (ACL) of 2 rem (20 mSv) TEDE. The two individuals who received exposures in excess of the 2 rem (20 mSv) TEDE administrative control limit resulted from plutonium intakes at Hanford and Rocky Flats. The individuals received 3.0 rem (30 mSv) committed effective dose equivalent (CEDE) and 2.8 rem (28 mSv) CEDE, respectively.

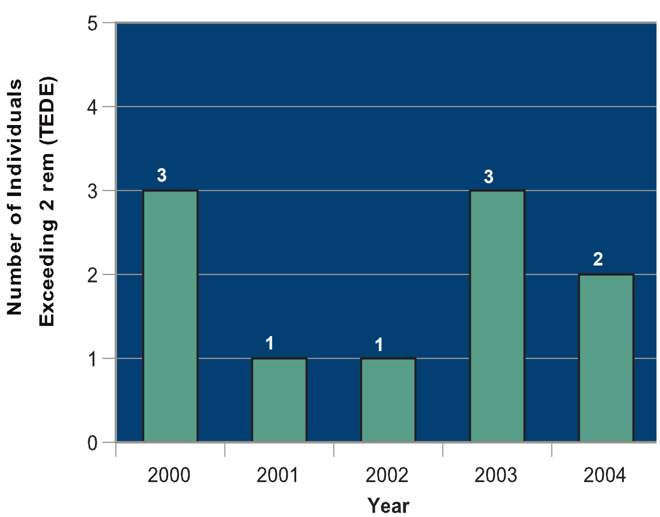
The collective internal dose (CEDE) decreased by 18% between 2003 and 2004. Due to the decrease in the collective CEDE and a 19% decrease in the number of internal depositions, the average measurable CEDE remained the same at a value of 0.037 rem (0.37 mSv) in 2004.

A transient worker, or transient, is defined as an individual monitored at more than one DOE site in a year. The results of the analysis on the transient workforce at DOE show that the number of transient workers monitored has decreased by 9% from 2,665 in 2003 to 2,422 in 2004 and still remains a very low percentage (2.4%) of the monitored workforce at DOE. The collective dose for these transients decreased by 54% from 56.1 person-rem (561 mSv) in 2003 to 25.6 person-rem (256 mSv) in 2004. As a result, the average measurable dose to transients decreased by 45% from 0.093 rem (0.93 mSv) in 2003 to 0.051 rem (0.51 mSv) in 2004. The average measurable dose to transient workers is 27% lower than the 0.070 rem (0.70 mSv) value for the overall DOE workforce in 2004.

To access this report and other information on occupational radiation exposure at DOE, visit DOE's Web Page for Information on Occupational Radiation Exposure at:

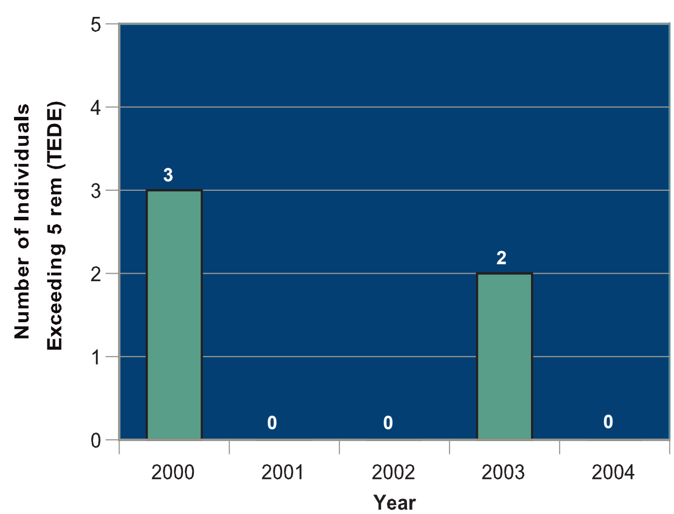
http://www.eh.doe.gov/rems/

***Exhibit ES-3:***
***Number of Individuals Exceeding 2 rem TEDE, 2000-2004.***




Note: Number of individuals exceeding 2 rem TEDE includes those individuals that also exceeded 5 rem TEDE shown in *Exhibit ES-4*.

***Exhibit ES-4:***
***Number of Individuals Exceeding 5 rem TEDE, 2000-2004.***



# Section One
# Introduction

1

Introduction

The *U.S. Department of Energy (DOE) Occupational Radiation Exposure Report, 2004,* reports occupational radiation exposures incurred by individuals at DOE facilities during the calendar year 2004. This report includes occupational radiation exposure information for all DOE employees, contractors, and subcontractors, as well as members of the public who are monitored for exposure to radiation. The 96 DOE organizations submitting radiation exposure reports for 2004 have been grouped into 25 geographic sites across the complex. This information is analyzed and trended over time to provide a measure of DOE's performance in protecting its workers from radiation.

## 1.1 Report Organization

This report is organized into the five sections listed below. This year, in an effort to streamline the printed report, most of the supporting technical information, tables of data, and additional items that were previously provided in the appendices have been removed and will be available on DOE's Web Page for Information on Occupational Radiation Exposure. Questions or comments on this change in the report should be directed to the DOE Radiation Exposure Monitoring System (REMS) project manager.

## 1.2 Report Availability

Requests for additional copies of this report, access to the data files, or individual dose records used to compile this report should be directed to:

Ms. Nirmala Rao
DOE REMS Project Manager
EH-32, 270 Corporate Square Building
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585-0270
E-mail: nimi.rao@hq.doe.gov

For more information concerning occupational radiation exposure in DOE and to access more detailed tables of data that were previously provided in the appendices of the report, visit the DOE Radiation Exposure Web Page at:

http://www.eh.doe.gov/rems/

| | |
|---|---|
| Section One | Provides a description of the content and organization of this report. |
| Section Two | Provides a discussion of the radiation protection and dose reporting requirements. |
| Section Three | Presents the occupational radiation dose data from monitored individuals at DOE facilities for 2004. The data are analyzed to show trends over the past 5 years. |
| Section Four | Includes examples of successful ALARA projects within the DOE complex. |
| Section Five | Presents conclusions based on the analysis contained in this report. |
| Appendices | In an effort to streamline this publication, the appendices are now offered in color on the DOE Radiation Exposure Web site. Please visit http://www.eh.doe.gov/rems/ and select Annual Reports to review. |

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Section Two

# Standards and Requirements

2

Standards and Requirements

One of DOE's primary objectives is to provide a safe and healthy workplace for all employees and contractors. To meet this objective, DOE's Office of Health establishes comprehensive and integrated programs for the protection of workers from hazards in the workplace, including ionizing radiation. The basic DOE standards are radiation dose limits, which establish maximum permissible doses to workers and members of the public. In addition to the requirement that radiation doses not exceed the limits, contractors and subcontractors are required to maintain exposures as low as reasonably achievable (ALARA).

This section discusses the radiation protection standards and requirements in effect for the year 2004. For more information on past requirements, visit DOE's Web Page for Information on Occupational Radiation Exposure at http://www.eh.doe.gov/rems/.

## 2.1 Radiation Protection Requirements

Current DOE radiation protection standards are based on federal guidance for protection against occupational radiation exposure promulgated by the U.S. Environmental Protection Agency (EPA) in 1987.[1] This guidance, initially implemented by DOE in 1989, is based on the 1977 recommendations of the International Commission on Radiological Protection (ICRP)[2] and the 1987 recommendations of the National Council on Radiation Protection and Measurements (NCRP).[3] This guidance recommends that internal organ dose be added to the external whole-body dose to determine the total effective dose equivalent (TEDE). Prior to this, the whole-body dose and internal organ dose were each limited separately.

In summary, the current laws and requirements for occupational radiation protection pertaining to the information collected and presented in this report are shown in *Exhibit 2-1*.

***Exhibit 2-1:***
***Current Laws and Requirements Pertaining to This Report***

| Title | Date | Description |
|---|---|---|
| 10 CFR 835 "Occupational Radiation Protection." [4] | Issued 12/14/93. Amended 11/4/98. | Establishes radiation protection standards, limits, and program requirements for protecting individuals from ionizing radiation resulting from the conduct of DOE activities. |
| DOE Order 231.1A [5] | Approved 8/19/03. Cancelled DOE O 231.1. | Requires the annual reporting of occupational radiation exposure records to the DOE Radiation Exposure Monitoring System (REMS) Repository. |
| DOE Manual 231.1-1A [6] | Approved 3/19/04. Cancelled DOE M 231.1-1. | Specifies the format and content of the reports required by DOE Order 231.1A. Readers should note that the revisions of this manual affect the content and reporting of radiation exposure records that will be reported to the DOE REMS Repository in March 2006. |

## 2.2 Radiation Dose Limits

Radiation dose limits are codified in 10 CFR 835.202, 206, 207, 208 and are summarized in *Exhibit 2-2*. While some of these sections have been revised, the limits remain the same.

Under 835.204, planned special exposures (PSEs) may be authorized under certain conditions, allowing an individual to receive exposures in excess of the dose limits shown in *Exhibit 2-2*. With the appropriate prior authorization, the annual dose limit for an individual may be increased by an additional 5 rems (50 mSv) TEDE above the routine dose limit as long as the individual does not exceed a cumulative lifetime TEDE of 25 rems (250 mSv) from other PSEs and doses above the limits. PSE doses are required to be recorded separately and are only intended to be used in exceptional situations where dose reduction alternatives are unavailable or impractical. No PSEs have occurred since the requirement became effective.

## 2.3 Reporting Requirements

On August 19, 2003, DOE approved and issued the revised DOE Order 231.1A. The DOE Manual 231.1-1A, which details the format and content of reporting radiation exposure records to the DOE, was approved on March 19, 2004. The revisions affect the content and reporting of radiation exposure records that will be reported to the DOE REMS Repository in 2006. Readers should take note of these revisions for the potential future impact on the recording and reporting of occupational exposure to the REMS Repository.

***Exhibit 2-2:***
***DOE Dose Limits from 10 CFR 835***

| Personnel Category | Section of 10 CFR 835 | Type of Exposure | Acronym | Annual Limit |
|---|---|---|---|---|
| General Employees | 835.202 | Total effective dose equivalent | TEDE | 5 rem |
| | | Deep dose equivalent + committed dose equivalent to any organ or tissue (except lens of the eye). This is often referred to as the total organ dose equivalent | DDE+CDE (TODE) | 50 rem |
| | | Lens (of the eye) dose equivalent | LDE | 15 rem |
| | | Shallow dose equivalent to the skin of the whole body or to any extremity | SDE-WB and SDE-ME | 50 rem |
| Declared Pregnant Workers * | 835.206 | Total effective dose equivalent | TEDE | 0.5 rem per gestation period |
| Minors | 835.207 | Total effective dose equivalent | TEDE | 0.1 rem |
| Members of the Public in a Controlled Area | 835.208 | Total effective dose equivalent | TEDE | 0.1 rem |

* Limit applies to the embryo/fetus.

# Occupational Radiation Dose at DOE



## 3.1 Analysis of the Data

Analysis and explanation of observed trends in occupational radiation dose data reveal opportunities to improve safety and demonstrate performance. Several indicators were identified from the data submitted to the central data repository, which can be used to evaluate the occupational radiation exposures received at DOE facilities. In addition, the key indicators are analyzed to identify and correlate parameters having an impact on radiation dose at DOE.

Key indicators for the analysis of aggregate data are number of records for monitored individuals and individuals with measurable dose, collective dose, average measurable dose, and dose distribution. Analysis of individual dose data includes an examination of doses exceeding DOE regulatory limits and doses exceeding the 2 rem (20 mSv) DOE administrative control level (ACL). Analysis of site data includes comparisons by site, labor category, and facility type. Additional information is provided concerning activities at sites contributing to the collective dose.

## 3.2 Analysis of Aggregate Data

### 3.2.1 Number of Records for Monitored Individuals

The number of records for monitored individuals represents the size of the DOE worker population provided with radiation dose monitoring. The number represents the sum of all records for monitored individuals, including all DOE employees, contractors, and subcontractors, as well as members of the public. The number of monitored individuals is determined from the number of monitoring records submitted by each site. Because individuals may have more than one monitoring record, they may be counted more than once. The number of records for monitored individuals is an indication of the size of a dosimetry program, but it is not necessarily an indicator of the size of the exposed workforce. This is because of the conservative practice at some DOE facilities of providing radiation dose monitoring to individuals for reasons other than the potential for exposure to radiation and/or radioactive materials exceeding the monitoring thresholds. Many individuals are monitored for reasons such as security, administrative convenience, and legal liability. Some sites offer monitoring for any individual who requests monitoring, independent of the potential for exposure. For this reason, the number of records for workers who receive a measurable dose best represents the exposed workforce.

### 3.2.2 Number of Records for Individuals with Measurable Dose

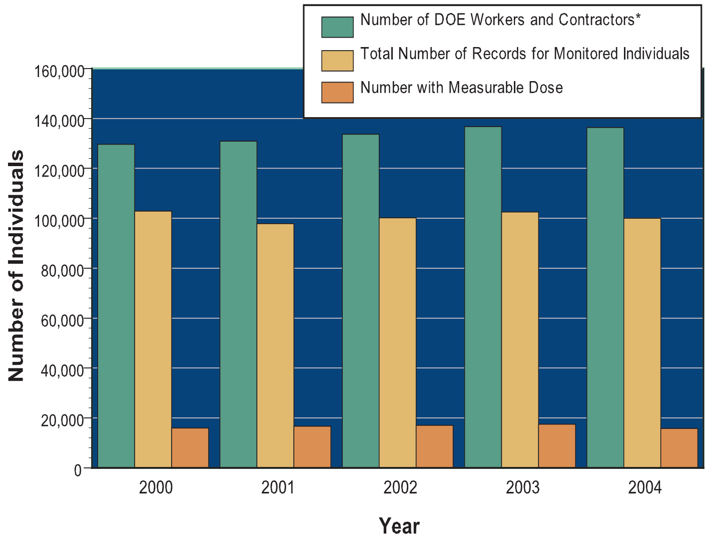
DOE uses the number of individuals receiving measurable dose to represent the exposed workforce size. The number of individuals with measurable dose includes any individuals with reported TEDE greater than zero.

*Exhibits 3-1a* and *3-1b* show the number of DOE and contractor workers, the total number of workers monitored for radiation dose, the number of individuals with measurable dose, and the relative percentages for the past 5 years.

For 2004, 73% of the DOE workforce was monitored for radiation exposure. Sixteen percent of monitored individuals received a measurable dose and 84% of the monitored individuals did not receive any measurable radiation dose. Over the past five years, the total number of records of individuals monitored for radiation exposure has remained within 3% of the five-year average; the monitored individuals receiving any measurable radiation dose is within 5% of the five-year average. The size of the overall DOE work force is within 3% of the five-year average.

***For 2004, 73% of the DOE workforce was monitored for radiation dose, and 16% of monitored individuals received a measurable dose .***

*Exhibit 3-1a:*
***Monitoring of the DOE Workforce, 2000-2004.***




* The number of DOE and contractor workers was determined from the total annual workhours at DOE [Ref. #7] converted to full-time equivalents (FTEs).

Fourteen of the 26 reporting sites (see *Exhibit 3-21*) experienced decreases in the number of workers with measurable dose from 2003 to 2004. The largest decrease in total number of workers with measurable dose occurred at Rocky Flats.The largest increase in the number of workers receiving measurable dose occurred at the Idaho National Laboratory. A discussion of activities at the six highest-dose facilities is included in Section 3.4.5.

### 3.2.3 Collective Dose

The collective dose is the sum of the dose received by all individuals with measurable dose and is measured in units of person-rem (person-Sv). The collective dose is an indicator of the overall radiation exposure at DOE facilities and includes the dose to all DOE employees, contractors, and subcontractors, as well as members of the public. DOE monitors the collective dose as one measure of the overall performance of radiation protection programs to keep individual exposures and collective exposures ALARA.

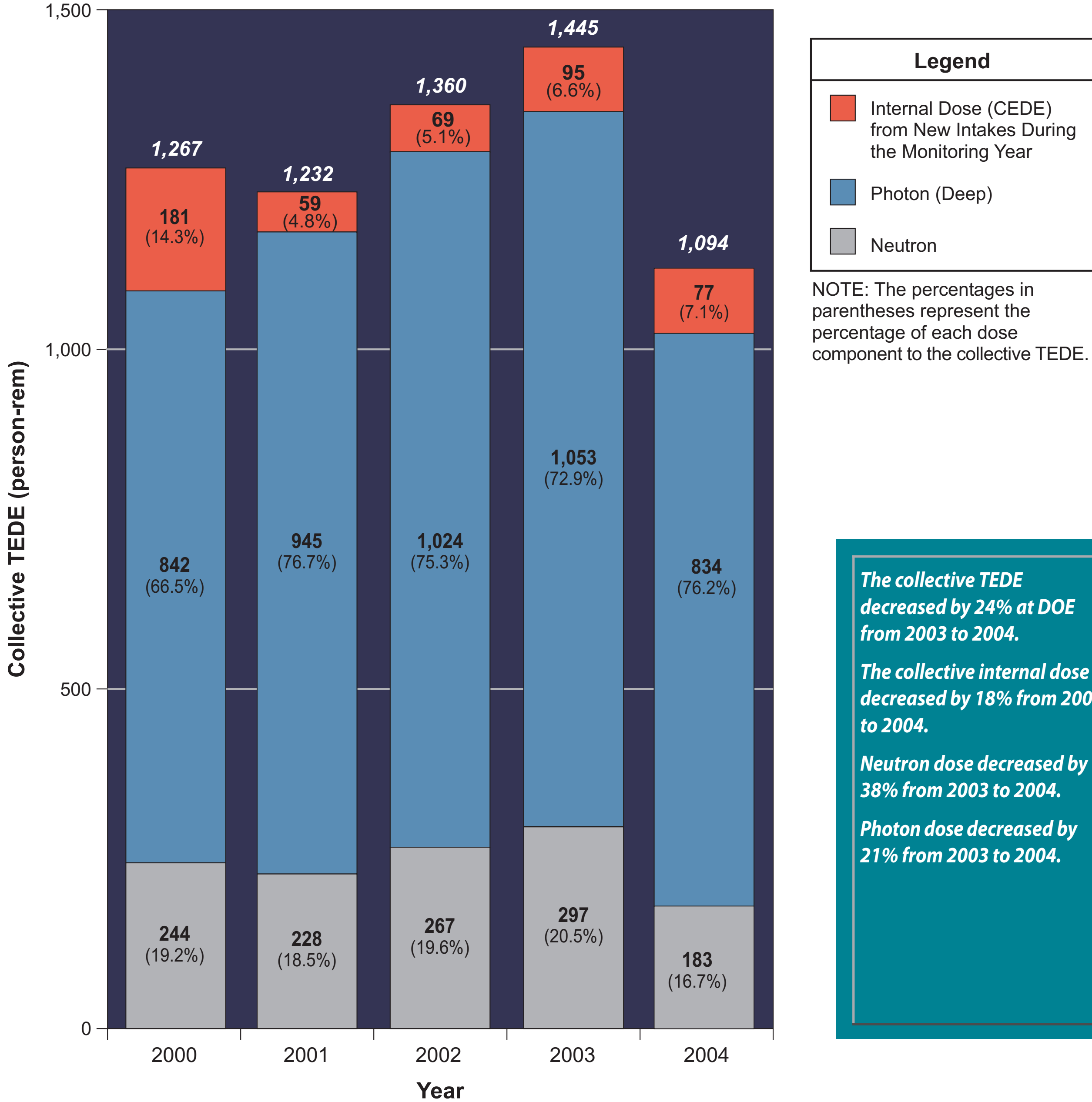
As shown in *Exhibit 3-2*, the collective TEDE decreased at DOE by 24% from 1,445 person-rem (14.45 person-Sv) in 2003 to 1,094 person-rem (10.94 person-Sv) in 2004. Only 27% of the DOE sites (7 out of 26 sites) reported increases in the collective TEDE from the 2003 values. Five out of six of the highest dose sites reported decreases in the collective TEDE. The six highest dose sites are (in descending order of collective dose for 2004) Hanford, Savannah River, Los Alamos, Oak Ridge, Idaho, and Rocky Flats. These sites attributed the decrease in dose to:

- ❖ a decrease in the isotope production work at ORNL
- ❖ a number of facilities were decommissioned at SRS
- ❖ a decrease in the number of tank farm entries at the Office of River Protection

*Exhibit 3-1b:*
***Monitoring of the DOE Workforce, 2000-2004.***

| Year | DOE & Contractor Workforce | Number of Workers Monitored | Percent of Workers Monitored | Number Monitored w/Measurable Dose | Percent Monitored w/Measurable Dose |
|---|---|---|---|---|---|
| 2000 | 129,653 | 102,881 | 79% ▼ | 15,983 | 16% ▲ |
| 2001 | 130,884 | 97,818 | 75% ▼ | 16,687 | 17% ▲ |
| 2002 | 133,703 | 100,221 | 76% ▲ | 17,051 | 17% |
| 2003 | 136,710 | 102,509 | 75% ▼ | 17,484 | 17% |
| 2004 | 136,353 | 100,011 | 73% ▼ | 15,739 | 16% ▼ |
| **5-Year Average** | **133,461** | **100,688** | **76%** | **16,629** | **17%** |

***Exhibit 3-2:***
***Components of TEDE, 2000-2004.***




***The collective TEDE decreased by 24% at DOE from 2003 to 2004.***

***The collective internal dose decreased by 18% from 2003 to 2004.***

***Neutron dose decreased by 38% from 2003 to 2004.***

***Photon dose decreased by 21% from 2003 to 2004.***

***Photon dose (deep) - the component of external dose from gamma or x-ray electromagnetic radiation. (Also includes energetic betas.)***

***Neutron dose - the component of external dose from neutrons ejected from the nucleus of an atom during nuclear reactions.***

***Internal dose - radiation dose resulting from radioactive material taken into the body.***

- the completion of thermal stabilization and repackaging of plutonium-bearing materials, and deactivation and decontamination activities at the Plutonium Finishing Plant (PFP) at Hanford
- Rocky Flats radioactive source material being shipped off site for disposal
- suspension of non-essential operations at LANL during the second half of 2004.

A discussion of the activities leading to this decrease is included in Section 3.4.5.

It is important to note that the collective TEDE includes the components of external dose and internal dose. *Exhibit 3-2* shows the types of radiation and their contribution to the collective TEDE. Internal dose, photon, and neutron components are shown.

It should be noted that the internal dose shown in *Exhibit 3-2* for 2000 through 2004 is based on the 50-year CEDE methodology. The internal dose component decreased by 18% from 95 person-rem (950 person-mSv) in 2003 to 77 person-rem (770 person-mSv) in 2004. There were two individuals who received a TEDE dose above 2 rem (20 mSv) in 2004. An individual at Rocky Flats received a CEDE of 2.8 rem (28 mSv) and an individual at Hanford received a CEDE of 3 rem (30 mSv). Both of these individuals received internal dose from plutonium and americium. The collective internal dose can vary from year to year due to the relatively small number of intakes of radioactive material and the fact that the intakes often involve long-lived radionuclides, such as plutonium, which can result in relatively large committed doses. Due to the infrequent nature of these intakes, care should be taken when attempting to identify trends from the internal dose records.

The external deep dose (comprised of photon, energetic beta, and neutron dose) is shown in *Exhibit 3-2* in order to see the contribution of external dose to the collective TEDE. The collective photon dose decreased by 21% from 1,053 person-rem (10.53 person-Sv) in 2003 to 834 person-rem (8.34 person-Sv) in 2004. The site that reported the largest increase in the external deep dose (Idaho) attributed the increase to cleanup/decontamination and decommissioning (D&D) work at Idaho Nuclear Technology & Engineering Center (INTEC) and Test Area North (TAN).

The neutron component of the TEDE decreased by 38% from 297 person-rem (2.97 person-Sv) in 2003 to 183 person-rem (1.83 person-Sv) in 2004. This is due primarily to decreases in the neutron dose at Rocky Flats, Los Alamos National Laboratory (LANL), and Hanford. All three sites also experienced decreases in the collective TEDE from 2003 to 2004. LANL and Rocky Flats process plutonium in gloveboxes, which can result in a neutron dose from the alpha/neutron reaction and from spontaneous fission of the plutonium. The collective neutron dose at Rocky Flats decreased by 94%, since much of the radioactive material has been shipped off site for disposal.

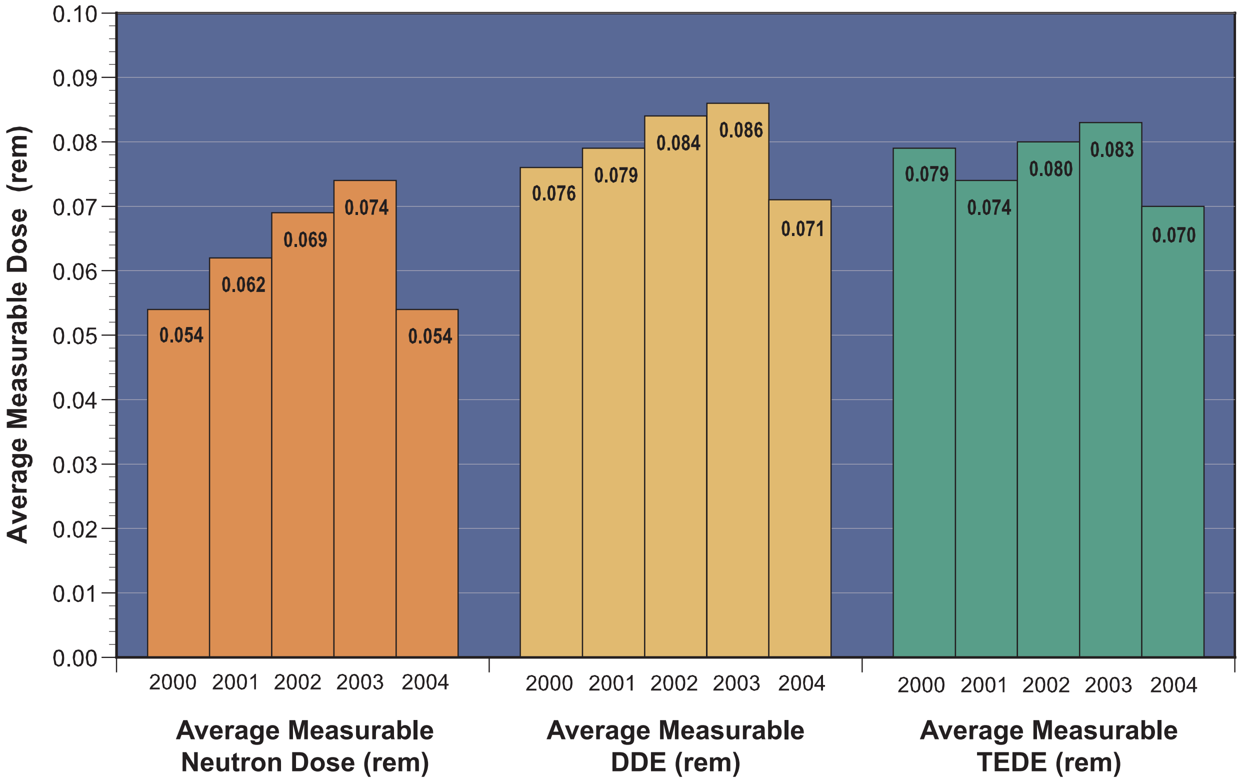
### 3.2.4 Average Measurable Dose

The average measurable dose to DOE workers presented in this report for TEDE, DDE, neutron, extremity, and CEDE is determined by dividing the collective dose for each dose type by the number of individuals with measurable dose for each dose type. This is one of the key indicators of the overall level of radiation dose received by DOE workers.

