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Health Physics Manual of Good Practices for Reducing Radiation Exposure to Levels that are As Low As Reasonably Achievable (ALARA)

L. H. Munson, Chairman

W. N. Herrington
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E. J. Vallario,
DOE Project Manager

June 1988

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

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FOREWORD

Reducing radiation exposures to levels that are "as low as practicable" (ALAP) or "as low as reasonably achievable" (ALARA) has long been the goal of the radiation protection programs of the U.S. Department of Energy (DOE), its predecessor agencies, and contractor organizations. The concept had its roots in the Manhattan District where, as early as 1944, the Director of the Health Division noted that the only safe practice for internal emitters was to avoid intake. By 1946, the ALARA philosophy had been incorporated into the radiation safety manual for the laboratory that would later become Oak Ridge National Laboratory (ORNL), and ALARA was conceptually introduced and published in 1954 into the recommendations of the National Committee on Radiation Protection, now the National Council on Radiation Protection and Measurements (NCRP). In 1959, the first publication of the International Commission on Radiological Protection (ICRP) used the phrase "as low as practicable."

Since 1954, the basic policy of DOE and its predecessor organizations, the Atomic Energy Commission (AEC) and the Energy Research and Development Administration (ERDA), has been to follow applicable guidance from the Federal Radiation Council (FRC), NCRP, and ICRP. As early as 1960, the AEC stated in its orders that "...human exposure to ionizing radiation shall be kept as low as practicable." In 1975, requirements for keeping radiation exposures as low as practicable were introduced in ERDA Manual Chapter 0524. In 1981, these requirements were included in the most recent DOE Order 5480.1, Chapter XI, and were continued in the 1988 draft revised DOE Order 5480.11. These requirements represent the formalization of a position long held and practiced by DOE and its contractors and, as such, are not a new philosophy or commitment. Although the phrase "as low as practicable" has, in recent years, been supplemented by "as low as (is) reasonably achievable," the basic concept has not changed. Indeed, although some argue that subtle differences exist between the two phrases as applied to radiation protection, ALAP and ALARA are identical in intent and may be used interchangeably. In addition, the term "optimization" was defined by the ICRP to be identical with ALAP and ALARA.

In 1976, the DOE Division of Operational and Environmental Safety (OES) supported a study to review the operations of DOE contractors with regard to implementing ALAP philosophy and identifying useful practices and potential areas of concern. In 1978, the Pacific Northwest Laboratory (PNL) produced a summary report by Gilchrist, Selby, and Wedlick. This report, PNL-2663, discussed the results and findings of surveys performed at 18 major DOE installations. A second phase of this effort was to develop "A Guide to Reducing Radiation Exposure to As Low As Reasonably Achievable (ALARA)," DOE/EV/1830-T5 issued in April 1980. This guide "represents an initial attempt to provide contractors and DOE staff with background in the philosophy and techniques of ALAP (now ALARA) programs."

The DOE Office of Nuclear Safety (ONS) has since determined that a revision and update to the original guide is needed to reflect advances in technology, changes in national and international guidance, and revisions of federal regulations. This revised manual of good practices is a product of that determination. The manual is directed to those contractor and DOE staff who are responsible for conduct and overview of radiation protection and ALARA programs at DOE facilities. The intent of the manual is to provide sufficient guidance to ensure that, if followed, radiation exposures will be maintained as low as reasonably achievable and that the basis for a formally structured and auditable program will be established.

E. J. Vallario, Acting Director
Radiological Controls Division
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U. S. Department of Energy

EXECUTIVE SUMMARY

A primary objective of the U.S. Department of Energy (DOE) health physics and radiation protection program has been to limit radiation exposures to those levels that are as low as reasonably achievable (ALARA). As a result, the ALARA concept developed into a program and a set of operational principles to ensure that the objective was consistently met. Implementation of these principles required that a guide be produced.

The original ALARA guide was issued by DOE in 1980 to promote improved understanding of ALARA concepts within the DOE community and to assist those responsible for operational ALARA activities in attaining their goals. Since 1980, additional guidance has been published by national and international organizations to provide further definition and clarification to ALARA concepts. As basic ALARA experience increased, the value and role of the original guide prompted the DOE Office of Nuclear Safety (ONS) to support a current revision.

The revised manual of good practices includes six sections: 1.0 Introduction, 2.0 Administration, 3.0 Optimization, 4.0 Setting and Evaluating ALARA Goals, 5.0 Radiological Design, and 6.0 Conduct of Operations. The manual is directed primarily to contractor and DOE staff who are responsible for conduct and overview of radiation protection and ALARA programs at DOE facilities. The intent is to provide sufficient guidance such that the manual, if followed, will ensure that radiation exposures are maintained as low as reasonable achievable and will establish the basis for a formally structured and auditable program.

Section 1.0 of the manual, Introduction, provides a statement of the purpose and scope of the document and a brief discussion of the philosophy of ALARA, possible relationships between the ALARA and radiation protection programs, and a type of management oversight risk tree (MORT) that may be used to develop audit programs and checklists for review of ALARA program elements.

Section 2.0, Administration, discusses the essential systems and tools available to management for implementing and controlling an ALARA program. This section emphasizes the value of strong management commitment and support, formal and informal communications systems, effective education and training programs in support of the program, and routine internal and external audits and appraisals of the implementation and function of the program. To ensure accountability for conduct of the ALARA program, management should delegate specific responsibilities and provide follow-up.

Section 3.0, Optimization, has been added to the revised manual because, in recent years, the importance of including optimization techniques in an ALARA program has greatly increased. It is now necessary for each operation to develop its own specific values for evaluating activities and actions against the ALARA criteria. Techniques and methodology for performing evaluations are provided.

Section 4.0, Setting and Evaluating ALARA Goals, provides guidance for techniques in setting ALARA goals and methods for periodic evaluation of the progress toward meeting them. Goals should be established at the outset of the program. The goals can be either quantitative or qualitative, but must be well defined and measurable, clearly understood, and achievable.

Section 5.0, Radiological Design, discusses the importance of considering ALARA factors at all stages of the design process of a facility. Many of the engineered systems for reducing and controlling radiation exposures can be best incorporated in a cost effective manner during this design phase.

The last section, Section 6.0, is Conduct of Operations. This section addresses the application of ALARA principles to work performance in the field, during both normal and emergency operations. Elements discussed in the preceding sections are combined and assist in achieving a coordinated and effective operation with a minimum of radiation exposure for the work accomplished. Accurate radiological measurements and routine radiological surveys combined with administrative controls are valuable and give continued assurance that systems are operating as designed. A brief discussion of the application of ALARA in emergency planning and response is included.

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The authors thank the many people who provided technical comments and support for this manual. Special thanks to E. J. Vallario, Office of Nuclear Safety, U.S. Department of Energy (DOE), for his continued support and guidance. Thanks also to the many members of the DOE family, who provided information, comments, and direction to make this manual more useful; and to the expert peer review panel, who provided technical input and reviewed this document for accuracy, appropriateness, and applicability of content.

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ACRONYMS

AEC	Atomic Energy Commission
ALAP	as low as practicable
ALARA	as low as reasonably achievable
ALI	annual limit on intake
ANSI	American National Standards Institute
ARHI	airborne radioactivity hazard index
CAM	continuous air monitor
CFR	Code of Federal Regulations
DAC	derived air concentration
DOE	U.S. Department of Energy
DOELAP	DOE Laboratory Accreditation Program
EPA	U.S. Environmental Protection Agency
ERDA	Energy, Research, and Development Administration
FRC	Federal Radiation Council
HEPA	high-efficiency particulate air
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IEC	International Electrotechnical Commission
ISO	International Standardization Organization
MORT	management oversight risk tree
NCRP	National Council on Radiation Protection and Measurements
NRC	U.S. Nuclear Regulatory Commission
ONS	Office of Nuclear Safety
ORNL	Oak Ridge National Laboratory
PNL	Pacific Northwest Laboratory
PWR	pressurized water reactor
QA	quality assurance
QC	quality control
RPT	radiation protection technologist (radiation monitor)
RWP	radiation work permit or procedure
SCBA	self-contained breathing apparatus
TED	track-etch dosimeter
TLD	thermoluminescent dosimeter

DEFINITIONS

airborne radioactivity hazard index (ARHI) - the product of the airborne radioactive material concentration in a room, the volume of the room, and the relative radiotoxicity of the material.

annual limit on intake (ALI) is the activity of radionuclide which, if taken alone, would irradiate a person, represented by Reference Man[a] to the limiting value for control of the workplace.

derived air concentration is the concentration in air obtained by dividing ALI for any given radionuclide by the volume of air breathed by an average worker during a working year (2.4×10^3 m^3). Numerical quantities are given in DOE 5480.11.[b]

dose equivalent (H_T) is the product of absorbed dose (D) in rad (gray) in tissue, a quality factor (Q), and other modifying factors (N). Dose equivalent (H_T) is expressed in terms of rem (sievert).

effective dose equivalent (HE) includes the dose equivalent from both external and internal irradiation and is defined by $\Sigma_T w_T H_T$, where H_T is the dose equivalent in tissue and W_T is the weighting factor representing the ratio of risk arising from irradiation of tissue T to the total risk when the whole body is irradiated uniformly. Effective dose equivalent is expressed in units of rem (sievert).

shall - is used when referring to any criteria that are requirements as defined in DOE orders or other documentation such as ANSI standards which are referenced in DOE orders.

should - is used when referring to any criteria that are good practices but not specific requirements per DOE orders.

(a) International Commisssion on Radiological Protection (ICRP). 1975. Report of Task Group on Reference Man. ICRP Publication 23, Pergamon Press, New York, New York.

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

radiation work permit or procedure - a form that describes the radiation protection requirements for performing work in a radiation area.

radiological controlled area - an area normally free of radioactive material but one that could potentially become contaminated.

radiological uncontrolled area - areas where no radioactive materials are permitted and radiological controls normally are not necessary (e.g., offices, lunchrooms).

radiotoxicity - the relative hazard of internally deposited radionuclides.

weighting factor (W_T) is used in the calculation of annual and committed effective dose equivalent to equate the risk arising from the irradiation to tissue T to the total risk when the whole body is uniformly irradiated. The weighting factors are:

Organ or Tissue	Weighting Factor
Gonads	0.25
Breasts	0.15
Red Bone Marrow	0.12
Lungs	0.12
Thyroid	0.03
Bone Surfaces	0.03
Remainder[a]	0.30

(a) "Remainder" means the five other organs with the highest dose, i.e., liver, kidney, spleen, thymus, adrenals, pancreas, stomach, small intestine but excluding skin, lens of the eye, and extremities. The weighting factor for each such organ is 0.06.
Taken from: International Commission on Radiological Protection (ICRP). 1987. Data for Use in Protection Against External Radiation. ICRP Publication 51, Pergamon Press, New York, New York.

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SECTION 1.0

INTRODUCTION

1.0 INTRODUCTION

Limiting radiation exposures to the lowest levels commensurate with economics and the work to be accomplished has long been an important part of the health physics and radiation protection programs of the U.S. Department of Energy (DOE), its predecessors, and its contractors. As a result, individual and collective radiation doses have declined steadily for about two decades, and contractors have generally kept radiation doses well below the regulatory limits. However, evaluating whether risks are associated with low levels of radiation dose, accepting the linear nonthreshold dose-effect curve, and promulgating revisions and refinements in recommendations and regulations, nationally and internationally, have focused increased attention on avoiding unnecessary doses and on reducing all radiation doses to, and keeping them at, levels that are as low as reasonably achievable (ALARA).

1.1 PURPOSE

The purpose of this document is to provide assistance to those who are responsible for developing, implementing, and/or evaluating ALARA programs. Because each DOE facility has needs, specific and critical to its individual radiation protection program, no single set of specific and detailed criteria can be decreed as a prescription for achieving ALARA goals. However, guidance such as defining elements of an ALARA program and identifying techniques for implementation can be coupled with site-specific criteria to assist in developing a formally structured ALARA program.

A primary objective of this manual is to provide definitive guidance to the operational health physics and ALARA staffs in the field and to promote consistent application of ALARA principles within the DOE community.

1.2 SCOPE

The scope of this manual is limited to applications within the DOE community. Basic guidance developed by national and international organizations is equally appropriate for all activities. However, specific application of that guidance may vary because of needs and policies of the

implementing organization. Because of the wide diversity of DOE operations, processes, and facilities, consistent guidance in ALARA program application can benefit all, in spite of the fact that all the individual practices and techniques described in this manual may not be applicable in every DOE operation, process, or facility.

Activities and controls imposed within a facility may significantly impact the potential for and magnitude of radioactivity released to the environment and would certainly be a part of an effective health physics program. However, this manual will not address applying ALARA principles to potential radiation doses to the environment. A separate environmental ALARA document is being prepared by the DOE Office of Environmental Guidance and Compliance. That manual should be consulted for guidance in implementing an environmental ALARA program.

1.3 PHILOSOPHY

The basic ALARA philosophy simply stated in a single phrase is "limiting personnel and environmental radiation exposures to the lowest levels commensurate with sound economic and social considerations." This basic statement presupposes that no radiation exposure should occur without a positive net benefit, considering technological, economic, and societal factors. Implicit in the ALARA philosophy is the cautious assumption that any radiation exposure, however small, carries with it some detriment or probability of detriment (i.e., risk), which should be balanced by an offsetting benefit. Indeed, this is the heart of the ALARA philosophy, and it implies that one should not stop looking for ways to incur less dose for a given output of work, as long as the cost of the consideration does not exceed the possible equivalent cost of the potential dose saving.

This philosophy is based on the linear nonthreshold hypothesis, which is based on the assumption that detriment from radiation is directly proportional to the dose incurred and that no threshold or dose exists below which there is no detriment. Although there is considerable controversy about the uncertainty of detriment, if any, from low levels of radiation dose and about which dose-response curve or combination of curves is correct, at this time

the linear nonthreshold hypothesis appears to best satisfy the need for a practical yet conservative approach to the controversy.

A cardinal principle of on-the-job safety is that safety is everyone's responsibility. This principle applies also to ALARA. Day-to-day operational ALARA responsibilities are borne by all; others have additional and special responsibilities. Management is responsible for establishing and fostering the ALARA climate; ALARA coordinators and radiation protection staff provide the technical support and assistance necessary to achieve ALARA goals; and line management adopts technical, administrative, and supervisory methods applicable to the operations under their control. Each individual worker then implements ALARA principles and procedures. In addition, as in other safety-related programs, the individual worker will often make a significant contribution.

1.4 THE RELATIONSHIP OF ALARA AND HEALTH PHYSICS PROGRAMS

The relationships of ALARA and health physics may become a source of question and confusion in establishing a formal ALARA program. The relationship between the two elements can range from two separate and independent programs to a program in which the identity of either element is lost. See Figures 1.1 through 1.4.

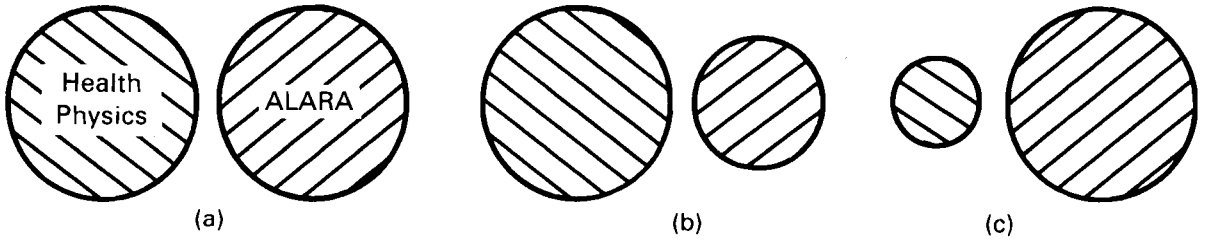

FIGURE 1.1. Independent Health Physics and ALARA Programs: (a) Equal Sizes, (b) Larger Health Physics Program, (c) Larger ALARA Program

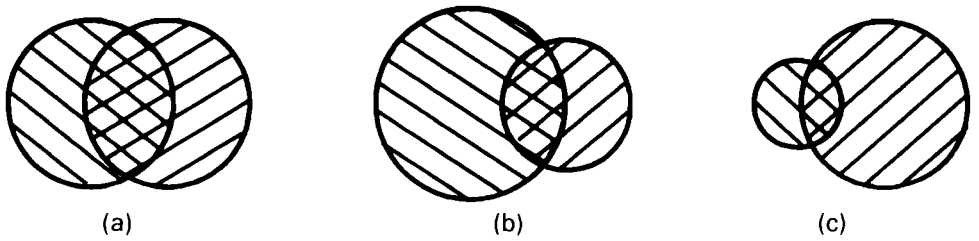

FIGURE 1.2. Health Physics and ALARA Programs with Common Elements and Individual Elements

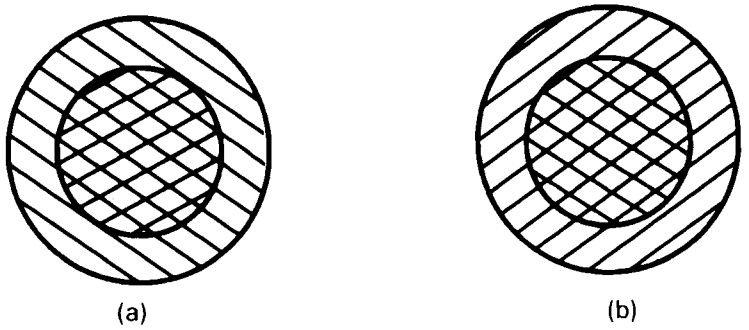

FIGURE 1.3. ALARA as a Part of a Health Physics Program (a) and the Converse (b)

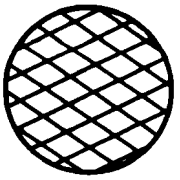

FIGURE 1.4. Identical Health Physics and ALARA Programs

The relationship in Figure 1.3 is important to ensure that ALARA is achieved. Consider, for example, the extreme cases illustrated in Figure 1.1. Two separate programs with separate staffs, budgets, and management may result in an increased cost for the overall radiation protection program, which, in turn, may increase the overall cost of the operation and the cost per unit dose reduction or the cost for maintaining a given level of

exposure. Thus, higher doses than might be deemed reasonable under one of the other options might result.

At the other extreme, a fully integrated radiation program, such as that illustrated in Figure 1.4, also has certain pragmatic limitations. Although it is possible to both achieve and maintain ALARA objectives effectively and efficiently if the ALARA and health physics programs are completely integrated, the relationship may be deficient because the ALARA efforts may be so diffuse that it is virtually impossible to monitor their effectiveness. Moreover, the ALARA program has no identity of its own, which may make it difficult for organizations outside the radiation protection organization to see their individual responsibilities for ALARA.

Any relationship may be used and may be made successful with the strong support of management and staff. However, both an effective health physics program and an aggressive, visible ALARA effort are necessary.

1.5 ALARA DECISION TREE

A useful tool in the development and evaluation of an ALARA program is an analytic tree analysis. An analytic tree is a graphic display of information to aid the user in conducting a deductive analysis of a system (Buys 1977). The use of analytic trees should be familiar to DOE and DOE contractors through the application and use of management oversight and risk tree (MORT) analyses. The system to be analyzed, developed, and ultimately evaluated in this case is the ALARA program at a contractor facility. Analytic trees provide a systematic approach to program development by means of identifying interrelationships and details that must be considered to ensure a comprehensive program. Once the program is functioning, the analytic tree may be used to develop checklists for ALARA program reviews or audits.

The trees shown in Figure 1.5 through 1.10 have been developed to illustrate the application of analytic trees to ALARA program development. The trees correspond to the major chapters in this guide, and have been developed to a level of detail corresponding to the level of detail in the text. They are by no means complete, nor are they necessarily appropriate

for every organization, but they may be used as guidelines for program development or evaluation.

In developing an ALARA program or evaluating ALARA performance, each element of each tree should be considered. The extent of its development and application and the commitment of resources to it should be based on the radiation exposure potential of the facility, the radionuclide inventory, the form of and the processes in which radionuclides are used, the resources available, and the judgment of qualified professionals. The size of the ALARA program for a facility using several small sealed sources would be different from the size of a program or a reactor or fuel reprocessing operation. However, in all ALARA programs, each element should be assessed and a considered judgment made of its applicability to the specific facility and the degree of program development required. Documenting the assessment, the conclusions, and the bases for them should be complete. Periodic review of the program should be performed to verify its adequacy (see Section 2.2).

As seen in the ALARA decision tree in Figure 1.5, if there is a potential for radiation exposure to personnel in a facility or operation, then both a health physics program and an ALARA program are needed. The branching to the two programs depicted in Figure 1.5 should not be interpreted to mean that the health physics and ALARA programs are separate and distinct. Rather, as stated earlier, the ALARA program derives from a strong, effective health physics program. Historically, keeping radiation doses ALARA has been part of the health physics function. The emphasis on reducing personnel doses has led to increased attention to those elements of the health physics program that further ALARA goals. This emphasis does not diminish the necessity for and importance of the other health physics activities. A strong ALARA program may, in fact, provide additional impetus to strengthen the health physics effort.

