Extremity Dosimetry at U.S. Department of Energy Facilities

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OF ENERGY FACILITIES

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FOREWORD

Knowledge of site-specific extremity dosimetry programs is a necessary prerequisite for the identification of feasible alternatives to the upgrading of extremity dosimetry practices. Therefore, the Department of Energy (DOE), Office of Nuclear Safety (ONS) initiated a study to review the status of extremity dosimetry programs at DOE and DOE contractor facilities. The study is a result of information obtained during an earlier evaluation of the status of beta dosimetry programs.

The objective of this study is to determine the adequacy of present extremity dosimetry programs and identify areas for improvement. This report is based upon the responses provided by DOE contractors throughout the United States.

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EXECUTIVE SUMMARY

A personnel dosimetry system must provide an accurate and reliable estimate of absorbed dose. Because extremity monitoring is one of the least well-defined facets of personnel dosimetry, the DOE Office of Nuclear Safety is interested in evaluating and, if necessary, upgrading extremity dosimetry. As part of the initial effort, a questionnaire on extremity dosimetry was distributed to DOE facilities along with a questionnaire on beta dosimetry. An informal telephone survey was conducted as a follow-up survey to answer a few additional questions concerning extremity monitoring practices. The responses to the questionnaire and the telephone survey are summarized in this report.

Background information, developed from operational experience and a review of the current literature, is presented as a basis for understanding the information obtained by the survey and questionnaire. The information contained in the background section as well as the survey responses are used as a basis for recommendations for areas of further research and improvement.

BACKGROUND INFORMATION

The background information includes a discussion of regulations and recommendations from advisory groups, extremity dosimeter design and calibration, dosimeter use and placement, and methods used for dose assessment.

The current regulations and recommendations specify dose equivalent limits to the hands, feet and forearms, which are different from the whole-body dose equivalent limit. Little guidance exists on the design or calibration of extremity dosimeters, the appropriate placement of extremity dosimeters, or methods of dose assessment.

A wide variety of extremity dosimeter designs exists. Many of the extremity dosimeters in use are simple modifications of whole-body dosimeters. However, the critical tissues for radiation damage in the extremity, the composition of the tissues, and the type of damage that may occur differs from that of the whole body. The measurement of beta or neutron radiation to the extremities presents special problems. Because of the shallower penetration of beta radiation, the material above the dosimeter must be thin enough for the

beta radiation to penetrate. Further, the thickness of dosimeter material will affect the estimate of the absorbed dose. TLD-albedo dosimeters have been designed as whole-body dosimeters for the measurement of neutron dose and have not been shown to be an effective extremity dosimeter. The effect on neutron albedo dosimeters of the small mass of the extremity and difference in bone-to-tissue ratio is not well known. The Q factors for converting neutron fluence to dose equivalent for extremities should be different than the factors used for whole-body calculations. Very little study has been done on this problem. Regardless of the type of radiation measured, extremity dosimeters should be designed to not interfere with the dexterity of the worker and to resist contamination.

The proper placement of the dosimeter on the extremities is a major factor in correctly determining the dose. Although current practices tend toward placement of a dosimeter on the wrist or on the base of the finger, it is important to measure or calculate the dose at the point of highest exposure. The determination of this location may be a complicated task; for example, during plutonium glovebox operations, the point of highest exposure may be anywhere along the worker's arm, depending on the operation. For other jobs, the dose to the finger tips on the same hand may vary by a factor of 50 or more.

The final topic discussed in the background summary is the assessment of dose. The appropriate assessment of dose depends on the evaluation of the extremity dose at the proper depth in tissue, the correct assignment of the dose when multiple dosimeters are used, and the use of appropriate quality factors for the calculation of dose.

SURVEY FINDINGS

As indicated from the questionnaire and survey replies, most facilities provide extremity dosimeters to less than 10% of those personnel monitored for whole-body exposure. The results of the telephone survey indicated that the majority of the extremity doses recorded were below 15 rem/yr although the doses ranged to a maximum of 68 rem/yr just under the regulatory maximum of 75 rem/yr. Thirty-five percent of the facilities that had extremity monitoring

programs indicated that they had personnel whose annual dose was limited by their extremity exposure rather than their whole-body exposure.

Extremity dosimeters are assigned to personnel based on the job classification, the exposure level, the dose gradient between the extremity and the whole body, or on an analysis of the specific operation. Extremity dosimeters are usually exchanged monthly or immediately following work with a significant exposure potential. In general, extremity monitoring at DOE sites is performed using one-chip or two-chip thermoluminescent finger dosimeters. Beta window thicknesses range from 7 to 100 mg/cm². Only 6 of 25 respondents distinguish between penetrating and nonpenetrating radiations for hand exposures. Among these six, two use shallow-dose criteria equivalent to the guidance of the American National Standards Institute in ANSI N13.11 "American National Standard Criteria for Testing Personnel Dosimetry Performance" (1983).

The survey respondents expressed concern about several aspects of extremity dosimetry including the design and calibration of dosimeters, dosimeter placement, general use of dosimeters and dose assessment methods.

CONCLUSIONS AND RECOMMENDATIONS

The survey findings indicate that the doses reported for personnel at DOE facilities are below the DOE regulatory limits. However, the accuracy of the dose measurements is questionable. Present extremity dosimeter designs and practices in many cases make it difficult for DOE facilities to accurately determine the dose to the extremities. Large variations in dose may occur between the point of highest exposure and the location where the dose is actually measured, which is commonly the wrist or the base of a finger. In addition, dosimeter responses to beta and low-energy photon radiations are commonly underestimated. The evaluation of neutron dose to the extremities has received little study.

Based on the background information and the survey results, we recommend the following areas for further research and/or improvement:

- standardize definitions and methods used in dose assessment (e.g., critical site for dose equivalent evaluation, critical depth)
- provide guidance on the proper placement and use of extremity dosimeters
- provide guidance to optimize the design and calibration of extremity dosimeters
- develop improved extremity dosimeters, especially for beta and neutron radiation measurements
- provide guidance on dose assessment methods including guidance on neutron quality factors for extremities and on the use of multiple dosimeters
- disseminate this information through symposia and workshops on extremity dosimetry.

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CONTENTS

FOREWORD	iii
EXECUTIVE SUMMARY	v
BACKGROUND INFORMATION	v
SURVEY FINDINGS	vi
CONCLUSIONS AND RECOMMENDATIONS	vii
ACKNOWLEDGMENTS	ix
INTRODUCTION	1
BACKGROUND INFORMATION	3
CURRENT REGULATIONS AND RECOMMENDATIONS	3
EXTREMITY DOSIMETER DESIGN AND CALIBRATION	6
Dosimeter Material	6
Physical Design of Extremity Dosimeters	12
Calibration	13
DOSIMETER PLACEMENT	14
DOSE ASSESSMENT	16
SURVEY RESULTS	19
DEFINITIONS USED IN DOSE ASSESSMENT	20
EXTREMITY-MONITORED POPULATION	21
TYPES OF DOSIMETERS	23
DOSE ASSESSMENT AND RECORDKEEPING PRACTICES	25
EXTREMITY DOSE AND ALARA PRACTICES	26
PERCEIVED PROBLEMS	28
CONCLUSIONS AND RECOMMENDATIONS	29
REFERENCES	31

APPENDIX A - DOE/DOE CONTRACTOR FACILITIES INCLUDED IN THE STUDY . . .	A.1
APPENDIX B - EXTREMITY DOSIMETRY QUESTIONNAIRE RESPONSES . . .	B.1
APPENDIX C - EXTREMITY DOSIMETRY FOLLOW-UP TELEPHONE SURVEY RESPONSES .	C.1

TABLES

1	Comparison of an Ideal Extremity Dosimeter System with an Available Extremity Dosimeter System	7
2	Commercial Dosimeter Responses to Beta Calibration Sources	14
3	Definition of Extremity	20
4	Jobs for Which Workers are Assigned Extremity Dosimeters	22
5	Percentage of Workers Monitored for Whole-Body Exposure Who are also Monitored for Extremity Exposure	22
6	Number of Workers Monitored for Extremity Dose	23
7	Criteria Used to Determine When Extremity Monitoring is Necessary	24
8	Maximum Annual Extremity Dose	26
9	Range of Extremity Dose	27
10	Administrative Action Levels for Extremity Dose	28

INTRODUCTION

An extremity dosimetry system should provide accurate and reliable estimates of dose. However, extremity monitoring is one of the least well-defined facets of personnel dosimetry. The critical tissues in the extremities that may be damaged by radiation exposure and the type of damage that may occur differ from that of the whole body, and yet many of the extremity dosimeters in use are simple modifications of whole-body dosimeters. The composition of tissues differs markedly from that in the whole body, leading to further problems in assessing dose because the backscatter of beta and gamma radiations, and the moderation and albedo scattering of neutrons will differ from that of the whole body. No standards exist for the calibration of extremity dosimeters, and little guidance exists on the selection, use, or placement of dosimeters or on the proper assessment of dose.