The average measurable neutron, DDE, and TEDE are shown in *Exhibit 3-3*. The average measurable neutron dose decreased by 27% from 0.074 rem (0.74 mSv) in 2003 to 0.054 rem (0.54 mSv) in 2004, due primarily to decreases in neutron dose at Rocky Flats and LANL. The average measurable neutron dose in 2004 was the same as the value in 2000. The average measurable DDE decreased by 17% from 0.086 rem (0.86 mSv) in 2003 to 0.071 rem (0.71 mSv) in 2004, the lowest value in the past 5 years. The collective TEDE decreased, as well as the number with measurable dose, resulting in a 16% decrease in the average measurable TEDE from 0.083 rem (0.83 mSv) in 2003 to 0.070 rem (0.70 mSv) in 2004. The average measurable TEDE in 2004 is also the lowest value in the past 5 years. The average measurable neutron, DDE, and TEDE values are provided for trending purposes, not for comparison among them.

While the collective dose and average measurable dose serve as measures of the magnitude of the dose accrued by DOE workers, they do not indicate the distribution of doses among the worker population.

**Exhibit 3-3:**
***Average Measurable Neutron, DDE, and TEDE, 2000-2004.***




## 3.2.5 Dose Distribution

Exposure data are commonly analyzed in terms of dose intervals to depict the dose distribution among the worker population. *Exhibit 3-4* shows the number of individuals in each of 18 different dose ranges. The dose ranges are presented for the TEDE and DDE. The DDE is shown separately to allow for analysis of the external dose, independent of changes in internal dose, and includes the photon and neutron doses. The number of individuals receiving doses above 0.1 rem (1 mSv) is also included to show the number of individuals with doses above the monitoring threshold specified in 10 CFR 835.402(a) and (c).

*Exhibit 3-4* shows that few individuals receive doses in the higher ranges, that the vast majority of doses are at low levels, and that the collective TEDE dose increased over the past 3 years from 2001 to 2003 but decreased in 2004. Another way to examine the dose distribution is to analyze the percentage of the dose received above a certain dose value as compared to the total collective dose.

The United Nations' *Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes, Volume I* [8] recommends the calculation of a parameter "SR" (previously referred to as CR) to aid in the examination of the distribution of radiation exposure among workers. SR is defined to be the ratio of the annual collective dose incurred by workers whose annual doses exceed 1.5 rem (15 mSv) to the total annual collective dose. The UNSCEAR report notes that a dose level of 1.5

***The average measurable neutron dose decreased by 27% and the average measurable DDE decreased by 17%, while the average measurable TEDE decreased by 16% from 2003 to 2004.***

rem (15 mSv) may not be useful where doses are consistently lower than this level, and they recommend that research organizations report SR values lower than 1.5 rem (15 mSv) where appropriate. For this reason, the DOE calculates and tracks the SR ratio at dose levels of 0.100 rem (1 mSv), 0.250 rem (2.5 mSv), 0.500 rem (5 mSv), 1.0 rem (10 mSv), and 2.0 rem (20 mSv). The SR values in this report were calculated by summing the TEDE to each individual who received a TEDE greater than or equal to the specified dose level divided by the total collective TEDE. This ratio is presented as a percentage rather than a decimal fraction.

Using this method of plotting the data, an ideal distribution would show only a small percentage of the collective dose delivered to individuals in the higher dose ranges. In addition, this method can be used to show the trend in the percentage of the collective dose above a certain dose range over time. For example, a significantly decreasing trend from year to year may indicate the effectiveness of ALARA programs to reduce doses to individuals, or may indicate an overall reduction in activities involving radiation exposure over time. An increasing trend over time may indicate deficiencies in the implementation of ALARA practices or an increase in production or cleanup activities resulting in radiation exposure.

*Exhibit 3-5* shows the dose distribution given by percentage of collective TEDE and DDE above each of five dose values, from 0.1 rem (1 mSv) to 2 rem (20 mSv). This graph facilitates the examination of two properties described above which may be used as indications of effective ALARA programs at DOE: (1) a relatively small percentage of the collective dose accrued in the high dose ranges and (2) a decreasing trend over time of the percentage of the collective dose accrued in the higher dose ranges. *Exhibit 3-5* also shows that each successively higher dose range is responsible for a lower percentage of the collective dose. The values for the external dose (DDE) have fluctuated within a 5% margin for

***Exhibit 3-4:***
***Distribution of Dose by Dose Range, 2000-2004.***

| | Dose Range (rem) | 2000 | | 2001 | | 2002 | | 2003 | | 2004 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TEDE | DDE | TEDE | DDE | TEDE | DDE | TEDE | DDE | TEDE | DDE |
| Number of Individuals in Each Dose Range* | Less Than Measurable | 86,898 | 88,621 | 81,131 | 82,950 | 83,170 | 84,874 | 85,025 | 86,756 | 84,272 | 85,656 |
| | Measurable < 0.1 | 13,020 | 11,498 | 13,559 | 11,881 | 13,500 | 11,994 | 13,865 | 12,352 | 12,700 | 11,563 |
| | 0.10 - 0.25 | 1,873 | 1,722 | 1,891 | 1,782 | 2,202 | 2,042 | 2,205 | 2,025 | 2,086 | 1,879 |
| | 0.25 - 0.5 | 727 | 690 | 840 | 820 | 919 | 893 | 910 | 880 | 703 | 676 |
| | 0.5 - 0.75 | 211 | 203 | 259 | 250 | 269 | 259 | 287 | 284 | 157 | 152 |
| | 0.75 - 1.0 | 91 | 93 | 89 | 88 | 95 | 94 | 117 | 118 | 63 | 60 |
| | 1 - 2 | 58 | 54 | 48 | 47 | 65 | 64 | 97 | 93 | 28 | 25 |
| | 2 - 3 | | | 1 | | 1 | 1 | 1 | 1 | 1 | |
| | 3 - 4 | | | | | | | | | 1 | |
| | 4 - 5 | | | | | | | | | | |
| | 5 - 6 | | | | | | | | | | |
| | 6 - 7 | | | | | | | | | | |
| | 7 - 8 | | | | | | | | | | |
| | 8 - 9 | | | | | | | 1 | | | |
| | 9 - 10 | 1 | | | | | | | | | |
| | 10 - 11 | | | | | | | 1 | | | |
| | 11 - 12 | 1 | | | | | | | | | |
| | > 12 | 1 | | | | | | | | | |
| Total Number of Records for Monitored Individuals | | 102,881 | 102,881 | 97,818 | 97,818 | 100,221 | 100,221 | 102,509 | 102,509 | 100,011 | 100,011 |
| Number with Measurable Dose | | 15,983 | 14,260 | 16,687 | 14,868 | 17,051 | 15,347 | 17,484 | 15,753 | 15,739 | 14,355 |
| Number with Dose >0.1rem | | 2,963 | 2,762 | 3,128 | 2,987 | 3,551 | 3,353 | 3,619 | 3,401 | 3,039 | 2,792 |
| % of Individuals with Measurable Dose | | 16% | 14% | 17% | 15% | 17% | 15% | 17% | 15% | 16% | 14% |
| Collective Dose (person-rem) | | 1,267 | 1,086 | 1,232 | 1,173 | 1,360 | 1,291 | 1,445 | 1,350 | 1,094 | 1,017 |
| Average Measurable Dose (rem) | | 0.079 | 0.076 | 0.074 | 0.079 | 0.080 | 0.084 | 0.083 | 0.086 | 0.070 | 0.071 |

* Individuals with doses equal to the dose value separating the dose ranges are included in the next higher dose range.

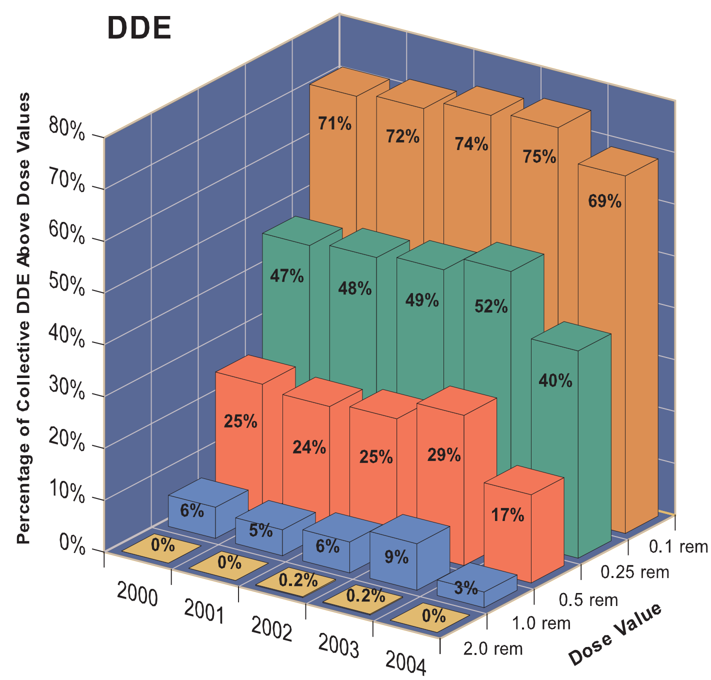
each dose range from 2000 to 2003 but decreased in every dose range from 2003 to 2004. The values for TEDE in each dose range increased from 2002 to 2003 and then decreased to the lowest values in the past 5 years for 2004. Five out of six of the highest dose sites reported decreases in the collective TEDE. The decrease in the values shown in the dose distribution indicate that, in addition to a decrease in the collective dose, individuals received doses at lower dose values.

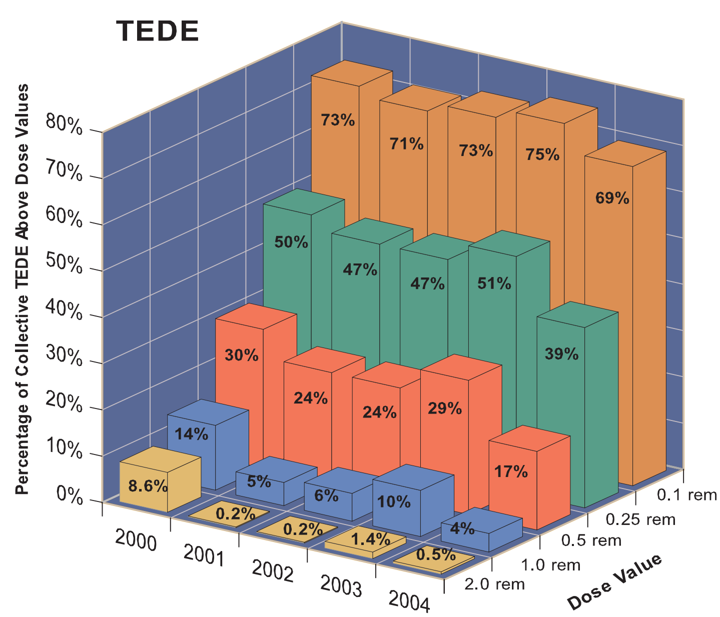
The neutron and extremity dose distributions are shown in *Exhibits 3-6* and *3-7*. The neutron dose is a component of the total DDE. Exposure to neutron radiation is much less common than exposure to photon radiation at DOE. In 2004, 3,422 individuals received measurable neutron dose, which is 22% of the individuals with measurable TEDE and 3% of the total monitored individuals. The collective neutron dose in 2004 represents 17% of the collective TEDE. All neutron doses were below 2 rem (20 mSv) for the past 5 years. The collective neutron dose decreased by 38% from 297 person-rem (2.97 person-Sv) in 2003 to 183 person-rem (1.83 person-Sv) in 2004. The average measurable neutron dose decreased by 27% from 0.074 rem (0.74 mSv) in 2003 to 0.054 rem (0.54 mSv) in 2004.

*Exhibit 3-7* shows the distribution of extremity dose over the past 5 years. "Extremities" are defined as the hands and arms below the elbow, and the feet and legs below the knee. 10 CFR 835.402(a)(1)(ii) requires monitoring for a shallow dose equivalent (SDE) to the extremities of 5 rem (50 mSv) or more in a year. As shown in *Exhibit 3-7*, less than 1% of individuals with measurable extremity dose have received doses above the 5 rem (50 mSv) monitoring threshold over the past 5 years.

Seventy-three percent of the individuals with extremity exposures above 5 rem (50 mSv) in 2004 occurred at Savannah River and Hanford, where operations involving the manipulation of radioactive materials are more common. The number of individuals receiving a measurable extremity dose decreased by 10% from 12,109 in 2003 to 10,911 in 2004, and the average extremity dose decreased by 24% from 0.391 rem (3.91 mSv) in 2003 to 0.298 rem (2.98 mSv) in 2004. The DOE annual limit for extremity dose is 50 rem (500 mSv). The absence of blood-forming organs

***Exhibit 3-5:***
***Percentage of Collective Dose Above Dose Values During 2000-2004.***



in the extremities allows a higher limit because extremity exposures involves less health risk to the individual. The highest extremity dose in 2004 was 23.7 rem (237 mSv) received by an individual at Hanford.

## 3.3 Analysis of Individual Dose Data

The above analysis is based on aggregate data for DOE. From an individual worker perspective, as well as a regulatory perspective, it is important to closely examine the doses received by individuals in the elevated dose ranges to thoroughly understand the circumstances leading to these doses in the workplace and to better manage and avoid these doses in the future. The following analysis focuses on doses received by individuals that were in excess of the DOE limit (5 rem TEDE) or (50 mSv) and the DOE recommended ACL (2 rem TEDE) or (20 mSv).

***Exhibit 3-6:***
***Neutron Dose Distribution, 2000-2004.***

| Year | No Meas. Dose | Meas. <0.100 | 0.10-0.25 | 0.25-0.50 | 0.5-0.75 | 0.75-1.0 | 1.0-2.0 | >2.0 | Total Monitored* | Number of Individuals with Meas. Neutron Dose | Collective Neutron DDE (person-rem) | Average Meas. Neutron DDE (rem) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | 98,353 | 3,809 | 554 | 144 | 17 | 4 | | | **102,881** | **4,528** | 243.802 | 0.054 |
| 2001 | 94,135 | 3,051 | 454 | 136 | 38 | 3 | 1 | | 97,818 | 3,683 | 228.494 | 0.062 |
| 2002 | 96,343 | 3,082 | 607 | 122 | 50 | 11 | 6 | | 100,221 | 3,878 | 267.029 | 0.069 |
| 2003 | 98,522 | 3,129 | 568 | 228 | 38 | 12 | 12 | | 102,509 | 3,987 | **296.874** | **0.074** |
| 2004 | 96,589 | 2,885 | 386 | 129 | 19 | 3 | | | 100,011 | 3,422 | 183.412 | 0.054 |

Note: Arrowed values indicate the greatest value in each column.

* Represents the total number of records reported. The number of individuals monitored for neutron radiation is not known because there is no distinction made between zero dose and not monitored.

***Exhibit 3-7:***
***Extremity Dose Distribution, 2000-2004.***

| Year | No Meas. Dose | Meas. <0.1 | 0.1-1.0 | 1-5 | 5-10 | 10-20 | 20-30 | 30-40 | >40 | Total Monitored* | Number with Measurable Dose | Number Above Monitoring Threshold (5 rem) ** | Collective Extremity Dose (person-rem) | Average Measurable Extremity Dose (rem) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | 91,329 | 7,279 | 3,322 | 818 | 88 | 37 | 8 | | | **102,881** | 11,552 | 133 | 4,309.5 | 0.373 |
| 2001 | 85,353 | 8,364 | 3,282 | 682 | 109 | 27 | | 1 | | 97,818 | **12,465** | 137 | 3,839.0 | 0.308 |
| 2002 | 87,921 | 7,902 | 3,461 | 777 | 115 | 39 | 5 | | 1 | 100,221 | 12,300 | 160 | 4,466.1 | 0.363 |
| 2003 | 90,400 | 7,726 | 3,445 | 761 | 108 | 56 | 13 | | | 102,509 | 12,109 | **177** | **4,736.1** | **0.391** |
| 2004 | 89,100 | 7,160 | 3,114 | 536 | 66 | 29 | 6 | | | 100,011 | 10,911 | 101 | 3,253.6 | 0.298 |

Note: Arrowed values indicate the greatest value in each column.

* Represents the total number of records reported. The number of individuals monitored for extremity radiation is not known because there is no distinction made between zero dose and not monitored.

** DOE annual limit for extremities is 50 rem. 10 CFR 835.402(a)(1)(ii) requires extremity monitoring for a shallow dose equivalent to the extremity of 5 rem or more in 1 year.

### 3.3.1 Doses in Excess of DOE Limits

*Exhibit 3-8* shows the number of doses in excess of the TEDE regulatory limit (5 rem) or (50 mSv) from 2000 through 2004. Further information concerning the individual doses, radionuclides involved, and sites where the doses in excess of the 5 rem (50 mSv) TEDE limit have occurred during the past 5 years is shown in *Exhibit 3-10*.

In 2004, no individuals were reported to have received a dose in excess of the 5 rem (50 mSv) TEDE limit.

### 3.3.2 Doses in Excess of Administrative Control Level

The Radiological Control Standard (RCS) recommends a 2 rem (20 mSv) ACL for TEDE, which should not be exceeded without prior DOE approval. The RCS recommends that each DOE site establish its own, more restrictive ACL that would require contractor management approval to be exceeded. The number of individuals receiving doses in excess of the 2 rem (20 mSv) ACL is a measure of the effectiveness of DOE's radiation protection program.

As shown in *Exhibit 3-9*, two individuals received a TEDE above 2 rem (20 mSv) during 2004. One of the individuals received a TEDE of 3 rem (30 mSv) at Hanford, and the other individual was reported to have received 2.833 rem (28.33 mSv) TEDE at Rocky Flats. Both of the individuals received CEDE doses in excess of 2 rem (20 mSv) as a result of intakes of plutonium. At Hanford, a radiological control technician (RCT) was exposed to plutonium and americium while performing radiological surveys in a high contamination area (HCA) (see Occurrence Report RL–BHI-REMACT-2004-0018). At Rocky Flats, the intake was due to a small puncture wound received during size reduction activities (see Occurrence Report RFO–KHLL-PUFAB-2004-0004).

### 3.3.3 Internal Depositions of Radioactive Material

As shown in *Exhibit 3-10*, some of the highest doses to individuals have been the result of intakes of radioactive material. For this reason, DOE emphasizes the need to avoid intakes and tracks the number of intakes as a performance measure.

The numbers of internal depositions of radioactive material (otherwise known as worker intakes)

***Exhibit 3-8:***
***Number of Individuals Exceeding 5 rem (TEDE), 2000-2004.***

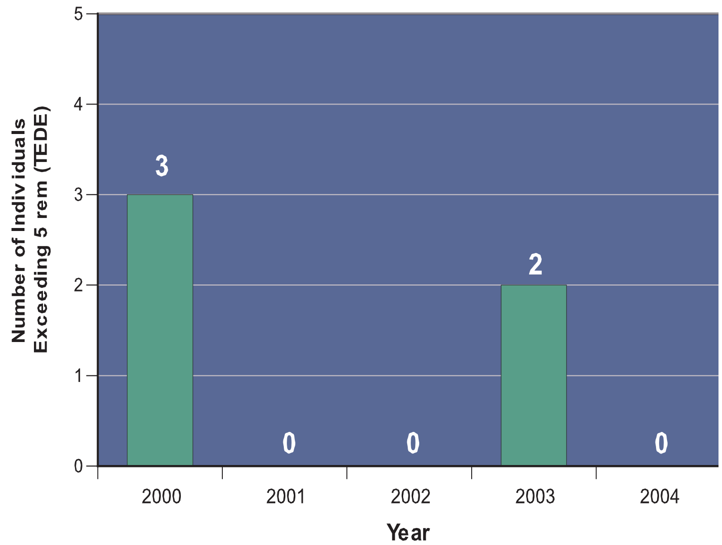



***Exhibit 3-9:***
***Number of Doses in Excess of the DOE 2 rem ACL, 2000-2004.***

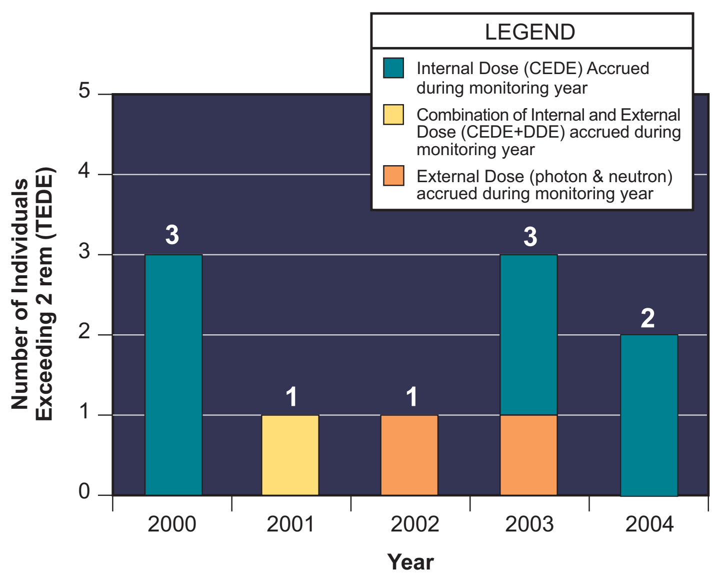


**Exhibit 3-10:**
**Doses in Excess of DOE Limits, 2000-2004.**

| Year | TEDE (rem) | DDE (rem) | CEDE (rem) | SDE Extremity (rem) | Intake Nuclides | Facility Types | Site |
|---|---|---|---|---|---|---|---|
| 2000 * | 9.692 | 0.322 | 9.370 | | Pu-238, Pu-239, Pu-240 | Research, General | LANL |
| | 11.745 | 0.245 | 11.500 | | Pu-238, Pu-239, Pu-240 | Research, General | LANL |
| | 87.156 | 0.156 | 87.000 | | Pu-238, Pu-239, Pu-240 | Maintenance and Support | LANL |
| 2001 | | | | None Reported | | | |
| 2002 | 0.080 | 0.080 | - | 111 | | Research, General | LLNL |
| 2003 | 8.170 | 0.949 | 7.221 | 1.302 | Pu-238 | Other | LANL |
| | 10.197 | 0.609 | 9.588 | 0.834 | Pu-238 | Waste Processing | LANL |
| 2004 | | | | None Reported | | | |

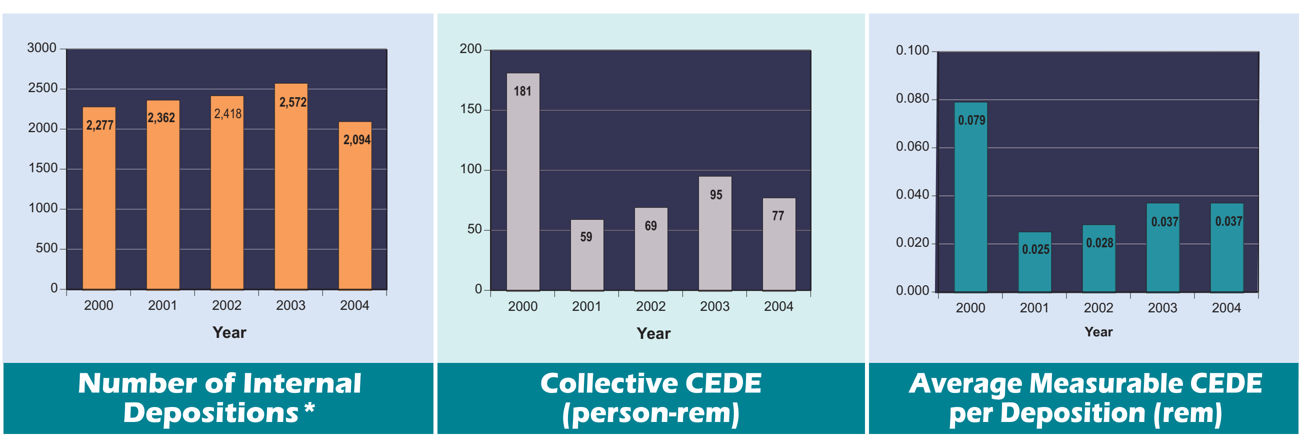
* These three doses were all a result of the same occurrence.

collective CEDE, and average measurable CEDE for 2000-2004 are shown in *Exhibit 3-11*. The number of internal depositions decreased by 19% from 2,572 in 2003 to 2,094 in 2004, while the collective CEDE decreased by 18%. Due to the similar percentage decrease in the collective CEDE and in the number of internal depositions, the average measurable CEDE remained unchanged at 0.037 rem (0.37 mSv) for 2004.

The number of internal depositions of radioactive material for 2002 through 2004 is also shown in *Exhibit 3-12*. The internal depositions were categorized into eight radionuclide groups. Intakes involving multiple nuclides are listed as "mixed." Nuclides where fewer than 10 individuals had intakes each year over the 3-year period are grouped together as "other." Only those records with internal dose greater than zero are included in this analysis. It should be noted that the different nuclides have different radiological properties, resulting in varying minimum levels of detection and reporting.

***In 2004, no individuals were reported to have received doses in excess of the 5 rem (50 mSv) TEDE limit.***

**Exhibit 3-11:**
**Number of Internal Depositions, Collective CEDE, and Average Measurable CEDE (Graph), 2000-2004.**




* The number of internal depositions represents the number of internal dose records reported for each individual. Individuals may have multiple intakes in a year and, therefore, may be counted more than once.