1.6 ALARA CHECKLIST DEVELOPMENT

Using the analytic tree to develop a check list for audit or appraisal requires rewording the elements of the tree. For example, the element identified as "Potential for Radiation Exposure to Personnel" in Figure 1.5 would

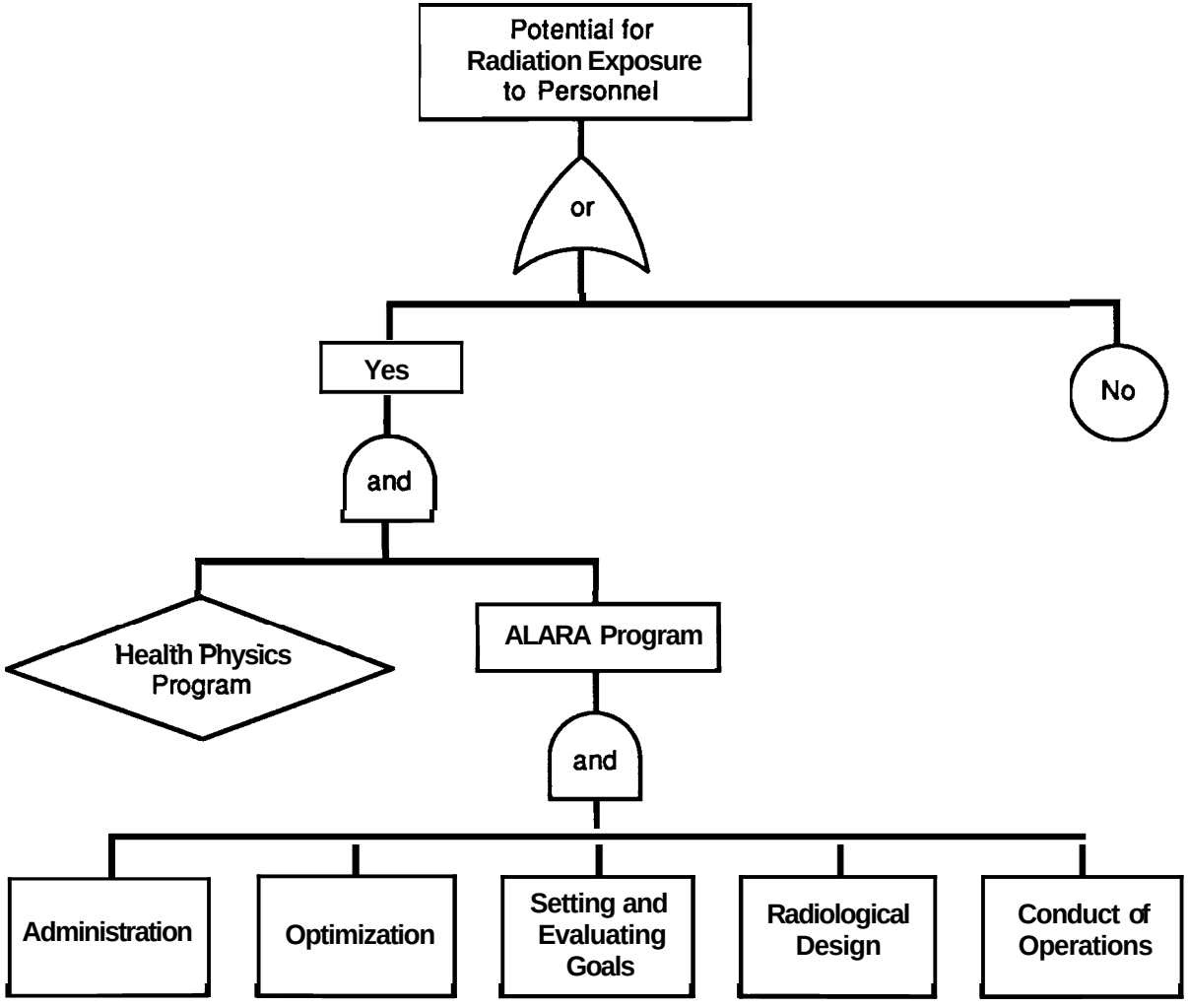

FIGURE 1.5. Basic Elements of an ALARA Program

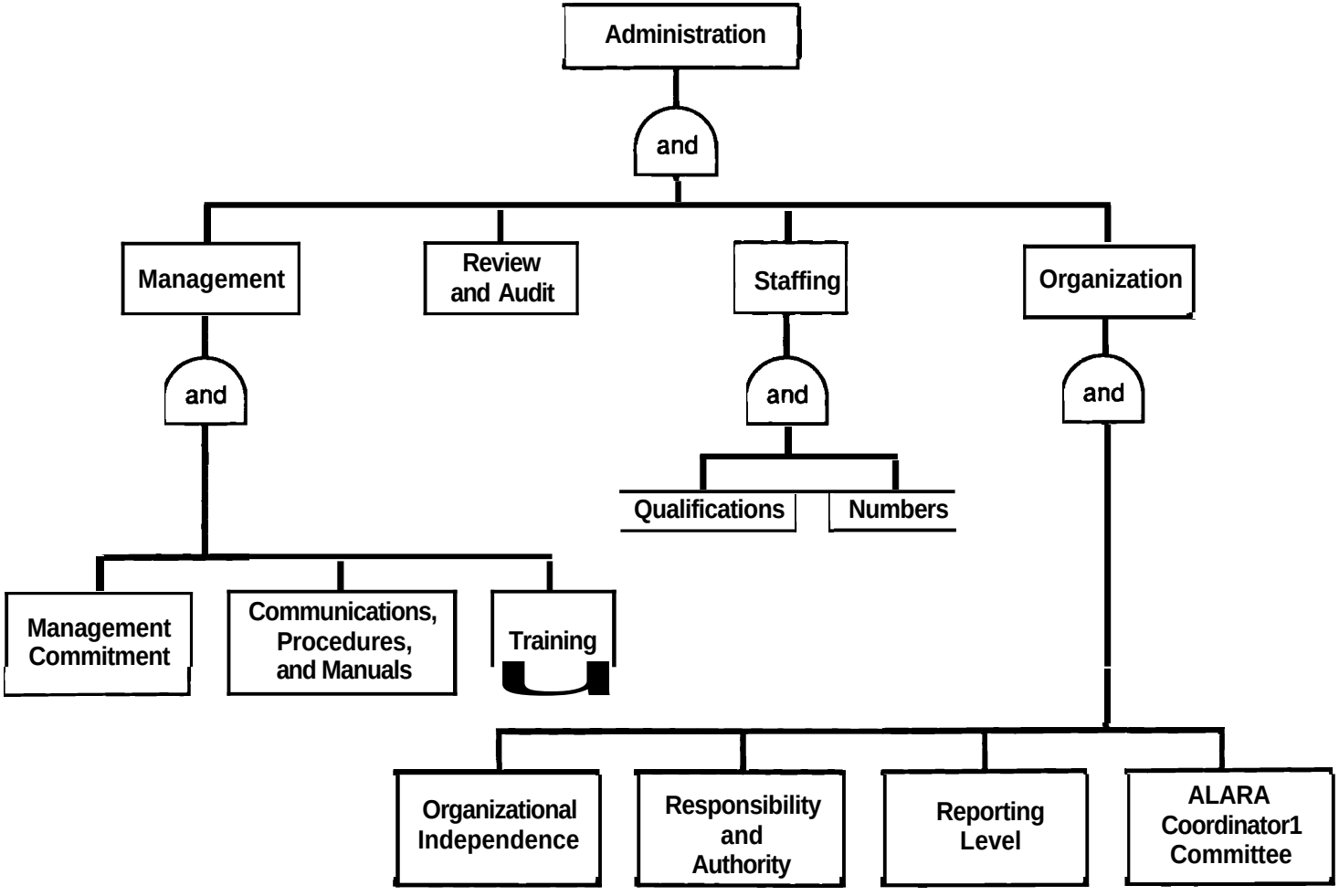

FIGURE 1.6. Basic Elements of ALARA Program Administration

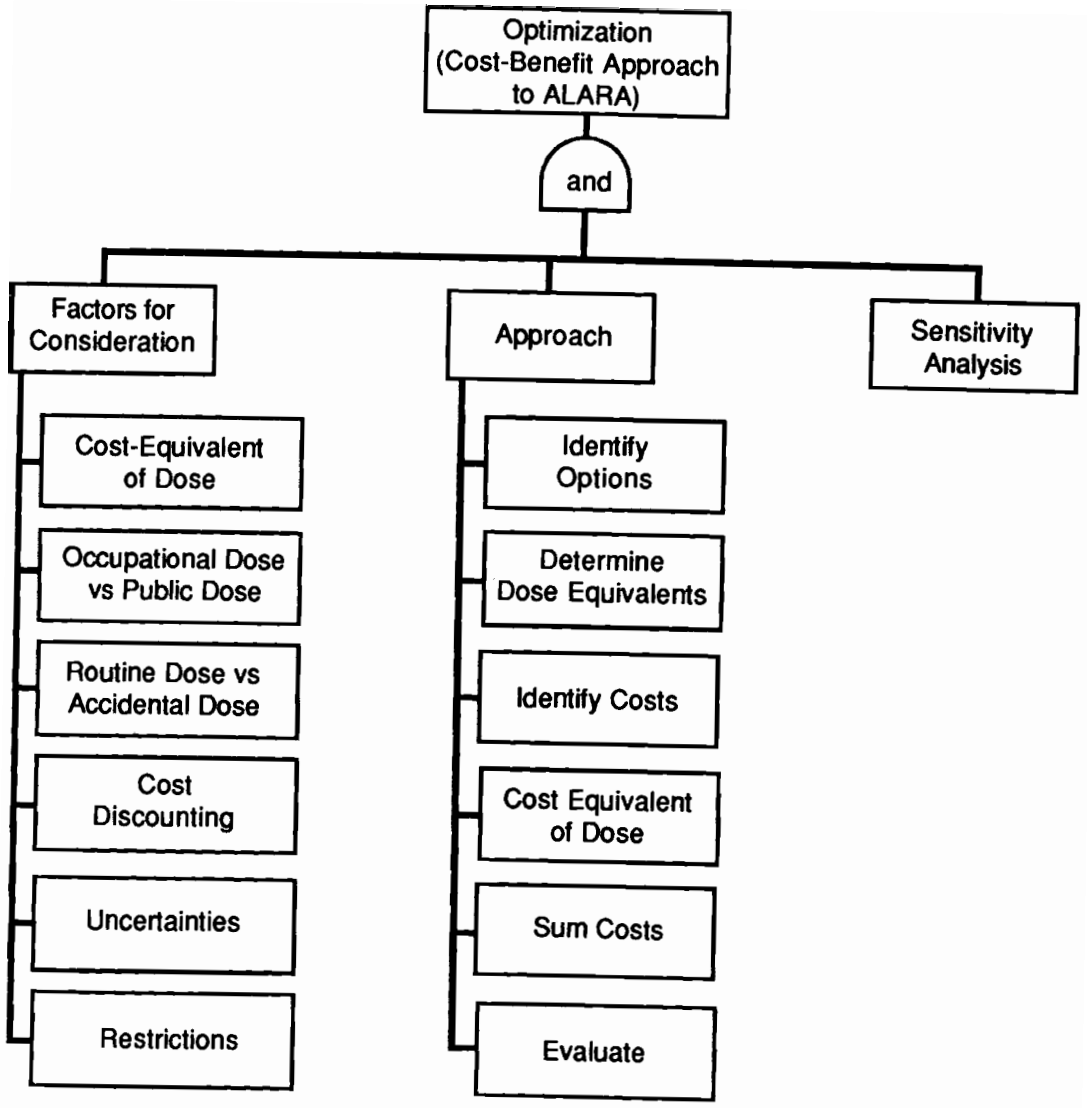

FIGURE 1.7. Basic Elements of Optimization

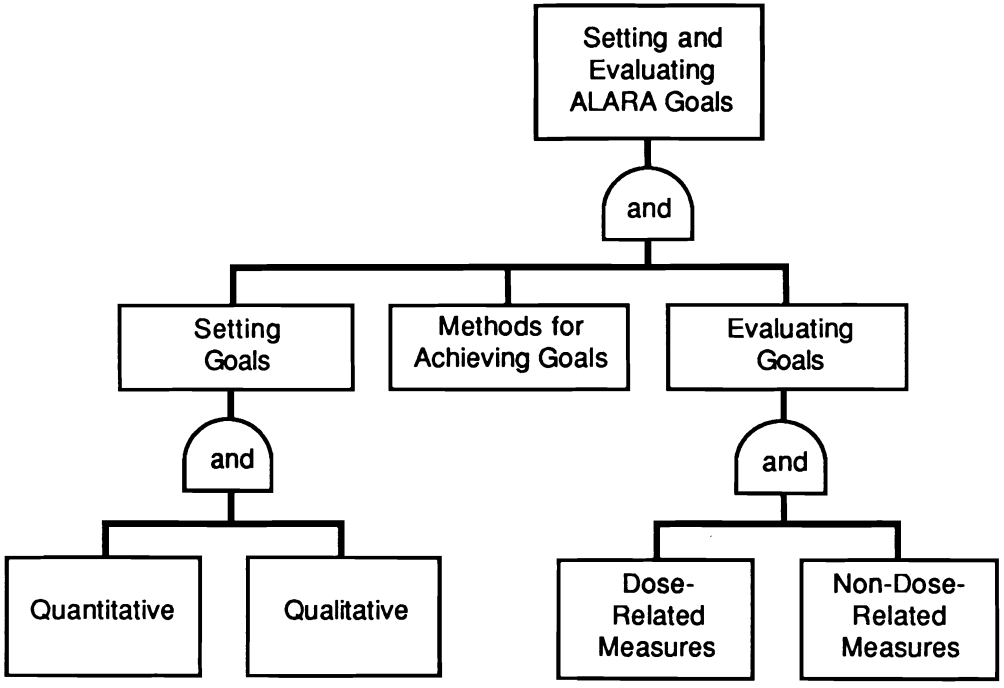

FIGURE 1.8 Basic Elements of Setting and Evaluating ALARA Goals

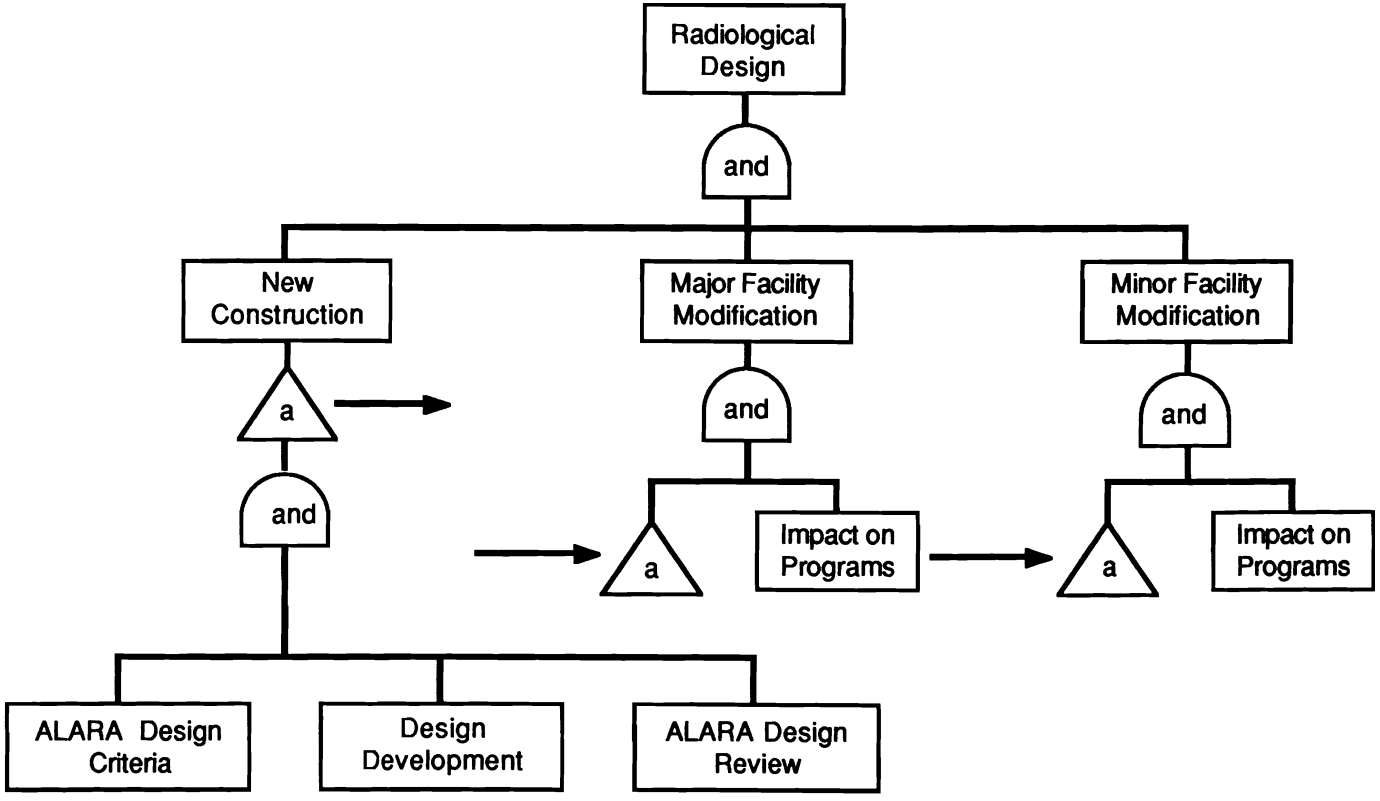

FIGURE 1.9. Basic Elements of Radiological Design

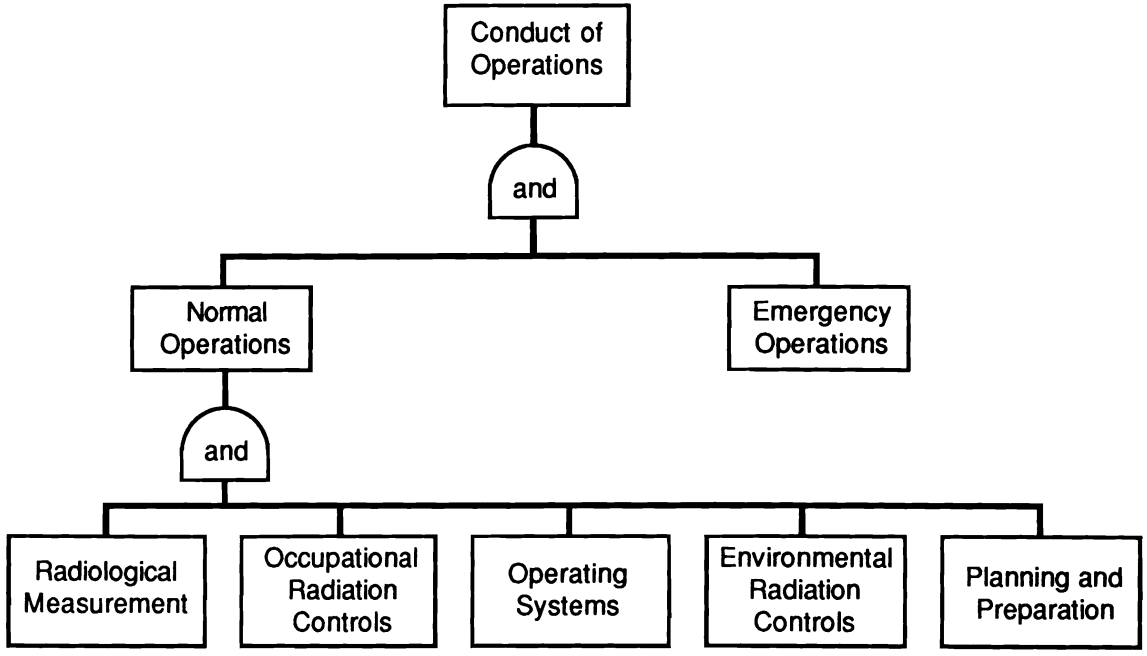

FIGURE 1.10 Basic Elements of the Conduct of Operations

be changed to "Adequate Control of Radiation Exposure to Personnel." The next level would become "Adequate Health Physics" and "Adequate ALARA Program." The analytic tree symbol indicates that both programs must be found adequate to assure that radiation control of exposure to personnel is adequate. Following the ALARA program branch of the tree to develop a check list would result in revising the next tier of elements to:

Administration	-	Administrative System Adequate
Optimization	-	Optimization System Adequate
Goal Setting and Evaluation	-	Setting and Evaluating ALARA Goals System Adequate
Radiological Design	-	ALARA Consideration in Radiological Design Adequate
Conduct of Operations	-	Application of ALARA in Conduct of Operations Adequate

Further detailed development of the "Administrative System Adequate" branch would result in the following diagrams (see Figures 1.11, 1.12, and 1.13). Each branch of the ALARA program is developed in the same manner to form a detailed analytic tree. This analytic tree can then be used to develop a detailed check list for establishing a program or for conducting an appraisal of an existing program. The checklist for the "Administration" branch of the tree would contain a list of questions such as the following:

I. Administrative System Adequate

A. Management

1. Management Commitment

a. Is a formal ALARA policy written and issued?

b. Has the ALARA policy been distributed to workers?

c. Does management demonstrate its support for ALARA?

d. Do the workers understand that management is committed to and supports ALARA?