The scope of the extremity monitoring problem is also not well defined. Department of Energy (DOE) Order 5484.1 (DOE 1981a) requires the submittal of an annual summary of whole-body exposure, and a summary of exposures resulting in internal body depositions. Extremity doses and numbers of personnel receiving these doses are not reported. The latter would be a requirement in a proposed revision to DOE Order 5480.1. Thus, the number of personnel whose dose is limited by their extremity exposures is not well known. The extremity dose measurement and assessment practices are also not well known. For these reasons, the DOE Office of Nuclear Safety, in response to the problem, initiated a study to evaluate and, if necessary, upgrade extremity dosimeters. As part of the initial effort, a questionnaire on extremity monitoring was distributed to DOE facilities along with a questionnaire on beta dosimetry. A later, informal survey was conducted to answer a few additional questions on extremity dosimetry practices, the number of personnel monitored and the range of doses received. This document contains background information on extremity dosimetry and the results of the survey. The responses to the surveys are summarized in this report.

Background information developed from operational experience and a review of the current literature, is presented as a basis for understanding the information obtained by the survey and questionnaire. The information contained in the background section as well as the survey responses are used as a basis for recommendations for areas of further research and development.

BACKGROUND INFORMATION

A review of the regulatory and technical basis for extremity dosimetry is presented as background information for understanding the survey results. This review contains a summary of the DOE regulations and the recommendations from various advisory groups regarding extremity dosimetry. Also included are descriptions of the design and calibration of extremity dosimeters, dosimeter placement, and dose assessment methods.

CURRENT REGULATIONS AND RECOMMENDATIONS

The radiation protection standards and requirements for extremity monitoring at DOE facilities are given in DOE Order 5480.1A, Chapter XI, "Standards and Requirements for Radiation Protection" (DOE 1981b). The current DOE requirements limit the dose equivalent to the hands and feet to 75 rem/yr or 25 rem/calendar quarter. The dose equivalent to the forearms is limited to 30 rem/yr or 10 rem/calendar quarter. The skin of the hands and forearms is subject to the same dose equivalent limits as the hands and forearms. Monitoring is required when the potential exists for the individual to receive a dose equivalent in excess of 10% of the quarterly standard. The DOE requires that all reasonable efforts be made to keep exposures of the forearms and hands to the limit for the skin of the whole body, which is 15 rem/yr or 5 rem/calendar quarter.

The requirements for extremity monitoring as outlined in the DOE Order 5480.1A may be revised. A draft of the proposed DOE Order 5480.1, Chapter XI, "Requirements for Radiation Protection," has been written based on the proposed Environmental Protection Agency (EPA) guidance. The draft regulations explicitly define the extremities to include the hands, the arms below the elbow, and the feet and legs below the knee. It states that the dose equivalent received in any one year by a radiation worker shall not exceed 50 rem to the extremities. Extremity monitoring is required for all radiation workers who have a potential to exceed 5 rem/yr to the extremities.

The current DOE radiation protection standards and requirements state that the "methods of estimating dose commitment to the organ of interest should be ... consistent with assumptions and recommendations of the EPA, the National Council on Radiation Protection and Measurements (NCRP), and the International Commission on Radiological Protection (ICRP)" (DOE 1981b). Before 1970, the Federal Radiation Council (FRC) was responsible for providing recommendations to the President in the form of Federal Radiation Protection Guidance for Occupational Exposure. During 1970, the administrator of the EPA was charged to "...advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with states" (Executive Order 1083, the Atomic Energy Act (as amended) and Reorganization Plan No. 3 of 1970). The current Federal Radiation Protection Guidance is the same as that promulgated by the FRC in 1960. The recommendations of the FRC, NCRP, and ICRP provide the background for the DOE requirements and in some cases provide additional guidance.

The recommendations of the FRC were transmitted in the federal guidance (25 FR 4402) approved by President Eisenhower on May 13, 1960 (FRC 1960). The FRC recommended a Radiation Protection Guide that included a dose equivalent limit of 75 rem/yr (25 rem/quarter) to the hands and forearms, feet and ankles.

The NCRP Report 39 (NCRP 1971) recommends as a guideline the same dose equivalent rates as in the DOE order: a maximum permissible dose equivalent of 75 rem/yr to the hands (with less than 25 rem/quarter) and 30 rem/yr to the forearms (with less than 10 rem/quarter). The NCRP recommends that personnel monitoring shall be performed for each occupationally exposed individual for whom there is a reasonable possibility of receiving a dose equivalent exceeding one quarter of the applicable maximum permissible dose equivalent. The report also states:

The significant area for skin irradiations can reasonably vary with the nature of the exposure. External radiation of low penetration could reasonably be averaged over a 1 cm^2 area Where actual sensitive manipulation ... can be proved necessary, the dose might logically be averaged over the fingers (NCRP 1971).

The ICRP Publication 9 (ICRP 1966) has been superseded by ICRP 26; however, a review of the recommendations in ICRP 9 is provided for information and to give a historical perspective. ICRP Publication 9 recommends a maximum permissible dose equivalent of 75 rem/yr for hands and forearms, feet and ankles. A maximum permissible dose equivalent of 30 rem/yr is recommended for the skin. In a period of a quarter of a year, up to 1/2 of the annual maximum permissible dose equivalent may be accumulated. Individual monitoring of workers is recommended for work conditions where the exposure is likely to exceed 30% of the annual maximum permissible dose. Publication 9 further states that for external exposure of the skin, especially when the distance to the source is very short or when the exposed area is very small, it would not be appropriate to average the dose over the entire surface of the skin. They recommend instead that the dose be averaged over an area of 1 cm^2 in the region receiving the highest dose. However, they state that with very narrow beams of extremely high intensity, such as those used in x-ray analysis, the averaged dose may be misleading and protection measures should be based on qualitative considerations.

In 1977 the ICRP published new recommendations on radiation protection and new limits for occupational exposure. The new recommendations in Publication 26 (ICRP 1977) include a dose equivalent limit for nonstochastic effects of 50 rem/yr for all tissues except the lens of the eye. For stochastic effects, the effective dose equivalent for irradiation of the whole body is defined as the sum of the product of the annual dose equivalent in each tissue and the corresponding weighting factor. The effective dose equivalent is limited to 5 rem/yr. The ICRP did not intend that the hands, forearms, feet, ankles and skin be included in the calculation of the stochastic dose equivalent for whole-body dose (ICRP 1978), so the 50 rem/yr limit for nonstochastic effects applies to the extremities. For the skin, the ICRP recommends the use of a range of 50-100 μm (5-10 mg/cm^2) for specifying the depth of the sensitive layer of the skin (ICRP 1977). A depth of 70 μm was chosen as a reasonable mean value.

The Administrator of the EPA, in cooperation with other federal agencies and national councils, is in the process of updating the previous guidance, written by the FRC (1960), for the protection of workers exposed to ionizing

radiation. The new guidance by the EPA is based in part on recommendations of national and international organizations, on proposed "Federal Radiation Protection Guidance for Occupational Exposure" published January 23, 1981 (46 FR 7836), on the guidance of an interagency ad hoc committee, and on public comments about the proposed federal radiation protection guidance. The EPA guidance forms the basis for the draft of the proposed DOE Order 5480.1, Chapter XI, "Requirements for Radiation Protection," which was described earlier.

EXTREMITY DOSIMETER DESIGN AND CALIBRATION

Several varieties of extremity dosimeter systems are available. The theoretical properties of an ideal extremity dosimeter system is compared to the properties of a commonly used extremity dosimeter system in Table 1. The characteristics of the commonly used, extremity dosimetry system do not reflect the many improvements found in dosimeters which are currently being developed. As Table 1 illustrates, there are many areas where the currently-used extremity dosimeter system given in the example falls short of the ideal dosimetry system.

Although an ideal extremity dosimeter system does not exist, a properly designed dosimeter is essential for determining the correct dose to the extremities. This involves using the correct type of material to measure the desired radiation. The dosimeter must be constructed to resist damage and prevent contamination and must be calibrated properly.

Dosimeter Material

Extremity dosimeters may be used to measure beta-gamma and/or neutron radiations. The design of the dosimeter is determined by the type of radiation to be measured.

Beta-Gamma Dosimeters

Extremity dosimeters used to measure beta-gamma radiation contain either thermoluminescent (TL) material or photographic film. The physical principles differ for each type of sensitive material. The form of the radiosensitive materials also vary.