*Exhibit 3-12:*
***Number of Internal Depositions, Collective CEDE, and Average Measurable CEDE by Nuclides (Data), 2002-2004.***

| Nuclide | Number of Internal Depositions* | | | Collective CEDE (person-rem) | | | Average Measurable CEDE per Deposition (rem) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2002** | **2003** | **2004** | **2002** | **2003** | **2004** | **2002** | **2003** | **2004** |
| Hydrogen-3 (Tritium) | 270 | 271 | 167 | 1.351 | 1.232 | 1.311 | 0.005 | 0.005 | 0.008 |
| Radon-222 | 15 | 19 | 12 | 2.115 | 0.568 | 0.160 | **0.141** ◄ | 0.030 | 0.013 |
| Thorium | 67 | 83 | 69 | 0.836 | 0.930 | 0.622 | 0.012 | 0.011 | 0.009 |
| Uranium | **1,664** ◄ | **1,607** ◄ | **1,320** ◄ | **55.962** ◄ | **54.946** ◄ | **50.029** ◄ | 0.034 | 0.034 | 0.038 |
| Plutonium | 298 | 492 | 439 | 6.868 | 33.524 | 24.175 | 0.023 | **0.068** ◄ | **0.055** ◄ |
| Americium-241 | 65 | 78 | 42 | 1.226 | 3.109 | 0.801 | 0.019 | 0.040 | 0.019 |
| Other | 26 | 11 | 32 | 0.091 | 0.069 | 0.091 | 0.004 | 0.006 | 0.003 |
| Mixed | 13 | 11 | 13 | 0.241 | 0.124 | 0.122 | 0.019 | 0.011 | 0.009 |
| **Totals** | **2,418** | **2,572** | **2,094** | **68.690** | **94.502** | **77.311** | **0.028** | **0.037** | **0.037** |

Note: Arrowed values indicate the greatest value in each column.
* The number of internal depositions represents the number of internal dose records reported for each individual.

The 18% decrease in the collective CEDE from 94.5 person-rem (945 person-mSv) in 2003 to 77.3 person-rem (773 person-mSv) in 2004 was due to decreases in the number of intakes and collective CEDE for every category of radionuclide, except for minor increases for "mixed" and "other."

During the past 5 years, there have been several intakes from plutonium or uranium in excess of 2 rem (20 mSv) each year, with some of the doses in excess of 5 rem (50 mSv) (see *Exhibit 3-9*). While the numbers of internal depositions above 5 rem (20 mSv) have been few, they contributed significantly to the collective internal dose for 2000 and 2003. In 2004, there were two individuals with internal dose above 2 rem (20 mSv) but no internal dose above 5 rem (50 mSv).

The highest collective CEDE and number of depositions in 2004 are due to uranium intakes. Almost all of the collective dose from uranium (96%) occurred at the Oak Ridge Y-12 facility during the continued operation and management of Enriched Uranium Operations (EUO) facilities at the site. The highest average measurable CEDE in 2004 is from plutonium. The sites with the majority of internal dose from plutonium are LANL and Rocky Flats.

Because relatively few workers receive measurable internal dose, fluctuations in the number of workers and collective CEDE can occur from year to year.

*Exhibit 3-13* shows the distribution of the internal dose from 2000 to 2004. The total number of individuals with intakes in each dose range is the sum of all records of intake in the subject dose range. The internal dose does not include doses from intakes (legacy annual effective dose equivalent [AEDE]) prior to the current year. Individuals with multiple intakes during the year may be counted more than once. Doses below 0.020 rem (0.20 mSv) are shown as a separate dose range to show the large number of doses in this low-dose range. There were two internal doses above 2 rem (20 mSv) in 2004, and these two individuals received CEDE doses of 2.8 rem (28 mSv) and 3.0 rem (30 mSv) from plutonium.

The internal dose records indicate that the majority of the intakes result in very low doses. In 2004, 65% of the internal dose records were for doses below 0.020 rem (0.20 mSv). Over the 5-year period, internal doses from intakes accounted for 8% of the collective TEDE, and 7% of the individuals who received internal doses were above the monitoring threshold specified (100 mrem or 1 mSv) in 10 CFR 835.402(c).

***The internal dose records indicate that the majority of the intakes result in very low doses.***

***Over the 5-year period, internal doses accounted for only 8% of the collective TEDE.***

***Exhibit 3-13:***
***Internal Dose Distribution from Intakes, 2000-2004.***

Number of individuals* with internal dose in each dose range (rem).

| Year | Meas. <0.020 | 0.020-0.100 | 0.100-0.250 | 0.250-0.500 | 0.500-0.750 | 0.750-1.000 | 1.0-2.0 | 2.0-3.0 | 3.0-4.0 | 4.0-5.0 | >5.0 | Total No. of Indiv.* | Total Collective Internal Dose CEDE (person-rem) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | 1,472 | 625 | 136 | 34 | 5 | 2 | | | | | 3 | 2,277 | 180.580 |
| 2001 | 1,673 | 574 | 90 | 19 | 4 | | 2 | | | | | 2,362 | 58.954 |
| 2002 | 1,534 | 734 | 131 | 16 | 3 | | | | | | | 2,418 | 68.690 |
| 2003 | 1,622 | 763 | 163 | 18 | 3 | | 1 | | | | 2 | 2,572 | 94.502 |
| 2004 | 1,364 | 521 | 184 | 12 | 7 | 3 | 1 | 1 | 1 | | | 2,094 | 77.311 |

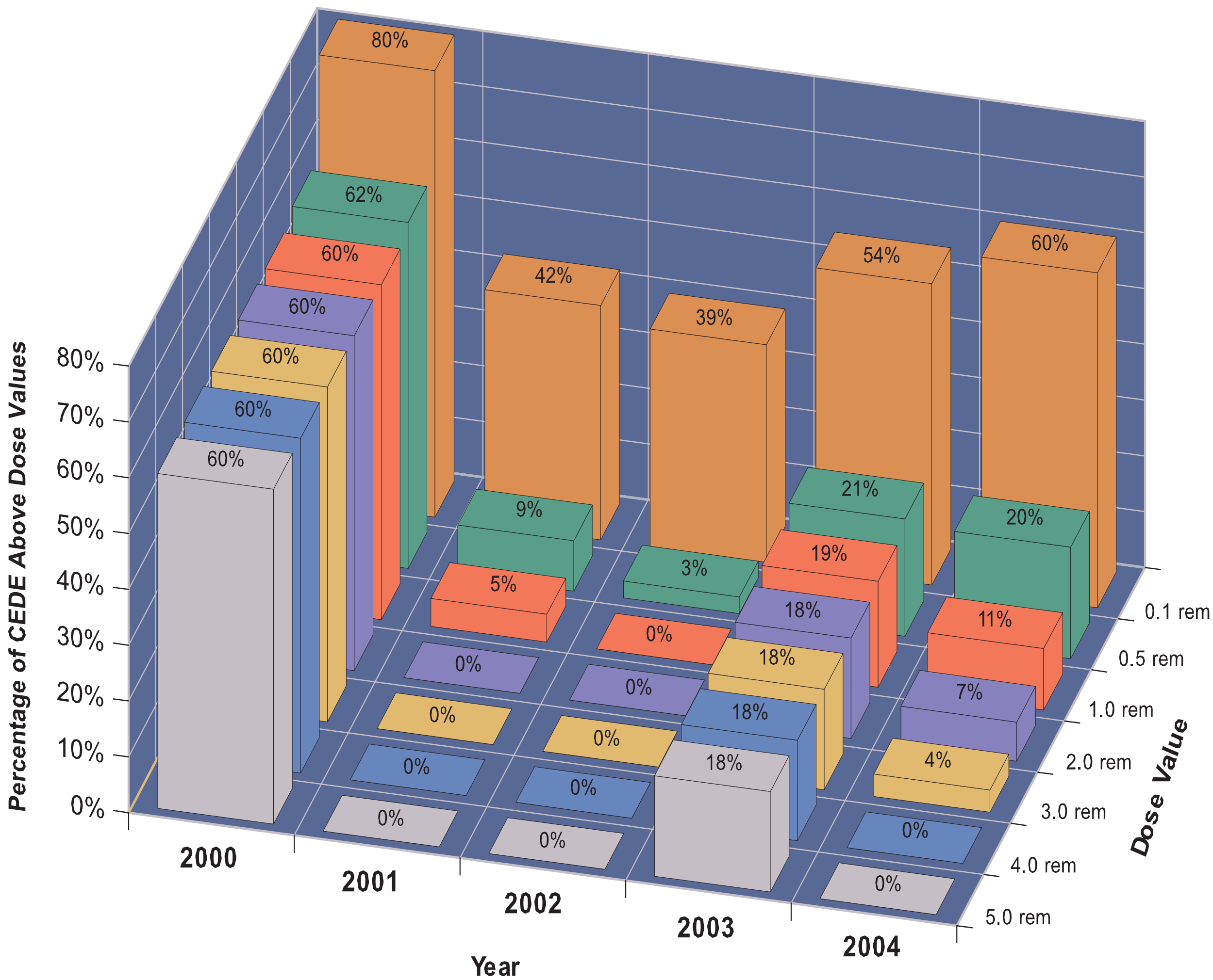
Note: Individuals with doses equal to the dose value separating the dose ranges are included in the next higher dose range.
* Individuals may have multiple intakes in a year and, therefore, may be counted more than once.

The internal dose distribution can also be shown in terms of the percentage of the collective dose delivered above certain dose levels. *Exhibit 3-14* shows this information for the CEDE for each year from 2000 to 2004. While the fluctuations in internal dose prohibit definitive trend analysis, it is evident from the graph that, in 2000, the percentages above 2 rem (20 mSv) were dominated by the three doses in excess of the DOE annual limit that occurred at LANL. For 2001 and 2002, the percentage of internal dose above each dose range decreased dramatically because of the lack of any internal doses above 2 rem (20 mSv).

In 2003, there were two internal doses above 5 rem (50 mSv), which increased the percentages for each dose range by about 18%.

When trends involving internal dose are examined, several factors should be considered. Some of the largest changes in the number of reported intakes over the years resulted from changes in internal dosimetry practices. Periodically, sites may implement new technology or change monitoring practices or procedures, which may involve increasing the sensitivity of the detection equipment, thereby increasing the number of individuals with measurable internal doses. Conversely, sites may determine that internal monitoring is no longer required due to historically low levels of internal dose or a decreased potential for intake. There are relatively few intakes each year, and the CEDE method of calculating internal dose can result in large internal doses from the intake of long-lived nuclides. This can result in variability of the internal dose data from year to year.

***Exhibit 3-14:***
***Distribution of Collective CEDE vs. Dose Value, 2000-2004***

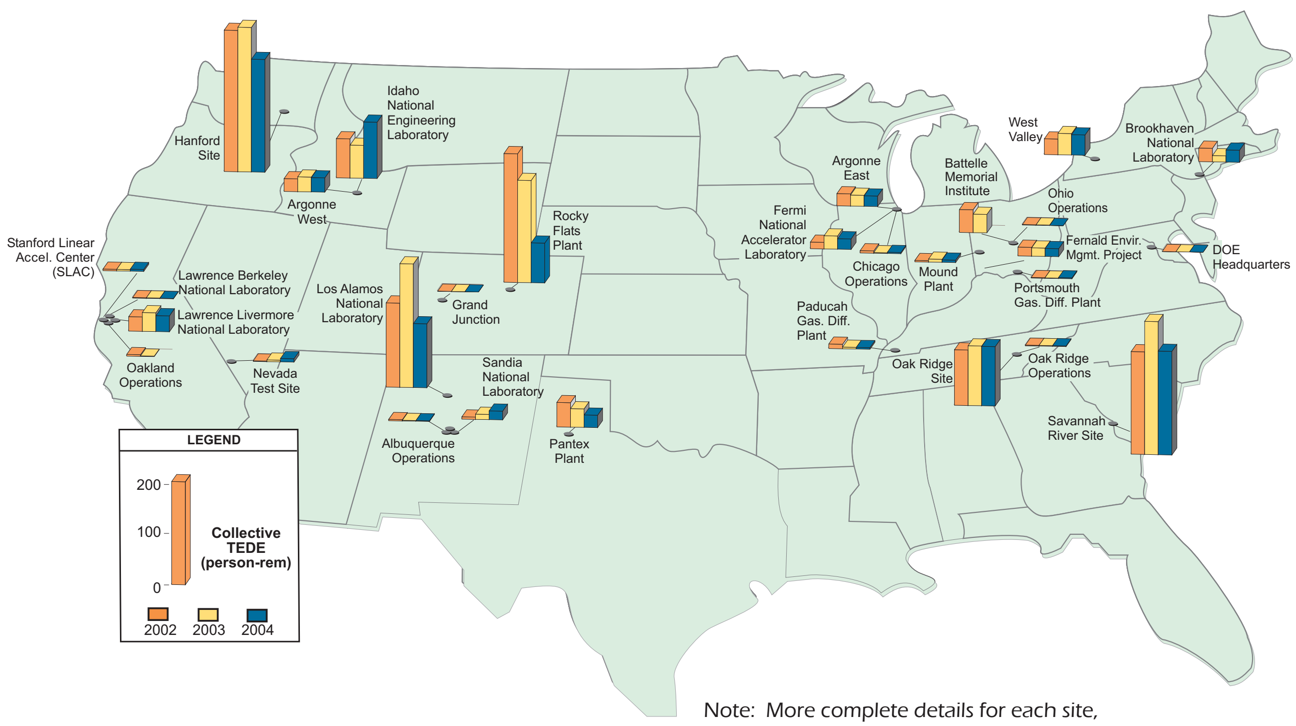


## 3.4 Analysis of Site Data

### 3.4.1 Collective TEDE by Site and Operations/ Field Offices

The collective TEDE for 2002 through 2004 for the major DOE sites and operations/field offices is shown in *Exhibit 3-15*. A list of the collective TEDE and number of individuals with measurable TEDE for the DOE sites and operations/field offices is shown in *Exhibit 3-16*. Operations/field office dose is shown separately from the site dose wherever it is reported separately. Other small sites and facilities that do not contribute significantly to the collective dose are included within the numbers shown for "Ops. and Other Facilities." The collective TEDE decreased by 24% from 1,445 person-rem (14.45 person-Sv) in 2003 to 1,094 person-rem (10.94 person-Sv) in 2004, with six of the highest dose sites (Hanford, Savannah River, Los Alamos, Oak Ridge, Idaho, and Rocky Flats) contributing 77% of the total DOE collective TEDE.

***Exhibit 3-15:***
***Collective TEDE by Site for 2002-2004.***




Note: More complete details for each site, operations/field office, and reporting organization can be found on the Web site. Please visit http://www.eh.doe.gov/rems/ and select Annual Reports to review the appendices.

***Exhibit 3-16:***
***Collective TEDE and Number of Individuals with Measurable TEDE by Site, 2002-2004.***

| **Operations/ Field Office** | **Site** | **2002** Collective TEDE (person-rem) | **2002** Number with Meas. TEDE | **2003** Collective TEDE (person-rem) | **2003** Number with Meas. TEDE | **2004** Collective TEDE (person-rem) | **2004** Number with Meas. TEDE |
|---|---|---|---|---|---|---|---|
| Albuquerque | Ops. and Other Facilities | 2.5 | 118 | 1.3 | 107 | 1.3 | 116 |
| | Los Alamos National Lab. (LANL) | 163.5 | 1,696 | 240.0 | 2,047 | 124.5 | 1,709 |
| | Pantex Plant (PP) | 47.3 | 292 | 35.9 | 290 | 24.3 | 270 |
| | Sandia National Lab. (SNL) | 4.5 | 109 | 10.2 | 250 | 17.1 | 317 |
| Chicago | Ops. and Other Facilities | 4.5 | 182 | 1.2 | 153 | 2.5 | 173 |
| | Argonne Nat'l. Lab. - East (ANL-E) | 23.6 | 233 | 21.4 | 231 | 20.5 | 172 |
| | Argonne Nat'l. Lab. - West (ANL-W) | 24.9 | 278 | 28.8 | 277 | 28.0 | 326 |
| | Brookhaven Nat'l. Lab.(BNL) | 26.2 | 439 | 12.2 | 306 | 23.7 | 301 |
| | Fermi Nat'l. Accelerator Lab.(FERMI) | 12.8 | 389 | 25.7 | 612 | 20.6 | 498 |
| DOE HQ | DOE Headquarters** | 0.0 | 0 | | | | |
| Idaho | Idaho Site | 76.0 | 1,089 | 64.0 | 1,141 | 109.5 | 1,471 |
| Nevada | Nevada Test Site (NTS) | 0.9 | 30 | 3.2 | 69 | 6.6 | 116 |
| Oakland | Ops. and Other Facilities | 3.2 | 81 | 0.9 | 64 | - | - |
| | Lawrence Berkeley Nat'l. Lab. (LBNL) | 0.9 | 33 | 1.0 | 20 | 0.7 | 18 |
| | Lawrence Livermore Nat'l. Lab. (LLNL) | 28.0 | 163 | 36.4 | 202 | 31.2 | 232 |
| | Stanford Linear Accelerator Center (SLAC) | 3.1 | 79 | 3.1 | 109 | 3.9 | 149 |
| Oak Ridge | Ops. and Other Facilities | 1.4 | 103 | 1.3 | 98 | 1.3 | 91 |
| | Oak Ridge Site | 107.8 | 2,304 | 116.0 | 2,389 | 115.5 | 2,132 |
| | Paducah Gaseous Diff. Plant (PGDP) | 8.8 | 232 | 3.2 | 38 | 3.4 | 41 |
| | Portsmouth Gaseous Diff. Plant (PORTS) | 1.0 | 37 | 0.6 | 26 | 1.9 | 32 |
| Ohio | Ops. and Other Facilities | 0.6 | 49 | 0.7 | 47 | 0.2 | 14 |
| | Battelle Memorial Institute - Columbus* | 44.4 | 103 | 35.9 | 100 | - | - |
| | Fernald Environmental Management Project | 17.0 | 572 | 16.2 | 631 | 15.5 | 615 |
| | Mound Plant | 2.7 | 198 | 5.8 | 237 | 4.6 | 152 |
| | West Valley | 30.5 | 239 | 41.7 | 207 | 39.7 | 241 |
| Rocky Flats | Rocky Flats Env. Tech. Site (RFETS) | **250.0** ◄ | 2,175 | 198.6 | 1,761 | 77.4 | 1,021 |
| Richland | Hanford Site | 249.3 | 2,242 | 243.5 | 2,177 | **205.2** ◄ | 2,278 |
| | Office of River Protection | 25.1 | 369 | 37.3 | 449 | 14.0 | 288 |
| Savannah River | Savannah River Site (SRS) | 199.1 | **3,217** ◄ | **258.6** ◄ | **3,446** ◄ | 201.2 | **2,966** ◄ |
| **Totals** | | **1,359.6** | **17,051** | **1,444.6** | **17,484** | **1,094.4** | **15,739** |

* No longer required to report to DOE.
** DOE Headquarters personnel are included in the data submitted by the site where the dose was accrued.

Note: Arrowed values indicate the greatest value in each column.

### 3.4.2 Dose by Labor Category

DOE occupational exposures are tracked by labor category at each site to facilitate identification of exposure trends, which assists management in prioritizing ALARA activities. Worker occupation codes are reported in accordance with DOE M 231.1-1 and are grouped into major labor categories in this report. The collective TEDE for each labor category for 2002 through 2004 is shown in *Exhibits 3-17* and *3-18*. Technicians and production staff have the highest collective TEDE and average measurable TEDE for the past 3 years because they generally handle more radioactive sources than individuals in the other labor categories. In 2004, 55% of the technician dose was attributed to radiation protection technicians, and 74% of the dose to production personnel is attributed to plant operators.

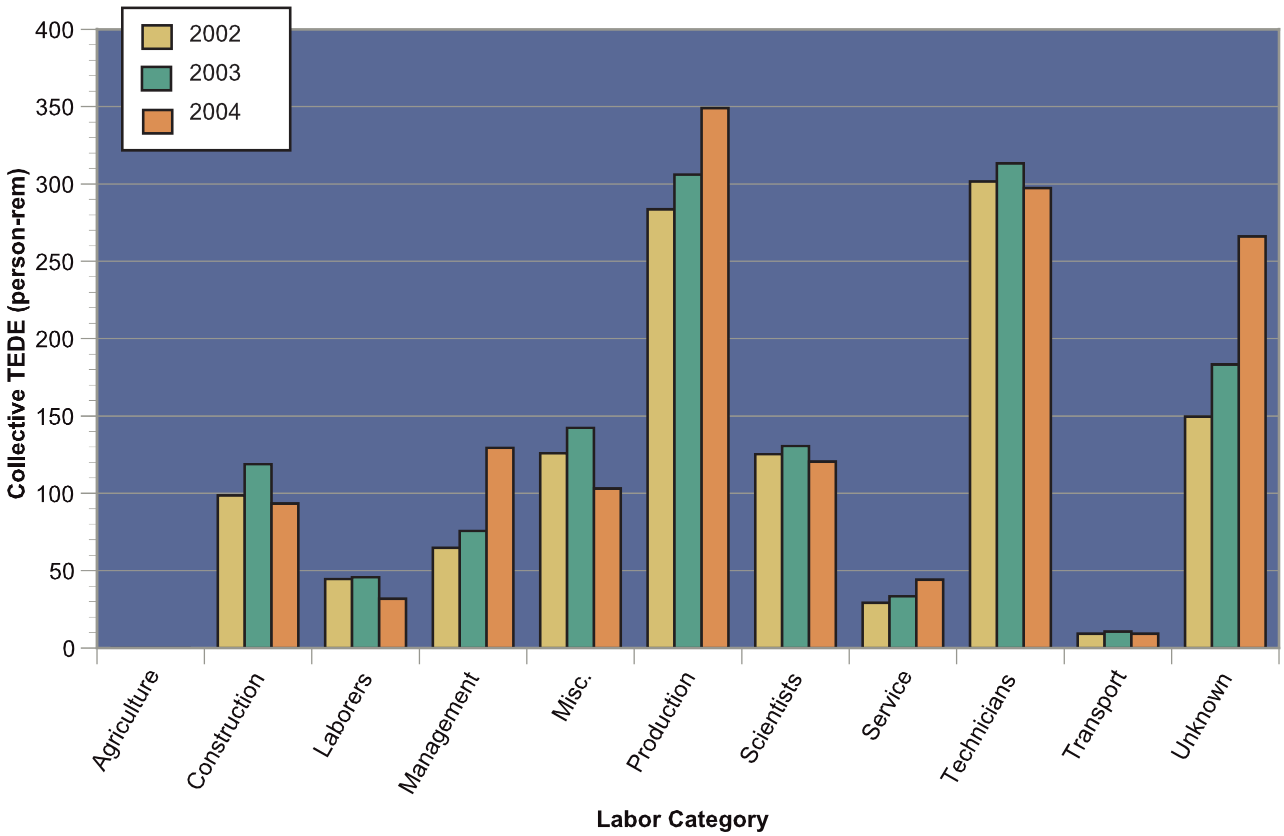
As in past years, the "unknown" category had a large number of individuals with measurable TEDE. Eighty-three percent of the dose in the "unknown" category for 2004 is attributed to LANL. Currently, the LANL computer system does not maintain the data necessary to report occupation codes in accordance with DOE M 231.1-1. Other sites also report individuals with an occupation code of "unknown." Typically, these workers are subcontractors or temporary workers. Information concerning these workers tends to be limited.

***Exhibit 3-17:***
***Number with Measurable Dose, Collective TEDE, and Average Measurable TEDE by Labor Category, 2002-2004.***

| Labor Category | Number with Meas. Dose | | | Collective TEDE (person-rem) | | | Average Meas. TEDE (rem) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2002 | 2003 | 2004 | 2002 | 2003 | 2004 | 2002 | 2003 | 2004 |
| Agriculture | 1 | 0 | 2 | 0.0 | 0.0 | 0.0 | 0.012 | 0.0 | 0.012 |
| Construction | 1,949 | 1,865 | 1,792 | 118.8 | 93.5 | 95.3 | 0.061 | 0.050 | 0.053 |
| Laborers | 605 | 530 | 454 | 45.8 | 31.9 | 34.4 | 0.076 | 0.060 | 0.076 |
| Management | 1,392 | 2,095 | 1,957 | 75.6 | 129.4 | 104.5 | 0.054 | 0.062 | 0.053 |
| Misc. | 1,527 | 1,170 | 1,254 | 142.2 | 103.2 | 106.1 | 0.093 | 0.088 | 0.085 |
| Production | 2,419 | 2,431 | 2,231 | 306.1 | **349.1** ◀ | **242.0** ◀ | **0.127** ◀ | **0.144** ◀ | **0.108** ◀ |
| Scientists | 2,908 | 2,699 | 2,388 | 130.6 | 120.4 | 96.5 | 0.045 | 0.045 | 0.040 |
| Service | 631 | 830 | 643 | 33.4 | 44.2 | 38.4 | 0.053 | 0.053 | 0.060 |
| Technicians | **2,956** ◀ | 2,758 | **2,443** ◀ | **313.3** ◀ | 297.3 | 219.0 | 0.106 | 0.108 | 0.090 |
| Transport | 245 | 247 | 215 | 10.6 | 9.3 | 8.8 | 0.043 | 0.038 | 0.041 |
| Unknown | 2,418 | **2,859** ◀ | 2,360 | 183.2 | 266.1 | 149.2 | 0.076 | 0.093 | 0.063 |
| **Totals** | **17,051** | **17,484** | **15,739** | **1,359.6** | **1,444.6** | **1,094.4** | **0.080** | **0.083** | **0.070** |

Note: Arrowed values indicate the greatest value in each column.

**Exhibit 3-18:**
***Graph of Collective TEDE by Labor Category, 2002-2004.***




## 3.4.3 Dose by Facility Type

DOE occupational exposures are tracked by facility type at each site to better understand the nature of exposure trends and to assist management in prioritizing ALARA activities. The contributions of certain facility types to the DOE collective TEDE are shown in *Exhibits 3-19* and *3-20*.

The collective TEDE for 2002 through 2004 was highest at weapons fabrication and testing facilities. Eighty-four percent of this dose was accrued at Rocky Flats and the Oak Ridge Y-12 facility in 2004. It should be noted that, although weapons fabrication and testing facilities account for the highest collective dose, these sites are now primarily involved in nuclear materials stabilization and waste management.