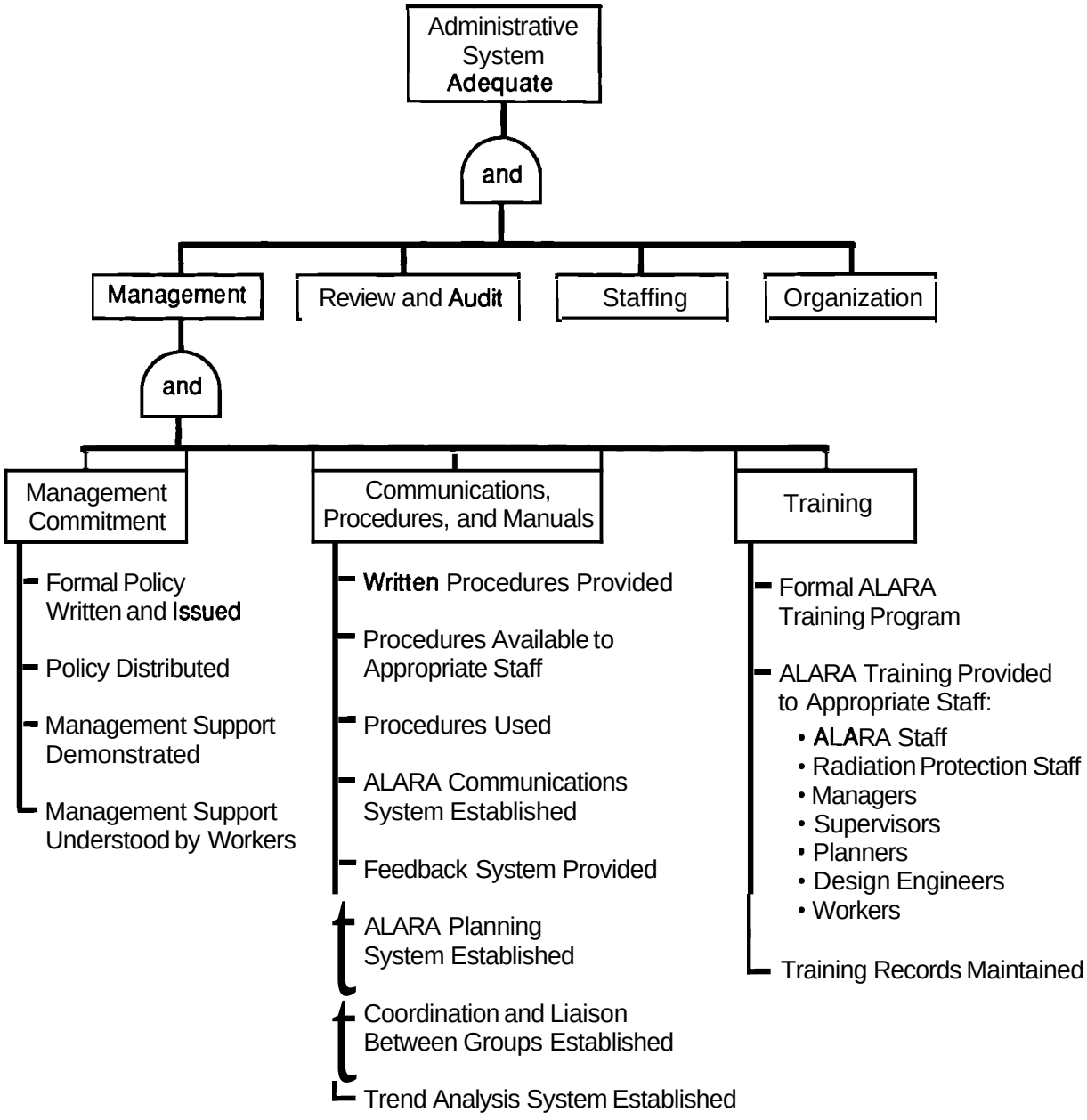

FIGURE 1.11. Administrative System Adequate, Detail of Management Branch

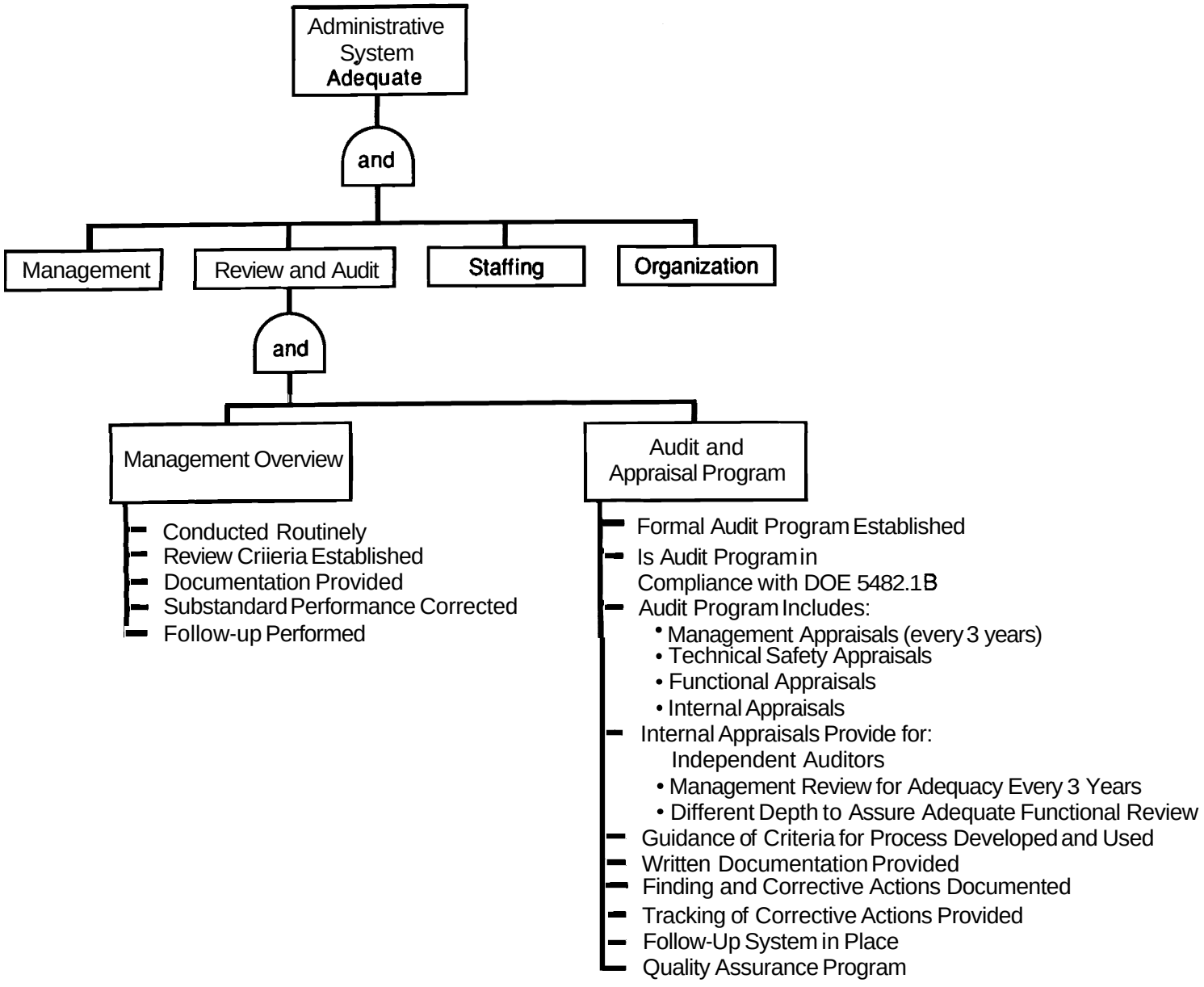

FIGURE 1.12. Administrative System Adequate, Detail of Review and Audit Branch

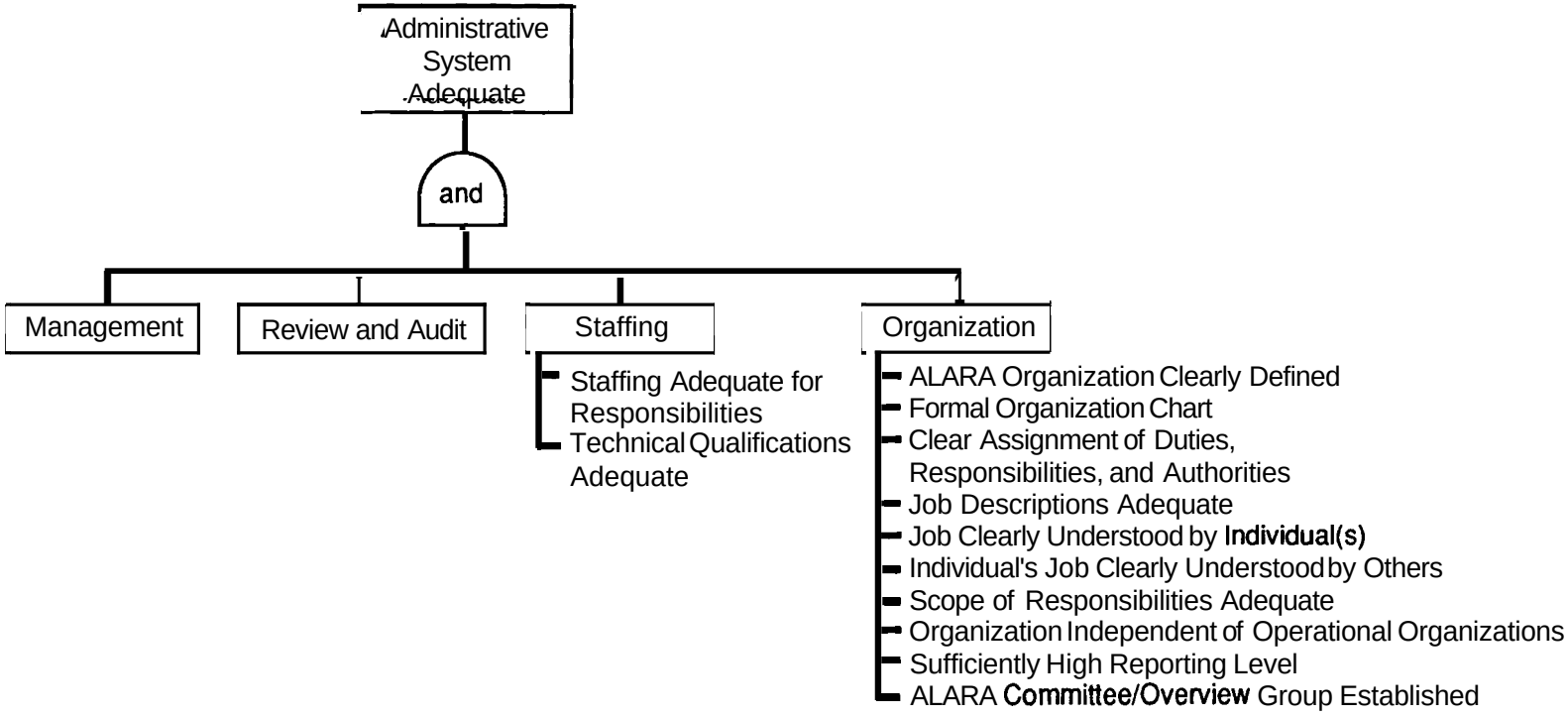

FIGURE 1.13. Administrative System Adequate, Detail of Staffing and Organization Branches

2. Communications, Procedures, and Manuals

   a. Are written procedures for application of ALARA provided?

   b. Are the procedures available to the appropriate staff?

   c. Are the procedures adequate and used?

   d. Is there an ALARA communications system provided?

   e. Does the ALARA communications system provide for feedback from the field?

   f. Is there an ALARA planning system established, or is ALARA planning formally included in other work planning systems?

   g. Has a system for coordination and liaison between working and planning groups been established?

   h. Has a system been established that uses trend analysis for tracking ALARA performance?

      - Is trend analysis performed by craft and facility type for both routine and repetitive operations?

      - Does management review these analyses on a specified frequency?

      - Are there provisions for implementing corrective actions and follow-up to assure completion?

3. Training

   a. Is there a formal ALARA training program, or is ALARA training specifically provided in other facility training?

   b. Is ALARA training provided to appropriate staff? i.e.,

      - ALARA coordinator/staff

      - Radiation protection staff

      - Managers

      - Supervisors

      - Planning staff

      - Design engineering staff

      - Workers

c. Is ALARA training documented and records maintained?

B. Review and Audit

1. Management Overview

a. Does management conduct routine reviews of the ALARA program?

b. Have formal review criteria been established?

c. Are the management reviews documented?

d. Is substandard performance corrected?

e. Does management perform tracking and follow-up of action items?

2. Audit and Appraisal Program

a. Is there a formal ALARA audit program established?

b. Is the audit program in compliance with DOE 5482.16 (DOE 1986)?

c. Does the audit program include the following:

- Management appraisals (at least once every three years)?
- Technical Safety Appraisals?
- Functional Appraisals?
- Internal Appraisals?

d. Do internal appraisals provide for:

- Auditors independent of those responsible for performance?
- Internal appraisals reviewed by management for adequacy of performance at least every three years?
- Audit depth sufficient to assure adequate functional review of the ALARA program?

e. Are written guidance and criteria for the audit process developed and used?

f. Are the audits and appraisals documented?

g. Are findings and corrective actions documented?

h. Are corrective actions tracked and documented?

i. Is there a follow-up system to evaluate effectiveness of actions taken?

j. Is a Quality Assurance (QA) Program in place?

- Formal QA program document written?
- Organizationally independent?
- Systematic audits performed?
- Tracking of corrective actions?
- Documented reports to management and audited organizations?

C. Staffing

1. Is the staffing of the ALARA program adequate for the responsibilities assigned?

2. Are the technical qualifications of the staff adequate?

D. Organization

1. Is the ALARA organization clearly defined?

2. Is there a formal organizational chart?

3. Is there a clear assignment of duties, responsibilities, and authorities?

4. Are the job descriptions adequate?

5. Is the job clearly understood by the individual(s)?

6. Are each individual's duties, responsibilities, and authorities clearly understood by others?

7. Is the scope of responsibilities adequate?

8. Is the ALARA organization independent of the operational organizations?

9. Is the reporting level for the ALARA coordinator/manager sufficiently high to ensure senior management access?

10. Is there an ALARA committee/overview group established?

As evident from the above development of one element of an ALARA program (e.g., the administrative element), development of all elements of the program would result in a detailed list of questions that include all aspects of ALARA.

A successful ALARA program complements a strong, effective health physics program. Both are necessary for the successful maintenance of radiation doses ALARA. Because of the importance of the health physics functions to ALARA and their close objectives, development (or assessment) of an ALARA program should include assurance that the health physics program is performing adequately. To assist the user of this manual in providing this assurance, the "Performance Objectives and Criteria for Technical Safety Appraisals," developed by the U.S. DOE Office of the Assistant Secretary for Environment, Safety, and Health, covers Radiological Protection and is included as the appendix.

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SECTION 2.0

ADMINISTRATION

2.0 ADMINISTRATION

Program administration is essential to an effective ALARA program. A functional administrative structure provides definition, direction, and control to the program. The basic elements of ALARA program administration are management, review and audit, staffing, and organization. Although the discussion in this section pertains to ALARA program administration, it should not be construed as advocating the establishment of a completely independent ALARA organization. An effective ALARA program should be an integral part of a contractor's overall safety program and may in many cases overlap with existing safety functions.

In some facilities, those assigned responsibility for the ALARA program may be in an organization separate from health physics and radiation protection. However, because of the many interrelated functions, areas of common concern, and importance of effective radiation protection, much of the discussion and emphasis in the manual is directed to the radiation protection organization and function.

2.1 MANAGEMENT

Implicit in the ALARA concept is strong overt support and active participation by senior management to demonstrate the importance placed on reducing radiation exposures to the lowest practicable levels. Without this strong support and participation by senior management, operating personnel might consider ALARA goals and objectives to be secondary in importance and easily overridden by production or other requirements. The most technically competent health physics staff available cannot be effective in solving radiation protection problems without strong, demonstrated management leadership.

No less important is the support and implementation of sound radiation protection practices by operating management and personnel at all levels. Each employee should recognize the importance of individual effort in the ALARA program and should be encouraged not only to work with ALARA in mind, but also to make the ALARA concept an integral part of the job, from both the planning and the operational standpoints.

The ultimate responsibility for ALARA rests with the line organization. The radiation protection staff provides technical assistance, support, and guidance, serving both as a technical resource to staff at all levels and as an independent agency, as it were, to verify and evaluate the state of the program or the degree to which ALARA objectives are being met.

2.1.1 Management Commitment

Management commitment is by far the most important basic characteristic of a successful ALARA program. Management commitment includes providing the person(s) coordinating the ALARA program with the responsibility and authority needed to carry out an effective program. In addition, responsibility and authority for implementing ALARA practices should be assigned to line management and to engineering, operations, and maintenance staff. A clear-cut, positive ALARA policy statement shall be formally issued by the facility director. This policy should be unequivocal in stating the commitment of the facility to ALARA through an appropriate program of radiological and environmental protection and should delegate both the responsibility and the authority for coordinating this program to the facility radiation protection officer, health physics manager, or other qualified expert.

By word and action, management must demonstrate its own commitment to ALARA. Making adherence to ALARA practices one criterion in the evaluation of job performance can be an effective means of demonstrating and fostering such commitment. Together, line management and radiation protection personnel should develop a workable program in agreement with both operational needs and ALARA principles. It should be stressed that ALARA and production are not incompatible, but the elements of job analysis and preplanning inherent in the ALARA approach will increase efficiency and cost-effectiveness.

To attract and retain competent qualified personnel for the radiological and environmental protection staff, salaries and other benefits (including working conditions and tools such as instrumentation) should be on a par with those provided to operational or research staff members. The radiation protection function should be designed in such a way that it is not a professional or administrative dead end for those who choose to work in this area.

2.1.2 Communications, Procedures, and Manuals

Certain formal communications are essential if the ALARA program is to be effective. The facility director's formal policy statement of commitment to ALARA should be provided to each employee individually, perhaps in the form of a memo or by inclusion in an employee handbook. In addition, line managers should reiterate this commitment orally and on a less formal basis to their staffs; this can readily be accomplished at staff meetings, safety meetings, or ad hoc meetings.

Detailed and specific policies and procedures relating to the ALARA program shall be formalized in a manual, with provision made for its periodic review and updating. The manual should meet quality assurance requirements for a controlled manual and should be freely available to all personnel. New policy statements and procedures, however, should be circulated among the staff and given to those to whom they apply. Procedures and policies should be reviewed and approved by responsible upper management.

Applicable portions of the manual should be reviewed at group safety meetings, with time allowed for and a climate conducive to questions and answers. Radiation workers should be convinced that keeping individual exposure ALARA is in their best interest and that management is truly and deeply committed to the ALARA program.

Procedures for the ALARA program should assure that ALARA is considered in the planning and scheduling of all activities that may involve personnel exposure to radiation. Depending on the size of the facility, complexity of the operation, and radiation doses to be received, it may be beneficial to establish a system in which the rigor of the ALARA planning is determined by the radiation dose estimated for a particular task. This type of system establishes a dose level, typically the collective dose estimate for a task, at which specified ALARA reviews and management approvals are required. As the estimated radiation dose increases, increased involvement of ALARA staff, radiation protection personnel, and management is required. However, some degree of ALARA review and consideration is needed for all activities in which radiation exposure is received, in order to limit unnecessary exposure.

Management procedures should include a system for assuring that trend analysis and radiation dose tracking are performed. Trend analyses and dose tracking can be instrumental in identifying locations and activities which could benefit from an in-depth ALARA evaluation, even in low-exposure facilities (Mahathy, Bailey, and Lay 1984). Preparing and analyzing control charts for department and individual exposures and analyzing radiation monitoring data are just two of their many uses.

A contractor-wide publication, such as an internal newsletter or safety bulletin, may be used to increase ALARA awareness among all staff members. Regular discussions of both problems and program successes will enhance credibility and promote an atmosphere of cooperation.

Nonmanagement personnel should be provided with an appropriate communication link to management and the radiation protection organization. It should be stressed that ALARA is a team effort and that each staff member is an important part of the team. Suggestions, questions and comments, no matter how severe, critical, or seemingly trivial, should be fairly considered, and no staff member should fear to make his or her views known. In some instances, the preservation of anonymity might be desirable.

The ALARA communications system should assure that effective coordination and liaison has been established among all the groups that manage, plan, schedule, design, establish controls and requirements, and evaluate activities that may involve radiation exposure.

Communication also includes the orientation and education of management and employees in the ALARA program and the specific roles of both in implementing it. An important aspect of orientation is to prepare personnel for their jobs, clearly indicating what is expected of them and what measures management has taken to ensure their well-being. Orientation sessions also offer a forum for employee feedback and questions because they often produce highly cost-effective suggestions. Education and training should provide personnel with retraining in addition to new information (See Section 2.1.3).