TABLE 1. Comparison of an Ideal Extremity Dosimeter System
with an Available Extremity Dosimeter System

Property	Ideal Dosimeter System	An Available Dosimeter System (Finger Rings)
Uniform sensitivity	Dosimeter has 4π sensitivity - dosimeter reading is not affected by directional or spatial changes within a radiation field.	Dosimeter does not have 4π sensitivity - dosimeter reading is affected by directional or spatial changes within a radiation field.
Beta, gamma, and neutron sensitivity	Able to measure beta, gamma, and neutron radiations of all energies.	Responds low to Sr-90, Kr-85 beta sources, sensitive to Cs-137, and overresponds to 16 keV to 200 keV x-rays. Relatively insensitive to neutrons.
Environmental insensitivity	Dosimeter response is unaffected by adverse temperature or humidity.	Dosimeter response is unaffected at 100% relative humidity for 1 week; temperature range from 10°F to 100°F.
Low energy insensitivity	Protects against lost, induced, or modified signal when dosimeter is exposed to very low-energy x-ray, ultraviolet, visible, infrared, or microwave and radio-frequency radiations.	Insensitive to microwave radiation; others unknown.
Unintended-radiation insensitivity	Insensitive to all radiation while not being worn to monitor occupational exposure.	Sensitive to radiation while not being worn to monitor occupational exposure.
Self-irradiation protection	Components of the dosimeter should not be radioactive.	Components of the dosimeter are not radioactive.
Energy response	Determines correct dose over wide energy range.	Dosimeter response is flat from 100 keV to 1250 keV; moderate overresponse at photon energies below about 100 keV; typically responds low to beta radiation.
Linear dose/response relationship	Dosimeter should be able to be fully calibrated over entire dose range when the dose/response relationship is accurately determined at just one dose.	Linear over entire working range.
Response/dose-rate independent	Response should be independent of dose rate.	Response is independent of dose rate.
Low detection threshold	Low minimum dose detection point.	10 mR under laboratory conditions.
Wide measurement range	Wide range capability of dosimeter.	Covers a wide range.

TABLE 1. (contd)

<u>Property</u>	<u>Ideal Dosimeter System</u>	<u>An Available Dosimeter System (Finger Rings)</u>
Precise dose calculability	Dosimeter should be designed so that the dose is determined at the correct depth in tissue on the extremity.	Dose is measured between 25 mg/cm ² and 225 mg/cm ² . Thereby underestimating dose to basal cell layer.
Efficient physical design	Comfortable to wear (small, lightweight, no interference with the workers activities), easy to attach and remove, but will not slip or fall off during regular use.	Flexible plastic finger ring containing a single TLD chip. Can only be used on base of finger. Reportedly may fall off during use.
Contamination protection	Protected against contamination that could contribute to the radiation-induced signal.	Contamination problems have been reported.
Element accessibility	The sensitive element should be readily accessible to authorized personnel for ease of disassembly and for rapid processing.	The sensitive element is readily accessible for ease of disassembly and for rapid processing.
Proper labeling	The identification label should be protected, visible and easy to attach and remove.	The identification label is wrapped around the TLD chamber. It is unprotected.
Manufacture	Should be capable of being uniformly mass produced at a low cost.	Dosimeter is available at a reasonable cost.
Repeatability	Dosimeter should yield the same reading between successive evaluations under the same conditions.	Adequate.
Batch homogeneity	The results obtained from different batches of dosimeters exposed and analyzed under the same conditions should be the same.	Adequate.
Remanence	Residual information retained after dosimeter has been reset to zero.	Residual information is in some circumstances retained after dosimeter has been reset to zero.
Minimal fading	Stability of dosimeter over long time periods.	Dosimeter is stable over long periods of time.

Thermoluminescent Dosimeters. Thermoluminescent dosimeters (TLDs) are composed of inorganic crystals that contain a high concentration of impurities or defects (Knoll 1979). The thermoluminescent material used most commonly is lithium fluoride with a thulium activator. Other types of TL material (phosphors) contain impurities that have been added as activators: $\text{CaSO}_4\text{:Mn}$, $\text{Li}_2\text{B}_4\text{O}_7\text{:Mn}$ and $\text{CaF}_2\text{:Mn}$ contain manganese as the activator; $\text{MgB}_4\text{O}_7\text{:Dy}$ and $\text{CaSO}_4\text{:Dy}$ contain dysprosium as the activator.

The physical form of the TL phosphors varies (Cameron, Suntharalingam, and Kenney 1968). Loose powder can be used in various shapes or evenly spread over a surface. The powder may be mixed with teflon or embedded in carbon. It may be heated and extruded through dies to form rods or chips or be hot pressed into chips.

The characteristics of the TL phosphors vary. The most important characteristics include the sensitivity of the phosphor (the amount of light released by the phosphor per unit of radiation exposure), the shape of the dose response curve, the energy responses and the stability (the tendency to resist fading at ambient temperatures). Ideally, the dose response curve would be linear over the useful exposure range (to simplify calibration and use), and the phosphor would show little change in its response per roentgen between photon energies. Phosphors with good stability show insignificant loss of thermoluminescence at room temperature. Comparisons of the characteristics of various types of TL phosphors can be found in Cameron, Suntharalingam, and Kenney (1968), McKinlay (1981), and Becker (1973).

The measurement of the absorbed dose to the skin from low-energy beta particles is complicated. Because of the shallower penetration of beta radiation, the material above the dosimeter, which protects it from light and contamination, must be thin enough for the beta radiation to reach the TL material. The thickness of the dosimeter material is also critical. The American National Standards Institute specifies a depth of 5 to 10 mg/cm^2 for the measurement of nonpenetrating or shallow dose and a depth of 1000 mg/cm^2 for the measurement of the penetrating or deep dose (ANSI 1983). The International Commission on Radiation Units and Measurements recommends a depth of 0.07 mm (7 mg/cm^2) for the calculation of the individual dose equivalent, superficial, resulting from weakly penetrating radiation and 10 mm (1000 mg/cm^2) for the calculation of the individual dose equivalent, penetrating, resulting from

strongly penetrating radiation (ICRU 1985). Thus, the use of dosimeters thicker than 5 to 10 mg/cm² results in an underestimate of the absorbed dose resulting from beta irradiation.

The TLD chips are commonly manufactured with a thickness of 0.89 mm (235 mg/cm²). The thickness of the window or covering over the TL material is commonly more than 5 mg/cm² and often as much as 100 mg/cm² depending on the design of the dosimeter. A 235-mg/cm² thick dosimeter with a 10-mg/cm² beta window essentially averages the dose between 10 and 245 mg/cm². Thus, most available dosimeters will underestimate the skin dose unless properly calibrated.

The sensitivity of TLDs to low-energy beta-ray emitters can be improved by a variety of methods. The thickness of the dosimeter can be reduced. The thinner dosimeters, however, are difficult to produce and are easily damaged and broken. Thermoluminescent material, such as LiF, may be embedded in a thin teflon matrix (8.9 mg/cm²) resulting in a dosimeter that is thin and resistant to damage (Marshall and Docherty 1971).

Kansas State University under contract to Pacific Northwest Laboratory has improved the sensitivity to low-energy beta-ray emitters by developing a beta dosimeter composed of thin LiF (13 mg/cm²) TLD wafers that are glued to a graphite backing. The TLD wafers measure the skin dose while the nearly tissue-equivalent graphite supports the fragile wafers. The overall size of the dosimeter is about the same as a standard commercial TLD chip (Swinth et al. 1985).

Another approach consists of loading the dosimeters with graphite, which absorbs the TL signal from deep inside the dosimeter during readout; thus the dosimeter reads only the TL signal from the surface layer. These dosimeters are the standard thickness but have some of the properties of thinner dosimeters. Unfortunately, the interpretation of dose is not as straightforward as it is for the transparent dosimeters because for the graphite-loaded dosimeter the luminescence presumably attenuates exponentially in relation to the depth of the dosimeter (Gesell et al. 1979).

Dosimeters may also be made by diffusing boron into LiF to a depth of 1 to 2 mg/cm². The upper section of the dosimeter, which contains the boron,

releases photons at a higher characteristic temperature (290°C) than the section without boron. Thus the photons released at 185°C are in response to irradiation of the entire dosimeter while the photons released at 290°C are indicative of the amount of surface radiation. This type of dosimeter is not yet commercially available (Gesell et al. 1979).

Multi-element dosimeters can also be used to measure the nonpenetrating exposure. One TLD is placed behind a filter, such as a cadmium filter, which shields it from low-energy radiations. A second TLD is not shielded. The difference in the readings of the two dosimeters is due to the nonpenetrating radiation (Cameron, Suntharalingam, and Kenney 1968).

Film Dosimeters. The response of film dosimeters to radiation is measured by the degree of ionization-induced darkening in the film emulsion. A wide variety of film types and grades are available. The limits of detection of film range from about 1 mR to more than 1000 R. Filters made of different materials of variable thicknesses can be used to differentiate various components of the radiation exposure.