***Exhibit 3-19:***
***Graph of Collective TEDE by Facility Type, 2002-2004.***

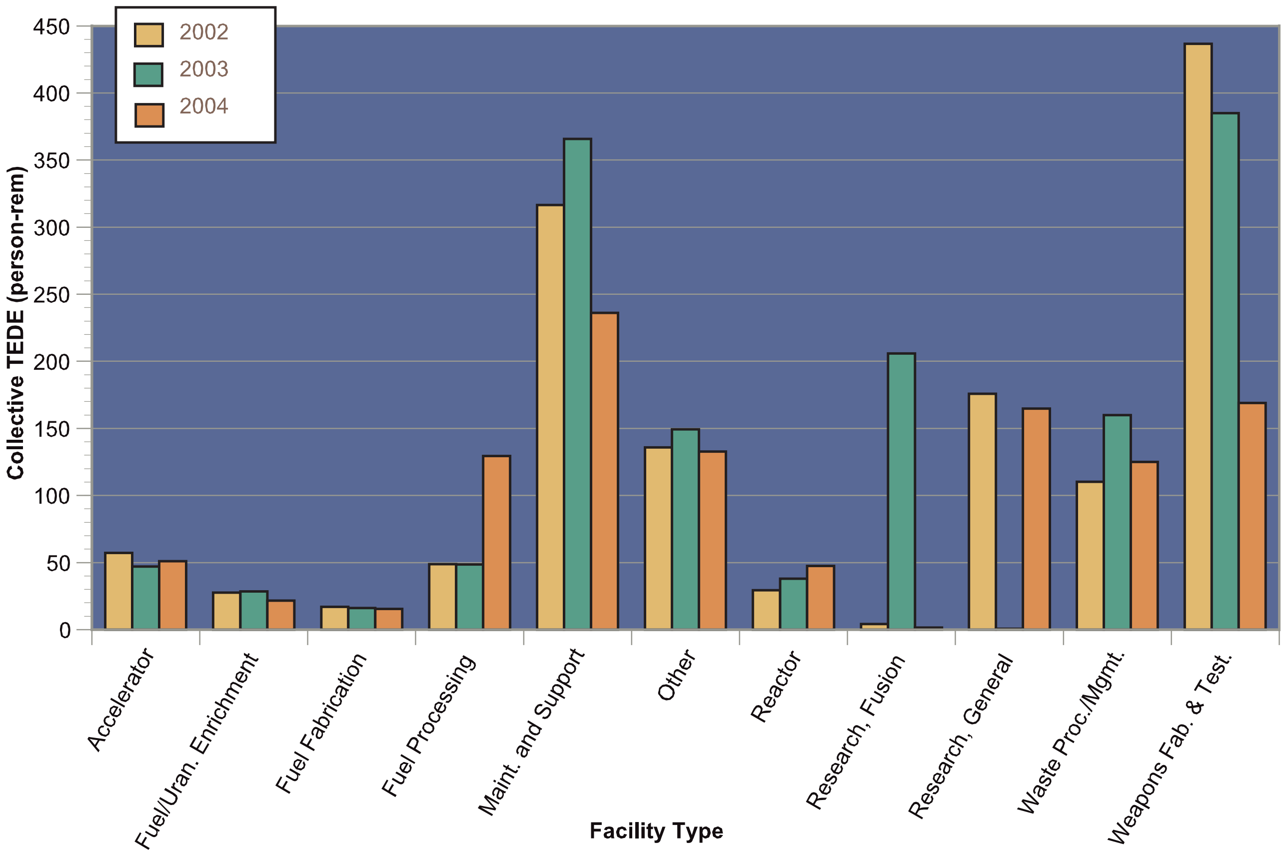



***Exhibit 3-20:***
***Number with Measurable Dose, Collective TEDE, and Average Measurable TEDE by Facility Type, 2002-2004.***

| Facility Type | Number with Meas. Dose | | | Collective TEDE (person-rem) | | | Average Meas. TEDE (rem) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2002 | 2003 | 2004 | 2002 | 2003 | 2004 | 2002 | 2003 | 2004 |
| Accelerator | 1,087 | 1,118 | 1,102 | 57.2 | 47.0 | 51.0 | 0.053 | 0.042 | 0.046 |
| Fuel/Uranium Enrichment | 744 | 713 | 491 | 27.7 | 28.5 | 21.7 | 0.037 | 0.040 | 0.044 |
| Fuel Fabrication | 572 | 631 | 615 | 17.0 | 16.2 | 15.5 | 0.030 | 0.026 | 0.025 |
| Fuel Processing | 1,137 | 1,080 | 1,298 | 48.9 | 48.6 | 129.5 | 0.043 | 0.045 | 0.100 |
| Maintenance and Support | 2,825 | 3,141 | **3,188** ◄ | 316.6 | 365.8 | **236.1** ◄ | **0.112** ◄ | **0.116** ◄ | 0.074 |
| Other | 1,576 | 1,646 | 1,722 | 135.8 | 149.3 | 132.8 | 0.086 | 0.091 | 0.077 |
| Reactor | 470 | 522 | 295 | 29.3 | 37.9 | 47.4 | 0.062 | 0.073 | **0.161** ◄ |
| Research, Fusion | 153 | 2,413 | 137 | 4.3 | 205.8 | 1.5 | 0.028 | 0.085 | 0.011 |
| Research, General | 2,172 | 118 | 1,836 | 175.9 | 0.7 | 164.8 | 0.081 | 0.006 | 0.090 |
| Waste Processing/Mgmt. | 1,875 | 2,114 | 2,231 | 110.3 | 159.9 | 125.1 | 0.059 | 0.076 | 0.056 |
| Weapons Fab. and Testing | **4,440** ◄ | **3,988** ◄ | 2,824 | **436.6** ◄ | **384.9** ◄ | 169.0 | 0.098 | 0.097 | 0.060 |
| **Totals** | **17,051** | **17,484** | **15,739** | **1,359.6** | **1,444.6** | **1,094.4** | **0.080** | **0.083** | **0.070** |

Note: Arrowed values indicate the greatest value in each column.

### 3.4.4 Changes by Operations Office and Site from 2003 to 2004

*Exhibit 3-21* shows the collective TEDE, the number with measurable dose, the average measurable TEDE, and the percentage of the collective TEDE delivered above 0.500 rem by site for 2004, as well as the percentage change in these values from the previous year. The highest values and percentages are highlighted in bold. Keep in mind that some of the largest percentages of change occur at relatively small facilities where conditions may fluctuate from year to year. The changes that have the most impact in the overall values at DOE occur at sites with a relatively large collective dose in addition to a large percentage change, such as LANL and Rocky Flats in 2004.

The percentage of the collective TEDE above 0.500 rem is an indicator of the distribution of dose to individuals. As this value increases, more individuals are receiving doses above 0.500 rem. See Section 3.2.5 for more information on the characteristics of the distribution of doses to individuals above a certain dose value.

See Section 3.4.5 for information concerning the current activities at these sites.

### 3.4.5 Activities Significantly Contributing to Collective Dose in 2004

In an effort to identify the reasons for changes in the collective dose at DOE, several of the larger sites were contacted to provide information on activities that significantly contributed to the collective dose for 2004. These sites (Hanford, Savannah River, Los Alamos, Oak Ridge, Idaho, and Rocky Flats) were the top six sites in their contribution to the collective TEDE for 2004 and comprised 77% of the total DOE dose. Five of the six sites reported decreases in the collective TEDE, which resulted in a 24% decrease in the DOE collective dose from 1,445 person-rem (14.45 person-Sv) in 2003 to 1,094 person-rem (10.94 person-Sv) in 2004. The six sites are shown in *Exhibit 3-22*, including a description of activities that contributed to the collective TEDE for 2004.

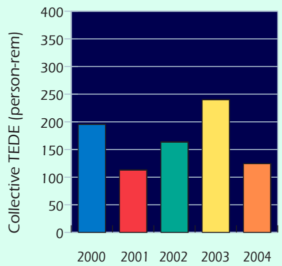
***Exhibit 3-21:***
***Operations Office/Site Dose Data, 2004.***

| | | 2004 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Operations/ Field Office** | **Site** | Collective TEDE (person-rem) | Percent Change from 2003 | Number with Meas. Dose | Percent Change from 2003 | Avg. Meas. TEDE (rem) | Percent Change from 2003 | Percentage of Coll. TEDE above 0.500 rem | Percent Change from 2003 |
| Albuquerque | Ops. and Other Facilities | 1.3 | 3% ▲ | 116 | 8% ▲ | 0.012 | -5% ▼ | 0% | 0% |
| | Los Alamos National Lab. (LANL) | 124.5 | -48% ▼ | 1,709 | -17% ▼ | 0.073 | -38% ▼ | 27% | -44% ▼ |
| | Pantex Plant (PP) | 24.3 | 32% ▲ | 270 | -7% ▼ | 0.090 | -27% ▼ | 15% | -40% ▼ |
| | Sandia National Lab. (SNL) | 17.1 | 68% ▲ | 317 | 27% ▲ | 0.054 | 32% ▲ | 12% | 100% ▲ |
| Chicago | Ops. and Other Facilities | 2.5 | 108% ▲ | 173 | 13% ▲ | 0.015 | 84% ▲ | 0% | 0% |
| | Argonne National Lab. - East (ANL-E) | 20.5 | -4% ▼ | 172 | -26% ▼ | 0.119 | 29% ▲ | 41% | 387% ▲ |
| | Argonne National Lab. - West (ANL-W) | 28.0 | -2% ▼ | 326 | 18% ▲ | 0.086 | -17% ▼ | 22% | 2% ▲ |
| | Brookhaven National Lab. (BNL) | 23.7 | 94% ▲ | 301 | -2% ▼ | 0.079 | 98% ▲ | 38% | 675% ▲ |
| | Fermi Nat'l. Accelerator Lab. (FERMI) | 20.6 | -20% ▼ | 498 | -19% ▼ | 0.041 | -2% ▼ | 0% | 0% |
| Idaho | Idaho Site | 109.5 | 71% ▲ | 1,471 | 29% ▲ | 0.074 | 33% ▲ | 9% | 159% ▲ |
| Nevada | Nevada Test Site (NTS) | 6.6 | 104% ▲ | 116 | 68% ▲ | 0.057 | 21% ▲ | 0% | 0% |
| Oakland | Ops. and Other Facilities | - | | - | | - | | 0% | 0% |
| | Lawrence Berkeley National Lab. (LBNL) | 0.7 | -29% ▼ | 18 | -10% ▼ | 0.041 | -21% ▼ | 0% | 0% |
| | Lawrence Livermore National Lab. (LLNL) | 31.2 | -14% ▼ | 232 | 15% ▲ | 0.135 | -25% ▼ | 55% | -20% ▼ |
| | Stanford Linear Accelerator Center (SLAC) | 3.9 | 25% ▲ | 149 | 37% ▲ | 0.026 | -8% ▼ | 0% | 0% |
| Oak Ridge | Ops. and Other Facilities | 1.3 | 6% ▲ | 91 | -6% ▼ | 0.015 | 13% ▲ | 0% | 0% |
| | Oak Ridge Site | 115.5 | 0% | 2,132 | -11% ▼ | 0.054 | 12% ▲ | 6% | 4% ▲ |
| | Paducah Gaseous Diff. Plant (PGDP) | 3.4 | 6% ▲ | 41 | 8% ▲ | 0.083 | -1% ▼ | 0% | 0% |
| | Portsmouth Gaseous Diff. Plant (PORTS) | 1.9 | 221% ▲ | 32 | 23% ▲ | 0.059 | 161% ▲ | 0% | 0% |
| Ohio | Ops. and Other Facilities | 0.2 | -74% ▼ | 14 | -70% ▼ | 0.014 | -11% ▼ | 0% | 0% |
| | Battelle Memorial Institute - Columbus | - | | - | | | | 0% | 0% |
| | Fernald Environmental Mgmt. Project | 15.5 | -4% ▼ | 615 | -3% ▼ | 0.025 | -2% ▼ | 0% | 0% |
| | Mound Plant | 4.6 | -22% ▼ | 152 | -36% ▼ | 0.030 | 22% ▲ | 39% | 100% ▲ |
| | West Valley Project | 39.7 | -5% ▼ | 241 | 16% ▲ | 0.165 | -18% ▼ | 22% | -66% ▼ |
| Rocky Flats | Rocky Flats Env. Tech. Site (RFETS) | 77.4 | -61% ▼ | 1,021 | -42% ▼ | 0.076 | -33% ▼ | 12% | -55% ▼ |
| Richland | Hanford Site | 205.2 | -16% ▼ | 2,278 | 5% ▲ | 0.090 | -19% ▼ | 18% | -57% ▼ |
| | Office of River Protection | 14.0 | -62% ▼ | 288 | -36% ▼ | 0.049 | -42% ▼ | 0% | 0% |
| Savannah River | Savannah River Site (SRS) | 201.2 | -22% ▼ | 2,966 | -14% ▼ | 0.068 | -10% ▼ | 18% | 17% ▲ |
| **Totals** | | **1,094.4** | **-24% ▼** | **15,739** | **-10% ▼** | **0.070** | **-16% ▼** | **17%** | **-40% ▼** |

Note: Boxed values indicate the greatest value in each column. Red arrows indicate an increase in change. Green arrows indicate a decrease in change.

**Exhibit 3-22:**
**Activities Significantly Contributing to Collective TEDE in 2004 for Six Sites**

## Los Alamos National Lab.



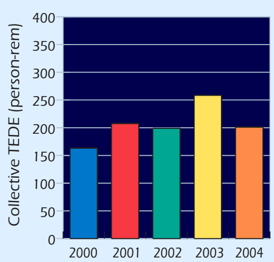

| Percent Change: 2003-2004 (last yr.) | Percent Change: 2002-2004 (3 yr.) | Percent Change: Since 2000 (5 yr.) |
|---|---|---|
| 48% ↓ | 24% ↓ | 36% ↓ |

**Description of Activities at the Site**

The collective TEDE at LANL decreased by 48% from 2003 to 2004. From January 2004 to July 2004, radiological operations were conducted at rates similar to 2003, and in some cases increased to meet programmatic demands. Notably, work with Pu-238 in the plutonium facility was increasing, and the criticality experiment facility at TA-18 was being decommissioned and the materials were moved.

On July 16, 2004, the LANL Director suspended operations across the Laboratory. The only activities allowed to continue were those deemed "essential." Operations that typically contribute most of the occupational dose at LANL (primarily in the plutonium facility) did not resume until the end of 2004. Consequently, approximately half of the expected occupational dose was accrued during the first half of the calendar year, and relatively little occupational exposure was accrued during the rest of the calendar year. For internal dose, there was a 57% decrease from 2003 to 2004. This reflects the impact of the LANL work suspension and an improving trend in significant radiological incidents.

## Savannah River Site

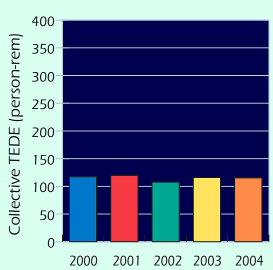



| Percent Change: 2003-2004 (last yr.) | Percent Change: 2002-2004 (3 yr.) | Percent Change: Since 2000 (5 yr.) |
|---|---|---|
| 22% ↓ | ↑ 1% | ↑ 23% |

**Description of Activities at the Site**

The collective TEDE at Savannah River decreased by 22% from 2003 to 2004. Radiation exposures had been rising since 2001 due to radioactive legacy material processing, accelerated facility closures, and waste processing activities. However, the site is now benefiting from the completion of that work, including de-inventory of a number of facilities. Examples of the work performed in 2004 include D&D of administrative or de-inventoried buildings in A, M, F, and T areas, de-inventory of F-Canyon and FB-Line, melter repairs, repackaging existing waste containers, and legacy source term removal.

## Oak Ridge Site



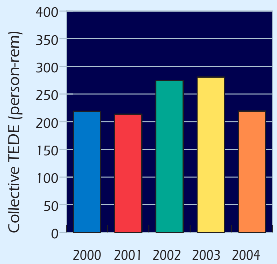

| Percent Change: 2003-2004 (last yr.) | Percent Change: 2002-2004 (3 yr.) | Percent Change: Since 2000 (5 yr.) |
|---|---|---|
| <1% ↓ | ↑ 7% | 2% ↓ |

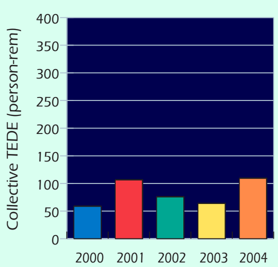
**Description of Activities at the Site**

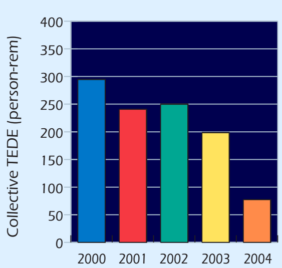
The collective TEDE at the Oak Ridge Site decreased less than 1% from 2003 to 2004. The Oak Ridge Site includes the Oak Ridge National Laboratory (ORNL), Y-12 National Security Complex (Y-12 Plant), and East Tennessee Technology Park (ETTP, formerly known as K-25).

ORNL: The reported TEDE for ORNL decreased by 9% between 2003 and 2004. This decrease can be attributed to a decrease in the isotope production work that took place at ORNL during 2004.

Y-12: The 2004 collective dose equivalent for the Y-12 Complex increased by 9.5% from 14.7 person-rem in 2003 to 16.1 person-rem in 2004. The increase in the deep dose equivalent was due primarily to a single thermoluminescent dosimeter (TLD) result of 1.483 rem to a radiographer (x-ray technician). The other contributor to the collective dose for 2004 was work activities associated with the Tennessee Valley Authority (TVA) Off-Specification Fuel repackaging project. The average measurable external and internal doses remained the same from 2003 to 2004.

| Hanford | Percent Change 2003-2004 (last yr.) | Percent Change 2002-2004 (3 yr.) | Percent Change Since 2000 (5 yr.) | Description of Activities at the Site |
|---|---|---|---|---|
|  | 22% ↓ | 20% ↓ | 0% | The collective TEDE at Hanford decreased by 22% from 2003 to 2004.<br><br>For the Richland Operations Office the collective TEDE decreased by 23% from 2003 to 2004. The largest contributors to the collective TEDE at Hanford were completion of thermal stabilization and repackaging of plutonium-bearing materials and deactivation and decontamination activities at the Plutonium Finishing Plant (PFP), processing of spent nuclear fuel in K-Basins for interim dry storage at the Canister Storage Building and processing of K-Basin sludge, Tank Farm activities and Solid Waste Stabilization and Disposal (predominantly the retrieval, processing, and shipment of transuranic [TRU] waste). Other contributors to the dose include Pacific Northwest National Laboratory activities and miscellaneous decontamination/demolition activities.<br><br>For the Office of River Protection (ORP), the collective TEDE for contractors decreased 63% from 2003 to 2004. The dose reduction was due mainly to the decreased number of tank farm entries resulting from the use of self-contained breathing apparatus for industrial hygiene concerns and work planning/conduct of operations corrective actions following the July 2004 thermocouple incident at 244-CR vault (occurrence report RP-CHG-TANKFARM-2004-0037). |

| Idaho | Percent Change 2003-2004 (last yr.) | Percent Change 2002-2004 (3 yr.) | Percent Change Since 2000 (5 yr.) | Description of Activities at the Site |
|---|---|---|---|---|
|  | ↑ 71% | ↑ 44% | ↑ 86% | The collective TEDE at the Idaho National Engineering and Environmental Laboratory (INEEL) increased by 71% from 2003 to 2004. Radiation exposure to INEEL employees is primarily the result of radiological work conducted in support of two major activities: Idaho Completion Project (ICP) and Idaho National Laboratory (INL) activities. The primary ICP activities involving radiation exposure included cleanup and D&D of liquid waste tanks at TAN, cleaning and sampling of the tank farm vessels, repackaging of recovered uranium in the Denitrator facility, and eliminating mixed low-level waste backlog at INTEC. The primary INL activities involving radiation exposure were the Core Internals Change out at the Advanced Test Reactor at the Test Reactor Area. The increase in collective TEDE from 2003 to 2004 was due primarily to the increase in Cleanup/D&D work at INTEC and TAN. |

| Rocky Flats | Percent Change 2003-2004 (last yr.) | Percent Change 2002-2004 (3 yr.) | Percent Change Since 2000 (5 yr.) | Description of Activities at the Site |
|---|---|---|---|---|
|  | 61% ↓ | 69% ↓ | 74% ↓ | The collective TEDE at Rocky Flats decreased by 61% from 2003 to 2004. The activities for calendar year 2004 included packaging and shipment of radioactive waste and the D&D of the four major plutonium facilities on site (two of which were demolished), as well as D&D of numerous uranium and administrative facilities. The collective dose decreased due to radioactive source material being shipped off site for disposal. Reported internal dose remained essentially unchanged (5.7 person-rem) from 2003. With the exception of one intake, there was a 49% reduction of internal dose (due to a reduction in high airborne contamination work, a reduction in the source term, and improved use of engineering controls during D&D). However, one worker received a 2.8 rem CEDE when he received a puncture wound in his right arm during size reduction activities (Occurrence Report RFO-KHLL-PUFAB-2004-0004). |

## 3.5 Transient Individuals

Transient individuals, or transients, are defined as individuals who are monitored at more than one DOE site during the calendar year. For the purposes of this report, a DOE site is defined as a geographic location. During the year, some individuals perform work at multiple sites and, therefore, have more than one monitoring record reported to the repository. In addition, some individuals transfer from one site to another during the year. This section presents information on transient individuals to determine the extent to which individuals travel from site to site and to examine the dose received by these individuals.

*Exhibit 3-23* shows the distribution and total number of transient individuals from 2000 to 2004. Over the past 5 years, the records of transient individuals have averaged 2.8% of the total records for all monitored individuals at DOE and received, on an average, 2.6% of the collective dose. As shown in *Exhibits 3-24* and *3-25*, the number of transients with measurable dose decreased by 16% from 602 in 2003 to 505 in 2004. The collective dose for transients decreased by 54% from 56.1 person-rem (561 person-mSv) in 2003 to 25.6 person-rem (256 person-mSv) in 2004. The average measurable TEDE decreased by 45% from 0.093 rem (0.93 mSv) in 2003 to 0.051 rem (0.51 mSv) in 2004. The average measurable TEDE for transients in 2004 was 27% lower than the average measurable TEDE (0.070 rem) for all monitored DOE workers. In 2003, the average measurable TEDE to transients was higher than the value for all DOE workers. The increase was due primarily to an increase in dose to transient workers at LANL. As seen in *Exhibit 3-26*, LANL has the largest percentage of dose to transients because workers at TA-55 (who generally receive elevated doses due to the nature of their work) tend to perform temporary work at sites such as Nevada Test Site (NTS), Rocky Flats, and Pantex as part of their routine duties. In 2004, the collective TEDE at LANL decreased by 48%, which contributed to the decrease in the average measurable dose to transient workers in 2004.

***Exhibit 3-23:***
***Dose Distribution of Transient Workers, 2000-2004.***

| | Dose Ranges (TEDE in rem) | 2000 | 2001 | 2002 | 2003 | 2004 |
|---|---|---|---|---|---|---|
| Transients | Less than Measurable Dose | 2,537 | 2,696 | 2,298 | 2,063 | 1,917 |
| | Measurable < 0.1 | 466 | 439 | 470 | 492 | 439 |
| | 0.10 - 0.25 | 37 | 31 | 50 | 59 | 52 |
| | 0.25 - 0.5 | 14 | 13 | 12 | 23 | 9 |
| | 0.5 - 0.75 | 4 | 1 | 11 | 9 | 4 |
| | 0.75 - 1.0 | | 1 | 5 | 7 | |
| | 1.0 - 2.0 | | 2 | 2 | 12 | 1 |
| | Total Number of Individuals Monitored * | 3,058 | 3,183 | 2,848 | 2,665 | 2,422 |
| | Number with Measurable Dose | 521 | 487 | 550 | 602 | 505 |
| | % with Measurable Dose | 17% | 15% | 19% | 23% | 21% |
| | Collective TEDE (person rem) | 23.632 | 25.138 | 36.477 | 56.141 | 25.609 |
| | Average Measurable TEDE (rem) | 0.045 | 0.052 | 0.066 | 0.093 | 0.051 |
| All DOE | Total Number of Records for Monitored Individuals | 102,881 | 97,818 | 100,221 | 102,509 | 100,011 |
| | Number with Meas. Dose | 15,983 | 16,687 | 17,051 | 17,484 | 15,739 |
| | % of Total Monitored Who Are Transient | 3.0% | 3.2% | 2.8% | 2.6% | 2.4% |
| | % of the Number with Measurable Dose Who Are Transient | 3.3% | 2.9% | 3.2% | 3.4% | 3.2% |

* Total number of individuals represents the number of individuals monitored and not the number of records.

One group of individuals who routinely travel from site to site is DOE employees from Headquarters or the field offices who visit or inspect multiple sites during the year. For 2004, this group accounts for 9% of the monitored transient individuals but only 2% of the collective dose to transients.

In 2004, 11% of the transient individuals were monitored at three or more sites. DOE Headquarters and field office personnel are included among these individuals. In 2004, 16% of the individuals monitored at three or more sites were DOE Headquarters or field office employees, and 20% of the individuals monitored at four or more facilities were DOE Headquarters or field office employees. The maximum number of sites visited by one monitored individual during 2004 was six, which was the same value for 2003.