Incentive programs of various kinds and their related publicity can sometimes be used to stimulate staff interest in the ALARA program. Incentives that involve group goals and awards seem to be most successful,

especially awards for suggestions for reducing exposure to as low as reasonably achievable. However, any incentive that is capable of eliciting staff support and commitment should be considered. Adequate controls must be implemented to ensure that competition does not become the overriding factor. Thus, goals or awards do not become so coveted that workers are tempted to distort records or to act in ways that are counter to ALARA practices, such as neglecting to wear dosimeters in order to obtain lower indicated exposures.

The procedures and manuals describing and implementing the ALARA program shall provide for systematic generating and retaining of records related to occupational radiation exposure and the evaluations and actions considered and taken to maintain exposures ALARA. Extensive and detailed radiation records, especially of radiation doses received by workers and the conditions under which the exposures occurred, are essential for trend analysis and identification of additional areas for ALARA efforts. Detailed guidance on radiation exposure records systems can be found in ANSI N13.6-1972, Practice for Occupational Radiation Exposure Records Systems (ANSI 1972). The DOE requirements can be found in DOE 1324.2 (DOE 1982) and in DOE 5480.11 (DOE 1988).

2.1.3 Education and Training

The education and training process can be conveniently divided into three broad areas:

- new employee preparation
- work-oriented, on-the-job training
- continuing education.

Each of these areas is important to ALARA, for a deficiency in any one area can lead to increased personnel exposures.

New employment preparation is usually formal classroom instruction. Every job requires certain general education requirements as well as specific job skills. The general education requirements for different jobs are highly variable and are important in developing ALARA education and training programs. The general education level of employees dictates to a great extent the training techniques to be used and the training requirements set.

Work-oriented, on-the-job training refers to specific experiences provided by the employer to acquaint the employee with job specifics. Training for ALARA is a continuous process that includes an initial training program plus periodic updating and reinforcement. Radiation worker training and retraining, required at least every two years (DOE 1988), shall include specific plant procedures for maintaining exposure as low as reasonably achievable. Semiannual or more frequent ALARA training sessions are suggested for all employees, and ad hoc sessions should be developed if substantive changes are made in operations, equipment, regulations, or other factors relating to the radiological aspects of the facility. Practice sessions using nonradioactive equipment or "mock-ups" may be especially beneficial in sharpening skills and reducing time spent in radiation areas. Practice sessions can also be helpful in identifying problem areas in task performance and procedures. ALARA concepts and practices should be an inherent part of task training for radiation work, e.g., training on pump seal replacement should be done in anti-contamination clothing with emphasis on completing the job quickly and well.

Specific ALARA training should be provided to selected groups to ensure effective participation in implementing the ALARA program. Included in the groups that should receive specific ALARA training are the ALARA and radiation protection staff, managers, supervisors, planners and schedulers, design engineers, and radiation workers.

Continuing education refers to the formal and informal knowledge, often highly specific, usually gained while the employee is in the work force. Such education may be designed to lead to specific certifications or degrees or to the renewal or updating of existing licenses or certifications, or it may be simply to acquire additional general knowledge. For those primarily concerned with the technical aspects of ALARA, namely, the health physics staff, such training will assist in maintaining professional vitality.

Health Physicist

For experienced health physicists, education involves continual professional development by attending and participating in scientific and technical meetings, short courses, and other continuing education courses. In addition, the professional health physicist needs to be broadly informed about

company programs, policies, and practices, as well as to obtain a background in engineering economics and related financial matters. The latter two areas are desirable if the reasonably achievable aspect of the ALARA goal is to be attained.

Professional staff members should be provided with the means to maintain and update their skills by participation in relevant seminars, short courses, and scientific and technical meetings, and should be strongly encouraged to participate vigorously in continuing education programs and to obtain certification or licensure by the American Board of Health Physics or other professional certifying or licensing bodies. Continuing education opportunities necessary to maintaining certification or licensure, or for general professional knowledge and health physics competency, must be provided.

Pertinent handbooks, publications, and journals should be made available, such as those of the International Commission on Radiological Protection (ICRP), National Council on Radiation Protection and Measurements (NCRP), American National Standards Institute (ANSI), International Standardization Organization (ISO), International Electrotechnical Commission (IEC), International Atomic Energy Agency (IAEA), and the Health Physics Society.

Health physicists with limited experience or no experience are more in need of specific ALARA training than education, assuming that the individual has an appropriate academic background. No health physicist (or other staff member) should be assigned major responsibility for ALARA programs without first having significant applied experience at the operational level.

Health Physics Technicians

Experienced health physics technicians should be well acquainted with specific methods that meet ALARA criteria and will probably benefit most from education in the underlying theoretical and applied science. Radiation protection technician training and retraining programs shall be established and conducted at least every two years. These shall include, among other topics, training in the proper procedures and techniques for maintaining exposures ALARA. Such personnel should be encouraged to enroll in academic courses to strengthen their scientific backgrounds, and should also be

encouraged to achieve certification from the National Registry of Radiation Protection Technologists.

Inexperienced health physics technicians should receive special classroom training before they are permitted to operate in the field alone. A typical course should have 24 to 60 hours and include, as a minimum, the following topics:

- basic atomic and nuclear physics
- radiation units
- radiation measurements
- radiation survey instrumentation--calibration and limitations
- biological effects of radiation
  standards, guides, and limits
- special considerations in the exposure of women of reproductive age
- mode of exposure--internal and external
  company radiation safety procedures
- ALARA philosophy and practices
- exposure-reduction and exposure-prevention techniques and procedures
- approved monitoring and surveillance techniques
- auditing and inspection skills
- organizational methods
- radiation worker training
- facility radiation protection guides or standards
- emergency procedures.

In addition to carrying out the classroom work, inexperienced health physics technicians should be closely guided by senior technicians or senior members of the professional staff in their day-to-day activities. They should also go through the training given to radiation workers (as should junior professional staff) and should be encouraged to become trainers rather than trainees.

Adminis rators

Specific ALARA educational programs for administrators should be developed. The education of new administrators should be formal and include the following:

- general nontechnical review of radiation hazards and radiation protection policies
- description of interdepartmental relations that influence the quality of the program
- description of specific ALARA policies that the administrator must consider
- guidelines for educating junior employees
- factors that will be used to evaluate the quality of the ALARA program.

These subjects are critical because they describe ALARA justification, specific individual functions, the interrelation of group functions, and the methods to constantly evaluate which functions are most productive.

The education of experienced administrators should be informal and concentrate on evaluating the efficacy of ALARA goal achievement. The need to provide management support and commitment to the ALARA program should be emphasized. Administrators should be reminded that administrative ALARA functions deal with an attitude or an outlook as well as specific tasks.

Primary educational areas for operating managers and supervisors are:

- the importance and overall justification of the ALARA program
- specific requirements to ensure that ALARA policies are being implemented at all employee levels
- development of ALARA goals
- the necessity of relying on the technical services and advice of the health physics group
- the effects of each organizational component's activities on the overall achievement of ALARA program goals

their responsibility for providing all workers with an awareness of specific safe job practices and ALARA implications

- procedures for evaluating ALARA performance.

Operating Personnel

In addition to the radiation protection orientation required for all employees, on-the-job training for operating personnel in specifics related to ALARA is essential, and whenever possible should include assigning inexperienced personnel to work with experienced staff. Training should include the description, demonstration, and practice of specific actions necessary for radiation control. In addition, each worker should receive some basic information regarding the company's radiation protection programs, along with an introduction to the philosophy and purposes of the ALARA program. Special training sessions in exposure reduction techniques may be especially beneficial to operating and maintenance personnel who routinely enter radiation areas. Training sessions should be personalized and include the introduction of key radiation protection personnel. Finally, optional additional education and training in radiation protection should be made available to all who desire it.

Education and Training Staff

The requirements for an education and training staff will vary widely among DOE contractors. As a result, the content of each individual curriculum will also vary. Large organizations may require one or more full-time professional health physicists in addition to specialists in other areas, such as educational methods and techniques. Smaller organizations may need only current staff members to fill part-time positions for teaching the education and training courses. These persons should be augmented by others familiar with the details of the operations. Generally, the smaller the facility, the higher the percentage of time spent providing or assisting in the training function.

As authoritative sources for decisions, guidance, and assistance pertaining to radiation safety and dose control, as well as ALARA education, some members of the education staff should possess advanced health physics

credentials and broad operating experience. As a minimum, such personnel should be available as resources and as teaching staff.

Qualifications indicating advanced capabilities are certification by the American Board of Health Physics, registration by the National Registry of Radiation Protection Technicians, academic training in health physics, and experience in operational health physics. Other instructors might include persons with direct knowledge of the operations, including design engineers and "hands-on" operators. It is vital that instructors possess excellent communication skills and an interdisciplinary background. The combination of health physics expertise and specific knowledge of the operations along with general knowledge and communication skills is essential to establish the dialogue and coordination that are needed to work with the diverse management groups and operating personnel in an organization. Training records shall be maintained to assist in assuring that training is provided to the appropriate staff at the required frequency and that the program is auditable.

The management staff assigned and committed to direct ALARA radiation safety programs must maintain a central role in and be supportive of the education program. Direct interactions with upper management and a supervisory relationship with the operational health physics specialists or technicians enable health physics management to support an ALARA framework at all levels of the organization.

2.2 REVIEW AND AUDIT

Management responsibilities for reviewing, auditing, and evaluating the ALARA program shall be clearly documented. Documentation should include descriptions of the purpose, scope, and frequency of ALARA program reviews and of techniques for these reviews. Documentation should be clearly auditable.

Evaluation of the ALARA program shall be conducted by an individual or individuals who have no direct responsibility for implementing the program. In some instances, this responsibility may be assigned to the radiation protection or ALARA committee, as long as provisions are made to ensure an objective and unbiased evaluation. The evaluation should be

commissioned by senior management. Personnel conducting it should, for the purpose of the evaluation, report directly to them. The use of independent consultants may be desirable. It may be appropriate to use an evaluation team for large and complex radiation facilities. The individual or the team members conducting the evaluation should, individually or jointly, have knowledge of and experience in health physics, facility operations, design, management systems, and ALARA. A formal report on the evaluation should be issued to senior management. The report should contain an overall assessment of the program and include the findings of the evaluation, areas of strengths and weaknesses, and recommendations for changes and improvements.

2.2.1 Evaluation Frequency

DOE 5480.11 (DOE 1988) specifies that internal audits of all functional elements of the radiation protection program, which includes ALARA, shall be conducted as often as necessary but no less than every three years. DOE Order 5482.1B (DOE 1986a) requires that internal appraisals be reviewed by management for adequacy of performance every three years, or more often, as required. More frequent evaluations may be necessary depending on the particular facility, the inventory of radioactive material, the total dose received, the potential dose, and unusual or unpredicted changes in operational or health physics programs. The findings of previous evaluations may indicate the need for more frequent assessments of the program. The frequency should be related to the need for improvement. In addition to the periodic internal reviews of the ALARA program, quality assurance audits are another management tool to assure that ALARA program activities are adequately documented and are carried out in accordance with written procedures and policies. Quality assurance audits should be conducted at least annually.

2.2.2 Quality Assurance Program

Quality assurance (QA) should be an integral part of any ALARA program. Quality assurance is the total of all actions necessary to ensure that the end result is as planned and desired. Quality assurance includes quality control (which is the testing and verification of performance), procedure implementation, records maintenance, and documentation. The QA program

ensures that records are adequate and accurate and that actions taken with regard to ALARA are appropriately documented and retrievable.

A QA program for ALARA should include as a minimum the following elements:

- a formal QA program document
- organizational independence
- quality control
- design participation
- procurement control
  systematic audits
- tracking of recommendations
- feedback and advice on corrective actions
- appropriate documentation.

The formal QA program document can take many forms, but essentially it includes the charter and procedures for QA. The document should clearly delineate the ALARA responsibilities and authority of the QA function. It should also establish specific procedures by which these ALARA responsibilities are to be carried out.

All QA functions should be organizationally independent of operating functions. In the case of ALARA, those responsible for QA for the ALARA program should be organizationally separate from those responsible for implementing the ALARA program. This does not mean that the latter have no QA responsibilities or functions, but that the line managers responsible for implementing ALARA should not also be responsible for QA audits and evaluations of their own programs. The guidance provided in ANSI/ASME NQA-1, Quality Assurance Program Requirements for Nuclear Facilities (ASME 1986), and DOE 5700.6B, Quality Assurance (DOE 1986b), should be considered.

Quality control (QC) is an element of the total QA program that is often erroneously considered to be synonymous with QA. The QC element is more restricted and is basically concerned with testing and verification of performance and materials. Thus, testing and evaluating a portable survey meter to verify that performance specifications have been met is a QC function and is only one element of the total QA program involving that instrument. The total QA program includes assessing procedures for use of the

instrument, verifying if procedures are followed, calibration, documentation of calibration, repair, and acceptance testing; the list of QA elements can be long.

Audits are essential to QA. A QA audit is a formal examination of certain specific phases of a program to verify that the program is being conducted in accordance with written procedures. Routine QA audits involve the detailed examination of specific activities according to a previously prepared checklist. However, management should recognize that a QA audit verifies compliance to procedures and does not assess the adequacy of the procedures or program in meeting performance requirements.

The results of a QA audit of the ALARA program primarily benefit the program planners and managers. Skilled auditors not only detect departures from recommended procedures but also provide useful recommendations for improved compliance. Thus, the fundamental goals of the ALARA program are better met, and responsible personnel are made aware of possible areas in which the ALARA program can be strengthened.

Quality assurance audits consist of reviewing documentation that demonstrates whether or not established procedures were followed in performing work. Some, if not all, of the following areas are important to health physics in general and are not unique to the ALARA program. All should be subject to review by the QA audits.

- changes, additions, and deletions to manuals, procedures, and program documents
- purchase specifications and procurement documents associated with dose reduction
- laboratory and field notebooks, logbooks, and data sheets
- monitoring and dosimetry records associated with dose reduction
- calibration, test, and evaluation documents
- source inventories and control documents.

Documentation for quality assurance for the ALARA program should include the following:

- formally issued QA policies and procedures
- audit checklists and reports of audit findings.

Policies and procedures may be kept as part of the ALARA manual, but most other QA documents are in the form of loose items in a file. An organized filing system including a method for tracking temporarily removed documents is essential to good documentation and retrievability. A central, permanent ALARA file is recommended, and an established policy on the retention time, microfilming, and protected storage of documents is strongly recommended.

2.3 STAFFING

Appropriate consideration should be given to the personnel and equipment needed to develop and implement an ALARA program. Development and coordination of the ALARA program should be performed in conjunction with management by well-qualified professional staff headed by a qualified health physicist. Implementation will require the support and efforts of all facility personnel. The ALARA staff, typically including the radiation protection organization, should include a sufficient number of health physics technicians and professionals who should be encouraged to maintain and upgrade their skills and to seek certification.

Staff qualifications are to a large extent facility- and assignment-specific. Generally, professional health physics staff will hold, as a minimum, graduate academic degrees in science or engineering; many will have completed graduate level work, usually leading to advanced degrees in health physics or related curricula. Senior staff should have several years of related professional experience. Indeed, appropriate experience in operational radiation protection may be of greater importance than formal education, although the latter should not be overlooked. It is important that the experience be relevant to the types of operations performed at the facility, both for operating and support (i.e., health physics) personnel. American Board of Health Physics certification is a clear indication of the professional competency in applied radiation protection needed for an ALARA program. Technician registration is available through another independent body, the National Registry of Radiation Protection Technologists.

For operating personnel, certification may be demonstrated in a similar fashion. Nuclear certifications are available in various crafts and other occupational specialties, such as quality assurance. These nuclear certifications imply a degree of knowledge and skill with regard to radiological exposure control. An internal system of denoting qualification for radiation work shall be used to ensure that only individuals with appropriate experience are assigned responsibility for tasks with the potential for radiation exposure.

The radiation protection staff is professionally obliged to provide management with a balanced program that takes into consideration not only the radiological aspects of an operation, but also costs, time, and legal and public relations constraints. Moreover, the staff must not lose sight of the fact that the production of the facility is the benefit that justifies not only the radiation exposure but the operating cost as well.

At contractor facilities, staffing requirements for radiological protection and ALARA range from about 1% to 10% of the facility's total staff, with the percentage dependent on both the extent of the nonnuclear activities and the level and hazard of the nuclear operations associated with the facility, as well as on its size. Ordinarily, 3% to 5% is the range at most nuclear facilities. If the ALARA program is ineffective and yet has adequate management support, more or better staff may be needed.

2.4 ORGANIZATION

Given sincere and strong commitment to ALARA by senior management, virtually any organizational structure can be made to work. However, to achieve maximum organizational and operating efficiency, certain constructs are needed. Because there is no "best" or universally applicable organizational structure, an organization appropriate to the operation should be developed by the contractor.

Although organizational structures may vary considerably, characteristics basic to an effective ALARA organization are:

- independence of designated ALARA and radiation protection personnel from operations, research, and engineering functions

- specific and formal assignments of ALARA responsibility
- a sufficiently high reporting level for the ALARA and radiation protection functions to ensure adequate management attention
- a manager trained and experienced in health physics.

Large organizations may also establish an independent ALARA committee to facilitate communication and make recommendations.

2.4.1 Organizational Independence

Organizational independence and a sufficiently high reporting level are vital to an effective ALARA program. A particularly effective organizational scheme combines all the occupational health and safety functions under a single manager who is highly placed in the organization, but there may also be personnel with ALARA responsibilities assigned to the operational component. Another organizational approach is to provide a dual reporting line, making the radiation protection group administratively responsible to the support services group (e.g., for time scheduling and budgeting) but technically responsible to a committee or a staff expert (e.g., for radiation protection). Yet another possibility is to have a separate ALARA review or staff group reporting at a high level in the organizational structure. In any case, the radiation protection and ALARA programs must be given sufficient stature within the organizational structure.

A caveat should be issued regarding inappropriate organization schemes. Organizational structures are to be avoided in which radiological protection is not given adequate voice at a high enough level in the overall organization, or in which it is not free of control by the line manager whose primary attention is to operations.

2.4.2 Assignment of ALARA Responsibility and Authority

Formal assignment of responsibility for the ALARA program should be delegated to a specific individual or organizational component and should be recognized as a major responsibility on which individual performance may be evaluated. Similarly, the overall expectations of higher management for the conduct of the program, the basic time schedule, and the goals to be achieved should be formally identified. It may be necessary to identify an ALARA

coordinator, just as emergency preparedness coordinators are identified. If so, the position and responsibilities of the ALARA coordinator should be clearly identified with respect to the overall contractor organization. The ALARA coordinator need not be given line authority. However, the coordination, evaluation, and planning of ALARA activities are staff or support functions that clearly fall within the scope of responsibilities of the ALARA coordinator. The formal structure for achieving goals, including review and approval statements from the director of the contractor organization to the cognizant line manager, should be included. Basic goals should be established by specific organizational groups where exposure problems are clearly distinguishable. Developing goals must be a function shared with line management.

Clear-cut authority must be granted to personnel whose primary function is radiation protection. (Ultimate authority, of course, rests with the head of the contractor organization, who exercises it through delegation to line management as well as to the radiation protection staff.) Specific ALARA authorities (responsibilities) granted to the health physicist should include the following:

- review and approval of plans for constructing or modifying facilities in which radioactive materials will be used or stored, or in which radiation-generating machines will be located
- issuance, review, and approval of radiation work permits (this implies the review and approval of operating plans and procedures before they are implemented)
- review of operational protective measures to ensure that ALARA goals are met
- approval of the training and qualification of radiation workers.

The above authorities and responsibilities should be clearly delineated in a policy manual or other written policy statements issued by upper management.

2.4.3 Reporting Level

The activities and results of the ALARA program must be reported to upper management to ensure adequate management attention to ALARA. The

results of ALARA audits and reviews must also be reported to upper management. The management level to which ALARA reports are directed must be sufficiently high to ensure independence from operational pressures and to ensure an adequate response to ALARA recommendation and findings. Ideally, the results and progress of the ALARA program should be reported at least annually in a formal report to the head of the contractor organization, with copies to other cognizant management.

2.4.4 ALARA Committee

In large organizations, communication can be facilitated through an independent ALARA review committee acting for (or perhaps even chaired by) the head of the contractor organization and reporting directly to him. Note that this committee can be a general safety or radiation safety committee whose functions include ALARA activities as described below.

The committee should make recommendations to those responsible for conducting the actual programs and also to upper management. These recommendations may eventually become company policy. The committee should receive, as a minimum, the results of all reviews and audits, both internal and external, and should review the overall conduct of the safety program. The members should be qualified to interpret findings from reviews and audits and to make appropriate recommendations to strengthen the overall program. The committee can also arbitrate differences among various organizational components, such as operating and radiation protection groups, and can impartially resolve complaints.

The suggested ALARA committee structure is as follows:

Various relevant technical disciplines in addition to health physics should be represented and should be chosen from departments other than the radiation protection department.

- The individuals chosen should be senior personnel and recognized as experts in their disciplines; technical personnel are in general preferable to management or administrative staff.

The director (manager) of the radiation protection department should be a non-voting member of the committee; for example, he might act as secretary.

- The chairperson should be the head of the contractor organization or an individual appointed by and reporting directly to him/her.
- The use of outside experts, either as consultants or as participating members, should be encouraged.