The disadvantages of using film include unavoidable darkening that occurs even in the absence of ionizations from background radiation; the necessity of wrapping the film to avoid light leaks, which lowers its sensitivity to beta radiation; and the higher average atomic number of most emulsions, which causes photographic film to overestimate exposure from lower energy x-rays (Gesell et al. 1979). Other disadvantages include problems that may arise during the development of the film.

Neutron Dosimeters

The neutron dose is of great importance in glovebox operations involving kilogram quantities of plutonium (Faust et al. 1977). The only type of dosimeter reported in the survey as being used to measure neutron dose to extremities at DOE/DOE contractor facilities is the TLD-albedo dosimeter. Other types of neutron dosimeters, such as track-etch and film dosimeters, are more commonly used to monitor whole-body exposures than extremity exposures and so are not discussed here. Even though the TLD-albedo dosimeter is used for an extremity dosimeter, it was designed for use as a whole-body dosimeter and it has not been shown to be an effective extremity dosimeter.

The TLD-albedo dosimeter contains both ^6LiF and ^7LiF components. The ^7LiF component is gamma sensitive but is insensitive to neutrons. The ^6LiF component is both neutron and gamma sensitive; however, it is most sensitive to slow neutrons. The TLD-albedo dosimeter uses the moderating and backscattering effect of the human body to measure the dose from fast neutrons (Becker 1973). The ^6LiF component of the dosimeter is heavily shielded on the side opposite the body so that it will measure the slow neutron field near the surface of the person exposed to intermediate or fast neutrons. Because ^6LiF also measures the gamma field, the ^7LiF component is used to determine how much of the response is caused by gamma radiation.

The TLD-albedo dosimeter responds to all neutron energies; however, the response decreases rapidly for neutron energies greater than 1 keV. Knowledge of the neutron energy spectra is required to interpret the dosimeter results. The dosimeter is angularly dependent and is sensitive to even minor variations in the detector-body distance.

Physical Design of Extremity Dosimeters

Extremity dosimeters are usually designed to be placed on the wrist or the base of the finger, or to be taped to the fingertip or to the palm. The particular design varies among facilities and depends somewhat on the task being performed. The commercially available wrist dosimeters are attached to a watch-type band that is strapped to the wrist. These dosimeters generally have a design similar to whole-body dosimeters. Ring dosimeters are usually constructed of plastic and can be placed on the finger. The design varies among commercial vendors and also among DOE contractor facilities, who often use finger rings of their own design. Thermoluminescent material in the form of chips or powder is placed in the ring and covered with a thin shield to protect the dosimeter from contamination. The thicknesses of the TL material and the cover vary.

Thin, flexible dosimeters that can be placed on the tip of the finger or on the palm of the hand are also available. These dosimeters may be composed of a thin mixture of graphite and TL material or of a powder that is heat-sealed inside the dosimeter.

Extremity dosimeters should be designed so that they will not interfere with the dexterity of the wearer and will not slip or fall off. Because many facilities do not change extremity dosimeters daily, dosimeters should be durable enough to last between changes. The length of time between dosimeter changes may be as long as a month, and three months is not uncommon. Wrist dosimeters are generally less subject to mechanical and heat damage than finger ring dosimeters (Smith et al. 1980). If the situation requires that the dose be measured to the finger tips, the palm, or any atypical location, special efforts would have to be made to prevent the dosimeter from being an inconvenience to the worker. Sharp edges on the dosimeter holder must be avoided since they might puncture plastic gloves, creating the potential for contaminating the worker and the dosimeter.

Contamination of the dosimeter may occur when the dosimeter is not tightly sealed within its holder. Radioactive contamination of the dosimeter element is not as frequent when plastic gloves are worn over the dosimeter (this is common practice for plutonium glovebox work). The glove powder or sweat from the hands, however, may contaminate a dosimeter that is not tightly sealed. If the dosimeter is contaminated, the readings from the dosimeter may be in error (Fix et al. 1981).

Calibration

Proper calibration of the dosimeter is required to relate dosimeter response to dose. Errors can result from variations in energy, the angular response of the dosimeter, and the size and shape of the source. Proper calibration for neutron and beta radiations is particularly important because of the effects of the energy spectra.

Accurate neutron dosimetry is difficult because of the wide range of neutron energies that must be measured and the wide range of linear energy transfers associated with neutron irradiations (Brackenbush et al. 1980). If a TLD-albedo dosimeter is calibrated with a ^{252}Cf source, it can overestimate the dose equivalent by as much as a factor of 20 when exposed near a nuclear reactor that exhibits low-energy neutron spectra (McDonald et al. 1983).

Proper calibration of beta dosimeters is also particularly important. The resulting measurement may be incorrect if the energy of the beta field

encountered in the work environment is markedly different from the energy of the beta radiation used for the calibration source (Gesell et al. 1979). Inadequacies in beta dosimetry were demonstrated in a study of the accuracies of beta radiation measurements at NRC-licensed facilities (Rathbun et al. 1984). The response of commercial dosimeters was studied using known beta fields. As part of this study, both calibration sources and beta fields characterized with spectrometers were used to study the response of commercial dosimeters. Table 2 indicates that the dosimeter responses were highly variable. In some cases, the dosimeter did not respond at all to a given source, in other cases the dosimeter overresponded by a factor of 3.5.

TABLE 2. Commercial Dosimeter Responses to Beta Calibration Sources^(a)

PNL Beta Source	Beta Exposure (mrad)	Dosimeter (mrad)								
		A	B	C	D	E	F	G	H	I
U slab	100	63	ND ^(b)	31	34	5	0	0	ND	ND
U slab	300	112	95	106	108	50	0	105	ND	90
U slab	500	ND	ND	ND	ND	ND	ND	ND	ND	152
U slab	675	234	232	198	212	160	0	0	ND	ND
U slab	4000	1487	1430	1295	1350	1040	60	55	ND	ND
⁹⁰ Sr	2000	ND	1934	ND	1057	1345	152	150	7050	0
⁹⁰ Sr	1000	901	ND	604	ND	ND	ND	ND	ND	ND
⁹⁰ Sr	500	605	327	ND	ND	ND	ND	ND	ND	ND
²⁰⁴ Tl	1000	1000	632	284	116	205	ND	ND	2400	ND
²⁰⁴ Tl	500	694	336	ND	ND	ND	ND	ND	ND	3
²⁴⁷ Pm	250	54	396	5.5	6.5	60	0	0	95	12

(a) From Rathbun et al. 1984.

(b) ND = no dosimeter exposed.

DOSIMETER PLACEMENT

The proper placement of the dosimeter on the extremities is a major factor in correctly determining the dose. The proper placement of extremity dosimeters is based on the definition of what constitutes an extremity and on the location of the critical tissue. The placement of extremity dosimeters is complicated by the various definitions for the location of the extremities that are given by the federal agencies or the national and international commissions. As explained earlier, the DOE requirements allow for a higher annual dose to be received by the hands, feet and forearms than by the whole body (DOE

1981). The FRC (1960) and the ICRP (1977) include the hands, forearms, feet and ankles in the higher dose limit. The NCRP (1971) mentions only the hands and forearms.

Not only is the proper placement of the dosimeter based on the definition of the extremities, but it is also based on the location at which the dose should be estimated. Current practices tend toward placement of a dosimeter on the wrist or on the base of the finger. Reece et al. (1985) suggested that the dose should be evaluated at the point of the highest exposure, which is often the tip of the fingers during the handling of compact sources. Placement of the dosimeter at locations such as the tip of the finger may interfere with worker dexterity. However, in some cases, the use of ratios to evaluate the dose may not be a prudent choice due to large variations which may occur between the dose at the point of highest exposure and the dose at the wrist or base of the finger. The ratios may vary considerably between specific jobs. For example, Reece et al. (1985) reported that for workers handling uranium oxide pellets, the dose to the finger tips on the same hand may vary by a factor of 50 or more.

The correct position for the placement of extremity dosimeters is a particularly difficult problem for plutonium glovebox workers. These workers are exposed to three sources of radiation. The first is the dust that builds up in the glovebox as it is used, the second is the sources that are in the glovebox, and the third is the source handled by the worker. Dose rate measurements using an arm phantom indicate that the general dust layer on the gloves and the glovebox background can contribute more to the upper arm dose than a source of up to 2 kg $\text{PuO}_2\text{-UO}_2$ mixed oxide sample (5% PuO_2) placed at the palm of an arm phantom (Smith et al. 1980). Even with a relatively large PuO_2 source (1 kg of pure PuO_2), the dose rate decreases rapidly with distance until, at positions farther away than the elbow, the contribution from the source can be relatively small compared to the dose rates contributed by the layer of dust on the glove and in the glovebox. Based on the phantom measurements, the ratio of the dose to fingers to the dose at the inside of the wrist was less than a factor of two. This corresponded to data collected from analytical laboratory workers handling small samples of plutonium (Smith et al. 1980). During a three-month period, many workers showed dose ratios between

the finger ring position and the inner wrist of less than two. Current DOE regulations limit the forearm dose equivalent to 30 rem/yr (10 rem/calendar quarter) which is 40% of the maximum dose equivalent allowed for the hands (75 rem/yr; 25 rem/calendar quarter). Because the ratio of the wrist dose to the fingers may fall below 40%, the forearm (which includes the wrist) rather than the fingers may be the limiting location for extremity exposure control for plutonium glovebox workers.