***Exhibit 3-25:***
***Collective and Average Measurable Dose to Transient Individuals, 2000-2004.***

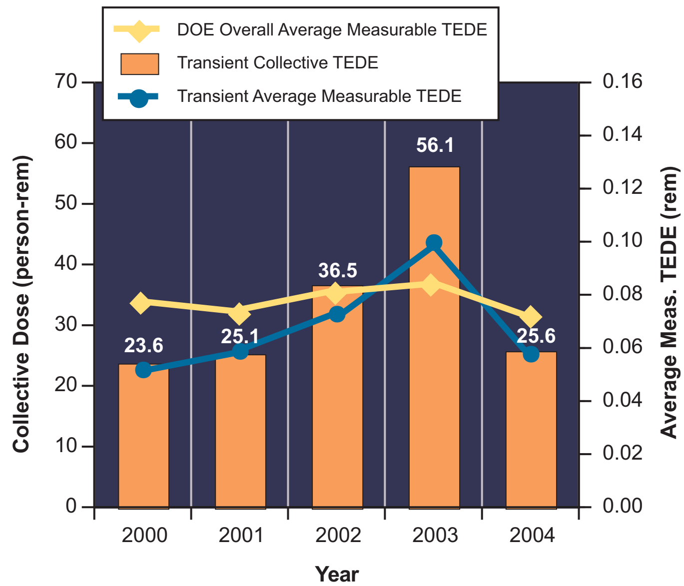



***Exhibit 3-24:***
***Individuals Monitored at More than One Site (Transients) During the Year, 2000-2004.***

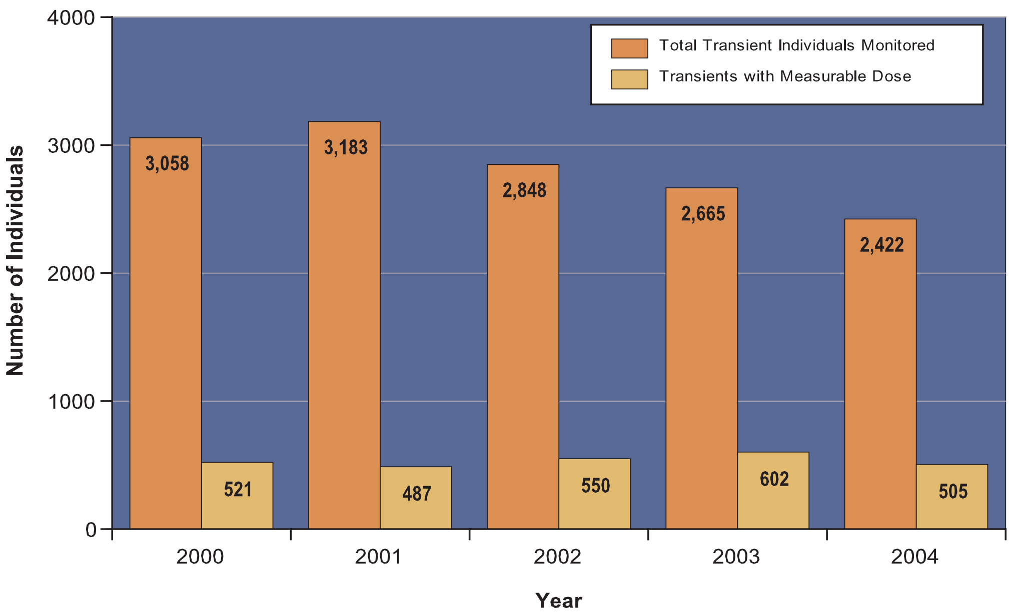
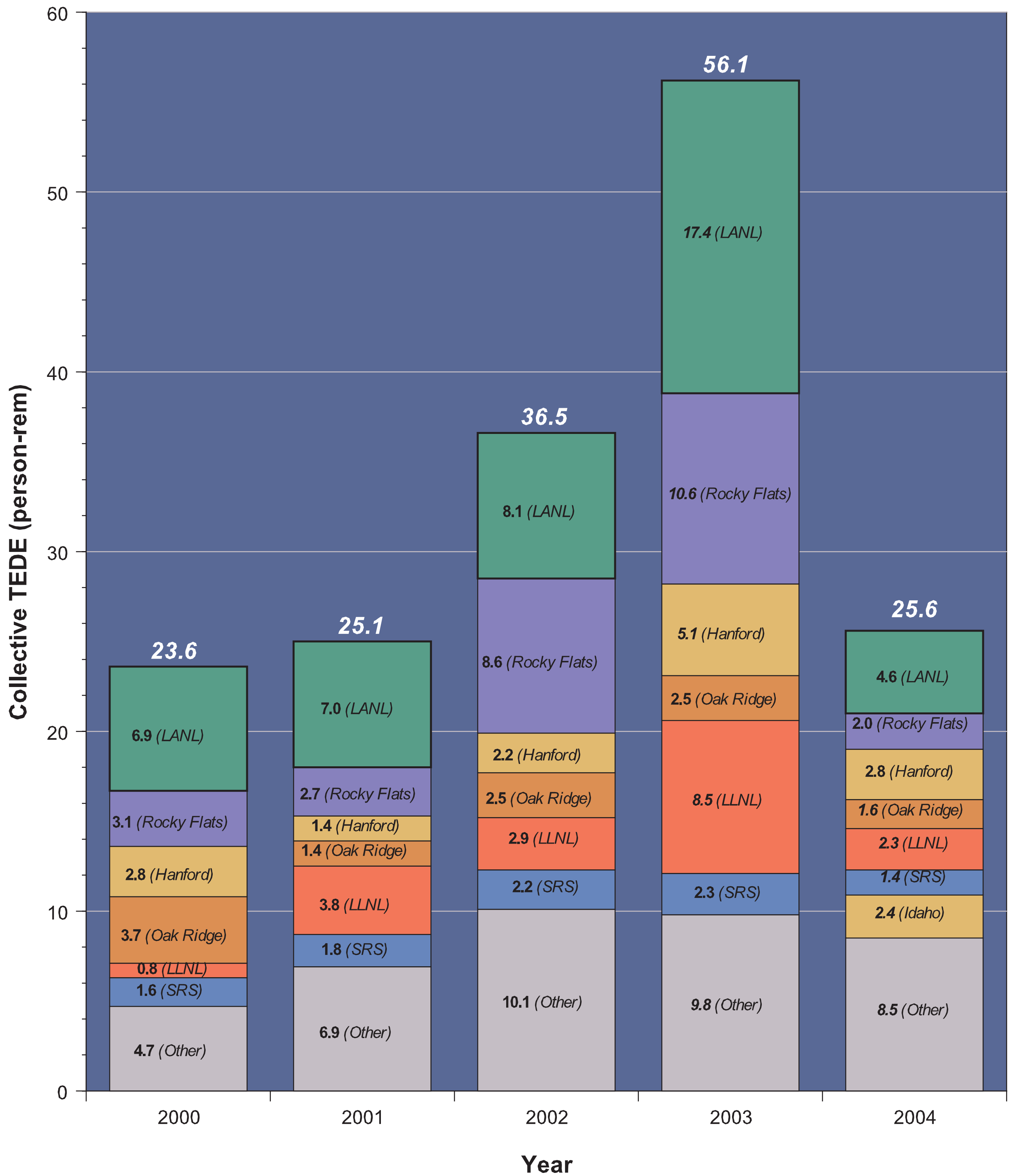


**Exhibit 3-26:**
**Collective TEDE to Transient Workers by Site, 2000-2004.**



## Section 3.6 Historical Data

### 3.6.1 Prior Years

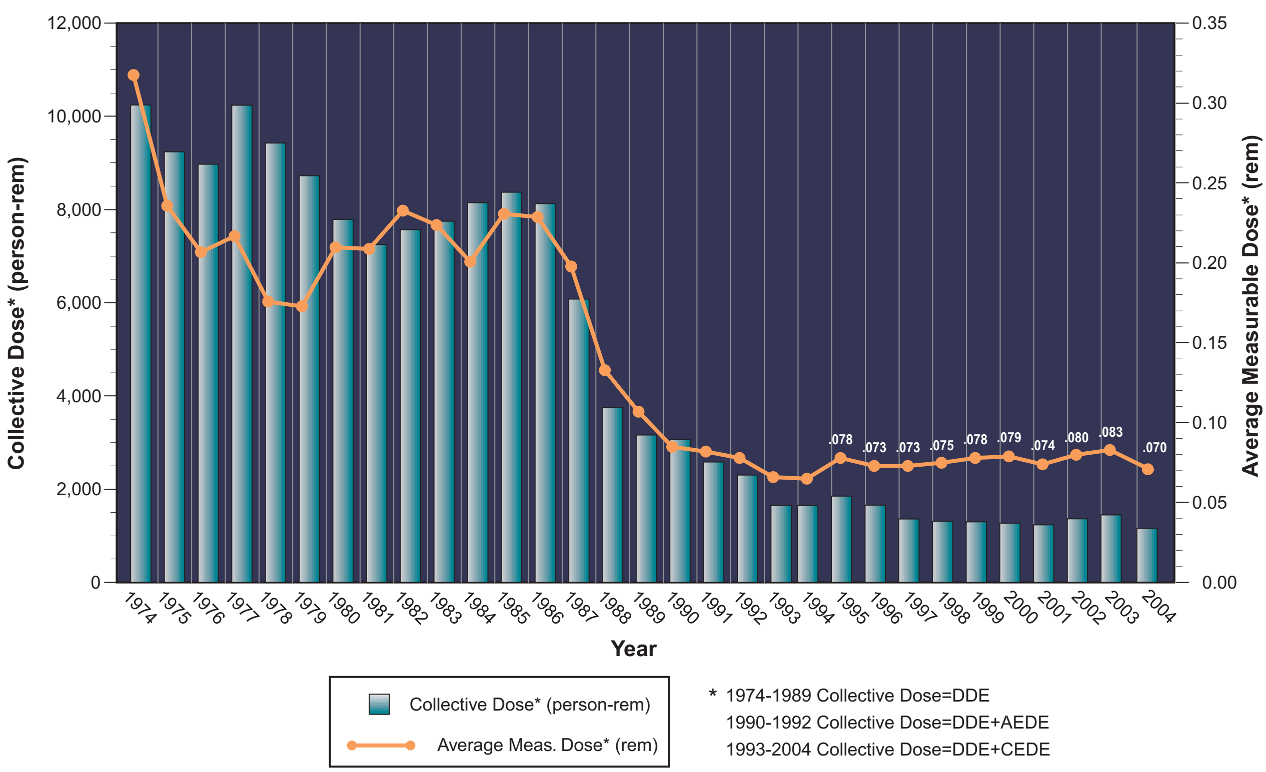
In order to analyze recent radiation exposure data in the context of the history of radiation exposure at DOE, it is useful to include information prior to the past five years as presented in this report. For this reason, the following exhibits are presented to show a summary of occupational exposure back to 1974, when the Atomic Energy Commission (AEC) split into the Nuclear Regulatory Commission (NRC) and Energy Research and Development Administration (ERDA), which subsequently became the DOE.

*Exhibits 3-27* and *3-28* show the collective dose, average measurable dose, and number of workers with measurable dose from 1974 to 2004. As can be seen from the graph, all three parameters decreased dramatically between 1986 and 1993. The main reasons for this large decrease were the shutdown of facilities within the weapons complex and the end of the Cold War era, which shifted the DOE mission from weapons production to shutdown, stabilization, and D&D activities.

*Exhibit 3-29* presents the dose distribution of the DDE from 1974 to 2004 and the TEDE from 1990 to 2004. Note that from 1990 to 1992 the TEDE was defined as the external DDE plus the AEDE from internal dose. Since 1993, the TEDE has been defined as the external DDE plus the 50-year CEDE from internal dose.

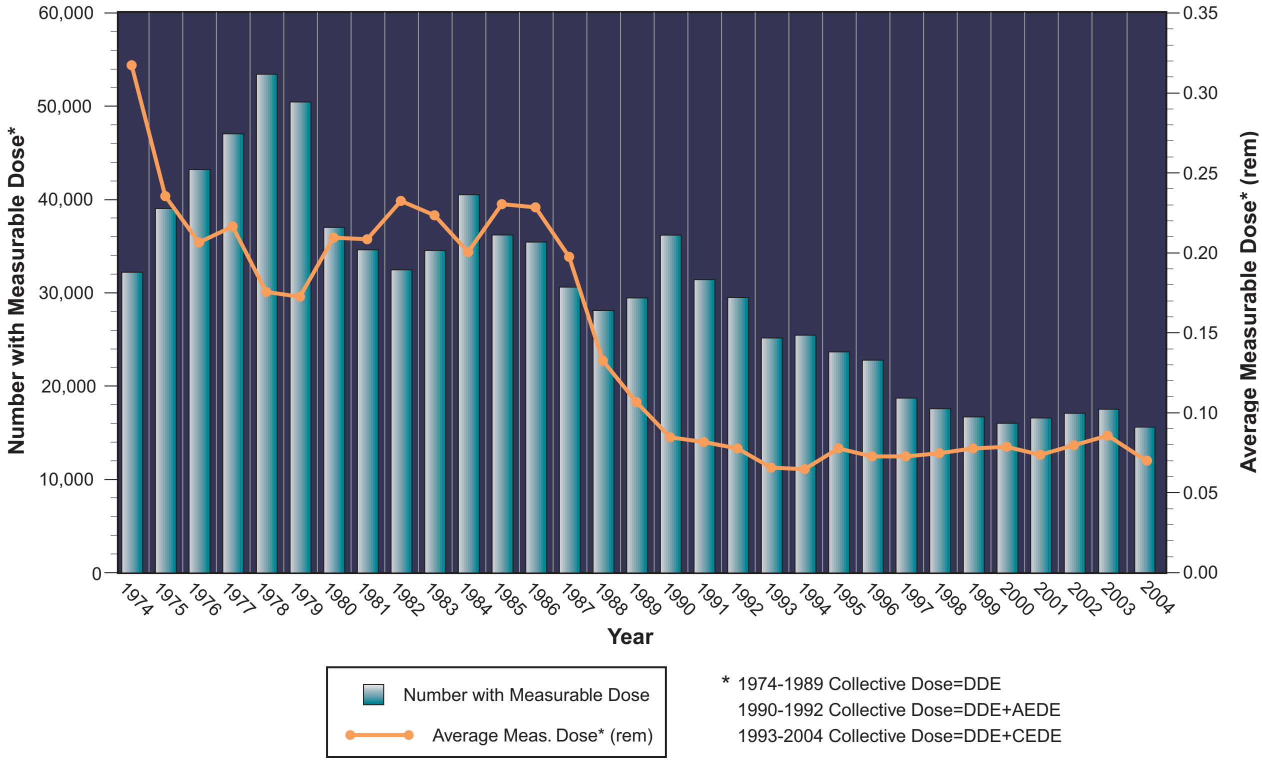
The highest number of monitored individuals occurred in 1995 due to the common practice at many DOE sites to monitor individuals for security reasons as well as radiation protection. The highest number of individuals receiving measurable dose occurred back in 1978 during peak production years at DOE. For the average measurable DDE, the value has decreased by 78% from 1974 to 2004, while the collective DDE has decreased by 88%. For the years 1990 through 2004 shown in the TEDE dose distribution, one should note that there are several individuals in the higher dose ranges due to intakes of radioactive materials that result in internal dose. For these years, the internal dose is included as a component of the TEDE, resulting in more individuals being reported in the higher dose ranges than are reported using only the external DDE.

***Exhibit 3-27:***
***Collective Dose and Average Measurable Dose, 1974-2004.***




* 1974-1989 Collective Dose=DDE
1990-1992 Collective Dose=DDE+AEDE
1993-2004 Collective Dose=DDE+CEDE

**Exhibit 3-28:**
**Number with Measurable Dose and Average Measurable Dose, 1974-2004.**




## 3.6.2 Historical Data Collection

In Section 3.7 of the 2000 and 2001 annual reports on occupational exposure, information was presented on historical data that had been collected to date. The DOE Office of Environment, Safety and Health requested the sites volunteer to provide historical exposure data. No additional sites have reported historical data during the year 2004.

Sites that have not yet reported historical dose records are encouraged to contact Ms. Nirmala Rao at DOE to obtain further information on reporting these records. This is a voluntary request to report historical data (records prior to 1987) that are available in electronic form in whatever format that is most convenient for the site to report. The data will be stored as reported in the REMS and, wherever possible, data will be extracted and loaded into the REMS database for analysis and retrieval. For detailed analysis, read Section 3.7 of the 2000 report.

Sites that have voluntarily reported historical data are:

- Fernald
- Hanford
- Idaho
- Kansas City Plant
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- Nevada Test Site
- Oak Ridge K-25 Site
- Pantex
- Portsmouth
- Rocky Flats
- Sandia National Laboratory
- Savannah River Site

***Exhibit 3-29:***
***Distribution of Deep Dose Equivalent (DDE) 1974-2004 and Total Effective Dose Equivalent (TEDE), 1990-2004.***

## Deep Dose Equivalent (DDE)

**Number of Individuals Receiving Radiation Doses in Each Dose Range (rem)**

| Year | Less than 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 | Total Monitored | No. with Meas. DDE | Coll. DDE (person-rem) | Avg. Meas. DDE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1974 | 37,060 | 29,735 | 1,531 | 652 | 149 | 40 | 4 | | | | | | | | 69,171 | 32,111 | **10,202** | **0.318** |
| 1975 | 41,390 | 36,795 | 1,437 | 541 | 122 | 28 | | | | 1 | | | | | 80,314 | 38,924 | 9,202 | 0.236 |
| 1976 | 38,408 | 41,321 | 1,296 | 387 | 70 | 6 | 1 | | | | | | | | 81,489 | 43,081 | 8,938 | 0.207 |
| 1977 | 41,572 | 44,730 | 1,499 | 540 | 103 | 23 | | | 1 | 2 | | | | 2 | 88,472 | 46,900 | 10,199 | 0.217 |
| 1978 | 43,317 | 51,444 | 1,311 | 439 | 53 | 11 | | | | | | | | | 96,575 | **53,258** | 9,390 | 0.176 |
| 1979 | 48,529 | 48,553 | 1,281 | 416 | 33 | 10 | 1 | | | | | | | 2 | 98,825 | 50,296 | 8,691 | 0.173 |
| 1980 | 43,663 | 35,385 | 1,113 | 387 | 16 | | | | | | | | | | 80,564 | 36,901 | 7,760 | 0.210 |
| 1981 | 43,775 | 33,251 | 967 | 263 | 29 | 5 | | | | | | | | | 78,290 | 34,515 | 7,223 | 0.209 |
| 1982 | 47,420 | 30,988 | 990 | 313 | 56 | 28 | | | | | | | | | 79,795 | 32,375 | 7,538 | 0.233 |
| 1983 | 48,340 | 32,842 | 1,225 | 294 | 49 | 31 | | | | | | | | | 82,781 | 34,441 | 7,720 | 0.224 |
| 1984 | 46,056 | 38,821 | 1,223 | 312 | 31 | 11 | | | | | | | | | 86,454 | 40,398 | 8,113 | 0.201 |
| 1985 | 54,582 | 34,317 | 1,362 | 356 | 51 | 8 | | | | 1 | | | | | 90,677 | 36,095 | 8,340 | 0.231 |
| 1986 | 53,586 | 33,671 | 1,279 | 349 | 35 | 1 | | 1 | | | | | 1 | | 88,923 | 35,337 | 8,095 | 0.229 |
| 1987 | 45,241 | 28,995 | 1,210 | 283 | 36 | | | | | | | | | | 75,765 | 30,524 | 6,056 | 0.198 |
| 1988 | 48,704 | 27,492 | 502 | 34 | | | | | | | | | | | 76,732 | 28,028 | 3,735 | 0.133 |
| 1989 | 56,363 | 28,925 | 428 | 21 | | | | | | | | | | | 85,737 | 29,374 | 3,151 | 0.107 |
| 1990 | 76,798 | 31,110 | 140 | 17 | | | | | | | | | | | 108,065 | 31,267 | 2,230 | 0.071 |
| 1991 | 92,526 | 27,149 | 95 | | | | | | | | | | | | 119,770 | 27,244 | 1,762 | 0.065 |
| 1992 | 98,900 | 24,769 | 42 | | | | | | | | | | | | 123,711 | 24,811 | 1,504 | 0.061 |
| 1993 | 103,905 | 23,050 | 86 | | | 1 | | | | | | | | | 127,042 | 23,137 | 1,534 | 0.066 |
| 1994 | 92,245 | 24,189 | 77 | | | | | | | | | | | | 116,511 | 24,266 | 1,600 | 0.066 |
| 1995 | 104,793 | 22,330 | 153 | | | | | | | | | | | | **127,276** | 22,483 | 1,809 | 0.080 |
| 1996 | 101,529 | 21,720 | 74 | 1 | | | | | | | | | | | 123,324 | 21,795 | 1,598 | 0.073 |
| 1997 | 89,805 | 17,331 | 45 | | | | | | | | | | | | 107,181 | 17,376 | 1,285 | 0.074 |
| 1998 | 92,803 | 15,669 | 36 | | | | | | | | | | | | 108,508 | 15,705 | 1,219 | 0.078 |
| 1999 | 98,125 | 14,877 | 62 | | | | | | | | | | | | 113,064 | 14,939 | 1,142 | 0.076 |
| 2000 | 88,621 | 14,206 | 54 | | | | | | | | | | | | 102,881 | 14,260 | 1,086 | 0.076 |
| 2001 | 82,950 | 14,821 | 47 | | | | | | | | | | | | 97,818 | 14,868 | 1,173 | 0.079 |
| 2002 | 84,874 | 15,282 | 64 | 1 | | | | | | | | | | | 100,221 | 15,347 | 1,291 | 0.084 |
| 2003 | 86,756 | 15,659 | 93 | 1 | | | | | | | | | | | 102,509 | 15,753 | 1,350 | 0.086 |
| 2004 | 85,656 | 14,330 | 25 | | | | | | | | | | | | 100,011 | 14,355 | 1,017 | 0.071 |

## Total Effective Dose Equivalent (TEDE)*

| Year | Less than 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 | Total Monitored | No. with Meas. TEDE | Coll. TEDE (person-rem) | Avg. Meas. TEDE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 71,991 | 35,780 | 226 | 47 | 8 | 8 | 1 | 2 | | 1 | | | | 1 | 108,065 | **36,074** | **3,052** | **0.085** |
| 1991 | 88,444 | 31,086 | 193 | 25 | 9 | 8 | | 2 | | 1 | | | | 2 | 119,770 | 31,326 | 2,574 | 0.082 |
| 1992 | 94,297 | 29,240 | 132 | 22 | 9 | 6 | | 2 | 1 | | 1 | | | 1 | 123,711 | 29,414 | 2,295 | 0.078 |
| 1993 | 101,947 | 25,002 | 87 | | | 2 | | | | 1 | 1 | | | 2 | 127,042 | 25,095 | 1,644 | 0.066 |
| 1994 | 91,121 | 25,310 | 79 | | 1 | | | | | | | | | | 116,511 | 25,390 | 1,643 | 0.065 |
| 1995 | 103,663 | 23,454 | 157 | | 1 | 1 | | | | | | | | | **127,276** | 23,613 | 1,845 | 0.078 |
| 1996 | 100,599 | 22,641 | 80 | 2 | 1 | | | | | | | | 1 | | 123,324 | 22,725 | 1,652 | 0.073 |
| 1997 | 88,502 | 18,627 | 48 | 1 | 2 | 1 | | | | | | | | | 107,181 | 18,675 | 1,356 | 0.073 |
| 1998 | 90,964 | 17,501 | 41 | 1 | | | | 1 | | | | | | | 108,508 | 17,544 | 1,309 | 0.075 |
| 1999 | 96,396 | 16,585 | 80 | 1 | 1 | | | 1 | | | | | | | 113,064 | 16,668 | 1,295 | 0.078 |
| 2000 | 86,898 | 15,922 | 58 | | | | | | | | 1 | | 1 | 1 | 102,881 | 15,983 | 1,267 | 0.079 |
| 2001 | 81,131 | 16,638 | 48 | 2 | | | | | | | | | | | 97,818 | 16,687 | 1,232 | 0.074 |
| 2002 | 83,170 | 16,985 | 65 | 1 | | | | | | | | | | | 100,221 | 17,051 | 1,360 | 0.080 |
| 2003 | 85,025 | 17,384 | 97 | 1 | | | | | | 1 | | 1 | | | 102,509 | 17,484 | 1,445 | 0.083 |
| 2004 | 84,272 | 15,709 | 28 | 1 | 1 | | | | | | | | | | 100,011 | 15,739 | 1,094 | 0.070 |

Note: Arrowed values indicate the greatest value in each column.

* 1990-1992 TEDE=DDE+AEDE 1993-2004 TEDE=DDE+CEDE

# ALARA Activities at DOE

This section on ALARA activities is a vehicle to document successes and to point all DOE sites to those programs whose managers have confronted radiation protection issues and used innovative techniques to solve problems common to most DOE sites. DOE program and site offices and contractors who are interested in benchmarks of success and continuous improvement in the context of Integrated Safety Management and quality are encouraged to provide input to be included in future reports.

## 4.1 ALARA Activities at the Savannah River Site

### 4.1.1 3H Evaporator Outage

The Westinghouse Savannah River Company's (WSRC's) Project, Design and Construction (PD&C) Business Unit successfully installed seal pot piping modifications (MODs) and structural supports, performed core drills, and replaced the east and west separator resistance temperature detectors (RTDs) during the outage of the H-Area Tank Farm 3H Evaporator. It took approximately 12 months of intermittent activity to plan the work and ensure all safety and radiological hazards were identified and appropriate controls were put in place to mitigate and/or eliminate these hazards.

Some of the engineering, safety, and radiological controls that were put in place to ensure the safety of the individuals and success of the project are as follows:

- A working platform (see *Exhibit 4-1*) was designed and utilized to perform the work. It was suspended from the top of the cell in lieu of building scaffolding inside the cell. This eliminated unnecessary time inside the cell for installing and removing scaffolding (approximately 160 man-hours of exposure).
- Operations performed a 4-day flush and drain of the pot to reduce the overall working rate. The working rate over the open cell, prior to the flushing, was approximately 450 mrem/hr. The working rate (unshielded) after the flush was 100 mrem/hr.
- The bottom of the cell was partially filled with water (after the pot flushing) to reduce exposure from any "hot spots," as well as reduce potential for airborne activity.
- Cell walls were pressure flushed prior to the start of work to eliminate potential for airborne contamination.
- Temporary lead blankets were used on the working platform to reduce the working rate from 100 mrem/hr to 15-30 mrem/hr.
- Wet taps were utilized to drain residual liquid from piping to the floor of the cell.
- The Seal Pot MOD was prefabricated in a clean area (see *Exhibit 4-2*). This eliminated the potential for contamination and individual radiation exposure.