The ALARA committee should meet at least semiannually; more frequent meetings may be required at large facilities. The committee must be convenable by the head of the contractor organization or the chairperson. Special meetings could result from the initiation of new programs, the occurrence of a serious accident, the recurrence of previously reported incidents, substantial changes in standards or regulations, or preparations for new operations (e.g., operational readiness reviews).

An important function of the ALARA committee is the review and audit of the facility's ALARA program. Accomplishing this task at large facilities might require assigning a qualified health physicist as staff member to the committee, along with secretarial and clerical help, as needed. It is essential that the committee keep accurate records of its deliberations and operations, documenting all significant actions.

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SECTION 3.0

OPTIMIZATION

3.0 OPTIMIZATION

One of the components of the system of dose limitation recommended in the Internal Commission on Radiological Protection (ICRP) Publication 26 is that "all exposures shall be kept as low as reasonably achievable, economic and social factors taken into account" (ICRP 1977). In ICRP Publication 37 (ICRP 1983), this component was referred to as "the optimization of radiation protection." The role of optimization in an effective ALARA program is discussed in this chapter.

3.1 THE CONCEPT OF OPTIMIZATION

Optimization of radiation protection is a process by which the optimal level of radiation protection can be identified and achieved. The optimal level of radiation protection for a particular radiation protection practice depends on many factors, including the cost of the practice, the reduction in risk (dose) from the practice, and the detriment associated with dose. Radiation doses are ALARA only when these factors are properly balanced. If an imbalance exists, either too many resources or too few resources are being spent to reduce occupational radiation doses. Cost-benefit analysis, the optimization method discussed in this chapter, can be used to ensure that proper consideration is given to both the costs of a radiation protection practice and the benefits derived from that practice.

3.1.1 Detriment Associated with Dose

Quantification of the detriment associated with a unit of radiation dose is essential to the cost-benefit process. Clearly, if radiation were not harmful to man, then the optimal level of radiation protection would be zero protection in all cases, and the providing of radiation protection could not be justified because the protection provided no benefit. In contrast, if radiation were harmful only above a certain individual dose threshold (which is the case if only nonstochastic effects are considered), then the optimal level of radiation protection would be the level that ensured that workers would receive doses less than the threshold (this is the concept that is applied to exposure to many hazardous chemicals). Currently, however, occupational radiation doses are believed to deliver small levels of

individual risk. Under the linear no-threshold hypothesis, the risk associated with radiation dose is proportional to dose. ICRP Publication 26 (ICRP 1977) suggests that the risk to an individual is about 10^{-4} per rem, although recent data have suggested that the actual risk may be a factor of two or more higher.

In order to determine how many dollars should be spent to reduce occupational doses, the costs associated with radiation dose can be represented by two components. The first component, termed a, is the detriment associated with the potential health effects of a unit of dose equivalent. Although many estimates for the value of a have been published, the most reasonable estimates suggest that this value is currently about $100 per person-rem (Auxier and Dickson 1981; Waite and Harper 1983; Vivian and Donnelly 1986; Cohen 1984; Voilleque and Pavlick 1982; Cohen 1973). In other words, if only the health effects of dose are considered, no more than $100 should be spent to reduce the collective dose to a group of workers by 1 rem. The reason that more than $100 should not be spent is that the money could be spent elsewhere and have a more positive impact on occupational health. Of course, the value of $100 per person-rem is only an estimate; the true value depends on many parameters that, including the stochastic risk associated with dose, are currently uncertain.

Exposing workers to ionizing radiation is costly in ways other than the associated health risks. Worker doses are subject to limits, and the existence of these limits requires that worker doses be tracked and recorded. When a worker's cumulative dose approaches the limits, additional costs may be incurred to ensure and demonstrate that the limits are not exceeded. Also, various individuals and groups, such as the general public, perceive that the risk of radiation exposure is greater than the risk generally agreed upon by experts. Because of these and other considerations, it is often prudent to spend more dollars to reduce doses to workers than would be optimal if only the health effects of exposure were considered. In these cases, the excess dollars spent would be more than offset by the dollars saved elsewhere. For example, spending dollars to reduce doses to workers who routinely receive doses approaching applicable limits might be justified because this would reduce the likelihood that additional workers would have

to be hired. Similarly, costs incurred by eliminating the exposure of workers to airborne radioactive material might be justified because costs would be saved by avoiding the need to evaluate internal depositions. Alternatively, it may be prudent to permit minor exposures to airborne material in consideration of the reduced efficiency of workers who wear respirators and the higher external doses associated with reduced efficiency. Regarding exposure of the public, the costs associated with reducing routine emissions of radioactive material might be offset by the benefits associated with greater public acceptance of the facility.

One method for incorporating these considerations into optimization analyses is to establish a second component for the costs associated with dose. This component is termed β, which is the non-health-related detriment of exposure to ionizing radiation. Similar to a, the objective health detriment, the units of β are $/person-rem. Unlike the a value, the specific value of β is highly dependent on the application. For example, for applications that involve relatively low routine occupational doses, the value of β is likely to be small. On the other hand, for applications that involve relatively high doses, dose rates, or numbers of workers, the value of β could be high. In these cases, the value of β may exceed the value of a by an order of magnitude or more.

For radiation protection practices that involve significant costs and/or dose reductions and are subject to optimization analyses, careful consideration should be given to the value of β chosen for the analyses. As a minimum, the β value should reflect the importance of personnel and public relations aspects of minimizing radiation exposure. Depending on the facility, the value of β based only on these considerations could exceed the value of a by up to an order of magnitude. While this is unfortunate because it suggests that such considerations are often more important than health considerations in determining the optimal level of radiation protection, the value of β reflects real costs imposed by society on the exposure of individuals to ionizing radiation and should therefore be incorporated into optimization analyses. For applications where other costs are involved in the exposure of persons to radiation (such as the costs that are incurred when worker doses approach administrative or regulatory limits), the value of β

used for optimization analyses should be set correspondingly higher. Section 3.5.3 in this report provides an example of the use of β in optimization analyses.

3.1.2 Role of Optimization in Achieving ALARA

Optimization should be used whenever decisions regarding the implementation of a radiation protection practice will be costly, complex, and/or involve significant dose savings. As a minimum, practices that should involve optimization include facility design and engineering controls. For radiation protection practices not readily subject to optimization, consistency with ALARA can be assured by following the guidelines in this manual.

3.2 OPTIMIZATION USING COST-BENEFIT ANALYSIS

Cost-benefit analysis is thoroughly described in ICRP Publication 37 (ICRP 1983) and is the preferred optimization method if sufficient data are available for its use. Cost-benefit analysis involves the quantification of all variables in monetary terms to determine the net benefit of a radiation protection practice. For a radiation protection practice, the net benefit can be expressed by Equation (1) :

$$B = V - (P + X + Y) \tag{1}$$

where B = the net benefit of the introduction of a practice
V = the gross benefit of the introduction of the practice
P = the basic production cost of the practice, excluding the cost of radiation protection
X = the cost of achieving a selected level of radiation protection
Y = the cost of the detriment resulting from the practice at the selected level of radiation protection (ICRP 1983).

For most applications in radiation protection, this equation can be simplified to determine the optimum level of radiation protection, as seen in Equation (2) :

$$M = X + Y \tag{2}$$

where M represents the costs to society associated with a specific radiation protection practice. A radiation protection practice can be defined as any practice designed to reduce occupational doses, whether it be at the design or operational stage of a facility.

The objective of cost-benefit analysis is to minimize the total cost to society [M in Equation (2)] based on the radiation protection options available. In some cases, numerous options may be available, such as variable thicknesses of shielding that can be used to reduce area dose rates or variable ventilation flow rates to reduce airborne radioactivity concentrations. In other cases, a single option may be available, such as the use of a robotic arm to perform a task that involves transportation of radioactive material. Regardless of the number of options available, the M value for each option should be calculated and compared to the base case M value (i.e., the value if no additional radiation protection is provided). The option with the lowest M value should be considered the optimal option, provided that the option meets applicable limits, standards, and other criteria.

The quantification of the variable Y in Equation (2) can normally be accomplished by determining the collective dose equivalent associated with a radiation protection practice and multiplying by an expression that represents the detriment of a person-rem:

$$Y = (\alpha + \beta)S \tag{3}$$

where a is the health-related detriment of a person-rem expressed in dollars, β is the non-health-related detriment of a person-rem expressed in dollars, and S is the collective dose equivalent resulting from a radiation protection practice. Equation (2) can thus be expressed as:

$$M = X + (\alpha + \beta)S \tag{4}$$

Examples of the use of cost-benefit analysis in radiation protection are presented in Section 3.5.

3.3 COMMON PROBLEMS

Optimization of radiation protection is often difficult because of the many problems that can be associated with its use. The most common problems are the lack of sufficient data to correctly perform the optimization calculations and the uncertainties in much of the available data. In these cases, optimization may have only limited use. Some of the potential problems are discussed below.

3.3.1 Occupational Dose Versus Public Dose

Some radiation protection practices, such as installation of effluent control systems, involve both reduced doses to the public and increased doses to workers. For example, assume an effluent control system that can be installed at a facility would reduce annual collective dose equivalents to the public by 2 rem per year for 30 years (y), the expected lifetime of the facility. Also assume that workers will receive 30 rem installing the system and an additional 30 rem during system maintenance over the 30-y lifetime of the facility. It appears that a cost-benefit analysis would suggest that the system should not be installed, because the benefit to society is zero (60 rem less to the public and 60 rem more to workers), not considering the cost of the system. However, in some situations, reducing doses to the public is given more weight than increasing doses to workers because of considerations other than expected health effects, e.g., avoidance of lawsuits and greater public acceptance of the facility.

3.3.2 Routine Doses Versus Accidental Doses

Some radiation protection practices involve increased occupational doses in order to reduce the likelihood and/or consequences of an accidental release of radioactivity in the workplace or to the environment. For example, at plutonium facilities, glove box gloves are frequently changed to minimize the likelihood of a glove failure that could lead to accidental inhalations of airborne material. While this practice reduces the expected detriment from an accidental release, it often increases the routine occupational doses received by workers who perform the changeout operations. In order to optimize the frequency of glove changeout operations, both effects

must be considered. In these cases, decisions on the proper frequency must often be made based on past experience and applicable standards and guidance.

3.3.3 Future Doses

Many radiation protection practices involve increases or decreases in occupational doses that will occur in the future. For example, consider a facility where a permanent shield could be installed at a cost of $500,000. If installed, the shield would result in the reduced collective dose equivalent to workers of 50 rem per year. The lifetime of the facility is 30 years. According to the principles of cost-benefit analysis, the shield should be installed only if the benefit (reduced occupational doses of 1500 rem) exceeds the cost ($500,000). If the 1500 rem savings were evaluated at a value of $1000 per person-rem, the benefits from the shield would appear to outweigh its cost. However, an important consideration is whether the detriment associated with dose should be discounted. In this case, if the benefits were discounted at a rate of 10% over a 30-y period, their present value would be $472,000, which is less than the cost of the shield.

The controversy surrounding the discounting of future doses is often based on the question of whether health effects should be discounted similar to other costs (equipment, manpower, etc.). As discussed previously, the detriment associated with radiation dose is often dominated by the β term, which refers to costs unrelated to health. Therefore, it is suggested that the detriment associated with future doses be discounted as well as all other costs that will be incurred in the future. Acceptable methods for economic discounting and calculation of present values can be found in Heaberlin et al. (1983).

Another problem associated with the assessment of future radiation doses regards integration of collective dose over large populations. For example, optimization of the design of a waste disposal facility would require the assessment of extremely small doses to many individuals. While some believe that the establishment of a collective dose evaluation cutoff criterion is appropriate to eliminate the consideration of negligible risks to individuals in optimization analyses, this problem is not addressed in this document.

3.3.4 Uncertainties

Probably the most difficult problem encountered when optimizing radiation protection practices is that of the uncertainties in the available data. In these cases, sensitivity analyses on the uncertain parameters can be used to determine the effect of a parameter change on the outcome of the analysis. For example, the analysis could be performed using different values of a person-rem to determine the importance of that parameter in determining the optimal level of radiation protection. An optimization example that includes sensitivity analysis is provided in Section 3.5.

3.3.5 Restrictions on Applying Optimization

Optimal radiation protection practices as identified using optimization methods might not always be practicable because of governing regulations or guidance, public sentiment, or other reasons. For example, consideration must be given to applicable dose or dose rate limits, availability of personnel, and availability of resources. In addition, some radiation protection practices are not amenable to formal optimization because of the lack of sufficient data to perform the analysis. For example, in theory, instrument calibration frequencies can be optimized based on instrument malfunction rates, the specific applications of the instruments, and other variables (Merwin et al. 1986). However, quantifying these variables is difficult, and determining a calibration frequency based on available guidance and standards may be more appropriate.

3.4 SUGGESTED APPROACH

Many radiation protection practices have several options depending on the level of radiation protection desired. For example, several different thicknesses of lead shielding are often available for reducing doses to workers who work in high dose-rate areas. Also, contamination surveys can be performed at various frequencies depending on the potential for an area to be contaminated. In each case, the optimum level of radiation protection is dependent on both the reduced doses to workers and the cost of achieving that level of protection.

The following steps are the minimum required for performing cost-benefit analysis to optimize a radiation protection (dose reduction) practice:

1. Identify all possible options. Include the "do nothing" option as a potential option to determine whether further dose reductions would have a positive net benefit with respect to current practice.
2. For each option, determine both the individual and collective dose equivalents that will result. An option should be regarded as being nonviable if the resulting doses or dose rates violate applicable limits or standards.
3. For each viable option, identify all associated costs and determine the net cost for each option by summing the identified costs. Cost savings should be included in this sum by applying a negative sign (for example, if using a respirator would eliminate the need for bioassay measurements costing $1000, the associated cost is -$1000).
4. Determine the cost equivalent of the doses resulting from each option. (see Sections 3.1 and 3.2).
5. Sum the costs identified in Steps (3) and (4) to determine the total net cost for each option.
6. The option with the lowest total net cost is the optimal option. If the "do nothing" option has the lowest total net cost, then further dose reductions are not reasonable as defined by the ALARA principle.
7. A sensitivity analysis should be performed to determine how the solution depends on the assumptions that are required to perform the optimization analysis. Judgment will be necessary if the optimal solution is highly dependent on the assumptions. Section 3.5.4 describes an acceptable sensitivity analysis method.

3.5 EXAMPLES

The following examples demonstrate the use of optimization techniques for ensuring that occupational doses are ALARA. Each example is successively more complex in order to demonstrate the factors that must be considered in a

typical optimization analysis. A cost-benefit analysis of one or more options for reducing doses to a group of workers is provided in each example.

3.5.1 Example 1

In this example, four workers are assigned to several jobs in a radiation area that will require a total of eight weeks to complete. Each worker will be in the area for an average of six hours per day for five days a week. The dose rate in the area is 15 mrem/h, essentially all of which is attributable to ^{60}Co.

The question facing the health physicist responsible for the workers is whether a shield should be erected between the source of radiation and the work area to reduce the dose rate to the workers. One option is to construct a wall of 2-in.-thick lead bricks, which would reduce the dose rate to the workers to 0.47 mrem/h. The bricks would cost $12,000 to procure. An additional $2000 would be required to procure materials for supporting the shield. Constructing the shield would require two workers eighteen hours each. The dose rate to these workers will be 20 mrem/h while the shield is being constructed. The hourly wage for all workers is $20.

This example demonstrates a common application of optimization principles. Although it will be possible to substantially reduce the doses to the four workers, providing shielding will be costly. The primary question is whether the benefits of the shield outweigh the costs. To answer this question, a cost-benefit analysis can be performed on both options (providing shielding and not providing shielding).

Option 1: No shielding

Both the costs (X) and doses (S) associated with this option must be determined:

X = 0 (no costs are associated with this option)

S = 15 mrem/h X 240 h/worker X 4 workers = 14,400 mrem

From Equation (4) in Section 3.2, the objective of optimization is to minimize the variable M in the equation

$$M = X + (\alpha + \beta)S$$

where a is the dollar value of avoiding the potential health effects of a person-rem, and β is the dollar value of avoiding the non-health-related costs of a person-rem. Assuming that a = \$100 per person-rem and β = \$900 per person-rem,

$$M = X + (a + \beta)S = 0 + (\$1000/\text{person-rem} \times 14.4 \text{ person-rem}) = \$14,400$$

<u>Option 2</u>: Shielding

$$X = \$12,000 + \$2,000 + (18 \text{ h/worker} \times \$20/\text{h} \times 2 \text{ workers}) = \$14,720$$

$$S = 0.47 \text{ mrem/h} \times 240 \text{ h/worker} \times 4 \text{ workers} + 20 \text{ mrem/h} \times 18 \text{ h/worker} \times 2 \text{ workers} = 1170 \text{ mrem}$$

$$M = X + (a + \beta)S = \$14,720 + (\$1000/\text{person-rem} \times 1.17 \text{ person-rem}) = \$15,900$$

Because the objective is to minimize M, the lower value of M for the first option indicates that shielding should not be provided. Note, however, that the values of M for both options are relatively similar; therefore, slight variations in the assumptions could affect the decision. In fact, other cost considerations, such as the resale value of the bricks or the value of having the lead bricks in stock after the work is completed, could render Option 2 as optimal.

One factor not considered thus far is the existence of dose limits. If the shield were not constructed, the four workers would receive a total of 14.4 rem, or 3.6 rem each. Many facilities have quarterly administrative limits that are lower than this value. If this were the case in this example, the cost associated with exceeding a quarterly administrative limit would likely outweigh all other costs and would require that shielding be provided.

3.5.2 <u>Example 2</u>

The next example demonstrates the use of optimization to determine the optimal shielding thickness assuming that variable shielding thicknesses are available.

In this example, all assumptions from Example 1 apply except that variable shielding thicknesses are available in 1/4" increments up to 2" (greater than 2" is not practicable because of stress limitations). The cost of the shielding is $6000 per inch of thickness. The cost of providing support material is $2000 regardless of the shielding thickness. The optimization method for this example is similar to the method used in Example 1. Each available thickness of shielding is treated as a separate dose reduction option and a value for M is calculated. The thickness having the lowest M value is the optimum thickness. Although this problem could be solved using differential equations, as described in ICRP Publication 37 (ICRP 1983), differential cost-benefit analysis is difficult to apply to many applications of optimization. The approach used here is consistent with the general cost-benefit principles described in ICRP 37 and can be used for most applications where more than one radiation protection option is available. The results are provided in Table 3.1.

Table 3.1 indicates that the optimal shielding thickness, based on the conditions described for this example, is 0.75 in. Note that with this shielding, the four workers (and the two shielding installers) would each receive less than one rem during the eight-week period; therefore, administrative limits would not be exceeded at most facilities.

TABLE 3.1. Results of Analysis to Determine Optimal Shielding Thickness for Example 2

Lead Thickness (in.)	X($)	$\alpha + \beta$ ($/person-rem)	S(rem)	M($)
0	0	1,000	14.4	14,400
0.25	4,220	1,000	10.1	14,300
0.50	5,720	1,000	6.78	12,500
0.75	7,220	1,000	4.66	11,900
1.00	8,720	1,000	3.27	12,000
1.25	10,220	1,000	2.38	12,600
1.50	11,720	1,000	1.80	13,500
1.75	13,220	1,000	1.42	14,600
2.00	14,720	1,000	1.17	15,900

The data in Table 3.1 are illustrated in Figure 3.1. The figure illustrates the relationship between the cost of the shielding, the reduction in doses associated with the shielding, and the optimal shielding thickness. The optimal thickness is that thickness where the net cost including the cost associated with the potential health effects is the lowest.

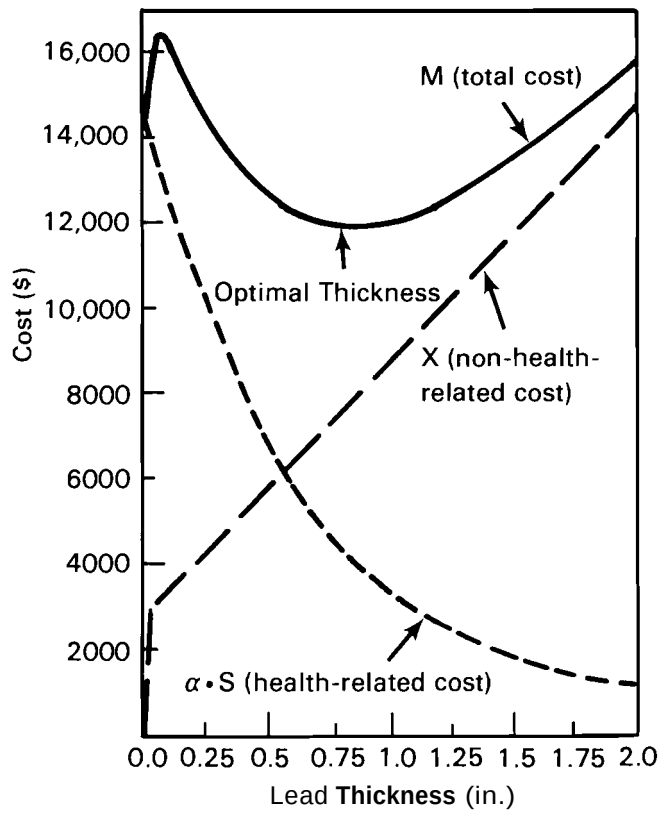

FIGURE 3.1. Cost and Dose Versus Shielding Thickness for Example 2

3.5.3 Example 3

In many cases, the relationship between cost and dose is not linear; that is, it may be more costly to allow a worker who has already received 3 rem in a year to receive one additional rem than to allow a worker who has no previous dose history to receive 1 rem. For this example, the non-health-related costs (β) of a unit of dose equivalent are assumed to increase as individual doses increase. All other parameters are the same as in Example 2.