DOSE ASSESSMENT

Dose assessment involves the evaluation of the extremity dose at the proper depth and over the proper area, the correct assignment of the dose when multiple dosimeters are used, and the use of appropriate quality factors for the calculation of dose equivalent.

Dosimeters should be designed to measure the dose at the same depth as the critical tissues. As discussed earlier, this involves using TL material of the proper thickness and using an appropriate amount of filter or shielding. Unfortunately, confusion exists as to the proper depth for measurement of the dose received by the extremities. Even the tissue at risk (the critical tissue) is not defined. Some authors (Reece et al. 1985) define the critical tissue for monitoring of the extremities as the basal cell layer of the skin. This view is based on the risk associated with each of the tissues contained in the extremity. The NCRP in NBS Handbook 59 (NBS 1954) concludes that even under conditions where the absorbed dose in the bones of the hands was considerably larger than in the skin, the skin is the critical tissue because of the "danger of eventual cancer formation." It was also concluded that the skin is the critical tissue in cases where the radiation is of such low penetrating power that it is almost entirely absorbed by the skin.

Publication 26 (ICRP 1977) indicates that the sensitive layer of the skin should be considered at a depth between 50-100 μm (5-10 mg/cm^2) with 70 μm (7 mg/cm^2) as a reasonable mean value. To measure the absorbed dose at this depth, a dosimeter 5 mg/cm^2 thick with a covering of 5 mg/cm^2 would be required. However, other researchers indicate that the depth of the sensitive cells in the basal layer of the skin varies with different locations on the

body. Whitton (1973) reports that the average epidermal thickness of the head, trunk, upper arm and leg is $40\text{ }\mu\text{m}$ (4 mg/cm^2), and for the palm of the hand and the sole of the foot, it is $400\text{ }\mu\text{m}$ (40 mg/cm^2). The remaining body sites average $80\text{ }\mu\text{m}$ (8 mg/cm^2).

The most popular commercially available LiF dosimeter chip has a thickness of 235 mg/cm^2 . The thickness of the window, or the covering over the TL material, is more than 5 mg/cm^2 and is often as much as 100 mg/cm^2 depending on the design of the ring. Small amounts of shielding or absorbers may cause wide variations or changes in the assessment of dose to a sensitive region of tissue. A thick chip may lead to an underestimate of the dose to the basal cell layer of the skin depending on the energy of radiation being measured. A thick covering will lead to an underestimate of the dose by attenuating lower energy photons. Plutonium glovebox operations are especially a problem because the plutonium emits primarily low-energy x-rays and the decay product, americium, emits low-energy x-rays and 60-keV gammas. This problem can be corrected with proper calibration of the dosimeter. However, interpretation of the results is complicated for mixed radiation fields (for example, plutonium mixed with fission products).

The assignment of dose received in a nonuniform radiation field may vary depending on the area over which it is measured. Both the NCRP (1971) and the ICRP (1966) indicated that in certain cases (for instance, with external radiation of low penetration or where the distance to the source is short or the exposed area is small) it is appropriate to average the dose over a 1 cm^2 area. The ICRP (1966) adds that this 1 cm^2 should be in the region receiving the highest dose. The NCRP (1971) indicated that where manipulation of the source by the fingers is shown to be necessary, the dose might logically be averaged over the fingers.

When multiple dosimeters are used to assess the dose, a decision must be made whether to average the readings, use the highest of the dosimeter readings or use a more complicated procedure. This can be a problem in situations such as working in a plutonium glovebox or handling compact sources. As mentioned earlier, the dose may vary considerably at different locations on the extremity.

The assessment of the dose equivalent from neutron radiation is possibly the least defined aspect of extremity dose assessment. The TLD-albedo technique of measuring neutron dose equivalent to the whole body cannot be applied directly to the extremities. Additional calibration is required because of the smaller size of the extremities. The angular dependence of the TL-albedo dosimeter is also a problem. The dosimeters must be calibrated to the angle of incidence for the neutrons. This poses a definite problem for extremity dosimetry where the source is frequently held and manipulated by the hand.

The quality factors used to calculate neutron dose equivalent apply to the whole body and are defined in terms of linear energy transfer as defined in NCRP 39 (NCRP 1971). Effective quality factors for neutrons are calculated as a function of incident neutron energy using Monte Carlo computer calculations. The use of the quality factors calculated for the torso in calculating the dose equivalent to the extremities is questionable. To further complicate matters, the scientific community is reviewing the appropriateness of quality factors such as those listed in Chapter XI of DOE Order 5480.1 and their use for whole-body dose calculations. The ICRP (1985) recommends a factor of two increase in the quality factor for fast neutrons. This changes the quality factor, Q , recommended for calculation of neutron dose equivalent to the whole body from 10 to 20 for fast neutrons.

SURVEY RESULTS

As part of an effort to evaluate extremity dosimetry, information was obtained from a questionnaire that had been distributed to DOE/DOE contractor facilities. The purpose of the questionnaire was to determine the general characteristics of beta dosimetry at these facilities. However, a section of the questionnaire addressed special dosimetry practices including extremity dosimetry. A later informal telephone survey was conducted as a followup to answer a few additional questions regarding extremity dosimetry practices. The results of the extremity monitoring and dosimetry section of the questionnaire and the results of the telephone survey are discussed here.

Twenty-nine facilities returned the initial questionnaire. A list of the facilities is found in Appendix A. The facilities included uranium enrichment, fuel fabrication and fuel processing plants, weapons fabrication sites, research laboratories, accelerators and reactors. Four of the facilities indicated that they did not have an extremity dosimetry program. Two of those added that their facilities did not require extremity monitoring because of the low potential for exposure. The responses (which are not identified by facility) of the remaining 25 respondents are tabulated in Appendix B.

The telephone survey was an effort to gather more information from the 25 respondents from the original questionnaire who had indicated that they had an extremity dosimetry program. Twenty-four facilities were actually reached. Four of these facilities indicated that their extremity dosimetry programs were extremely small or had been terminated because they were found to be unnecessary. The responses of the remaining 20 facilities are found in Appendix C.

The specific areas covered in the questionnaire and telephone survey include:

- definitions used in dose assessment
- identification of the personnel who are extremity monitored
- types of extremity dosimeters and their use
- dose assessment and recordkeeping practices
- extremity dose and ALARA practices
- specific problems associated with extremity monitoring.

DEFINITIONS USED IN DOSE ASSESSMENT

A facility's idea as to what body parts are to be measured for extremity monitoring and at what depth the dose is to be assessed is important to understanding that facility's extremity dosimetry practices. This information can be partially obtained from the definition each facility uses for the location of the extremity and the definition of penetrating versus nonpenetrating radiations.

DOE Order 5480.1, Chapter XI, currently defines the extremities as "hands, forearms, feet, and ankles." One of the survey respondents defined the extremities (Table 3) as "hands, forearms, feet, and ankles," two respondents included at least part of the leg above the ankle, and two respondents just included the "hands, forearms, and feet." Eight facilities responded with definitions of "hands and feet," five with "hands and forearms," and four with simply "hands." The remaining two facilities defined extremities as "other than whole body." The only consensus among the facilities seems to be that extremities include body parts other than the head or trunk.

Six respondents indicated their extremity dosimeters discriminate between penetrating and nonpenetrating radiations. These respondents were asked for the definition they used for penetrating versus nonpenetrating radiation as applied to extremity dosimetry. Two of these used the definition given in

TABLE 3. Definition of Extremity

<u>Definition</u>	<u>Number of Facilities</u>
Hands, forearms, feet, ankles	1
Hands, forearms, feet, leg below the knee	2
Hands, forearms, feet	2
Hands, feet	8
Hands, forearms	5
Hands	4
Other than whole body	2
No response	<u>1</u>
TOTAL	25

ANSI N13.11 (1983) for nonpenetrating or shallow dose at a depth of 5 to 10 mg/cm² and for penetrating or deep dose at a depth of 1000 mg/cm² or greater. One respondent defined nonpenetrating as radiation with a penetrating ability of less than or equal to 7 mg/cm². Another respondent estimated the nonpenetrating component of the extremity dose by subtracting the penetrating component of the whole-body dosimeter from the gross extremity dose. This technique assumes a constant ratio of penetrating to nonpenetrating radiation at varying distances from the source and is subject to considerable errors. One respondent stated that the nonpenetrating component was defined by the vendor. The final respondent was not clear on their method of defining penetrating versus nonpenetrating radiation.