***Exhibit 4-1: Working Platform.***

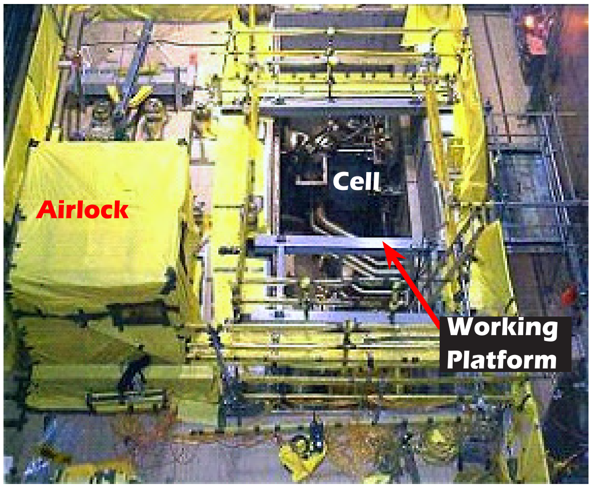



Photo Courtesy of Savannah River Site.

- ❖ A mock-up of the working platform and the installation of the Seal Pot MOD was conducted in a clean area. This mock-up was utilized to demonstrate effectiveness of the shielded work platform as well as familiarize the workers with the installation techniques of the seal pot MODs, that ultimately reduced the overall installation time.

- ❖ Socket weld connections were used for the tie-ins, thus reducing welding time and the need for x-rays.

- ❖ Decontamination efforts were employed at each line break and weld location.

- ❖ Teletrac™ dosimetry and electronic personal dosimeters (EPDs) were utilized to continuously track individual exposure remotely from a PC monitor.

- ❖ Daily dose reports were generated by construction contractors to ensure that individual exposure did not trigger any site ACLs.

***Exhibit 4-2:***
***Prefabricated Seal Pot MOD.***

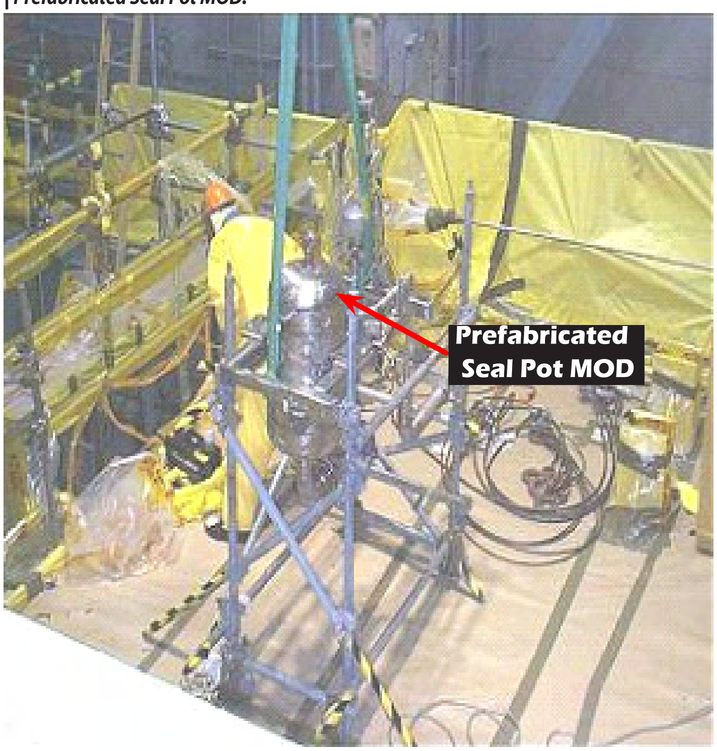



Photo Courtesy of Savannah River Site.

***Exhibit 4-3:***
***Vessel and Piping MODs.***

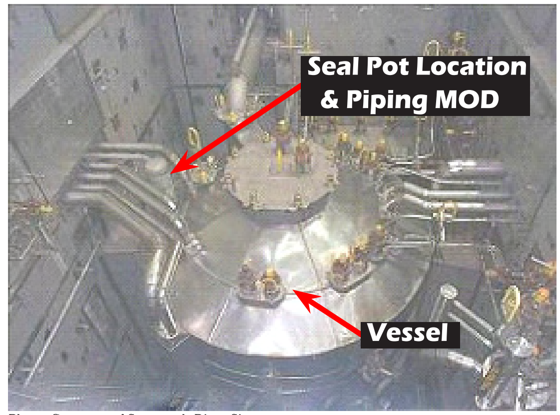



Photo Courtesy of Savannah River Site.

- ❖ Personnel were rotated to minimize exposure and instructed to remain in low dose areas when not performing hands- on activities.

- ❖ A team automated hazard analysis (AHA) was performed for the proposed scope of work. All responsible organizations (i.e., Radiological Control Organization [RCO], Industrial Hygiene [IH], Engineering, Operations, Construction, Safety, ALARA, etc.) approved the AHA.

- ❖ A Facility Radiological Action Team (FRAT) meeting was conducted by the facility and approval to proceed was granted.

- ❖ Based upon the expected cumulative exposure, Construction conducted a presentation for the Area Facility Management Safety Team and obtained their authorization to proceed with the proposed work activities.

In summary, the work was completed 2 weeks ahead of schedule and within budget (see *Exhibit 4-3*). Total cumulative dose for the job evolution under two separate job-specific radiological work permits (JSRWPs) was 2,100 mrem or 2.1 rem. Forecasted collective dose for the job (both combined JSRWPs) was 8.0 rem, which equates to 5.9 rem less exposure than what was forecasted.

For additional information about this project, contact Athena D. Freeman, Site ALARA Coordinator, at (803) 725-5030 or athena.freeman@srs.gov.

## 4.1.2 Savannah River Site—Radiological Operations Support Center

Modeled after the highly successful Hanford ALARA Center of Excellence, the Savannah River Site Radiological Operations Support Center (ROSC) is committed to providing centralized resources for practical applications of the ALARA approach to work as well as a clearing house of information (see *Exhibit 4-4* and *Exhibit 4-5*). The operations support center capitalizes on the uniqueness of conducting business at the site. The center consists of two support groups, the ALARA Center and the Containment Fabrication Facility (CFF). These groups are targeted at efforts in waste minimization and pollution prevention, radiological hazard reduction and safe, cost-effective operations.

***Exhibit 4-4:***
***The Radiological Operations Support Center (ROSC) Is a Central Site Contact That Conducts Vendor Demonstrations of Equipment.***

Photo Courtesy of Savannah River Site.

***Exhibit 4-5:***
***The Radiological Operations Support Center Provides ALARA Information for Practical Applications.***


Photo Courtesy of Savannah River Site.

### 4.1.2.1 ALARA Center

A team of radiological protection professionals is responsible for keeping abreast of new equipment, technologies, and techniques to support radiological work with cost-effective solutions. There are a variety of new and innovative items on display to allow visitors to operate and potentially borrow for field use. There are a number of demonstrations and visits from vendors to assist site personnel in the evaluation and implementation of equipment and techniques. Areas of expertise include decontamination and protective coatings, shielding, ventilation and filtration, personal protective equipment (PPE), radiation monitoring equipment, and radiological work practices.

- Passive Aerosol Generator—The passive aerosol generator (PAG) creates and slowly introduces a glycerol-based fog, which condenses to cover and coat all the exposed surfaces with a viscous, tacky coating. The purpose is to provide contamination control during work. A generator was used in the late 1990s in a cabinet in FB Line. The newly purchased generator has been used in E-area to control contamination in a TRU cabinet and in fogging an underground central transfer system pit in F- Area.

- Cutting Techniques—A handheld punch press, called a nibbler, was the preferred cutting method to volume reduce over 700 feet of radiological contaminated stainless piping. The volume of piping actually disposed of as waste was reduced by 75%.

- Personal Protective Equipment—A PPE Oversight Group is a direct link to field operation projects or business units by approving the use of new personal protective equipment and making recommendations on policies and initiatives which may impact personal protective equipment.

- Homeland Security—Containing hazards at the source are pertinent to radiological and other health hazards. Glove bags are provided to the site security force and other federal agencies, which may include the Federal Bureau of Investigation.

- Training—Training in radiological containments and the installation and removal of glove bags has been moved to the operations support center. The intent of the move is to provide students with an upfront and personal tour of the latest in safety efforts being championed across the site.

***Exhibit 4-6:***
***CFF is Capable of Constructing Unique and Complicated Glove Bags for Specific Applications.***

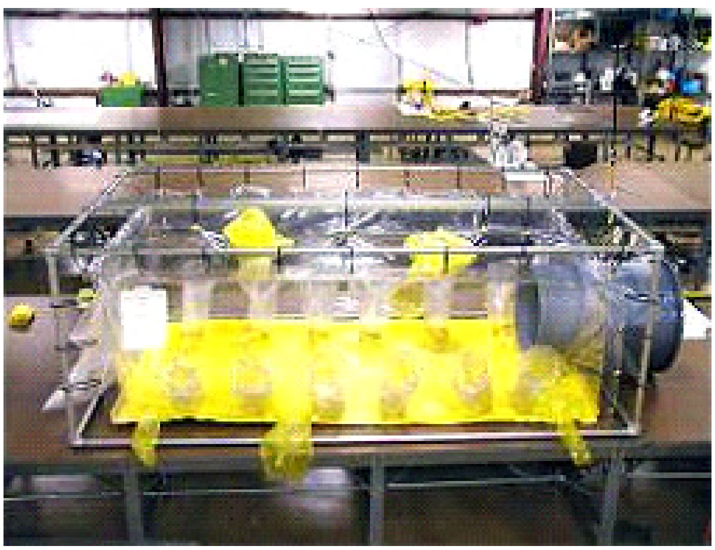


Photo Courtesy of Savannah River Site.

#### 4.1.2.2 Containment Fabrication Facility

A team of professional and technical personnel staffs the fabrication facility. Their mission is to streamline the fabrication, use, and reuse of specialized containment devices and fabricated materials. The personnel assist with planning and scheduling, in-field design walkdowns and field preparation. Specialized containment devices and fabricated material include huts, glove bags (see *Exhibit 4-6*), transfer bags, tarpaulins, sleeving, and equipment covers.

#### 4.1.2.3 Waste Minimization and Pollution Prevention

While there were many who shared the vision, it took a team of waste minimization and pollution prevention personnel from Solid Waste and DOE Savannah River to bring the vision to fruition. That team continues to function today. Most recently, the team was a champion and resource of funding for equipment. The team fostered the procurement of a radio frequency and heat-sealing machine for containment fabrication and a passive aerosol generator for radiological technology. In addition, the team provides an expert for Web site development, maintenance and oversight.

Access the ROSC Web site for additional information: http://www.srs.gov/general/enviro/rosc/index.html

For additional information about this project, contact Athena D. Freeman, Site ALARA Coordinator, at (803) 725-5030 or athena.freeman@srs.gov.

### 4.1.3 Use of the Passive Aerosol Generator at Savannah River Site

Built in 1968, F-Tank Farm's Concentrate Transfer System (CTS) (see *Exhibit 4-7*) was used to transfer concentrated supernate to and between 1,000,000-gallon storage tanks. Waste could not be transferred through a gravity drain line from the evaporator to a receipt tank because the evaporator is located at a lower level. The CTS, through a tie-in with a diversion box pit, became a crucial part of the operation. Waste was transferred from the evaporator to the even lower CTS through a gravity drain line and then pumped to receipt tanks.

Since 1992, both the evaporator and CTS have been classified as an inactive process area. Work has now begun to remove residual water accumulated in the CTS and permanently isolate the system from service. The dose rate in the CTS pit was 40 Rad/hr. One of the initial steps in the process was to remotely coat the interior surfaces to minimize the potential to spread contamination and airborne radioactivity during the isolation process of disconnecting pipes. The Savannah River Site ROSC provided the Encapsulation Technology Passive Aerosol Generator (PAG) to perform the work (see *Exhibit 4-8*).

***Exhibit 4-7:***
***F-Tank Farm's Concentrate Transfer System.***

Photo Courtesy of Savannah River Site.

***Exhibit 4-8:***
***Encapsulation Technology Passive Aerosol Generator.***

Photo Courtesy of Savannah River Site.

***Exhibit 4-9:***
***Ultraviolet Blue™ Coating Is Viewed By Using a Black Light.***


Photo Courtesy of Savannah River Site.

The PAG created an aerosol fog that was slowly but continuously pumped into the pit. The fog behaved as a gas then condensed as a liquid to cover all the exposed surfaces with a viscous, tacky coating. The coating encapsulated all surfaces for better contamination control during work. The coating gradually became less tacky due to moisture accumulation and could be stripped off the surface, if desired. The PAG uses a glycerol-based solution that contains Ultraviolet Blue™. Visual inspection and verification of coating is possible using a black light (see *Exhibit 4-9*).

When used to prevent the spread of contamination during the replacement of a panel in Solid Waste, the PAG was deemed highly successful. The PAG was used to coat a glove box that is used to remove prohibited items prior to shipment to the Waste Isolation Pilot Plant (WIPP) from TRU waste drums. Before the fogging, transferable contamination levels in the glove box were 800,000 dpm alpha per 100 $cm^2$. After the treatment, the survey results were less than 1,000 dpm alpha per 100 $cm^2$, with airborne radioactivity levels of 1.87 derived air concentrations/hr. Due to the success of minimizing the spread of contamination outside the glove box, the containment hut will no longer be routinely required when replacing panels in the TRU View Examination Facility.

For additional information about this project, contact Athena D. Freeman, Site ALARA Coordinator, at (803) 725-5030 or athena.freeman@srs.gov.

### 4.1.4 Savannah River Site Transuranic Waste Employees Take ALARA Initiative

Employees working in the TRU waste program at the Solid Waste Management Facility have taken to heart the message of ALARA. Despite the significant schedule pressures on the TRU waste shipping program to WIPP, they stopped work to develop an alternate approach to completing the job that would minimize exposure. The employees were performing radiography operations of concrete and steel casks containing higher radioactivity TRU waste to determine whether the casks contained any items that are not acceptable to the WIPP disposal facility in New Mexico. At the start of the campaign, this task was performed one night a week, taking X-rays of one disposal cask per night. That schedule has recently been accelerated to four casks per night, four nights per week in order to achieve AT-06 objectives.

***Exhibit 4-10:***
***Employees Attach Radiography Film to a Portable Wheeled Cart to Reduce Exposure While Performing Radiography Operations.***

Photo Courtesy of Savannah River Site.

***Exhibit 4-11:***
***Employees Roll the Cart into Position Adjacent to the Cask to Conduct Radiography Operations on Concrete and Steel Casks Containing Higher Radioactivity TRU Waste.***

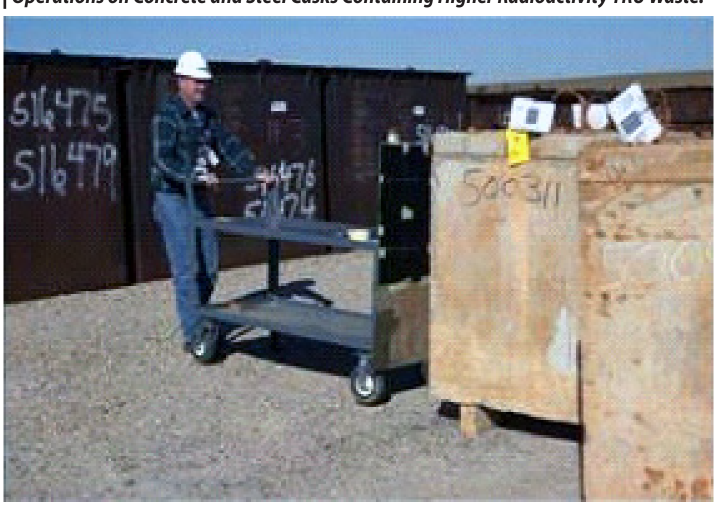


Photo Courtesy of Savannah River Site.

To X-ray four at a time, the casks were arranged in a pattern, with the radiography source positioned in the middle. In the original process, employees attached strips of radiography film to the outside face of each cask to capture the image. Attaching the film meant spending several minutes in direct contact with each cask while personnel strapped the film to the cask. The whole body dose rate where the casks were positioned for the radiographer to install the film ranged from 25 mrem/hr at 30 cms to 400 mrem/hr at 30 cms. At the end of the first night, they noted that the readings on their dosimetry, while still well within the allowable limits, were higher than expected.

The solution they came up with is a marvel of simplicity. Instead of attaching the radiography film directly to the casks, which could take up to thirty minutes of close contact, they decided to attach it to modified, portable wheeled carts (see *Exhibit 4-10* and *Exhibit 4-11*). To position the film for radiography, they simply roll the cart into position adjacent to the cask. They never have to get closer than six feet, the length of the cart, to the casks. Since the film is attached to the cart while it is off the high-radiation TRU storage pad area, the time spent near the radiation source is reduced from several minutes to the few seconds it takes to roll each cart into place.

Their innovation reduced employee exposure and made the task more efficient by attaching the film to the cart, thus making the task much simpler and faster than strapping it to the cask itself. Their efforts clearly supported the ALARA practices and principles of time, distance, and shielding.

For additional information about this project, contact Athena D. Freeman, Site ALARA Coordinator, at (803) 725-5030 or athena.freeman@srs.gov.

### 4.1.5 Savannah River Technology Center Cell 8 Shielded Window Replacement

The Cell 8 window "hot side" gasket had deteriorated over time, creating a significant oil leak through the degraded gasket. This original window needed to be removed from the cell and converted from a "hot side" load to a "cold side" loaded window. Conversion of the window assembly involved changes in the wall opening configuration. The window liner was cut out of the wall and a new one fabricated and installed to accommodate "cold side" or "clean side" loading. Job planning and execution involved laboratory operations, radiological control operations, engineering organizations, Bechtel Savannah River (BSRI), Bluegrass Concrete Cutting Services, and Hot Cells Incorporated.

***Exhibit 4-12: View of Cell Window.***

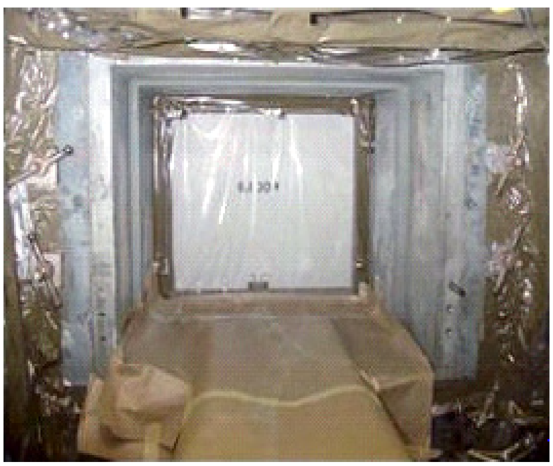


Photo Courtesy of Savannah River Site.

***Exhibit 4-13: Staff Working Inside a Hut Removing the Frame.***

Photo Courtesy of Savannah River Site.

Containment bags were constructed for removal and storage of cell wall liners and tank with deckplate. A cofferdam (see *Exhibit 4-12* and *Exhibit 4-13*) was built and installed to provide shielding and contamination control. In addition, a containment hut was designed and installed to allow access to the remaining shielded cells and allow operations to continue with minimal impact. The wet-cut method was used for cutting the concrete around the old window. This method further reduced airborne contamination levels. Water was controlled using a liner in the containment hut as well as pumps for removal of excess water. A temporary modification was installed for exhausting the containment hut into the existing exhaust system.

The estimated exposure for the window replacement was 1 rem. The actual exposure received due to ALARA initiatives was 0.532 rem, thus estimated dose avoided was 0.468 rem.

## 4.2 ALARA Activities at the Fermi National Accelerator Laboratory

At the Fermi National Accelerator Laboratory (Fermilab), a policy consistent with integrated safety management and in accordance with 10 CFR 835 requirements is to conduct activities in such a manner that worker and public safety and protection of the environment are given the highest priority. Fermilab management is committed in all its activities to maintain any safety, health, or environmental risks associated with ionizing radiation or radioactive materials at levels that are ALARA.

During 2004, the principal activities at Fermilab that resulted in occupational radiation exposures were associated with maintenance activities of the accelerator. Nearly all of the collective dose to personnel was due to exposures to items activated by the accelerator beams. Many maintenance activities were necessary as the Fermilab accelerator complex was challenged to meet the scientific objectives of Tevatron Run II while simultaneously operating the proton beam needed for the MiniBooNE experiment. The vast majority of this work occurred during a major shutdown of the accelerator carried out during the late summer and autumn of 2004. Fermilab accomplished several vital accelerator upgrades during this shutdown. This work included extensive ALARA pre-job planning, implementation of specific ALARA activities during radiological work, and post-job analyses. Several upgrades and component replacements were conducted in the Linac and Booster. Additionally, a new pulsed-beam focusing horn was installed for the MiniBooNE experiment. The following descriptions highlight ALARA efforts that were implemented as a part of these shutdown activities.

In preparation for this shutdown, a major and far-reaching ALARA step was taken when the Accelerator division head requested that the MiniBooNE experimental beamline be disabled one week in advance of the shutdown to reduce the proton production demand on the 8 GeV Booster synchrotron and to allow for adequate cooldown of the Booster in preparation for the planned extensive Booster work. This ALARA effort not only reduced the overall exposure during the planned work but also reduced exposure to personnel as they prepared accelerator areas for initial entry.

### 4.2.1 Linac Tank 5 Drift Tube Replacement

A quadrupole magnet failed within drift tube 19 in Linac tank 5. The Linac ran without it for several months, but the fall 2004 shutdown offered an opportunity to replace it (see *Exhibit 4-14* and *Exhibit 4-15*). In this cylinder, which is only 30 inches in diameter, a worker was required to be in very close proximity to activated components. The job was complicated because this vacuum vessel is a non-permitted, confined space that must be kept free of contaminants, including skin oil, and that has a smooth, soft copper surface that must not be scratched or damaged. Furthermore, the position and orientation of the new drift tube needed to be identical, to within a few thousandths of an inch, to that of the old drift tube, which demanded precise measurements that could be time-consuming. Initial exposure rates taken remotely with a long probe radiation survey instrument were greater than 2 R/hr near the upstream end of the drift tube. Therefore, a four-week cooldown period was required before work was allowed to begin. During this cooldown period, extensive ALARA pre-job planning was performed. To maintain worker exposures ALARA, several items were built:

❖ A team AHA shield to cap the ends of drift tubes, with flat surfaces to make end-to-end gap measurements easier and much faster.

❖ An azimuthal measuring fixture for quicker measurement of the distance between a drift tube and cavity walls.

❖ A Teflon™ cart with jack, for transporting drift tubes out and in and elevating them, so that removal and installation work did not require anyone to sit in the cavity. This cart consisted of a scissors jack that was manipulated remotely by electric motors and levers or by a ratchet wrench. The cart slid on nylon sliders (like a snow

**_Exhibit 4-14:_**
**_Linac Tank 5 Drift Tube Replacement Setup._**

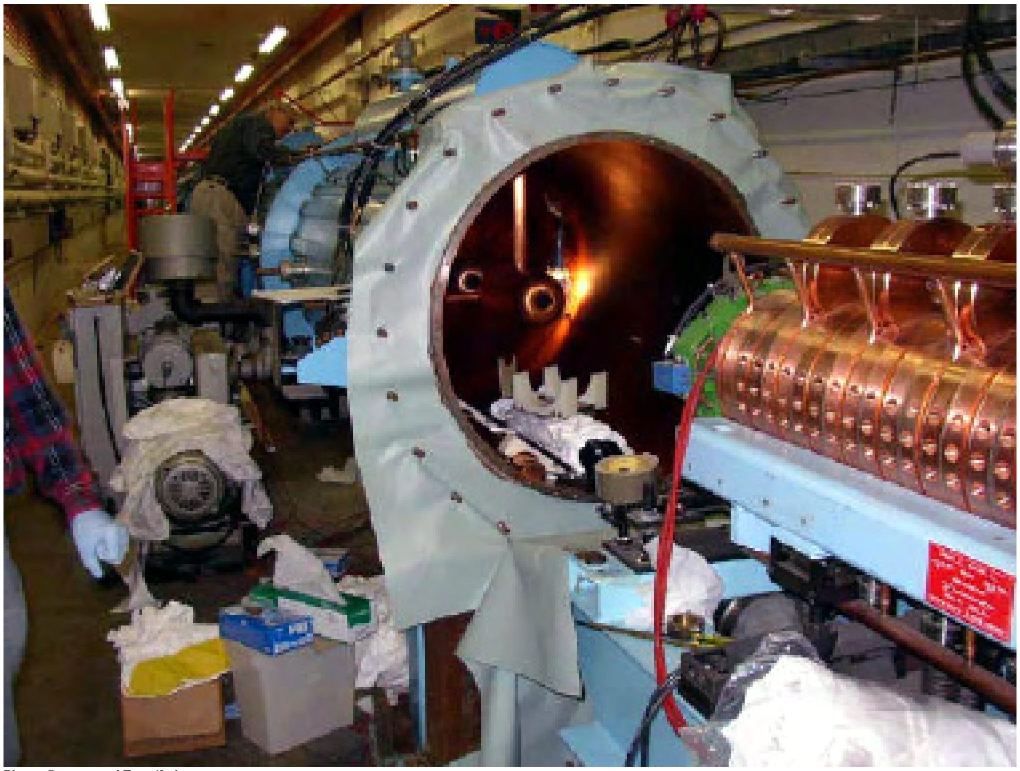


Photo Courtesy of FermiLab.

**_Exhibit 4-15:_**
**_Linac Tank 5 Drift Tube Replacement Work._**

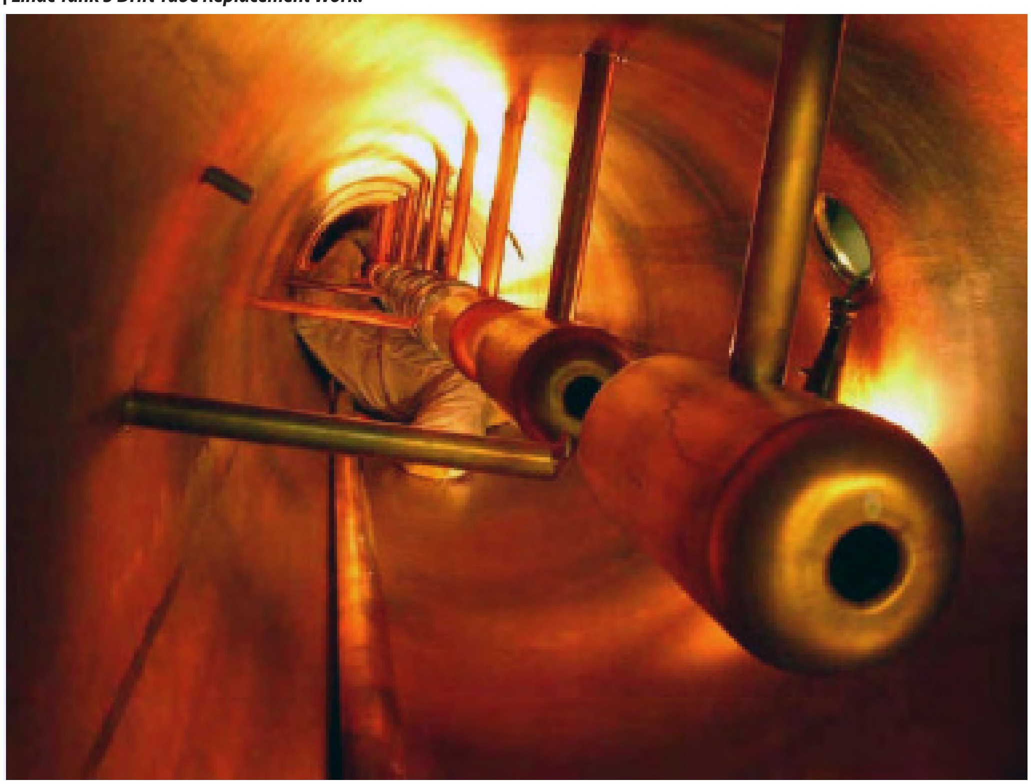


Photo Courtesy of FermiLab.

sled) and supported the quadrupole magnet for alignment as well as for removal and installation. This fixture eliminated the need for personnel to access the drift tube to manually hold up the quadrupole for this and subsequent jobs.