The specific value of β for individual workers is assumed to lie between \$900, the minimum value for this facility, and \$50,000, the maximum value based on replacement costs for workers who are no longer eligible for work in radiation areas. For this example, the value of β is assumed to be proportional to dose as expressed in Equation (5) :

$$\beta_i = 49{,}100 * D_i/5 + 900 \tag{5}$$

where β_i is the value of β for worker i based on the dose the worker will receive, and D_i is the dose the individual will receive. Therefore, if the work will involve extremely small individual doses, the value of β_i will be about \$900 per person-rem, the minimum value based on the importance of personnel and public relations aspects of minimizing collective dose at this facility. For work involving relatively high individual doses, the value of β_i will be higher than \$900 per person-rem, which reflects the costs associated with allowing workers to receive high individual doses relative to the dose limits.

The optimization equation in this example is thus

$$M = X + \sum_{i=1}^{N} (\alpha + \beta_i)\, D_i \tag{6}$$

where N is the number of workers (six in this example), β_i is the non-health-related cost associated with occupational dose to individual i, and D_i is the dose that will be received by individual i. Summation of the last term in the equation is performed for the six individuals involved with the work. Note that one set of values for β_i and D_i will be applied to each of the four primary workers, and another set of values for β_i and D_i will be applied to each of the two shielding installers. As in Example 2, the optimal shielding thickness is determined by minimizing M. The results are presented in Table 3.2.

Based on Table 3.2, the optimal shielding thickness is 1.75 in. The optimal thickness is higher than that calculated in Example 2 because in Example 3, the non-health-related costs are significant when high individual

TABLE 3.2. Results of Analysis to Determine Optimal Shielding Thickness for Example 3

Lead Thickness (in.)	X($)	a ($/person-rem)	β ($/person-rem) Workers	β ($/person-rem) Installers	S (rem)	M($)
0	0	100	36,000	900	14.4	520,000
0.25	4,220	100	24,000	4,400	10.1	230,000
0.50	5,720	100	16,000	4,400	6.78	110,000
0.75	7,220	100	11,000	4,400	4.66	52,000
1.00	8,720	100	7,200	4,400	3.27	31,000
1.25	10,220	100	5,000	4,400	2.38	22,000
1.50	11,720	100	3,500	4,400	1.80	19,000
1.75	13,220	100	2,600	4,400	1.42	18,000
2.00	14,720	100	2,000	4,400	1.17	19,000

doses are involved. In many cases, these costs may be high enough so that the value assigned to the health-related costs of a person-rem (the objective health detriment) is relatively unimportant. Vivian and Donnelly (1986) have demonstrated that the objective health detriment is rarely a decisive influence in optimization analyses.

3.5.4 Sensitivity Analyses

The results of the optimization examples demonstrated above would be valid if the variables were known with certainty. However, this is rarely the case; many variables can only be assumed and cannot be evaluated with certainty. In optimization analyses, sensitivity analyses of the uncertain variables are essential in determining the degree to which the solution depends on the values assigned to the variables. Table 3.3 below lists the results of Example 3 if certain variables are varied.

The underlined values in Table 3.3 indicate the optimal shielding thickness for each variation from the initial conditions. For most cases, between 1.5 in. and 2 in. of lead is optimum. Therefore, for Example 3, using 1.75 in. of lead to shield the workers would be justified by optimization analyses.

TABLE 3.3. M Value (in $K) for Example 3 Based on Variations from the Initial Conditions

Variation from Initial Condition	Lead Thickness (in.) 0	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00
No variation	520	230	110	52	31	22	19	18	19
α = 100	540	240	110	57	33	24	21	20	20
β_{max} = 10,000[a]	110	54	30	19	15	14	15	15	16
Job duration = 4 weeks	130	66	35	22	17	16	16	17	18
Dose rate (no shielding) = 10 mrem/h	240	110	53	30	21	18	17	17	19
Shielding cost = $2000/in.	520	230	100	49	27	17	13	11	11
Installation time = 10 h/worker	520	230	100	50	28	19	16	16	17

(a) The maximum value of β is $10,000/person-rem rather than $50,0001 person-rem. See the discussion associated with Equation (5).

3.5.5 Other Examples

Optimization can be used at both the design and operational stages of a facility. At the design stage, the design of work areas, ventilation systems, radwaste storage areas, and so forth, can all benefit from optimization analyses. At the operational stage, radiation protection practices designed to reduce occupational exposures below applicable limits and guidelines should be optimized to ensure that the dose reductions are reasonable. In addition, radiation protection practices and programs such as bioassay measurements, instrument calibrations, workplace air monitoring, contamination control, and equipment maintenance can benefit to some degree from optimization. However, in these cases, the relationship between cost and occupational dose is not always known, and relying on established

guidelines and standards may be more beneficial than applying rigorous optimization analyses.

3.6 REFERENCES

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SECTION 4.0

SETTING AND EVALUATING ALARA COALS

4.0 SETTING AND EVALUATING ALARA GOALS

In principle, ALARA is the goal and other goals should not be necessary. In practice, however, subtler goals are required to assist in assuring that the primary goal, ALARA, is achieved. Goals for the ALARA program should be established at the outset of the ALARA program and re-established periodically thereafter. Typically, goals are established and achievement is evaluated at least annually. The goals should be related to specific characteristics of operations or programs and should correspond to real problems. Setting practical ALARA goals depends on how well the ALARA program is understood and can be characterized. Section 4.0 discusses the different types of ALARA goals, methods for achieving the goals, and the periodic evaluation of progress towards meeting the goals.

4.1 SETTING GOALS

Goals should be measurable and realistic and have one or more clearly defined end points. Without a definite end point, achieving and evaluating goals are difficult tasks. Definite end points can prevent the scope of an evaluation from becoming too broad. Broad evaluations may evolve into merely evaluation of goal suitability and not goal achievement. A preestablished means of achievement is desirable, although not a requirement.

Determining realistic goals is best accomplished by a team including representatives from operations, engineering management, and radiation protection. Specifically, personnel responsible for the ALARA program (e.g., the ALARA coordinator, the ALARA committee, and operational health physics staff) and personnel closest to the facility operations (e.g., workers and first-line supervisors) are essential to the process. These persons have the greatest effect on the success of the ALARA program and the attainment of its goals. Upper management support for setting ALARA goals and working toward meeting the goals is also required.

4.1.1 Types of Goals

Goals are based on quantitative or qualitative measures, and may or may not be related to dose received. Reducing person-rem by a specific amount within a specific time period is an example of a quantitative, dose-related

goal. Increasing staff awareness of the importance of the ALARA program by creating an internal ALARA communications network is an example of a qualitative non-dose-re1ated goal, which may indirectly reduce personnel exposure. For example, this could lead to suggestions for changes to accomplish dose reduction.

Quantitative Goals

Quantitative goals can be dose-re1ated or non-dose-re1ated. Dose-related quantitative goals are based on and involve a specific reduction (e.g., percentage or number) in the measures listed below.

- average individual effective dose equivalent for penetrating dose to the whole body
- average individual annual effective dose equivalent for intakes of radioactive material
- average effective dose equivalent by radiation type
- ratio of doses from different types of radiation
- average individual committed effective dose equivalent
- number of workers with measurable internal depositions
- specific organ doses from external or internal sources
- statistical distribution of mean individual dose
- collective penetrating effective dose equivalent to the whole body[a]
- collective effective dose equivalent to complete a given repetitive task
- average individual effective dose equivalent by job classification[a]
- average individual effective dose equivalent by location[a]
- average individual effective dose equivalent by task.[a]

(a) Can also be used as a rate, i.e., collective effective dose equivalent per hour worked.

Many activities and actions that ultimately affect the received radiation dose are not directly measurable using dose. These activities and actions, although not directly dose related, are important to an ALARA program and may result in significant dose reductions. Consequently, non-dose-related measures should be included in the goals established for the ALARA program. Typical measures on which non-dose-related quantitative goals are based are listed below:

- size of radiation area
- size of contaminated area
- airborne-radioactivity hazard index (product of the airborne radioactive material concentration in a room, the volume of the room, and the relative radiotoxicity of the material)
- number of days a positive air concentration is detected
- number of persons exceeding administrative dose levels
- production per unit exposure
- frequency of radiation protection and/or ALARA training
- hours of radiation protection and/or ALARA training
- frequency of prejob briefings
- frequency of skill practices and use of mockups
- number of hours workers spend wearing respiratory protection.

This list may not be entirely applicable to, or complete for, all facilities. An example of a non-dose-related quantitative goal is a 25% reduction in the size of contaminated area within a facility.

Qualitative Goals

All measures previously listed for dose-related- and non-dose-related-' quantitative goals are applicable to qualitative goals. However, qualitative goals do not specify a specific percentage or number reduction associated with a goal. Qualitative goals can also be administrative, such as establishing an ALARA suggestion program with awards (Dionne and Baum 1985); making first-line supervisors more visible in radiologically controlled areas

(McArthur et al. 1984); revising radiation work procedures or training procedures; or establishing a computer-based system for tracking personnel doses, area radiation levels, and contamination levels for high-exposure jobs.

4.1.2 Developing Realistic Goals

Realistic and measurable goals must be developed carefully, with significant consideration given to the interpretation of results when obtained. As stated previously, goals can be based on quantitative or qualitative measures. Quantitative goals are usually more precise and more realistic. However, some ALARA program areas such as organization and training are not meaningfully represented by numbers or amounts and need to be addressed using qualitative goals. Qualitative goals are more subjective and require more carefully defined goal statements and more descriptors to measure the goal end point.

The availability of useful data must be considered when establishing ALARA goals. For example, most dosimetry programs have been developed to meet federal and state regulations. These regulations specify maximum limits, which can be an order of magnitude or more higher than the doses relevant to ALARA. When establishing an ALARA goal based on personnel exposure, the facility's dosimetry program must be able to reliably measure dose in the range of the goal. Factors influencing reliability are the detection capability of equipment, precision of measurements, and accuracy of measurements.

Goals developed for established facilities should be more quantitative because a data base of personnel exposure data, radiation and contamination surveys, air sampling data, and skin contamination surveys will be available to use as a basis for goal development. New facilities with no personnel exposure data or plant radiological condition data will have to base their goals on preoperational ALARA reviews and past experiences at similar types of plants. These goals will likely be based more on qualitative measures.

As previously stated, goal development is best accomplished as a team effort including representatives from operations, engineering management, and radiation protection. Depending on the size of the facility, goals could be developed for the facility as a whole or for individual departments or

processes within the facility. Representatives from operations, engineering management, and radiation protection who are responsible for goal development must seek ideas from management, peers, and subordinates to allow everyone to have input into the goal-setting process.

Established Facilities

An operating facility can base ALARA goals on information obtained from the following sources:

- trend analysis of the dose-related and non-dose-related measures discussed in Section 4.1.1 (e.g., mean individual effective dose equivalent for penetrating dose to the whole body)
- job-specific dose estimates
- experiences at a similar type of facility
- reviews of administrative aspects of the radiation protection and ALARA programs
- reviews of the training programs for the ALARA and radiation protection programs.

The above sources are more fully discussed.

Trend analysis of dose-related and non-dose-related information should take place over a specific time period (e.g., time since last ALARA goals were developed to the present) to identify potential areas of concern. Quantitative or qualitative information can be used in trend analysis. Air sampling data is traditionally amenable to trend analysis, as are personnel exposures. Reliability data and contamination data are also suitable sources of quantitative trend information. Qualitatively, occurrence reports and facility profiles can support trend reviews. The frequency and severity of occurrences can indicate specific operations that must be more carefully controlled. Correlations between facility equipment and types of occurrences point out possible trends that should be constantly reviewed. Such correlations are particularly important because they affect facility design, an area where specific designs and their impacts on operations can only be estimated.

Mahathy, Bailey, and Lay (1984) used trend analysis to identify significant sources of exposure by 1) reviewing radiation incident reports,

2) preparing and analyzing control charts for department and individual exposures, 3) statistical regression analysis of monitoring data, and 4) reviewing individual employee doses to identify employees with nonrandom occurrences of higher than average doses. Based on this analysis, the following three qualitative goals were developed: 1) reduce employee beta exposures at two specific locations, 2) reduce the number of employees exceeding their established plant action level for skin dose, and 3) reduce the number of reported gross alpha air concentrations exceeding a certain limit at two specific locations.

Trend analysis can be assisted by the use of computer data base systems for maintaining individual personnel records, collective dose records, dose records by worker type, dose records by job locations, skin contamination events, airborne radiation levels, and others as identified in Courtney et al. (1984), Stansbury (1984), Paine and Hall (1984), and Gentile, Miele, and Collopy (1984).

Buchanan (1979) presented an interesting application for trend analysis of the effective dose equivalent which is expressed as a rate (i.e., effective dose equivalent per hour worked). This permits direct comparisons to be made among workers on the same task and for different iterations of the same task. Thus, "unsafe" or "un-ALARA" workers and tasks can be identified and appropriate goals and dose reduction controls instituted. Similarly, the use of a collective effective dose equivalent per hour worked (or per hour worked in radiation zones) is a more valid index of trends than merely the collective effective dose equivalent. Thus, this measure may provide certain information and insights not easily attained with other measures.

Information based on job-specific dose estimates can form a basis for developing optimal dose control and, potentially, ALARA goals. As part of the radiation work procedures and ALARA reviews before starting a job, most facilities perform estimates of the total collective dose to the worker for completing a job. Based on this estimate, ALARA goals can be developed (e.g., complete the job with 10% less than the estimated collective effective dose). The validity of this type of goal is highly dependent on the dose estimate calculation. If the estimate is unrealistically conservative,

achieving the goal will have little meaning. The more realistic the estimate, the better the goal.

The ALARA goals can also be based on experiences at similar types of facilities. For example, if Facility A had an excessive number of skin contaminations during a certain operation, Facility B with a similar operation might establish a goal to reduce skin contaminations to a certain percentage lower than that of Facility A.

Reviews of the radiation protection, ALARA, and training organizations can be used to identify specific ALARA goals. Qualitative non-dose-related goals would likely be developed from these reviews (e.g., upgrade the ALARA training for radiation workers).

New Facilities

ALARA goals for a new facility could be based on job-specific dose estimates and past experiences at similar types of facilities, as discussed above for established facilities. The ALARA reviews during the design phase and a preopertional review of the completed facility are also useful in developing ALARA goals. Greene (1987) describes a preoperational ALARA review of the Shearon Harris nuclear power plant. The review took a year to complete and was done by a corporate health physicist and an outside radiological engineer with support from operations and maintenance personnel at the facility as necessary. Detailed checklists of ALARA items were completed for each room or operating area. In addition, photographs of the rooms were taken for historical reference and indexed for future use. The review revealed several inadequately shielded areas. The goal was developed to remedy this situation, and the areas were modified prior to startup. Therefore, the preoperational review was and can be used as a tool to develop ALARA goals.

4.2 METHODS FOR ACHIEVING GOALS

As previously stated, upper management of a facility must support the development and efforts to meet ALARA goals. To achieve goals, the ALARA staff must have the financial backing of management to purchase equipment and supplies or to hire additional staff needed to achieve goals. Methods for

achieving goals (i.e., engineering and design changes, administrative changes, and radiation measurements) are discussed in this section.

4.2.1 Engineering and Design

Many ALARA goals can be met with engineering and design changes such as additional shielding, use of robotics, or equipment relocation. Mahathy, Bailey, and Lay (1984) established an ALARA goal to reduce employee beta exposures at two locations in a gaseous diffusion plant. One specific act accomplished to meet this goal was to use metal plugs to close openings in the UF_6 transfer system that shielded workers from beta exposure. The value of robotics in dose reduction is described in White et al. (1984) and Baum and Matthews (1985). Baum and Matthews also provide information on reducing dose by relocating equipment (e.g., remote readout near a pressurized-water reactor (PWR) seal).

4.2.2 Administrative Models

Administrative methods can be used to achieve optimization of radiation dose control; for example, revising radiation work procedures, conducting more detailed pre-job briefings, using dry runs with "cold" systems, and using photographic techniques and video tapes in the prejob briefing. Mahathy, Bailey, and Lay (1984) identified the following two administrative means to attain their goals: 1) retain discarded UF_6 drain and fill lines for a 6-month period to allow decay of ^{238}U daughter-product activity before cleaning and salvaging these items and 2) use time and distance to minimize personnel exposures to open surfaces of solution containing uranium daughter products or to solid material deposits arising from these solutions.

Coon (1984) described an administrative method to reduce doses to workers who maintain valves and components in high-radiation areas of nuclear power plants. A map showing valve locations is provided at the entry to the high-radiation area. Each valve is tagged with a highly-visible colored tag with the corresponding color also shown on the map. Thus, workers can readily identify the valve they will be working on as they enter the room. Preliminary tests of valve tagging and map system indicated that time for finding valves was reduced by 90%, which will in turn reduce dose to personnel. Dodd and Parry (1984) discussed establishing a program for

photographing high-radiation areas to identify radiation sources and equipment so that workers are familiar with key areas prior to entry. Baum and Matthews (1985) discussed a remote-photography method for PWR steam generator tube-plugging inspection.

4.2.3 Radiation Measurements

ALARA goals can be achieved by proper use of radiation measurements. Mahathy, Bailey, and Lay (1984) used beta-sensitive radiation alarm devices to increase worker awareness of beta sources in order to reduce personnel beta exposures. Hadlock (1981) described a program that characterized background radiation at selected facilities using thermoluminescent dosimeters (TLDs). This program was established to assist in meeting an ALARA goal of no annual personnel whole-body penetrating exposures over 3 rem. Areas of high background radiation identified during the program were then evaluated based on worker time in the area to determine if additional shielding or decontamination were needed. Other measuring devices, such as pocket dosimeters that alarm at preset dose rates and/or doses, and telemetering devices may also be used to alert workers and management to potential dose reduction actions.

4.3 EVALUATING GOALS

An ALARA program should be evaluated in terms of achievement of goals. In general, goals should be evaluated annually. However, certain goals need to be evaluated more frequently. For example, if an ALARA goal is specific to a short-duration high-exposure job, the goal should be evaluated at the completion of the job. In addition to periodic evaluation of ALARA goals, the entire ALARA program including organization and training should be evaluated annually. This evaluation was discussed in Section 2.2.

Evaluation of the goals should be conducted by individuals who have direct responsibility for implementing the ALARA program (e.g., ALARA coordinator, ALARA committee, radiation protection staff). The means by which established goals are measured and assessed is critical to their usefulness both in providing direction to the program and in evaluating program performance. Various techniques use dose-related and non-dose-related measures as indicators of progress towards ALARA goals.

4.3.1 Evaluating Goals Using Dose-Related Measures

The simplest and probably the most common index or measure for evaluating ALARA goals is the average individual effective dose equivalent, which is simply the total effective dose equivalent for all exposed personnel divided by the number of persons exposed. As indicated in Section 4.1.1, a variety of average individual doses or effective dose equivalents can be determined and compared from year to year. However, the average individual effective dose equivalent should be interpreted with caution. The size of the population can be diluted by including workers with a low exposure potential, such as administrative and stockroom personnel. Average individual dose can be distorted by one or a few extraordinarily high exposures. In addition, the collective dose for the activity could increase while the average dose was reduced. Both individual and collective effective dose equivalent should be evaluated. Thus, although a useful ALARA measure, particularly for trend analysis, the average individual effective dose equivalent must be properly applied and interpreted.

The average individual effective dose should be used together with other measures of central tendency, such as the median, and with distributive measures, such as the variance or standard deviation. The standard deviation is particularly valuable in evaluating trends or in comparing means from year to year. Tests of significance such as the t-test and the χ^2 (Natrel la 1966) should be used to ensure that comparisons are valid. Another useful way to use the average individual effective dose equivalent is to determine and evaluate ratios for different types of radiation or exposure. Observing the photon:neutron dose ratio, for example, can provide important information on specific exposure control situations and help indicate where additional dose reduction can occur.

Evaluating effective dose equivalent by job category and by type of work performed may be most revealing from the standpoint of ALARA goal achievement. The distribution of effective dose equivalent by job classification and/or task can be used not only to determine potential problem areas (i.e., to develop ALARA goals) but also to more precisely measure progress towards meeting goals. Evaluating effective dose equivalent distribution by job

category or administrative component may also be effective in identifying ALARA opportunities.