EXTREMITY-MONITORED POPULATION

A list of the jobs for which workers were assigned extremity dosimeters is shown in Table 4. The jobs include equipment maintenance, x-ray diffraction, handling sealed sources, and radiochemistry; these were mentioned with nearly equal frequency. The list also includes work in gloveboxes and miscellaneous jobs.

As shown in Table 5, 3 of the 25 respondents reported that more than 10% of their personnel monitored for whole-body exposure were also monitored for extremity exposure.

Although DOE requires submittal of an annual summary report of whole-body exposure, a summary of extremity exposures is not required. During the telephone survey, the facilities were asked for the number of personnel monitored for extremity dose and the total number of radiation workers at the facility. The results are shown in Table 6. Some of the responses are approximations made by the facilities. The approximations are due to variations in the number of workers assigned extremity dosimeters each month and the nonavailability of precise facility records on extremity dosimetry at some of the facilities. Because only 20 facilities gave positive responses to this question, the number of workers monitored for whole-body dose in Table 6 represents a sample of the data found in the annual report to DOE which encompasses all DOE and DOE contractor employees. The information provided in Table 6, although obtained later, complements the information in Table 5.

TABLE 4. Jobs For Which Workers Are Assigned Extremity Dosimeters

	<u>Finger Monitoring</u>	<u>Forearm Monitoring</u>
Equipment maintenance	3	2
X-ray diffraction	2	2
Radiochemistry	3	0
Handling small sources	2	1
Glovebox	7	3
Miscellaneous	9	6

TABLE 5. Percentage of Workers Monitored for Whole-Body Exposure
Who are also Monitored for Extremity Exposure

<u>Percentage of Workers Monitored for Whole-Body and Extremity Exposure</u>	<u>Number of Facilities</u>
<1%	5
1%	2
2-5%	8
6-10%	5
11-15%	1
16-20%	0
21-25%	1
26-30%	1
No response	<u>2</u>
TOTAL	25

During the telephone survey we asked what criteria were used to determine when extremity monitoring is necessary. The answers are listed in Table 7. Several of the facilities used more than one criterion. Seven facilities routinely assigned dosimeters to all workers performing a specific type of job. Five facilities used the measured exposure rate or estimated the exposure from experience with similar jobs. The ratio of the dose to the hands and the dose to the whole body was used as the criterion at two facilities. These facilities used instrument measurements to determine the dose and assigned extremity

TABLE 6. Number of Workers Monitored for Extremity Dose^(a)

<u>Approximate Number of Workers Monitored for Extremity Dose</u>	<u>Approximate Number of Workers Monitored for Whole-Body Dose</u>
100	1,000
125	-
4-5	1,200
30	2,000
100-200	1,000-2,000
30-50	300-400
30	200
12	2,000
30-35	-
50-60	400
50	10,000
91	-
360	1,200
3-4	60
30	-
178	1,100
20	2,000
<hr/> 1,243-1,380	<hr/> 22,460-23,560

(a) Twenty facilities provided a response to this question although three of the facilities reported that these numbers were unknown or not available. The number of workers monitored for whole-body dose, as presented in this table, represents a sample of the data found in the annual report to DOE, which encompasses all DOE and DOE contractor employees.

dosimeters if the gradient exceeded a 5-to-1 or a 6-to-1 ratio. Nine facilities did not have specific criteria, but instead evaluated each operation separately to determine if extremity monitoring was necessary.

TYPES OF DOSIMETERS

Analysis of the survey responses initially indicated that the dose to the extremities and finger tips was assessed predominantly with "special dosimeters" as opposed to "routine dosimeters." However, some of the facilities use their extremity dosimeters routinely and refer to them as "routine dosimeters." Other facilities, which do not routinely measure extremity dose, refer to the

TABLE 7. Criteria Used to Determine When Extremity Monitoring is Necessary^(a)

Job Type - 7 facilities
Jobs Specified - Glovebox work
Nuclide handling
Plutonium work
Handling physically small beta-gamma sources with high dose rates, glovebox work
Handling sealed sources, plates, and collimators
Reactor component work
Undesignated
Exposure Level - 5 facilities
Levels Specified - 1.5 rem/quarter
25% of the quarterly limit
750 mrem
2.5 rem/quarter or 200 mrem/week
0.25 R/hr
Dose Gradient - 2 facilities
Gradient Specified - 5-to-1 ratio - hands to whole body
6-to-1 ratio - extremity to whole body
Each Job Evaluated Separately - 9 facilities
Unknown - 3 facilities
Not Applicable - no new applications - 1 facility

(a) Several facilities used more than one criteria.

dosimeters issued to measure extremity dose as "special dosimeters" and to whole-body dosimeters as "routinely used dosimeters." Still other facilities base their assessment of dose to the extremities on the whole-body ("routinely used") dosimeter measurement.

All facilities responding to the survey measured the beta-gamma exposure to fingers with 1- or 2-chip TLD-100 or -700 dosimeters. Beta exposures were measured with a 7- to 100-mg/cm² overlying attenuator. Ankle dosimeters contained 1- or 2-chip TLD-100 or -700 dosimeters. Wrist doses were measured using TLD-700 dosimeters, CaSO₄:Dy TLDs, or film.

Only four facilities attempt to measure neutron extremity exposure. Two of the facilities indicated they used TLD-600 dosimeters placed on fingers. They did not indicate whether they used TLD-700 dosimeters to estimate the dose from gamma radiation. The third facility indicated use of both TLD-600s and TLD-700s. One facility applied a multiplication factor obtained from survey instruments to the TLD-700 gamma dose.

About half of the facilities indicated they exchange extremity dosimeters after completing a job with significant exposure potential. The other half exchange extremity dosimeters biweekly, monthly, or quarterly.

Although there appeared to be a considerable amount of confusion regarding the definition of "accuracy" and "precision" of dosimeters, approximately 50% of the respondents believed both the accuracy and the precision of their extremity dosimeters were within $\pm 25\%$. Three facilities felt either the accuracy or the precision was greater than $\pm 25\%$ or that it was worker dependent. The remainder of the facilities either did not know or did not respond to the question.

DOSE ASSESSMENT AND RECORDKEEPING PRACTICES

Fourteen respondents distinguished between component parts of the extremity (i.e., hand, finger, foot, forearm, etc.) when recording dose to the extremity. Nine of these distinguished between left and right extremities. One of the respondents who did not distinguish between the component parts of the extremity did distinguish between right and left extremities.

When multiple dosimeters were used to monitor personnel in a nonuniform exposure field, nine respondents assessed the dose using the highest of the dosimeter readings and three used "professional judgment." One site took an average of the doses from the component parts. Twelve sites did not respond to this question.

Nineteen of the facilities questioned during the telephone survey indicated that they do not average the skin dose over a given area or over the entire hand or extremity. Instead, the reading from the extremity dosimeter is assigned to the entire hand. One facility multiplies the dose read off the wrist dosimeter by a factor of three and assigns that number to the extremity dose.

The four respondents who attempted to measure neutron dose used different quality factors for their assessments. Three of the facilities indicated that the quality factors were source/use dependent. The fourth facility used a quality factor of 10.

EXTREMITY DOSE AND ALARA PRACTICES

A report of extremity doses received by personnel at DOE facilities is not required (although this would be a requirement in a proposed revision to DOE Order 5480.1). Thus, the statistics indicating the range of extremity doses received at DOE facilities may not be readily available. During the telephone survey, the contractors were asked for the range of doses typically measured by their extremity dosimetry programs and the number of workers in each range. Most of the answers represent approximations made by the facilities because the exact numbers were not readily accessible. This, combined with variations in the annual extremity doses, resulted in broad ranges of doses. The information obtained is summarized in Tables 8 and 9.

Table 8 lists the maximum annual extremity dose recorded by each facility. The majority of facilities indicate a maximum dose below 15 rem/yr, although two facilities record a maximum dose in the 20-30 rem/yr range and one facility reported doses approaching the 75 rem annual limit.

The range of doses is shown in Table 9. Many of the facilities reported that the doses were below a specific number. The majority are below 15 rem/yr.