Other ALARA activities that occurred during cooldown of this drift tube were dry runs of the work to be performed. These dry runs were conducted on low activity drift tubes at the downstream end of the tank. These rehearsals allowed task durations to be estimated for ALARA planning purposes. It also provided every worker the opportunity to practice the work in a less hazardous environment. The ambient exposure rate during the job was 5 mR/hr. The estimated collective dose for the replacement of the drift tube was 127 person mrem. The actual collective dose was 109 person-mrem.

By allowing at least four weeks cooldown, use of an unmanned cart for exposure rate measurements, and use of additional shielding, significant personnel dose reduction was achieved.

### 4.2.2 Booster Long 13 MP01 Magnet Replacement

This ALARA work consisted of magnet replacement and reconfiguration at a location identified as Long 13 in the Booster. Two dogleg magnets, along with magnets ML01 and MP01 were replaced in this area (see *Exhibit 4-16*). A four-week cooldown was required before work was performed in this area. Cooldown time also allowed radioactive contamination to decay, thus reducing overall decontamination efforts. The highest exposure rate measured during the removal phase of this work was 100 mR/hr at one foot. However, the removal of highly activated components from the area and use of lead walls and lead blankets resulted in an ambient exposure rate of only 20 mR/hr during all phases of this work. The projected collective dose for the removal of Long 13 magnet was 226 person-mrem. The actual collective dose for the removal phase was 181 person-mrem. The projected collective dose for the installation phase was 1825 person-mrem and the actual dose received was 1208 person-mrem. The reduced values actually realized resulted from enthusiastic worker participation in all facets of dose minimization planning. A total of 18 people worked on this job, and the installation phase of this work lasted approximately 18 days. The ALARA plan for the installation phase was revised to account for adjusted time estimates for certain tasks, based on experience and observations by the radiological control technician covering this work. As a result of this work, it is anticipated that beam losses during future operations of the Booster synchrotron will be reduced, with anticipated lower future exposures to maintenance personnel.

### 4.2.3 Booster Beam Positioning Monitors Replacement in Long 6 and 7

The tasks in the Booster also included beam positioning monitor (BPM) replacement at two separate locations (see *Exhibit 4-17* and *Exhibit 4-18*). By allowing at least four weeks cooldown, personnel dose was significantly reduced. Because the highest exposure rate observed during this job was 100 mR/hr, this work required detailed ALARA pre-job planning. The projected dose for this work was 486 person-mrem. The actual dose received was 42 person-mrem. The discrepancy in dose received vs. projected dose was due to the highly localized nature of the exposure rate encountered when the work actually commenced. Workers were not required to spend any significant time in the highest exposure rate area. Workers either worked under or behind the area of highest induced radioactivity. Time estimates for each task were overestimated and this work was completed in less than half the time estimated in the ALARA plan. Prefabrication of some parts in low-dose areas also reduced personnel exposure. In summary, it is clear that steps were well-planned and performed efficiently in less time than anticipated due to careful ALARA planning.

***Exhibit 4-16:***
***MP01 Long 13 Magnet Replacement.***


Photo Courtesy of FermiLab.

***Exhibit 4-17:***
***Beam Positioning Monitor Replacement in Long 6.***

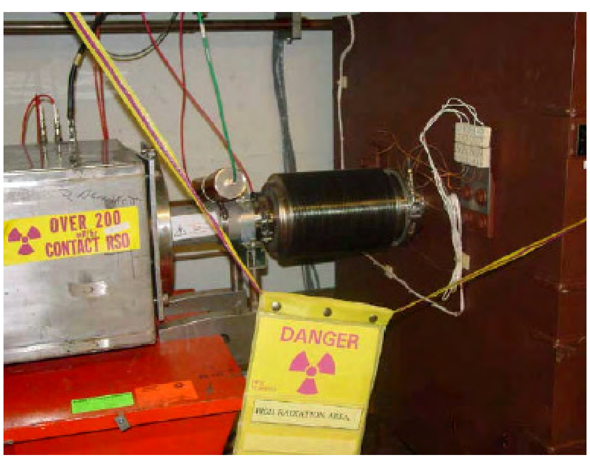



Photo Courtesy of FermiLab.

***Exhibit 4-18:***
***Beam Positioning Monitor Replacement in Long 7.***

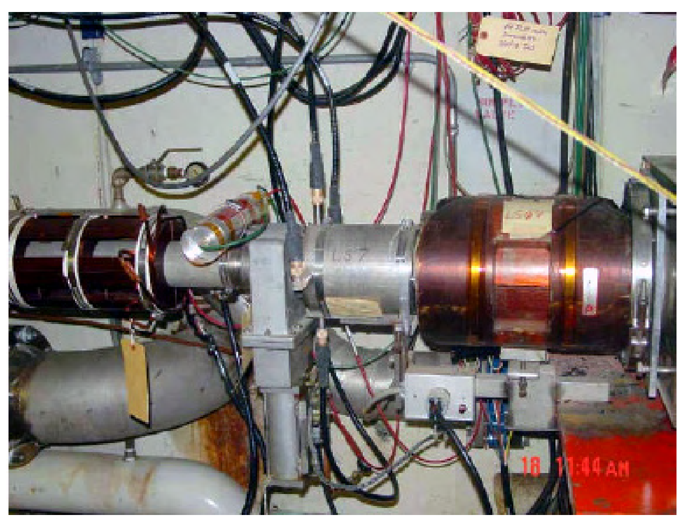


Photo Courtesy of FermiLab.

## 4.2.4 Booster Water Tube Replacements

Water tubing replacement work occurred at four locations in the Booster lattice (see *Exhibit 4-19*). The previous plastic tubing and orange "garden" hoses were replaced with PEEK™ tubing. PEEK™ tubing is quite resistant to the effects of radiation damage. This work was performed to minimize potential water leaks in the future, thus preventing personnel exposure due to repair work that would have to be performed under higher exposure rate conditions. Also, this work was performed to increase machine reliability. Lead blankets and self-shielding of magnets were used extensively to reduce personnel exposure during this work. As the work progressed, the ALARA plan was revised to reflect a change in procedure that included brazing coupling fittings and the use of shorter lengths of PEEK™ tubing. The highest exposure rate observed during the work was 80 mR/hr at one foot. The ambient exposure rate was 5 mR/hr. The projected collective dose was 371 person-mrem and the actual collective dose received was 200 person-mrem. The actual dose was lower than anticipated because localized exposure rates allowed workers to position themselves in lower exposure rate areas.

## 4.2.5 Replacement of MiniBooNE Pulsed Beam Focusing Horn

The MiniBooNE horn is a pulsed beam focusing device that is subjected to high flux densities of high energy hadrons and intense instantaneous electrical currents during operations (see *Exhibit 4-20*). After two years of operation, the horn began to malfunction. This was exhibited by water leaks and electrical failures. The horn module was expected to fail over time due to mechanical stress as a result of delivering a beam through the horn module to run the MiniBooNE experiment. This particular focusing horn had withstood a world-record number of pulses but finally unexpectedly failed only a few weeks before the scheduled shutdown (see *Exhibit 4-21*). While the "bare" horn was never directly exposed, it is estimated that the residual dose rates were as high as 120 R/hr at one foot. The MiniBooNE horn replacement work presented several radiological issues. Therefore, ALARA considerations for

***Exhibit 4-19:***
***Booster Water Tube Replacement.***

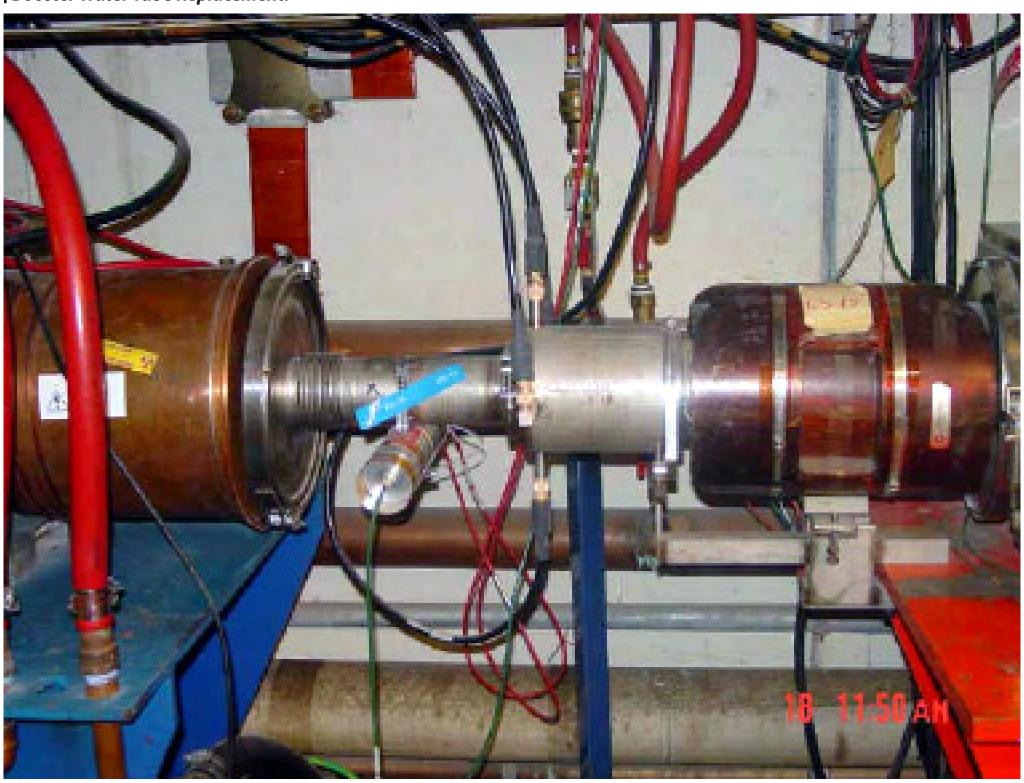



Photo Courtesy of FermiLab.

this complicated task included contamination controls, exposure rate controls, and airborne radioactivity controls. The ALARA planning phase of this task lasted several months. Because of the various nonradiological safety aspects associated with this task, a complete written hazard analysis was also prepared.

Initial work for this task involved the removal of all shielding blocks and steel plates from the MI-12 B enclosure. Magnets, magnet stands, and other beamline components were removed from the enclosure. Next, all systems were disconnected from the horn module. The power striplines were disconnected from the upstream end of the horn module, the radioactive water system was disconnected, and the target air cooling system components were removed. The horn module was pulled out of the target vault into a set of steel coffins using a system of extension rods connected to hydraulic cylinders. The set of inner and outer coffins was used to accommodate the 20-ton lifting capacities of the cranes at the removal and storage locations (see *Exhibit 4-22*). The horn module contained inside these coffins was transported to Target Service Building for storage. The new horn module was installed by pushing it into the target vault using the same system of extension rods and hydraulic cylinders. Once the new horn module was installed, the power striplines, radioactive water system, and target air cooling systems were reconnected. The magnets and other beamline components were installed in the MI-12 B enclosure as well. The shielding blocks, steel plates, and two air barriers between the first and fourth layers of shield blocks were reinstalled.

The highest exposure rate near the horn (with target vault shutter doors open) in the MI-12 B enclosure was 200 mR/hr. However, the ambient exposure rate during horn removal and installation was only 2 mR/hr. This low ambient exposure rate was achieved by removal of various

***Exhibit 4-20:***
***Pulsed Beam Focusing Horn Used in MiniBooNE Experiment.***

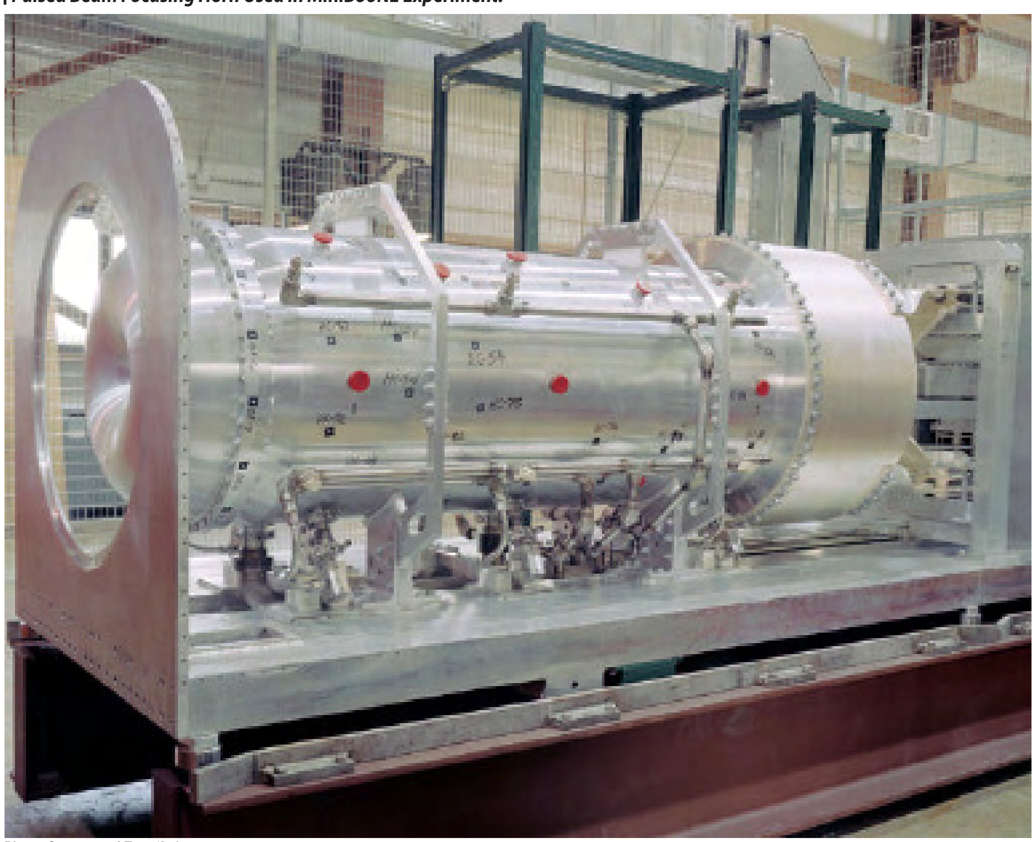


Photo Courtesy of FermiLab.

***Exhibit 4-21:***
***MiniBooNE Focusing Horn Before Removal.***

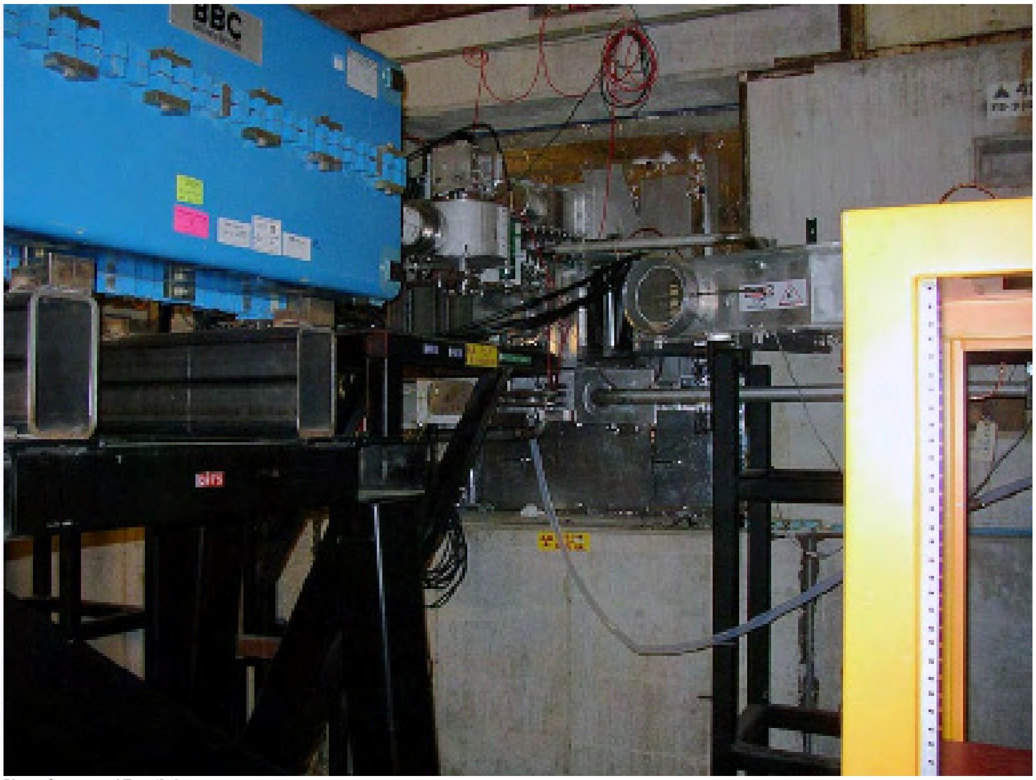
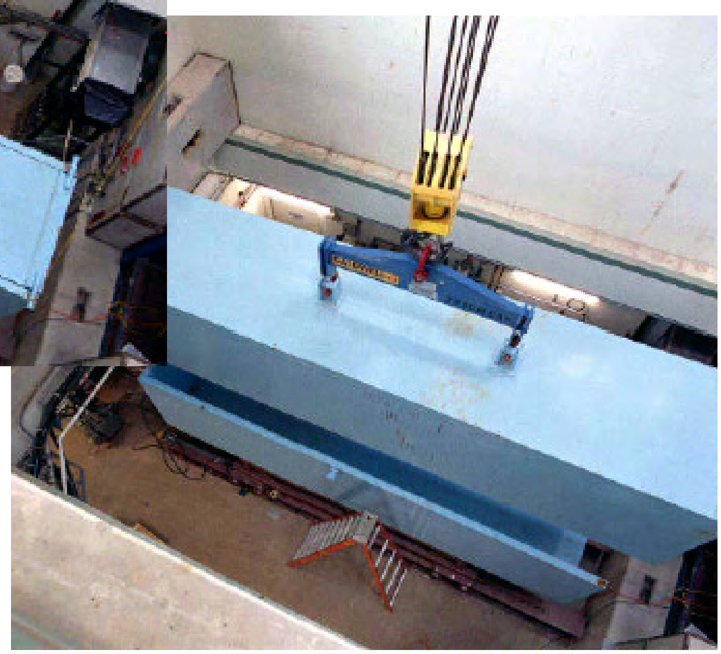


Photo Courtesy of FermiLab.

***Exhibit 4-22:***
***Inner and Outer Coffins in MI-12 B Enclosure (left). The Used MiniBooNE Focusing Horn Was Lifted Out of MI-12 B Enclosure (right).***



Photos Courtesy of FermiLab.

radioactive beamline components, closing target vault shutter doors as much as possible, and use of steel coffins that provided effective shielding of the horn module when it was outside of the target vault. As part of the ALARA planning process, collective dose estimates were predicted for both the MiniBooNE horn removal and installation phases of the work. The predicted collective dose for the MiniBooNE horn removal was 260 person-mrem. Upon completion of the horn removal, the collective dose received was 141 person-mrem. The predicted collective dose for the horn installation was 189 person-mrem. Upon completion of the horn installation, the collective dose was 186 person-mrem. Therefore, the total collective dose received for the replacement work was 327 person-mrem. The following actions were taken to maintain contamination levels, airborne radioactivity, and radiation exposure levels ALARA:

- ❖ A dry run of the MiniBooNE horn replacement was conducted when the original focusing horn was installed in the MI-12 B enclosure. These dry-run activities were videotaped and thus provided excellent time estimates for ALARA planning purposes. As in all dry-run activities, it also provided workers the opportunity to practice difficult, tedious, and time-consuming tasks on nonradioactive components.

- ❖ Considerable decontamination efforts were completed before horn removal work began, upon completion of horn removal, and prior to the new horn installation. The floors, stairs, and stairwells were decontaminated as well as beamline components that were removed from the enclosure. Continuous RCT coverage was in place during all phases of horn removal and installation work.

- ❖ All beamline components, power stripline components, radioactive water system pipes, and target air cooling components that were disconnected and removed from the horn module were bagged and all end pieces were capped and sealed to prevent the spread of contamination.

- ❖ A contamination catch tray was built and installed under the front of the used horn module to catch loose contamination during horn removal and to contain any radioactive liquids that were removed from the horn.

- ❖ To maintain ALARA, new power stripline parts, air barrier panels, and other components were machined to replace highly contaminated components that were removed. These new parts were installed to prevent handling of contaminated components.

- ❖ The prominent exposure control factor utilized during removal of the horn module was the use of one inner and two outer steel coffins. The inner coffin was 1.5 inches thick, whereas the steel outer coffins were 3.5 inches thick, for a total shield thickness of 5 inches. Two outer coffins were used to allow the inner coffin to be lifted from the enclosure and placed in a second outer coffin staged on the truck bed while the first outer coffin remained on rails in the enclosure.

- ❖ Target vault shutter doors remained closed as much as possible during horn removal and installation to reduce exposure to personnel working in the enclosure.

- ❖ Temporary shield walls were located both in the enclosure pit and on the main floor of the MI-12 Service Building. Workers used these temporary shield walls at appropriate times during horn removal.

- ❖ An outdoor perimeter was established to prevent personnel exposure while the inner coffin was being lifted out of the enclosure and placed inside the outer coffin located on a lowboy truck bed (see *Exhibit 4-23*).

- ❖ Numerous high volume air grab samples were collected at various key times during horn removal and installation. The results of these airborne radioactivity grab samples were used to determine area work conditions and personal protective equipment (PPE) requirements for workers and observers.

- ❖ Because there was a potential for airborne radioactivity, all workers were required to wear air-supplied hoods during most horn removal and installation work to maintain exposures ALARA.

- ❖ Immediately following the removal of the aluminum air barrier panels, a temporary plastic air barrier was installed to control airborne radioactivity. This plastic air barrier remained in place and was cut out around the coffin as it was being pushed into the target vault. This greatly minimized airborne exposure to workers.

- ❖ When work was not being performed, a large blue curtain was pulled down over the plastic air barrier in front of the target vault opening to reduce air movement in this region (see *Exhibit 4-24*).

The MiniBooNE pulsed focusing horn removal and installation project was a complicated task. Additionally, all phases of this work presented numerous radiological issues. The MiniBooNE horn replacement project was successful in maintaining exposures ALARA due to careful planning, performance of dry-run activities, thorough decontamination efforts, effective airborne radioactivity controls, and extensive use of shielding by means of steel coffins and use of target shutters, lead blankets, and portable shield walls to control personnel exposures.

***Exhibit 4-23:***
***Coffin Containing MiniBooNE Horn Being Loaded onto Lowboy Truck.***

Photo Courtesy of FermiLab.

***Exhibit 4-24:***
***Blue Curtain Pulled Down over Air Barrier in MI-12 B Enclosure Before Horn Removal.***

Photo Courtesy of FermiLab.

## 4.3 ALARA Activities at the Hanford Site

### 4.3.1 Fluor Hanford, Inc., Uses a Robot, TRUDY, to Remove Plutonium and Debris From the Plutonium Reclamation Facility Canyon Floor, Saving 7.0 Person-Rem

The Plutonium Reclamation Facility (PRF) is a six-story 520 $m^2$ (5,600 $ft^2$) reinforced concrete structure located next to the main PFP (Bldg 234-5Z). The PRF began operating in 1964 to reclaim or recycle usable weapons-grade plutonium left over from the process of making plutonium metal in the 234-5Z building. In 1972, PRF began receiving plutonium-bearing scrap from other facilities within the DOE complex. The recoverable material was treated to produce soluble plutonium as plutonium nitrate.

The facility contains 44 pencil tanks, ranging in size from 50 liters to 200 liters (approximately 13-53 gallon capacity, or about two to seven cubic feet in size), which were so named because they are tall and thin to meet criticality configuration needs. The pencil tanks hang from the canyon walls, some as high as three stories up. Equipment leakage during operations spreads plutonium contamination to the canyon floor creating high dose rates and very high airborne radioactivity levels.

PRF is a highly contaminated facility and is considered the most contaminated facility per square foot in the 60-building PFP complex, and its total volume of legacy TRU waste is second only to the much larger 234-5Z building.

Fluor Hanford, Inc. (FHI) has begun the deactivation & decommissioning of PRF. Cleanout of the PRF includes removing encrusted plutonium contaminated waste from the 1,350 square-foot canyon floor. To help perform this task, the project designed a robot known as TRUDY (see *Exhibit 4-25*). The name is a combination acronym that stands for TRU waste and D&D.