The logical extension to evaluating effective dose equivalent by job category is to evaluate the incurred effective dose equivalent by specific job task. For example, changing a light bulb over a pool type of reactor may be a high-dose task because of the location of the bulb or the manner in which the task is done. By reexamining the task, perhaps on a time-motion basis with the additional dimension of dose, the dose incurred while performing the task could be significantly reduced. Merely looking at dose by job category might not reveal that electricians who perform this task receive much of their exposure from this one task, and this could lead to the erroneous conclusion that the effective dose equivalent received by electricians was ALARA.

Thus far, discussion has been limited to measures of individual effective dose equivalent (i.e., the effective dose equivalent to individuals). Because the basis for ALARA is minimization of potential health effects, which are in turn related to collective effective dose equivalent, some may feel that ALARA should more properly consider only collective effective dose equivalent. However, because the collective effective dose is the sum of all the individual effective doses in the group being considered, optimization of the individual doses should be an appropriate activity for ALARA in addition to assuring maintaining doses below regulatory limits.

4.3.2 Evaluating Goals Using Non-Dose-Related Measures

Other practical ALARA measures are not based on the dose incurred, although they may be related to it and indicate the potential for exposure. A useful but often overlooked non-dose-related measure is the size -- that is, the actual physical area -- of a radiation zone. This measure can be an index of control because, in general, the smaller the radiation zone, the greater will be the attempt to reduce effective dose equivalent rates through engineering means. The area, in units of square meters or square feet of floor space, can be multiplied by the mean, effective dose equivalent rate or boundary effective dose equivalent rate to obtain a useful value for comparison and trend analysis. Areas in which unfixed (loose) contamination exists can be quantified in an analogous manner. These measures may reveal

a great deal about the operational implementation of ALARA principles. However, this approach has limitations in that an extremely small area with a very high dose rate (or a large area with a very low dose rate) might be misrepresented by the numerical value obtained.

The product of air concentration and air volume is another non-dose related ALARA measure. It is dimensionally expressed in units of activity and is simply a measure of how much radioactive material is airborne at a given time. Thus, it is a highly useful measure of potential internal hazard and provides the means to assess ALARA aspects of internal exposure. This measure can be refined by considering the relative radiotoxicity of the radionuclides as discussed in International Atomic Energy Agency (IAEA) Safety Series No. 7 (1961). An airborne-radioactivity hazard index (ARHI) is expressed by

$$ARHI = \sum C_i V t_i \tag{4.1}$$

where C_i is airborne radioactivity concentration from nuclide i, V is room volume, and t_i is relative radiotoxicity of nuclide i. The index can be further extended by factoring in the number of people exposed and the time of exposure.

Progress towards ALARA goals can also be measured in terms of the radioactive material released to radiologically uncontrolled areas. This measure can be expressed not only in terms of total activity but also in terms of specific nuclides and their forms. A release index that includes the quantity and relative hazard of the nuclides released can assist in appraising the degree of ALARA goal achievement. Although activity and dose are related, the ultimate test should be based on the collective effective dose equivalent delivered to the workers at risk.

In addition, other measures indirectly related to dose can be used to gauge the success of meeting ALARA goals. For example, a computer program can track the number and frequency of persons receiving more than a specified administrative dose level over a period of time (e.g., 200 mrem/month or 500 mrem/quarter). As previously stated, Courtney et al. (1984), Stansbury

(1984), Paine and Hall (1984), and Gentile, Miele, and Collopy (1984) provide examples of computer programs that can track such dose information.

When evaluating goals based on qualitative measures (e.g., revising the ALARA training program), it is necessary to define the actions that were taken to achieve the ALARA goal. It is difficult to determine the value of the actions except that action indicates effort. This type of effort provides a means for program development and is part of an integrated ALARA effort that encompasses all areas of health physics and management.

Finally, production per unit effective dose equivalent incurred may be a useful index of ALARA. This measure inherently takes into account changes in numbers and types of both personnel and operations. If production is quantifiable in units of product produced, this measure will be quantitative; however, production may also be quantified in terms of hours worked or work accomplished.

4.3.3 Summary

In summary, the quantitative or qualitative measures discussed in Section 4.1.1 can be used for evaluating ALARA goals. Not all of these measures will be applicable at all facilities, and the list could easily be expanded based on the characteristics and programs of a particular facility. However, as a minimum, it is proposed that the following measures be used to evaluate goals for all facilities, supplemented by others on the basis of need:

- collective effective dose equivalent
- average individual effective dose equivalent
- average individual effective dose equivalent by job classification
- average individual effective dose equivalent by location.
- statistical distribution of average individual dose
- production per unit exposure.

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SECTION 5.0

RADIOLOGICAL DESIGN

5.0 RADIOLOGICAL DESIGN

The basic design criteria for ALARA is the optimization concept itself. If ALARA (optimization) is implemented throughout the design of a facility, no other radiation protection design criteria should be required beyond that necessary to keep exposures below the regulatory limits. The design criteria discussed below are no different than those required for good radiation protection design. Selected criteria are included here to emphasize the importance of the design function in achieving optimization of radiation exposure ALARA. Because a comprehensive treatment of radiological design is beyond the scope of this manual, an extensive bibliography has been included at the end of this chapter.

Radiological design refers to the specific set of features planned for a facility because of the anticipated presence of radioactive material or radiation-generating devices, and implies the planning and development of an idea in contrast to the actual construction and operation of a facility. Although the terms "facility design" and "radiological engineering" are often used interchangeably with radiological design, in this manual the following definitions apply. Facility design refers to a plan for a building or installation as a whole, and thus includes nonradiological as well as radiological design features. Radiological engineering includes review of the implementation of the radiological design (the actual construction) and can also be used in a broader context to include design. The objectives presented in this chapter involve the radiological design of new facilities and the modification of existing facilities.

Optimization of radiation exposure should be considered as early as the designing of buildings that will contain radiation. If the potential for radiation exposure is considered early in designing a new facility, the effort required to ensure ALARA once the facility goes into operation can be minimized. Once a facility is built, changes in shielding or facility layout are difficult to accomplish and often cannot bring about the desired dose equivalent rates without considerable added cost and loss of usable work space. In many cases, modifying existing facilities presents a major challenge to the radiological engineer, because the need to avoid impact on

existing programs may restrict the number of options available. Therefore, the design of shielding and work spaces for new facilities should permit the later installation of additional shielding to accommodate anticipated increases in workload.

This chapter discusses design review responsibilities, first in new facilities (including design criteria and development, building layout, methods of contamination control and ventilation, waste removal systems, and designing to account for abnormal conditions). Then, the design review criteria for modifying existing facilities are covered.

5.1 DESIGN REVIEW RESPONSIBILITIES IN NEW FACILITIES

To meet satisfactory ALARA design objectives, it is necessary to closely integrate the various disciplines responsible for a new building. When planning for a new building is initiated, a design review team composed of specialists in engineering, maintenance, operations, and safety (including ALARA) must be assembled to ensure the continuity of design and enable the free and open discussion of plans and needs. The primary function of this team, however, is to review and verify the adequacy of the design. The team needs to establish that the scope of the work to be performed is as defined in terms of work purpose, proposed inventories, and expected building life.

Specific attention to radiation protection design features should be evident in the plans. A well-developed design should minimize conflicts between the safety features and the operations and maintenance. Representatives from maintenance as well as process or research operations should evaluate the design's efficiency and the adequacy of the planned equipment and processes, from the standpoints of production and radiation control.

The radiation protection and/or ALARA representative(s) should be qualified to provide an overall review of the facility design and should evaluate and approve the completeness of the designed safeguards, including redundancy, fail-safe features, interlocks, and alarms. They should also assess and approve the features of the design to assure provision of an ALARA working environment. The radiation protection and/or ALARA representative(s) should, as a minimum, perform the following tasks in reviewing facility designs:

1. Review the general facility layout, considering traffic patterns, radiation zoning, change room location and size, adequacy of personnel decontamination facilities, location of fixed survey equipment, and provision of adequate space for anticipated maintenance needs.
2. Verify that design criteria are consistent with recognized standards and guides and with applicable DOE guidance for ALARA.
3. Verify that the ventilation system design provides the required level of protection from airborne contamination with particular attention to air flow patterns and locations of air inlets and exhausts.
4. Evaluate and confirm the adequacy of plans for controlling effluents and wastes, to ensure that releases to the environment are ALARA.
5. Evaluate and confirm the adequacy of specific radiological control devices for reducing occupational exposures, including hoods, glove boxes, shielded cells, decontamination areas, and remote operations.
6. Verify that shielding meets ALARA requirements, and coordinate shielding calculations and design to meet ALARA requirements.
7. assess the adequacy of planned radiation monitoring and nuclear criticality safety instrumentation, including considering whether the proposed instrumentation is appropriate for the radiation types and intensities and whether it has suitable redundancy and capability for operation, both under normal operating conditions and in emergency situations.

5.1.1 ALARA and Radiological Design Criteria

As stated previously, ALARA is optimization. Designing to ALARA uses the cost-benefit process of optimization to achieve ALARA. It is important to maintain a separation between those concepts related to keeping radiation exposures below limits and those aimed at optimization or ALARA. Most radiological design criteria, including those discussed here, are a mix and are important to both concepts.

The use of pre-established radiological design criteria has several practical advantages. Foremost is the relative ease with which a design engineer can apply the criteria in developing a facility design. It is a

relatively simple matter, for example, to design a shielding system that will reduce the radiation intensity to a given fraction of the maximum annual dose limits. Also, design additions and changes made during the design phase are more cost-effective than those attempted at other times.

U.S. Department of Energy (DOE) 5480.11 (DOE 1988) recommends that "Radiation exposure rates in work areas should be reduced to ALARA by proper facility design and equipment layout." It also states that "the primary means for maintaining exposure ALARA shall be through physical controls such as confinement, ventilation, remote handling, and shielding."

For design criteria, DOE has issued the following design objectives. For areas that are continuously occupied, radiation areas shall not exceed 0.5 mrem per hour. Exposure rates in other areas not continuously occupied shall be controlled by design so that potential exposures to a radiation worker will not exceed 20% of the standards [8a(1) and (2)] listed in DOE 5480.11. For internal radiation exposure, the design objective is to avoid inhalation of materials during normal operating conditions to the extent (reasonably) achievable.

Incorporating these criteria into optimization of the design must include consideration of estimated occupancy times, number and frequency of persons exposed, protective clothing, and collective dose. Thus, additional reductions in personnel exposures (equated to benefits to personnel) may be warranted beyond the design criteria. Discussion on optimization and cost benefit is found in Section 3.0. However, application of the design criteria presented here should result in consistent, plant-wide facility design doses that restrict actual doses to levels significantly below applicable standards.

5.1.2 Design Development

The assigned radiation protection group should have approval authority over each step in the design of new facilities. The normal design process at DOE contractor facilities involves the following major steps, each of which should have radiation protection review, input, and approval:

- preconceptual design
- functional design criteria

- conceptual design

  Title I - preliminary design

- preliminary safety analysis report or safety assessment document
- Title II - detailed design
- final safety analysis report or safety assessment document
- assessment to ensure that construction has achieved the required safety objective(s)
- documented operations safety requirements

  operational readiness review.

During these steps, the radiation protection group can streamline its work by looking for key features in building layout, ventilation, contamination control, and waste removal systems, and in built-in contingencies for abnormal conditions. Each of these areas of concern is considered in the following sections.

5.1.3 Building Layout

Building layout is an important factor in controlling personnel exposure by regulating the flow of personnel and material. Proper layout reduces casual or transient exposures to radiation fields by segregating heavily used corridors and the work areas of nonradiation workers from the areas of high radiation and contamination exposure. The layout should effectively limit occupational dose to areas where the performance of an assigned task requires some degree of radiation exposure.

An acceptable technique for achieving proper building layout is to establish a system of sequential areas. This concept is frequently used because it is adaptable for the physical control of external and internal dose equivalents. In addition, the design is an excellent precursor to planning and establishing operational radiological control areas.

Two major types of areas are included in any nuclear facility: uncontrolled areas and controlled-access areas [Note that each of these terms does not have the same meaning as similar terms used in DOE 5480.11 (DOE 1988)]. Uncontrolled areas are normally places to which public access is restricted

but where direct radiation exposure is not necessary for job performance, such as the work areas of administrative and nonradiological support personnel. These areas include conference rooms, file rooms, clerical and other support offices, lunch rooms, and rest rooms. Controlled-access areas are normally those areas controlled for purposes of radiation protection. They include various building areas in which individuals may receive dose equivalents that are higher than those normally received by nonradiation workers. The two types of controlled access areas are contingent areas and radiation areas.

Contingent areas are corridors that are adjacent to, or connect with, areas that contain radioactive materials, change rooms, emergency decontamination facilities, or special offices for radiation workers. Contingent areas should contain offices only if the facility design criteria dictate that the offices must be near radiation areas. The primary functions of contingent areas are to control contamination and to isolate controlled areas from uncontrolled areas. Contingent areas can provide for moderate direct control of external doses. Radiation doses in contingent areas resulting from residual radiation that penetrates the wall shielding and wall openings should be subject to optimization. Direct radiation doses in contingent areas should result only from the intermittent transfer of radioactive materials.

Radiation areas, the second type of controlled access area, are areas in which direct exposure to radiation can occur. There are generally four types of radiation areas:

- general operation and laboratory
- process operation
- remote operation
- isolation.

Radiation designs should provide for anticipated exposure risk by including analysis of the tasks and processes that occur in these areas, the anticipated exposure rates for the area, and the proposed inventories of radioactive materials. Moreover, the numbers of workers and the amount of time they are expected to spend in the area should be taken into consideration.

For example, general operation and laboratory areas consist of those areas with small or moderate inventories of radioactive materials. Examples are general radionuclide research labs, rooms containing properly shielded x-ray diffraction and spectroscopy units, and operation areas with low contamination and low dose-rate potential.

Work in process operation areas, however, typically involves more radioactive material than does work in general operation areas. Examples of process operation areas are glove box and hot-cell operating areas, control areas for high-exposure rooms, and selected areas of accelerator facilities where experiments with moderate dose-rate or contamination potential cannot be remote-controlled.

It is important in building layout to minimize simultaneous exposure from multiple sources at locations where maintenance personnel may be required to work. Similarly, individual work stations should be shielded from one another if work by one individual may expose others in the same area to unnecessary exposure.

Functions in remote operation areas are usually remotely or automatically controlled. Occupancy in these areas is predominantly for process monitoring or the adjustment of operations occurring in areas of high hazard and forbidden occupancy. Examples of this type of area are hot-cell service and maintenance areas, and transfer areas where highly dispersible materials of high-dose-rate are entered into the process system or hot cell.

Isolation areas include areas with high dose rates or airborne contamination levels. Unauthorized and unmonitored entry is forbidden in these areas, and design features shall prevent the unauthorized entry of personnel. All personnel are prohibited from entering when conditions in the area present an immediate hazard to human life. Physical controls are required to limit doses when these areas are occupied.

Within radiation areas, contamination should be limited as follows:

- Contamination levels in occupied radiation areas should not exceed established in-house standards.

- Higher contamination may be allowable in isolation areas when unauthorized entry is prohibited by physical barriers and locks or interlocks.
- Contamination in one area should not result from minor or moderate accidents that occur in any other radiation area.

Outside radiation areas, radioactive surface contamination should not exceed the minimum detectable levels achievable with state-of-the-art portable detection instruments.

5.1.4 Contamination Control

In facilities where unsealed sources are used or where loose contamination may be present, design features should be incorporated to prevent the buildup and spread of contamination. One preventive measure is to eliminate surfaces from which material can be resuspended (e.g., scaffolding, open rafters, hanging light fixtures, cable runs). Of particular importance in design to facilitate contamination control is the facility ventilation system, which should adequately diffuse the air so that resuspension is minimized.

5.1.5 Ventilation

The following criteria should be used to design controls for limiting exposures to airborne radioactive materials:

- The annual average concentration of airborne radioactive materials within radiation areas, at all locations normally accessible to personnel, must be kept ALARA.
- Areas with significant concentrations of airborne radioactive materials should be provided with physical barriers to prevent the entry of persons who are not wearing respiratory protection.
- Room air may be recirculated if adequate filtration and monitoring are provided. However, recirculation from an area of higher contamination to an area of lower contamination shall be prohibited.
- Air sampling and monitoring should be provided for the detection and measurement of airborne radioactive material.

Under abnormal operating conditions, a ventilation system should be a major means for controlling internal radiation doses in occupied areas. The primary radiological function of a ventilation system is to reduce the internal depositions resulting from abnormal conditions or from accidents that generate airborne radioactive materials outside normal containment. Thus, ventilation systems have two tasks: to direct airborne contamination away from personnel and to provide an adequate method to recontain any airborne radioactive materials that are accidentally released. Key ventilation systems in a radiological facility must be provided with emergency power to assure continued operation when normal power is lost.

To attain these objectives, ventilation systems must have two essential features: 1) appropriate pressure differential between different areas and the outside and 2) high-efficiency particulate air (HEPA) filtration.

A system of pressure differential should be used to govern the flow of any airborne radioactive material that escapes containment. Similar areas do not always require identical ventilation characteristics, especially pressure differential and filtration. Ventilation design criteria need to accommodate a measure of flexibility, as this is essential for localizing and containing radioactive aerosols.

Isolation areas shall always have the least pressure in a facility (relative to the outside atmosphere). A recommended pressure difference between isolation areas and adjacent areas is at least 0.5 in. water gauge (WG) (Burchsted, Fuller, and Kahn 1976). The exhaust volume rate in the isolation area should be at least 10% of the actual room air volume per minute.

Recommended pressure differences between any of the other types of controlled areas should range from 0.1 in. WG to 0.5 in. WG (Burchsted, Fuller, and Kahn 1976). A gradient should be established, on a facility and room basis, so that the lowest pressure and exhaust collection points are located in areas with potentially dispersible material.

Single-stage HEPA filtration is recommended in areas where air contamination from particulates is not expected except during a severe accident. Multistage HEPA filtration is advisable for facilities that contain

radioactive materials in a dispersible form and in facilities, areas, or containment boundaries that contain unsealed, highly radiotoxic material. Each stage must be designed and located to allow for independent testing as specified in ANSI/ASME-N510 (ASME 1980).

The proper design of the ventilation system permits filters to be changed easily and with a minimum potential for the release of radioactivity and worker exposure. The design shall provide the capability for in-place testing of the filtration system. The design should allow for continuous particulate sampling before the first testable stage and after the last stage, to provide direct evidence of filter performance. Areas with a high potential for airborne radioactivity may require sampling between intermediate stages to verify the performance of each stage.

5.1.6 Waste Removal Systems

Locations for the temporary storage of radioactive wastes must be designed into both the building plan and the plan for each laboratory room or individual radiation area. Laboratory areas should be designed with a special area for waste accumulation. This area should be removed from the generally occupied areas of the laboratory. Special attention should be paid to fire prevention, spill control, and (if necessary) vapor or odor control.

Laboratory or operating areas should not be prime areas for bulk waste storage. Instead, all major facilities should be designed with a special bulk storage area. This area should be located so that wastes being removed from the building will not have to be transported along major personnel traffic routes or through uncontrolled-access areas. To prevent accumulations of waste in operating areas if normal disposal methods are temporarily interrupted, the waste storage area should be large enough to accommodate twice the expected volume of waste.

Other recommendations pertaining to waste removal systems include the following:

- When transporting liquid radioactive waste by pipes, the pipe route should be isolated from uncontrolled areas.
- When transporting potentially contaminated air, the exhaust duct route should be isolated from uncontrolled areas.

- Minimize distances over which moderately and highly radioactive wastes are transported from operating areas to disposal points.
- Design drain basins, curbs, and catch or retention tanks for efficient and complete drainage.
- Install monitoring systems to detect any leaks or spills in areas where drainage or retention is unattended or is remote-controlled.
- Install fire-suppression systems in all areas where combustibles may accumulate or be stored.

5.1.7 Abnormal Conditions

Although discussions on ALARA design review are usually concerned with normal operating conditions, the same principles should be applied when designing a facility to handle an abnormal condition. Specifically, the primary criterion for mitigating the impact of an off-normal condition is that the failure of a single component shall not result in an unacceptable consequence and should not result in an undesirable consequence (two contingency rule).

An unacceptable consequence is defined as an accidental criticality event or radiation exposures or radioactive material release in excess of the limits in DOE 5480.11 (DOE 1988). Undesirable radiological consequences include radiation exposures in excess of administrative limits, loss of containment or confinement of radioactive materials, and skin contaminations.

Radiation exposures should also be maintained ALARA during a facility accident when unacceptable consequences, as described above, occur. Good radiological design can significantly decrease worker and environmental exposures to radiation. Specific items to consider are accessibility to process areas and safety and assessment equipment, habitability of control rooms and emergency facilities, and means for limiting radioactive material releases.

5.2 DESIGN REVIEW RESPONSIBILITIES IN MODIFICATIONS TO EXISTING FACILITIES

Proposed modifications to existing buildings should be reviewed and approved by the ALARA committee or ALARA coordinator prior to initiating any

construction activity. The extent of the design review required depends upon the extent of the modification. Major modification may require all of the steps involved in design of new facilities and may therefore require the same or additional attention. The radiation protection or ALARA representative on the design review team has the same responsibilities as those previously listed for new facilities, plus the following responsibilities that are created when an existing facility is being upgraded:

- evaluating the modification design to verify that radiation exposures will be kept ALARA during the modification process

  assessing the impact of an interruption in utilities

- assessing the impact of the modification on existing radiological control devices and instrumentation, including shielding, interlocks, barriers, and ventilation

- evaluating and verifying the adequacy of temporary radiological controls (such as greenhouses and special waste containers) for modifications in contaminated areas.