The facilities were asked if they had personnel whose annual dose was limited by their extremity exposure rather than their whole-body exposure. Thirteen facilities indicated that they did not. Seven facilities indicated

TABLE 8. Maximum Annual Extremity Dose

<u>Maximum Annual Dose (rem)</u>	<u>Number of Facilities</u>
<1	3
1-5	6
5-10	1
10-15	5
15-20	-
20-30	2
30-40	-
40-60	-
60-75	1
No response	<u>2</u>
TOTAL	20

TABLE 9. Range of Extremity Dose^(a)

<u>Extremity Dose (rem) Ranges Reported by Facilities</u>	<u>Number of Dosimeters Receiving This Dose</u>
<1	408-435
<2	50-60
<2.5	20
3-4	6
<5	72
1-5	28
<5-6	50
1-10	20
<11	115
<12	90
<13 (ave. 3-4 rem)	100-200
10-14	4
5-15	54
12-15	1
11-22	10
25	1
15-50	78
>50	12

(a) Some of the entries in this table represent approximations given by the facilities; two of the 20 facilities gave no response.

that they did have workers whose extremity exposure was limiting. Several facilities indicated that the number of workers in this category did not remain constant from year to year. The estimates of the number of people whose extremity exposure was limiting ranged between 1 to 10 workers at each of these facilities.

The ALARA practices of each facility were addressed during the telephone survey. Nine facilities indicated that extremity records were periodically reviewed to determine trends and determine if action was required to reduce the doses to a lower level. Six facilities indicated that the dose rates were currently so low or that previous ALARA programs had been so effective in reducing extremity doses that this type of analysis was no longer necessary. One facility indicated that the answer depended on the specific job.

The facilities were also asked if they had an administrative investigation level or action level for extremity dose. Six facilities indicated that they

had no administrative action level. Eight facilities indicated that they did have such an action level. When asked to specify the action level, the answers ranged from 100 mrem/month to 30 rem/year as shown in Table 10. The number of workers exceeding this level ranged from zero to 10 per year depending on the facility.

TABLE 10. Administrative Action Levels for Extremity Dose

100 mrem/month
900 mrem/month
1500 mrem/month
5 rem/quarter
8.3 rem/quarter
30 rem/year
75 rem/year
Should not exceed whole-body ALARA goal by greater than a factor of 3

PERCEIVED PROBLEMS

The survey respondents expressed concern about several aspects of extremity dosimetry including the design and calibration of dosimeters, dosimeter placement and general use, and the methods for dose assessment.

The design of the dosimeter posed a special problem for the measurement of the nonpenetrating dose as did the methods used to calibrate for nonpenetrating dose. Other design problems mentioned include interference with the worker's dexterity and dislodging or loss of the dosimeter caused by sweating, movement and glove removal. Another problem related to dosimeter design was contamination of the dosimeter.

The survey respondents were concerned with the proper placement of the dosimeters including the directional response and the ratio between the dose equivalent to the wrist and to the hand. The major concern over dose assessment involved the lack of guidance regarding the critical area for dose assessment and the difficulties of determining the dose equivalent from neutron irradiation, especially in regard to quality factors and energy dependence.

CONCLUSIONS AND RECOMMENDATIONS

The survey findings indicated that the doses received by the personnel at DOE facilities are below the DOE regulatory limits. However, the accuracy of the dose measurements is questionable. Large variations may occur between the dose at the point of highest exposure and the measured dose at locations such as the wrist or base of the finger as indicated in the background information section. In addition, dosimeter responses to beta and low-energy photon radiations are commonly underestimated and little study has been done on the problems of evaluating neutron dose to the extremities.

The recommendations provided in this section result from the survey findings as well as the background information, which is based on operational experience and a review of the current literature (including standards and recommendations).

The recommendations include the development and adoption of standards and codes of good practices to provide guidance for extremity dosimetry. Definitions should be standardized including the critical site for dose equivalent measurement and the depth at which the dose should be measured. Further guidance should explain the proper placement and use of the extremity dosimeters. This is especially needed for certain glovebox workers.

Guidance should also be provided on the design and calibration of an optimal extremity dosimeter. Improved dosimeters are especially needed for measuring nonpenetrating radiation and neutron radiation. An appropriate dosimeter material and beta window thickness should be identified for beta extremity dosimeters. Advanced options in neutron dosimetry should be explored, especially as they relate to extremity dosimetry. The calibration of extremity dosimeters could be improved by a laboratory accreditation program such as the DOE Laboratory Accreditation Program (DOELAP).

Written guidance should address the methods of assessing the dose to the extremities. This includes methods of determining the area over which the extremity dose should be averaged and methods of determining dose when multiple extremity dosimeters are used. Methods of assessing the dose resulting from

neutron irradiation of the extremities should be included, especially in relation to quality factors and energy dependence.

It is apparent from problems identified by the respondents that assistance is both needed and desired. The answers to the survey also indicated that some aspects of extremity dosimetry were not well understood. Symposia, workshops, and intercomparison studies could educate responsible individuals and enhance extremity dosimetry techniques and practices.

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APPENDIX A

DOE/DOE CONTRACTOR FACILITIES INCLUDED IN THE STUDY

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DOE/DOE CONTRACTOR FACILITIES INCLUDED IN THE STUDY

<u>Facility</u>	<u>Location</u>
Argonne National Laboratory - Argonne	Argonne, Illinois
Argonne National Laboratory - West	Idaho Falls, Idaho
Brookhaven National Laboratory	Upton, New York
EG&G Idaho Inc.	Idaho Falls, Idaho
EXXON Nuclear Idaho Co., Inc.	Idaho Falls, Idaho
Goodyear Atomic Corporation	Piketon, Ohio
Fermi National Acceleration Laboratory	Batavia, Illinois
Inhalation Toxicology Research Institute	Albuquerque, New Mexico
Lawrence Berkeley Laboratory	Berkeley, California
Lawrence Livermore National Laboratory - Nevada Test Site	Mercury, Nevada
Los Alamos National Laboratory	Los Alamos, New Mexico
Mound Laboratory	Miamisburg, Ohio
NLO, Inc., Feed Materials Production Center	Cincinnati, Ohio
Oak Ridge Gaseous Diffusion Plant	Oak Ridge, Tennessee
Oak Ridge Y-12 Plant	Oak Ridge, Tennessee
Pacific Northwest Laboratory	Richland, Washington
Paducah Gaseous Diffusion Plant	Paducah, Kentucky
Pinellas Plant	St. Petersburg, Florida
Princeton Plasma Physics Laboratory	Princeton, New Jersey
Reynolds Electrical and Engineering Co. - Nevada Test Site	Las Vegas, Nevada
Rockwell Hanford Operations	Richland, Washington
Rocky Flats Plant	Golden, Colorado
Sandia National Laboratories - Albuquerque	Albuquerque, New Mexico
Sandia National Laboratories - Livermore	Livermore, California
UNC Nuclear Industries, Inc.	Richland, Washington
Union Carbide Corporation	Oak Ridge, Tennessee
United States Department of Energy Idaho Operations Office	Idaho Falls, Idaho
United States Department of Energy New Brunswick Laboratory	Argonne, Illinois
Westinghouse Hanford Company	Richland, Washington

APPENDIX B

EXTREMITY DDSIMETRY QUESTIONNAIRE RESPONSES

APPENDIX B

EXTREMITY DOSIMETRY SURVEY RESPONSES

1. How is "extremity" defined at your facility.

Hands, forearms, feet, ankles	1
Hands forearms, feet, leg below the knee	2
Hands, forearms, feet	2
Hands, feet	8
Hands, forearms	5
Hands	4
Other than whole body	2
No response	1

2. Do you distinguish between penetrating and nonpenetrating radiation?

Yes	6
No	18
No response	1

If yes, how do you define penetrating versus nonpenetrating radiation as it applies to extremity dosimetry?

ANSI N13.11

Penetrating $>1000 \text{ mg/cm}^2$; nonpenetrating $<5-10 \text{ mg/cm}^2$

Nonpenetrating $\leq 7 \text{ mg/cm}^2$

Subtract penetrating component of whole-body dosimeter from the gross extremity dose

Defined by vendor

Unclear

3. During what types of worker activities are you concerned with measuring the dose through special dosimeter placement?

	<u>Fingers</u>	<u>Forearms</u>	<u>Legs</u>	<u>Feet</u>	<u>Head</u>	<u>Lens of Eye</u>
Equipment maintenance	3	2	0	0	0	1
X-ray diffraction	2	2	0	0	1	2
Radiochemistry	3	0	0	0	0	0
Handling small sources	2	1	0	0	0	0
Glovebox	7	3	0	0	1	1
Miscellaneous	9	6	4	4	6	6

4. What percentage of your workers monitored for whole-body exposure are also monitored for extremity exposure?

<1%	5
1%	2
2-5%	8
6-10%	5
11-15%	1
16-20%	0
21-25%	1
26-30%	1
No response	2

5. For what percent of your workers is the extremity exposure rather than the whole-body exposure limiting in control of occupational exposure?