***Exhibit 4-25:***
***TRUDY Inside the Plutonium Reclamation Facility Canyon Hard at Work.***

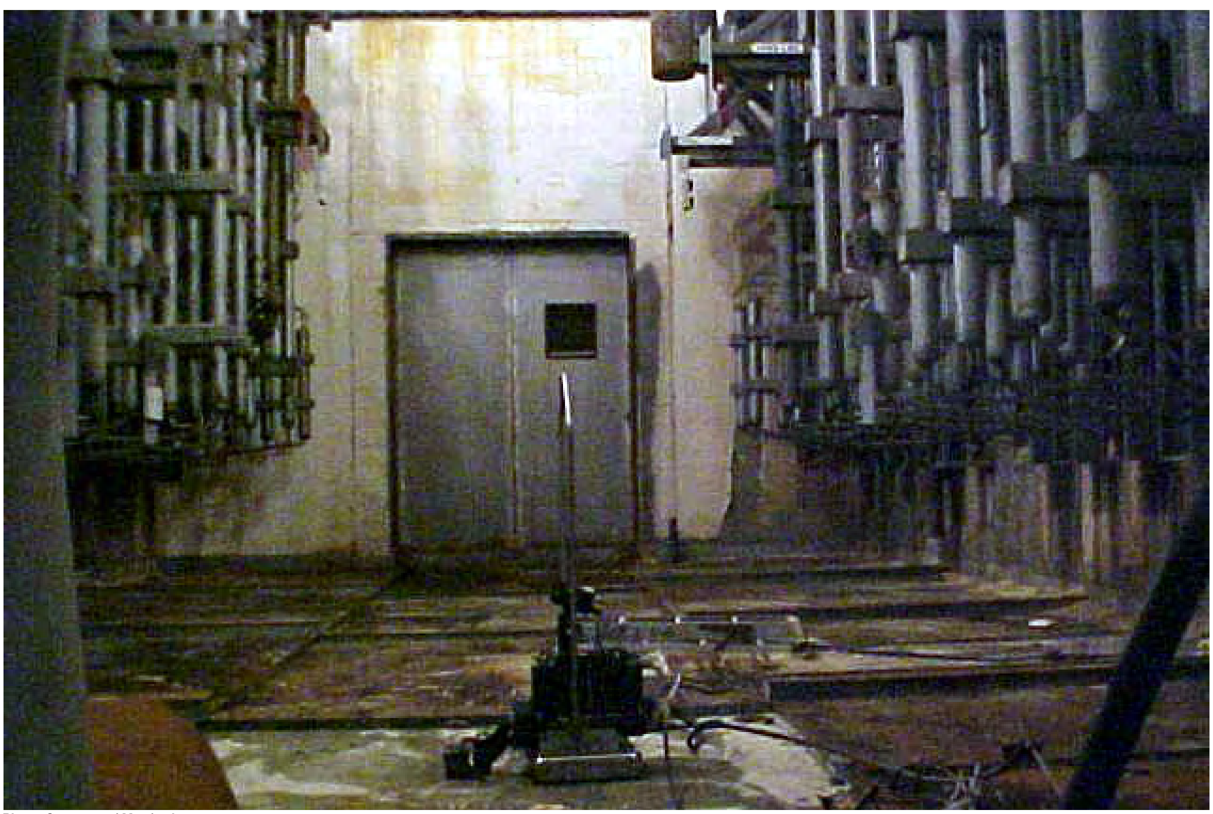


Photo Courtesy of Hanford.

TRUDY is a box-like crawler equipped with a camera, a scoop, and a lift. TRUDY is used to collect plutonium and debris from the floor. The material is accumulated in a box attached to an arm on the robot. When the box is full, the crane can be used to move the unit to a glove port or the unit can be driven to a glove port. At the glove port the contents of the box are transferred to poly bottles for seal out.

The project estimates the use of TRUDY will save a total of 7.0 person-rem.

### 4.3.2 Bechtel Hanford, Inc., Finds Several Pieces of Spent Nuclear Fuel in 118-B-1 and 118-C-1 Burial Grounds; ALARA Practices Reduce Dose

A burial ground, 118-B-1, operated between 1944 and 1973 and received metallic wastes and general reactor waste from B-reactor and N-reactor. The 118-C-1 burial ground operated between 1953 and 1969 and received miscellaneous solid waste from C-reactor. The waste profiles indicated these burial grounds contained process tubes, aluminum spacers, control rods, soft waste, and reactor hardware.

Bechtel Hanford, Inc., (BHI), the prime contractor for remediation of these burial grounds, expected high dose reactor components and established ALARA practices to minimize the potential dose to the workers.

The BHI project team used the museum exhibits located inside B-Reactor facility to train its workers to visually recognize various reactor components that were expected to be high dose items in the burial ground. Although spent fuel was not expected, the museum had mock reactor fuel as well as other expected reactor components on display. This training resulted in an RCT's quick recognition of the situation when spent nuclear fuel and pieces of spent nuclear fuel were visually identified during remediation of the burial ground. The pieces of spent nuclear fuel were yellow in color adding to the ability to visually identify any pieces of fuel (see *Exhibit 4-26*).

***Exhibit 4-26:***
***A Piece of Spent Fuel Found at 100 B/C Burial Ground.***

During remediation, reactor hardware was found with radiation levels up to 10 Rad/hour on contact and 1.6 Rad/hour at 30 cm. Radiation levels on the spent nuclear fuel were up to 45 Rad/hour on contact and 10 Rad/hour at 30 cm. The BHI project team used heavy equipment and long-handled tools to remotely handle high-dose materials and monitor radiation levels and used concrete shielding to reduce the dose to workers from the high-dose items (see *Exhibits 4-27* to *4-30*).

An RCT was present with each laborer performing sorting of materials removed from the burial ground to ensure changing radiation levels were quickly detected. The RCT performed radiation surveys by using an extendable survey instrument over the sorted debris, looking for elevated dose rates. If an area of elevated dose rate was revealed, the RCT investigated the source of radiation. If a discrete source could not be identified by the RCT survey, the laborers used long-handled tools to remove soil and uncover the object.

The high dose items were segregated from other waste. The spent nuclear fuel was segregated for shipment to K-Basins, and the high dose reactor components were moved to a shielded bunker (see *Exhibit 4-31)* so they could be placed in the center of the truckloads of waste headed for disposal in the Environmental Restoration Disposal Facility (ERDF). Placing the high dose items in the center of the load reduced dose rates at the surface of the waste containers.

Since finding spent nuclear fuel at 118-B-1 and 118-C-1 burial grounds, BHI has incorporated the lessons learned, adding the discovery of small amounts of spent nuclear fuel as a potential hazard when remediating reactor burial grounds.

***Exhibit 4-27:***
***Heavy Equipment Is Used to Remove Material from the Burial Ground.***

Photo Courtesy of Hanford.

***Exhibit 4-28:***
***Heavy Equipment Used to Remotely Place Burial Ground Materials into Sorting Piles.***


Photo Courtesy of Hanford.

***Exhibit 4-29:***
***Long-Handled Tool Used to Move Suspect Spent Nuclear Fuel Piece for Nondestructive Analysis.***

Photo Courtesy of Hanford.

## 4.3.3 Tools Developed by Fluor Hanford, Inc., Employees Speed Cleanout at the Plutonium Finishing Plant

Workers cleaning out contaminated equipment from major glove boxes and process lines in the PFP have devised a number of unique tools that are speeding the removal work and reducing associated radiation doses (see *Exhibit 4-32)*. On the remote mechanical A (RMA) and C (RMC) lines, nearly 60 aged glove boxes come in various shapes and sizes, but all exist in cramped quarters that strain body positions and angles of force. They are also filled with equipment having sharp edges that can puncture gloves and fastening bolts that have swollen or are corroded tight. Working with these glove boxes, trying to dislodge equipment inside, is difficult. But the PFP project team has used ingenuity and creative thinking to find better ways to perform the work.

One of the most helpful innovations is a collapsible sleeve or bag that can be fitted over glass tanks that hang on flanges and rod assemblies inside glove boxes. The glass tanks were once used in converting plutonium solutions to plutonium metal. The sleeve is made of heavy, rubber-like material and can fit over tanks up to six feet long. Operators reach into glove boxes, encase the tank with the sleeve, then unfasten the tank and break it inside the sleeve. They then collapse the sleeve, load it into a metal bucket, and seal out the entire bundle in a waste bag. With this new process, operators never touch the contaminated glass, which reduces the chance of a punctured glove. They are also able to get more accomplished during a shift, which further reduces dose.

Other improvements being used by the equipment removal teams include a hard plastic glove port extender, a specially designed auger for cleaning out pipes, and a glove box window polisher. All of the innovations are simple and easy.

The cylinder glove port extenders simply fit over the contaminated port openings, making it easier to change waste sealout bags and minimize the transfer of contamination.

The PFP's special augers, machined out of Teflon™ blocks and mounted on stainless steel cores, are being used with "quick connect" extension rods to clean out legacy plutonium-bearing materials held up in piping (see *Exhibit 4-33)*. The extension rods can be added as needed to reach legacy material in lines, and the teams have used the augers at distances up to 15 feet. The auger is simply pushed into a pipe, rotated, and pulled out, with the held-up material dropping into pre-staged, criticality safe containers through a transparent "tee" (short branch) attached to a line flange. Special scrapers, brushes, and core drill bits have

***Exhibit 4-30:***
***Shielded Bunker for Temporary Storage of High Dose Items.***

Photo Courtesy of Hanford.

***Exhibit 4-31:***
***High Dose Reactor Components Inside the Shielded Bunker.***

Photo Courtesy of Hanford.

*Exhibit 4-32:*
***Special Tools Developed by Plutonium Finishing Plant Closure Project.***

Photo Courtesy of Hanford.

also been developed by PFP teams to address various challenges. Precious time has been saved in many cases because the augers have allowed hold-up removal to proceed without actually removing the pipes.

The glove box window polisher consists of a sander disk embedded with resins in a plastic matrix, sometimes used to clean the canopies on F-16 fighter jets. It works well on glove box windows because the windows—made of various types of plastic—have been clouded by radiolysis. Cleaning away the clouding allows workers to see what they are doing more clearly, improving safety and efficiency. The sander disk pads are mounted on poles that can be extended inside PFP's glove boxes.

Spending time in planning has definitely resulted in less time spent in executing the work in radiation zones. This kind of innovation is good for everyone.

### 4.3.4 Fluor Hanford, Inc., Operators Pair up with Engineering to Design Special Tools for Cleanout of the K East Basin "Weasel Pit," Increasing Productivity and Reducing Dose

Fluor Hanford, Inc., is the contractor responsible for the K Basins Closure Project. Now that the spent fuel has been removed, the contractor is working on the removal of the sludge and debris in the basins. The "weasel pit" in K East Basin is an area that juts out from the main basin and is approximately 5 feet wide, 34 feet long, and 20 feet deep.

"Weasel pit" is an historical term derived from a type of long-handled radiation detection equipment deployed during the defense production years to examine special fuel in the pit.

K East Basin's weasel pit comprises less than two percent of the basin's total area, yet it held nearly the same amount of sludge as the entire K West Basin. Sludge, varying from flighty and swirling to dense and heavy had been relocated to the weasel pit from other basin areas during preparations for storing N Reactor fuel assemblies in the 1970s (see *Exhibit 4-34*).

The remote location of the weasel pit made it the most attractive location for containers to receive and settle sludge for transfer out of the K East basin for eventual treatment and disposal. The project needed to keep the sludge tanks out of the way of D&D work in the basin, so D&D work could be done in parallel with sludge retrieval with minimal interference.

Fluor's K Basin Closure project began cleaning out the pit in 2004 to prepare it for the sludge tanks—an effort that became one of the most challenging tasks undertaken in the long road to remediate the K Basins. The weasel pit was filled with sludge four to six feet deep and an array of equipment, tools, and other debris concealed by the heavy sludge cover. Nuclear chemical operators retrieving sludge from the K East Basin weasel pit stood on grating 20 feet above the pit's floor using a long-handled tool to vacuum the sludge. Operators viewed the sludge through a camera. Poor water clarity complicated the task.

After initially starting vacuuming in the weasel pit with the originally designed end effector (a 2-inch-diameter pipe with crosshatch guard on the bottom), there was considerable trouble encountered with the end effector plugging and requiring constant back flushing. Each time a back flush was performed, it took approximately 20-30 minutes to complete the evolution and get back to vacuuming.

During one of the breaks, an operator began to discuss a better design for the end effector. The operator was sent to the engineering group to discuss a prototype end effector that was shaped differently (spherical design) and had a built-in back flush capability using demineralized water. The operator and engineer devised the first prototype end effector (see *Exhibit 4-35*). As soon as it was fabricated, it was placed into service and was widely recognized by all of the operators as a significant improvement over the previous end effector. In fact, it was so well liked, the operators began to compete over who was going to get to perform the vacuuming operation.

**_Exhibit 4-33:_**
**_A Lead Nuclear Chemical Operator Demonstrates Auger and Catch Container Developed to Clean Out Plutonium Hold-up in PFP Piping._**

Photo Courtesy of Hanford.

Following implementation of this end effector, production numbers increased each shift due to greater time devoted to pumping sludge as opposed to having to stop sludge retrieval to back flush the end effector with the pumping system.

This design worked well in areas where deep piles of sludge had accumulated. However, not all areas of the basin contain the same levels of sludge. For this reason, the project has continued to have operators work with engineers to design new prototype end effectors for each type of situation encountered. This process has really worked well in providing a quick turnaround on implementing operator ideas while maintaining a solid engineering basis for change.

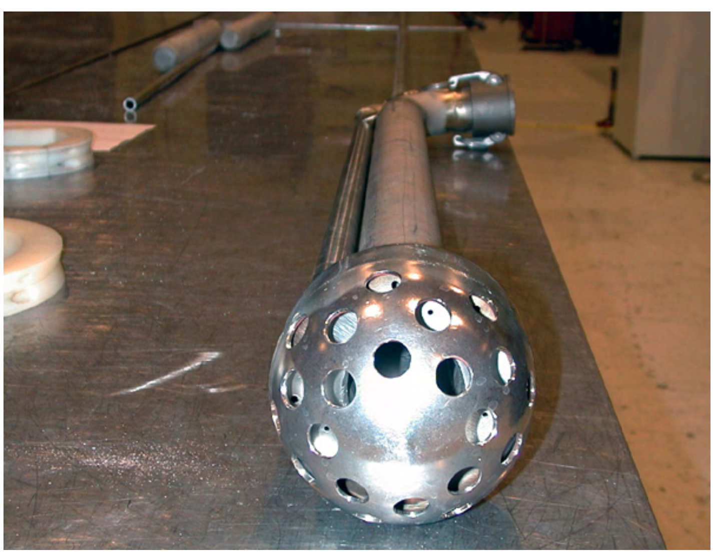
*Exhibit 4-34:*
***The Dark Area on the Left Side of the Wall of the Weasel Pit Shows the Depth of the Sludge at the Start of This Project.***

Photo Courtesy of Hanford.

## 4.4 Submitting ALARA Success Stories for Future Annual Reports

Individual success stories should be submitted in writing to the DOE Office of Corporate Performance Assessment. The submittal should describe the process in sufficient detail to provide a basic understanding of the project, the radiological concerns, and the activities initiated to reduce dose.

*Exhibit 4-35:*
***The Improved End Effector Was the Result of the Team Efforts of an Operator with a Great Idea and an Engineer Turning the Idea into Reality.***



The submittal should address the following:

- Mission statement
- Project description
- Radiological concerns
- Information on how the process implemented ALARA techniques in an innovative or unique manner
- Estimated dose avoided
- Project staff involved
- Approximate cost of the ALARA effort
- Impact on work processes, in person-hours if possible (may be negative or positive)
- Figures and/or photos of the project or equipment (electronic images if available)
- Point-of-contact for follow-up by interested professionals.

## 4.5 Lessons Learned Process

The Department of Energy has a mature lessons learned process that was initially developed in 1994. The current DOE lessons learned process is described in DOE Technical Standard, DOE-STD-7501-99. The purpose of the DOE lessons learned process is to facilitate the identification, documentation, sharing, and utilization of lessons learned from a review of actual operating experiences throughout the DOE complex. This is accomplished by lessons sharing between DOE sites through a common corporate database. A recent review of the lessons learned process has led to a redesign of the process to add a more corporate component to the process. This new corporate component, modeled after the Institute of Nuclear Power Operations (INPO) Significant Event Evaluation and Information Network (SEE-IN) program, has introduced an additional corporate role in the review of DOE site performance and crosscutting operating experience, and has started to provide additional lessons learned information to the DOE community in addition to that already provided by DOE field sites.

The collected information is currently located on an Internet Web site as part of the Environment, Safety & Health (ES&H) Web page. This system allows for shared access to lessons learned across the DOE complex. The information available on the system complements existing reporting systems presently used within DOE. DOE is taking this approach to enhance those existing systems by providing a method to quickly share information among the field elements. Also, this approach goes beyond the typical occurrence reporting to identify good lessons learned. DOE uses the Web site to openly disseminate such information so that not only DOE, but also other entities will have a source of information to improve the health and safety aspects of operations at and within their facilities. Additional benefits include enhancing the workplace environment and reducing the number of accidents and injuries.

The Web site contains several items that are related to health physics. Items range from off-normal occurrences to procedural and training issues. Documentation of occurrences includes the description of events, root-cause analysis, and corrective measures. Several of the larger sites have systems that are connected through this system. DOE organizations are encouraged to participate in this valuable effort.

The Web site address for DOE Corporate Operating Experience Review Lessons Learned Web page is:

**http://www.eh.doe.gov/ll**

The specific Web site address may be subject to change. ES&H information services can be accessed through the main Office of Environment, Safety and Health Web page at:

**http://www.eh.doe.gov**

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# Conclusions

## 5.1 Conclusions

The collective dose at DOE facilities has experienced a dramatic (86%) decrease since 1986. The main reasons for this large decrease were the shutdown of facilities within the weapons complex and the end of the Cold War era, which shifted the DOE mission from weapons production to shutdown, stabilization, and D&D activities. The DOE weapons production sites have continued to contribute the majority of the collective dose over these years. Sites reporting under the category of weapons fabrication and testing account for the highest collective dose. Even though these sites are now primarily involved in nuclear materials stabilization and waste management, they still report under this facility type. As facilities are shut down or undergo transition from operation to stabilization or D&D, there are significant changes in the opportunities for worker radiation exposure.

The detailed nature of the data available has made it possible to investigate distribution and trends in data and to identify and correlate parameters having an effect on occupational radiation exposure at DOE sites. A summary of the findings for 2004 is shown in *Exhibit 5-1*.

***Exhibit 5-1:***
***2004 Radiation Exposure Fact Sheet.***

- ❖ The collective TEDE decreased 24% from1,445 person-rem (14.45 person-Sv) in 2003 to 1,094 person-rem (10.94 person-Sv) in 2004. This is the largest decrease in the collective dose in the past 15 years since the decrease in the collective DDE between 1989 and 1990.
- ❖ The six highest dose sites (in descending order of collective dose: Hanford, Savannah River, Los Alamos, Oak Ridge, Idaho, and Rocky Flats) accounted for 77% of the collective dose at DOE in 2004.
- ❖ Decreases in collective dose at five of the top six sites were attributed to Rocky Flats radioactive source material being shipped off site for disposal; completion of thermal stabilization and repackaging of plutonium-bearing materials, and deactivation & decommissioning activities at the PFP and a decreased number of tank farm entries at Hanford; completion of work, including de-inventory of a number of facilities at Savannah River; suspension of nonessential operations at LANL during the second half of 2004; and a decrease in the isotope production work that took place at ORNL during 2004.
- ❖ There were no exposures in excess of the DOE 5 rem (50 mSv) annual TEDE limit.
- ❖ There were two exposures in excess of the DOE ACL of 2 rem (20 mSv) TEDE. The two individuals who received exposures in excess of the 2 rem (20 mSv) annual TEDE limit resulted from plutonium intakes at Hanford and Rocky Flats.
- ❖ The collective internal dose (CEDE) decreased by 18% between 2003 and 2004. Due to the decrease in the collective CEDE and a 19% decrease in the number of internal depositions, the average measurable CEDE remained the same at a value of 0.037 rem (0.37 mSv) in 2004.
- ❖ The collective dose for transient workers decreased by 54% from 56.1 person-rem (561 mSv) in 2003 to 25.6 person-rem (256 mSv) in 2004. As a result, the average measurable dose to transients decreased by 45% from 0.093 rem (0.93 mSv) in 2003 to 0.051 rem (0.51 mSv) in 2004.

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# Glossary



**Administrative Control Level (ACL)**
A dose level that is established below the DOE dose limit in order to administratively control exposures. ACLs are multitiered with increasing levels of authority required to approve a higher level of exposure.

**ALARA**
Acronym for "as low as reasonably achievable," which is the approach to radiation protection to manage and control exposures (both individual and collective) to the workforce and the general public to as low as is reasonable, taking into account social, technical, economic, practical, and public policy considerations. ALARA is not a dose limit but a process with the objective of attaining doses as far below the applicable limits as is reasonably achievable.

**Annual Effective Dose Equivalent (AEDE)**
The summation for all tissues and organs of the products of the dose equivalent calculated to be received by each tissue or organ during the specified year from all internal depositions multiplied by the appropriate weighting factor. Annual effective dose equivalent is expressed in units of rem.

**Average Measurable Dose**
Dose obtained by dividing the collective dose by the number of individuals who received a measurable dose. This is the average most commonly used in this and other reports when examining trends and comparing doses received by workers because it reflects the exclusion of those individuals receiving a less than measurable dose. Average measurable dose is calculated for TEDE, DDE, neutron dose, extremity dose, and other types of doses.

**Collective Dose**
The sum of the total annual effective dose equivalent or total effective dose equivalent values for all individuals in a specified population. Collective dose is expressed in units of person-rem.

**Committed Dose Equivalent (CDE) ($H_T$,50)**
The dose equivalent calculated to be received by a tissue or organ over a 50–year period after the intake of a radionuclide into the body. It does not include contributions from radiation sources external to the body. Committed dose equivalent is expressed in units of rem.

**Committed Effective Dose Equivalent (CEDE) ($H_E$,50)**
The sum of the committed dose equivalents to various tissues in the body ($H_T$,50), each multiplied by the appropriate weighting factor ($w_T$) (i.e., $H_E$,50 = $w_T H_T$,50). Committed effective dose equivalent is expressed in units of rem.

**CR**
See SR.

**Deep Dose Equivalent (DDE)**
The dose equivalent derived from external radiation at a depth of 1 cm in tissue.

**DOE Site**
A geographic location operated under the authority of the Department of Energy (DOE). The DOE sites considered in this report are listed in Appendix A by Operations Office. Please visit http://www.eh.doe.gov/rems/annual.htm to view the appendices.

**Effective Dose Equivalent ($H_E$)**
The summation of the products of the dose equivalent received by specified tissues of the body ($H_T$) and the appropriate weighting factor ($w_T$)—i.e., $H_E = \sum w_T H_T$. It includes the dose from radiation sources internal and/or external to the body. The effective dose equivalent is expressed in units of rem.

**Exposure**
As used in this report, *exposure* refers to individuals subjected to, or in the presence of, radioactive materials which may or may not result in occupational radiation dose.

**Lens (of the Eye) Dose Equivalent (LDE)**
The radiation dose for the lens of the eye is taken as the external equivalent at a tissue depth of 0.3 cm.

**Members of the Public**
Individuals who are not occupationally exposed to radiation or radioactive material. This includes visitors and visiting dignitaries.

**Minimum Detectable Activity (MDA)**
The smallest quantity of radioactive material or level of radiation that can be distinguished from background with a specified degree of confidence. Often used synonymously with minimum detection level or lower limit of detection.

**Number of Individuals with Measurable Dose**
The subset of all monitored individuals who receive a measurable dose (greater than limit of detection for the monitoring system). Many personnel are monitored as a matter of prudence and may not receive a measurable dose. For this reason, the number of individuals with measurable dose is presented in this report as a more accurate indicator of the exposed workforce. The number of individuals represents the number of dose records reported. Some individuals may be counted more than once if multiple dose records are reported for the individual during the year.

**Occupational Dose**
An individual's ionizing radiation dose (external and internal) as a result of that individual's work assignment. Occupational dose does not include doses received as a medical patient or doses resulting from background radiation or participation as a subject in medical research programs.

**Rad/hour**
A measure of the energy absorbed per unit mass.

**Shallow Dose Equivalent (SDE)**
The dose equivalent deriving from external radiation at a depth of 0.007 cm in tissue.

**SR (formerly CR)**
SR is defined by the UNSCEAR as the ratio of the annual collective dose delivered at individual doses exceeding a specified dose value to the collective dose. UNSCEAR uses a subscript to denote the dose value (in mSv) used in the calculation of the ratio. Therefore $SR_{15}$ would be the ratio of the annual collective dose delivered at individual doses exceeding 1.5 rem (15 mSv) to the total annual collective dose.

**Total Effective Dose Equivalent (TEDE)**
The sum of the effective dose equivalent for external exposures and the committed effective dose equivalent for internal exposures. Deep dose equivalent to the whole body is typically used as effective dose equivalent for external exposures. The internal dose component of TEDE changed from the annual effective dose equivalent (AEDE) to the committed effective dose equivalent (CEDE) in 1993.

**Total Number of Records for Monitored Individuals**
All individuals who are monitored and reported to the DOE Headquarters database system. This includes DOE employees, contractors, subcontractors, and members of the public monitored during a visit to a DOE site. The number of individuals represents the number of dose records reported. Some individuals may be counted more than once if multiple dose records are reported for the individual during the year.

**Transient Individual**
An individual who is monitored at more than one DOE site during the calendar year.

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# References

References

References


1. EPA (U.S. Environmental Protection Agency), 1987. "Radiation Protection Guidance to Federal Agencies for Occupational Exposure," *Federal Register* 52, No. 17, 2822; with corrections published in the *Federal Registers* of Friday, January 30, and Wednesday, February 4, 1987.

2. ICRP (International Commission on Radiological Protection), 1977. "Recommendations of the International Commission on Radiological Protection," ICRP Publication 26, Annals of the ICRP, Vol. 1, No. 3 (Pergamon Press, New York).

3. NCRP (National Council on Radiation Protection and Measurements), 1987. "Recommendations on Limits for Exposure to Ionizing Radiation," NCRP 91; superceded by NCRP Report No. 116.

4. 10 CFR Part 835, "Occupational Radiation Protection." Final Rule; DOE *Federal Register,* November 4, 1998.

5. DOE Order 231.1A, "Environment, Safety and Health Reporting," August 19, 2003.

6. DOE Manual 231.1-1A, "Environment, Safety and Health Reporting Manual," Approved March 19, 2004.

7. Computerized Accident and Incident Reporting System (CAIRS), "DOE and Contractor Injury and Illness Data by Year by Quarter" report. Online at: http://www.eh.doe.gov/CAIRS/cairs/dataqtr/menu.html.

8. United Nations, *Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR 2000 Report to the General Assembly, with scientific annexes, Volume I*, General Assembly of Official Records, United Nations, New York, 2000.

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