0	18
<1%	3
1%	1
No response	
or unknown	3

6. How do you assess the dose to:

	<u>Routinely Used Dosimeter</u>	<u>Special Dosimeter</u>
lens of the eye?	8	7
fingertips?	3	15
extremities?	9	18
head?	4	11

7. For extremity dosimetry, which of the following radiation types are monitored:

alpha	0
beta	7
gamma	9
neutron	4
beta/gamma combined	18
no distinction made among radiation types	2

8. For each type of special dosimeter used to measure beta dose, please supply the following information:

Monitoring Location	Dosimeter Material	Beta Window Material	Beta Window Thickness mg/cm ²	No. of Chips
Finger	LiF	Paper & Al	25	1
	LiF	---	---	2
	TLD	Mylar	7	1
	TLD	Plastic	12.7	2
	TLD	Adhesive aluminum absorber	30	1
	TLD-100	Polyethylene	10	
	TLD-700	Plastic	10	2
	TLD-700	Plastic	10	2
	TLD-700	Plastic	10	2
	TLD-700	Plastic	10	2
	TLD-700	Mylar	10	1
	TLD-700	Al & plastic	14	1 or 2
	TLD-700	Al & plastic	14	1 or 2
	TLD-700	PVC	15	1
	TLD-700	Plastic	20-25	1
	TLD-700	Plastic	20-25	1
	TLD-700	Plastic	20-25	1
	TLD-700	Plastic	20-25	1
	TLD-700	Paper & mylar	33	2
	TLD-700	Al & plastic	67	2
	TLD-700	Plastic	102	1
Ankle	TLD	Adhesive	Unknown	1
	TLD-100	Mylar	10	1
	TLD-700	Plastic	26	2
	TLD-700	Plastic	26	2
Wrist	Film	Open	25	---
	Film	Film packet	---	---
	TLD	Adhesive	Unknown	1
	TLD-700	Heat-shrink plastic	25	1
	TLD-700	Plastic	26	2
	CaSO ₄ :Dy	Plastic	Unknown	3
	---	Mylar	7	3

9. For each type of special dosimeter used to measure neutron dose, please supply the following information:

Location	Material	No. of Chips	Quality Factor
Finger	TLD-600 & -700	2 each	Source dependent
	TLD-600	2	Determined for each use by spectrometry
	TLD-600	1	10
	TLD-700	2	Multiplication factor obtained from instrument surveys

10. How frequently are special dosimeters exchanged?

Quarterly	3
Monthly	10
Biweekly	1
Daily	1
Varies with job	9
No response	1

11. What are the accuracy and precision of your extremity dosimeter?

	<u>Accuracy</u>	<u>Precision</u>
±0-5%	4	0
±6-10%	4	4
±11-15%	1	5
±16-20%	3	4
±21-25%	1	1
±26-30%	0	1
±50%	1	0
Worker dependent	1	0
Undetermined	6	6
No response	4	4

12. When recording dose, do you distinguish between component parts of the extremity (i.e., hand, finger, foot, forearm, etc.)?

Yes	14
No	9
No response	2

If yes, do you distinguish between left and right extremity?

Yes	9 (includes one respondent who answered "no" above)
No	6

13. If you use multiple dosimeters to monitor personnel in a nonuniform exposure field, how is the dose assessed?

Average of the dose from the component parts	1
Record the highest dose	9
Other (specify) - <u>Professional evaluation</u>	3
No response or not applicable	12

14. What problems do you face in extremity/special dosimetry?^(a)

A. Significant problems in extremity dosimetry are of two types:

(a) The order of these response does not relate to the alphabetical list of facilities in Appendix A.

1. Lack of formal guidance as to acceptable dosimetry practices, such as in measuring neutron dose.
 2. Limitations of available dosimetry methods for extremity dosimetry, for example, using 235-mg/cm² TLD-700 chips to estimate 7-mg/cm² depth dose.
- B. Lack of a specified depth and area over which to measure extremity dose.
 - C. Lack of specified depth and area over which to measure extremity and/or skin dose.
 - D. Energy dependence and low-energy neutron sensitivity for neutron dosimetry.
 - E. Calibrations
 - F.
 - Placing extremity dosimeters on the extremities can be inhibiting to the workers.
 - Patch dosimeters can become dislodged due to movement of the extremity and sweating.
 - Finger rings can be removed during the removal of gloves, causing the ring to be lost.
 - Interpretation of results from single chip: impossible to separate nonpenetrating contribution from penetrating contribution.
 - G. Dosimeter contamination. Wear and tear: a dosimeter designed to measure absorbed dose at 7 mg/cm² depth would be too delicate to use in field operations.
 - H. Contamination of dosimeter.
 - I. Contamination
 - J.
 - Being able to actually determine the type of radiation to the desired extent so that a proper evaluation can be made is not always possible.
 - Funding constraints do not allow the desired dosimetry upgrading.
 - Funds limit the manpower such that assurance of a comprehensive dosimetry program is not possible.
 - K. Return of dosimeters to lab, hand-to-wrist ratio, proper use by personnel, and directional response.

- L. The major problem is accurately measuring neutron exposure to the hands. Measurement of beta exposure is not considered a problem, because we have few (if any) intense beta sources.
- M. At the present we have no problems; as we start to produce activated material requiring hands-on maintenance, we will have some of these problems. Also, we will use tritium with the potential for absorption or ingestion.

APPENDIX C

EXTREMITY DOSIMETRY FOLLOW-UP TELEPHONE SURVEY RESPONSES

APPENDIX C

EXTREMITY DOSIMETRY FOLLOW-UP TELEPHONE SURVEY RESPONSES

1. What criteria do you use to decide when extremity monitoring is necessary?
(Note: Several facilities used more than one criterion.)

Job Type - 7 facilities

Jobs Specified - Glovebox work
Nuclide handling
Plutonium work
Handling physically small beta-gamma sources
with high dose rates, glovebox work
Reactor component work
Handling sealed sources, plates, and collimators
Undesignated

Exposure Level - 5 facilities

Level Specified - 1.5 rem/quarter
25% of the quarterly limit
750 mrem
2.5 rem/quarter or 200 mrem/week
0.25 R/hr

Dose Gradient - 2 facilities

Gradient Specified - 5-to-1 ratio - hands to whole body
6-to-1 ratio - extremity to whole body

Each Job Evaluated Separately - 9 facilities

Unknown - 3 facilities

Not Applicable - no new applications - 1 facility

2. Area of skin over which extremity skin dose is averaged.

TLD reading assigned to entire extremity - 19 facilities

Other - 1 facility

Specify - Wrist TLD reading is multiplied by 3 and assigned to entire extremity

3. Number of workers monitored for extremity dose.

<u>Approximate Number of Workers Monitored for Extremity Dose</u>	<u>Approximate Number of Workers Monitored for Whole-Body Dose</u>
100	1,000
125	-
4-5	1,200
30	2,000
100-200	1,000-2,000
30-50	300-400
30	200
12	2,000
30-35	-
50-60	400
50	10,000
91	-
360	1,200
3-4	60
30	-
178	1,100
20	2,000
<u>1,243-1,380</u>	<u>22,460-23,560</u>

Unknown or not available: 3 facilities

4. Maximum annual extremity dose.

<u>Maximum Annual Dose (rem)</u>	<u>Number of Facilities</u>
<1	3
1-5	6
5-10	1
10-15	5
15-20	-
20-30	2
30-40	-
40-60	-
60-75	1
No response	2

5. Range of extremity dose^(a)

<u>Extremity Dose (rem) Ranges Reported by Facilities</u>	<u>Number of Dosimeters Receiving This Dose</u>
<1	408-435
<2	50-60
<2.5	20
3-4	6
<5	72
1-5	28
<5-6	50
1-10	20
<11	115
<12	90
<13 (ave. 3-4 rem)	100-200
10-14	4
5-15	54
12-15	1
11-22	10
25	1
15-50	78
50	12
No response	2

(a) Some of the entries in this table represent approximations given by the facilities.

6. Do you periodically review records to determine trends and determine what, if anything, may be done to lower doses, or are the doses generally so low that this type of analysis is unnecessary?

Reviewed - 9

Not reviewed - 6

Procedure varies with job - 1

No response - 4

7. Do you have an investigative level or an action level for extremity dose?

Yes - 8

Specify - 100 mrem/month

900 mrem/month

1500 mrem/month

5 rem/quarter

8.3 rem/quarter

30 rem/year

75 rem/year

Should not exceed whole-body ALARA

goal by greater than a factor of 3

No - 6
No response - 4
Uncertain - 2

If yes, how many workers fall below this level?

None - 3 facilities
A few - 1 facility
1 or 2 per year - 1 facility
10 - 1 facility
No response - 2 facilities

8. Do you have workers whose dose is limited by their extremity exposure rather than their whole-body exposure?

Yes - 7
No - 13

If yes, how many?

- 1-2 workers per year
- 10 workers per year
- Varies
- 1 worker per year
- 2 workers per year
- 1 worker per year
- Unknown

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