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SECTION 6.0

CONDUCT OF OPERATIONS

6.0 CONDUCT OF OPERATIONS

Applying ALARA principles to field work performance is the ultimate purpose of the ALARA program and effort. The operational application of ALARA design, engineering, planning, and administration results in maintaining radiation exposure to workers as low as reasonably achievable. The operational application of ALARA requires the cooperation and coordination of numerous functional groups, including radiation protection, operations, maintenance, planning and scheduling, training, engineering, and administration.

Previous sections of this manual defined and explained the philosophy of ALARA and the management and organization considerations that best support its effective implementation. Responsibilities for developing and coordinating the ALARA program, providing training, making measurements, providing surveillance and consultation, and performing program audits may be assigned to specific individuals or groups. However, the primary control of radiation exposures remains with the individual and with the individual's immediate supervisors. In most facilities, a major part of radiation exposure is received during maintenance, handling of radioactive wastes, in-service inspection, refueling, and repairs (Ilari, Horan, and Franzen 1980). These activities are performed primarily by maintenance and operations personnel, with assistance from support staff. The supporting staff may include personnel from health physics, quality assurance, engineering, and training. With the diversity of disciplines and skills involved, it is necessary that work activities be closely coordinated and that management support and cooperation be maintained.

This section focuses on applying ALARA principles to the work performance in the field. Both normal and emergency operations are discussed. The information in this section is not intended to be an exhaustive discussion of routine and emergency health physics practices but rather a review of key health physics information necessary to develop and implement an ALARA program. For more information on health physics practices, the reader is referred to the DOE series of health physics manuals of good practice which includes the following publications and drafts:

Health Physics Manual of Good Practices for Accelerator Facilties (McCall et al. 1988)

- Health Physics Manual of Good Practices for Uranium Facilities (Rich et al. 1988)
- Health Physics Manual of Good Practices for Plutonium Facilities (Faust et al. 1988)

Health Physics Manual of Good Practices for the Prompt Detection of Airborne Plutonium in the Workplace (Mishima et al. 1988)

Health Physics Manual of Good Practices for X-Ray Generating Devices and Sources at DOE Facilities - DRAFT[a]

- Health Physics Manual of Good Practices for Tritium Facilities - DRAFT[b]
- Health Physics Manual of Good Practices for Radiation Protection Training - DRAFT[c]
- Expert Group Recommendations on Implementation of DOE Orders for Internal Dosimetry (DRAFT)[d]
- Operational Health Physics Training (DRAFT).[e]

Several of these manuals in draft form will be published concurrently with the ALARA manual.

(a) Selby, J. M., and J. G. Stephan. 1988. Health Physics Manual of Good Practices for X-Ray Devices and Sources at DOE Facilities - DRAFT. Pacific Northwest Laboratory, Richland, Washington.

(b) Anderson, H. et al. 1988. Health Physics Manual of Good Practices at DOE Tritium Facilities - DRAFT. Mound National Laboratory, Miamisburg, Ohio.

(c) Robinson, J. et al. 1988. Health Physics Manual of Good Practices for Radiation Protection Training - DRAFT. Idaho National Engineering Laboratory, Westinghouse Idaho Nuclear Company, Inc., Idaho Falls, Idaho.

(d) R. Hall, Chairman, Savannah River Plant, and D. R. Fisher, Pacific Northwest Laboratory, are contacts for the draft health physics manual of good practices involving internal dosimetry.

(e) Moe, H. J., and E. J. Vallario. 1988. Operational Health Physics Training - DRAFT. ANL-88-26, Argonne National Laboratory, Argonne, Illinois.

6.1 NORMAL OPERATION

Fundamental to any ALARA program are the measurement of personnel doses (personnel dosimetry) and the characterization and quantification of radiation exposures in the field (radiological surveys). For ALARA purposes (e.g., trend analysis), measurements need to be accurate and comparable. The comparability of measurements, which may extend over a period of years, implies a degree of precision and accuracy of measurement that permits two or more data points to be compared with a high degree of confidence.

Occupational and environmental radiation control measures should be applied to ensure that work with radioactive materials is carried out in the safest manner that is reasonably achievable. Occupational, nonoccupational, and population exposures should be minimized by means of engineered and administrative control mechanisms. This section concentrates primarily on occupational radiation control measures. An additional ALARA guidance document supported by DOE will cover environmental radiation control measures.

Adequate planning and preparation is necessary before beginning work in radiation areas to maintain worker exposures ALARA. Of primary importance to the ALARA program are training of personnel, scheduling work, briefing and debriefing workers, and documenting and analyzing historical data and work experiences.

6.1.1 Personnel Dosimetry

Accurate and precise characterization of personnel doses is necessary to measure progress towards ALARA goals. The following discussion provides guidance for using external and internal dosimetry as tools to maintain radiation doses ALARA.

Dosimeters must be appropriately worn on the person in order to approximate the exposure to the individual. The location of the dosimeter on the body, the uniformity of the field of exposure, and the characteristics of the dosimeter (e.g., sensitivity to environmental effects) all affect its response and must be considered when evaluating personnel dose assessments.

Dosimeters should be appropriate for the kinds, energies, and intensities of the anticipated radiation fields, should have adequate detection capability and precision, be convenient to wear, provide accurate reliable

information, and be unaffected by environmental parameters. The use of such devices provides measurement of individual radiation exposure as well as a dependable data base for planning or evaluating ALARA goals and dose optimization efforts. In some instances, dosimeters may not be the best method, or even a suitable method, for radiation exposure control because they provide after-the-fact information. Dosimeters used for legal purposes should not be used for control if the control use changes the frequency of processing. Real-time exposure information (e.g., self-reading dosimeters) may be more useful in reducing doses.

The most common external radiation exposures are to beta and photon radiation. The two devices normally used for measuring whole-body exposures from these radiations, photographic film and thermoluminescent dosimeters (TLDs), can provide a useful estimate of individual external exposure. Unfortunately, with the present state of the art, it is not possible to obtain meaningful organ doses or the dose equivalent index. However, beta-photon dosimeters that measure both nonpenetrating (i.e., 7 mg/cm2 depth dose) and penetrating dose are available; the latter is ordinarily obtained for a 1-cm depth in soft tissue. In field situations, dosimeters for non-penetrating radiations still have limited capability. Knowledge of the field (i.e., the ratio of penetrating dose to nonpenetrating dose) can be of great value in ALARA programs, indicating the origin of the exposure and, hence, how to minimize it.

A diversity of whole-body neutron dosimeters is in use among DOE contractors. In large measure, this diversity is due to the difficulties inherent in obtaining a dosimeter that provides a reasonably accurate dose response over the wide range of neutron energies encountered in the field. In general, personnel neutron dosimetry is accomplished by one or a combination of the following:

- nuclear track emulsions
- TLDs
- track etch
- $(\eta, 7)$ reaction with film or TLD

- measuring dose equivalent rates with survey meters and assigning a dose equivalent based on stay-time calculations.

Recent work in developing neutron dosimeters has shown the combination thermoluminescent/track-etch (TLD/TED) dosimeter to be the neutron dosimeter of choice. Implementation of this combination dosimeter is imminent at DOE facilities where the potential exists for significant neutron exposures to some portion for the work force.

The ALARA program should consider not only whole-body exposures but also controllable exposures to individual organs or portions of the body. For external exposures, the skin and the lens of the eye frequently require special consideration. It is possible that the lens of the eye could receive a greater dose than the whole body when a person is working behind a shadow shield or if the head is otherwise exposed, and this risk should be evaluated. If the risk is significant, the exposure should be monitored with a dosimeter worn in an appropriate location (e.g., clipped to the safety glasses).

Film badges should meet the criteria specified in American National Standards Institute (ANSI) Standard N13.7 (ANSI 1983). Although no comparable standard exists for TLDs, much valuable information is available in ANSI N545 (ANSI 1975), which refers to the environmental applications of thermoluminescence dosimetry. Neutron dosimetry should be in conformance with ANSI N319 (1976). Personnel dosimeters need to be routinely calibrated and maintained to meet the requirements of the DOE Laboratory Accreditation Program (DOELAP) for personnel dosimetry as found in DOE 5480.15 (DOE 1987a).

Listed below are technical requirements offered as guidance in selecting dosimeters. Adherence to this partial listing of criteria should aid in developing a data base suited to ALARA comparisons and trend analyses. Typical dosimetry criteria are:

- range: 10 mrem to 1000 rem (beta-photon)
  100 mrem to 1000 rem (neutron)
- nominal overall accuracy in field: ±30% (photons); ±50% (beta, neutrons) [includes error from angular and energy dependence]
- detector capability: the larger of 10 mrem or ±10% of dose level

- precision (laboratory): ±5% (1a)
- radiations detected: beta, photon, and neutron, as required, in mixed fields; should categorize beta-photon radiations by penetrating (soft-tissue depth dose) and nonpenetrating (<7 mg/cm^2)
- shelf life: >1 yr
- wearing location: constant, consistent, and on the portion of the trunk where exposure is most representative of the whole-body exposure
- resistance to environment: temperature, humidity, light, and handling effects.

Internal radiation doses are caused by radioactive materials within the body. Even a small amount of a radionuclide within the body may provide a significant dose to the specific organ in which it concentrates. Although internal concentrations of radionuclides are ordinarily evaluated by radiochemical assay of excreta (i.e., urine or feces) or by large, sophisticated, and expensive whole-body counting systems with low-background capabilities, simple monitoring systems have been devised to detect relatively large amounts of activity in vivo. These systems include shadow shield in vivo counters, thyroid counters, and lung counters.

With the implementation of DOE 5480.11 (DOE 1988), facility management will have to assure that the annual effective dose equivalent from both internal and external sources (retrospective) received in any year by an occupational worker does not exceed 5 rem and that the workplace is operated within the 5 rem committed effective dose equivalent guidance. To meet this requirement, some facilities may need to perform additional air sampling or monitoring of the workplace to determine more accurately the air concentrations in worker zones. In addition, bioassay sample frequency may need to be increased to better quantify internal effective dose equivalent. ALARA programs should use this additional air sampling and bioassay data as another measure to evaluate program progress.

Periodic whole-body counts, with frequency determined by program requirements, may provide assurance that the safety program is operating properly and may provide data for trend analyses. Although routine radio-

urinalysis and other bioassay techniques can be used to verify the effectiveness of field operations, these programs, like external dosimetry programs, provide an after-the-fact indication of exposure. Bioassay or in vivo counting should be used to support positive dose reduction techniques, such as planning, design, and before-the-fact measurements and surveys, and should be supported by routine measurements of airborne radioactivity concentration and ambient radiation levels.

6.1.2 Radiological Surveys

The measurement of radiological conditions in the field is essential to establishing a data base from which to operate an ALARA program. Survey information can aid in dose minimization efforts during the initial design of a facility, during operations, and during facility modification. Confidence in the data base should stem from confidence in survey personnel, uniform survey methods and locations, and survey instrumentation.

Radiation survey methods should be designed with ALARA concerns in mind and should lead to accurate data being collected efficiently, with minimum dose to the surveyor. Sources of exposure should be accurately characterized during each survey.

Surveys should be performed according to established procedures. Procedures approved by management offer the following advantages: 1) management is given indirect oversight and control of day-to-day operations without extensive supervision; 2) the opportunity for planning and evaluating the safety of a task is assured, including an ALARA review; and 3) the survey program is more consistent, thus aiding in obtaining reproducible results.

Survey frequencies should be adequate for personnel protection purposes. Continuous monitoring may be required where exposure rates change frequently or where ambient radiation levels are high. Follow-up surveys are a good practice, and additional survey data should always be procured to assure the protection of personnel. Surveys should be made before work is begun in any radiation area. The information obtained provides the basis for an ALARA review of proposed work activities before any workers are exposed and for the definition of radiation protection requirements. Follow-up surveys also

should be performed after the completion of the job to assure that radiological conditions are acceptable and documented.

Surveys should be made after facility modifications and after a change in operations. These surveys should verify that the radiological conditions are consistent with predictions made during the ALARA review.

Survey equipment should have certain characteristics to permit the efficient gathering of information. The most important requirement is reliability. Instruments should be dependable and provide accurate, reproducible readings. Performance and calibration criteria for survey equipment are found in several American National Standards Institute reports - ANSI N317 (ANSI 1980), ANSI N323 (ANSI 1978), ANSI N13.1 (ANSI 1969), and ANSI N42.18 (ANSI 1974). Other developments include draft ANSI performance standards for portable health physics instrumentation use in normal work conditions,[a] portable health physics instrumentation use in extreme environmental conditions,[b] and portable health physics air monitoring instruments.[c] Kenoyer et al. (1986) reported the results of testing selected instruments against draft ANSI N42.17A.[a] General requirements are noted by instrument type below.

- Portable instruments should be lightweight, simple to use, and simple to read. Because the surveyor is usually exposed to the same radiation field as the instrument measures, efforts to minimize survey times will aid in minimizing personnel doses. In addition, if high-radiation areas are being monitored, instruments with extendable probes should be used.

(a) American National Standards Institute (ANSI). 1988. Performance Specifications for Health Physics Instrumentation - Portable Instrumentation for Use in Normal Environmental Conditions. Draft ANSI N42.17A-D9, American National Standards Institute, New York. New York.

(b) American National Standards Institute (ANSI). 1987. Performance Specifications for Health Physics Instrumentation - Portable Instrumentation for Use in Extreme Environmental Conditions. Draft ANSI N42.17C-D4, American National Standards Institute, New York, New York.

(c) American National Standards Institute (ANSI). 1987. Performance Specifications for Health Physics Instrumentation - Occupational Airborne Radioactivity Monitoring Instrumentation. Draft ANSI N42.17B-D5, American National Standards Institute, New York, New York.

- Fixed monitors equipped with remote readouts are desirable for obtaining dose rate and air concentration levels in radiation environments while exposing no personnel.
- Personnel monitors may be valuable agents for controlling exposures. They may be used to inform personnel of radiation areas, of changes in radiation dose rates, or of pre-established dose levels that have been reached.
- Analytical equipment is important to ALARA in assuring that air, biological, contamination, and environmental samples are accurately analyzed.

6.1.3 Occupational Radiation Controls

Operational measures for controlling occupational exposure must be applied to assure that any work with radioactive materials is carried out in the safest manner that is reasonably achievable. The following sections discuss engineered and administrative control mechanisms for limiting exposure.

Engineered Controls

Applying engineering to the control of radiation exposures is probably the most cost-effective phase of radiation exposure optimization, if included in the design and construction of a facility. The initial design and design modification stages provide the opportunity to evaluate engineered features to minimize radiation exposures before they occur and to incorporate the best features. Engineered controls as discussed in Section 4.0 should be considered and implemented whenever possible. Administrative controls are not an adequate substitute for engineered features. However, administrative systems must be established for the periodic review and assessment of the engineered controls to ensure that they are effective in performing their intended function.

Administrative Controls

Administrative controls are composed of the management systems, developed and implemented to provide guidance, direction, and limitations for operational activities.

These controls include documents that describe organizational interfaces, including radiation protection and ALARA organizations. The documents also prescribe activities affecting safety-related structures, systems, or components. The documents include operating and special orders, operating procedures, test procedures, equipment control procedures, maintenance or modification procedures, material control procedures, and emergency plan implementing procedures. Procedures are necessary tools to ensure that specific guidance is provided for work that:

- needs to be done in a precise way
- needs to be done in the same way repetitively
- is complex and detailed
- requires specific or unique instructions
- must be specially controlled.

Work with radioactive materials or in radiation areas usually falls into one or more of these categories. Procedures and the procedure development process should be used to ensure that ALARA considerations are included in work activities. The approval and issuance of all of these procedures, including changes, should be regulated by facility management.

Guidance should be provided to ensure that documents, including revisions or changes, are reviewed for adequacy by qualified personnel and approved for release by authorized personnel. Once authorized, the documents should be distributed according to current distribution lists. Management should issue procedures that delineate the issuance, accountability, modification, and disposal processes for the various types of procedures, to avoid the misuse of outdated or inappropriate documents. Information pertaining to procedural requirements, format, and contents can be found in ANSI/ANS-3.2 (ANS 1982).

Operational Procedures. The need for comprehensive and detailed operational procedures is dictated by the need to think through and understand each task on a step-by-step basis. Each step in a procedure should be fully thought out and its impact on exposure rigorously evaluated. Shielding, remote operation, distance, specialized tools, protective equipment, manpower requirements, exposure rates, exposure times, and alternative procedures should all be carefully considered. The procedures should also convey a

clear picture of what needs to be done to accomplish the task while keeping the exposures ALARA. The procedures can then be used as a component of a worker's training and as a basis for practicing the tasks. The final, complete procedure should be the result of cooperation and agreement among radiation protection specialists, management, and workers.

Procedures for operational activities should reflect the conditions that exist at the time the procedures are written. For a given operation, these conditions would include industry experience with the operation, technical information about it, and plant-specific information regarding the system's behavior. To ensure that the existing procedures are adequate, a systematic review and feedback of information about the procedure, based on use, should be established.

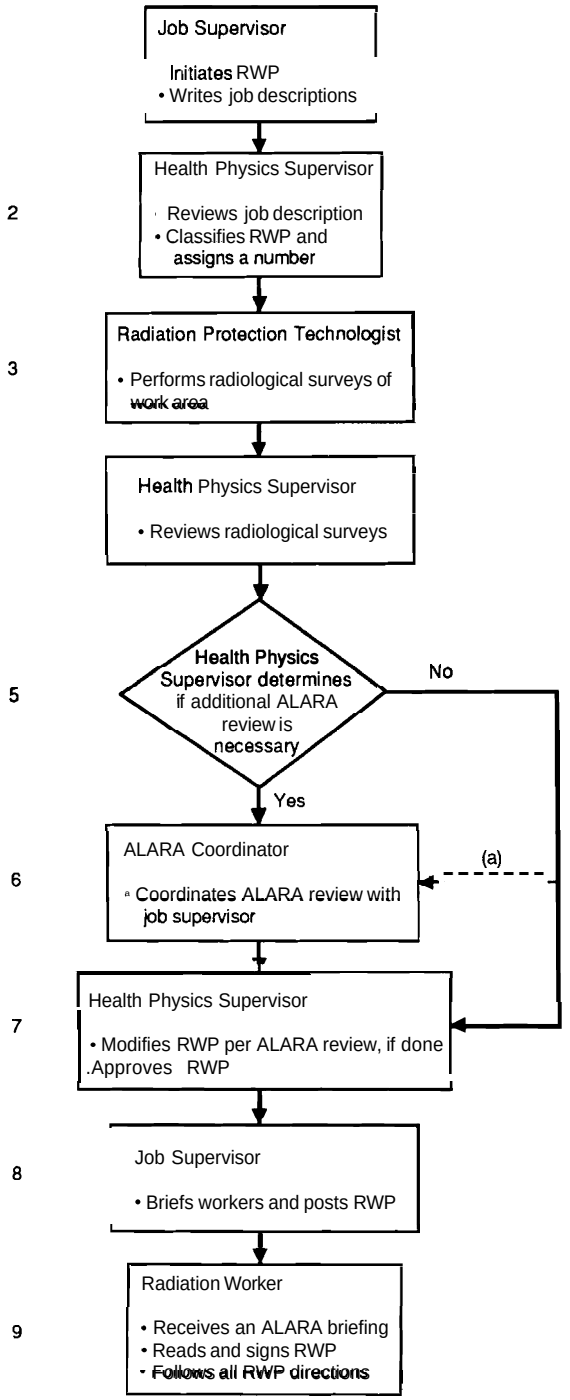
After the initial review, approval, and issuance of an operational procedure, subsequent reviews will depend on the type and complexity of the operation involved as well as on modifications to any system included in the procedure. Each procedure should indicate when it is due for review. The operational procedure should also be reviewed following an unusual incident, such as an accident, an unexpected transient, a significant operator error, or an equipment malfunction. As a minimum, each operational procedure should be reviewed once every two years by an individual knowledgeable in the area affected by the procedure. If a given procedure is revised during that period, the revision may constitute the equivalent of a review.

Radiation Control Procedure. It is generally recognized that knowledge of and familiarity with radiation control procedures are important for any type of radiation zone work. Radiation control procedures are one way of emphasizing a contractor's policy of maintaining personnel exposure ALARA. In some instances, worker cognizance of the requirements and restrictions for work in radiation zones may be insufficient because the work activities are not routinely performed. Workers may be inadequately trained in the use of specialized equipment or techniques needed for nonroutine activities. In addition, these activities may have the potential for exposing involved personnel to substantially higher levels of radiation and/or radioactive materials than are normally encountered. For these reasons, personnel directly involved in work with radioactive materials should be thoroughly

briefed on radiation control procedures. Proper performance of radiation control procedures should be stressed.

The Radiation Work Permit or Procedure (RWP) is classified as a radiation control procedure. The RWP system is typically initiated by operations, prepared by the health physics group, and approved by concerned operating and/or maintenance supervisors. This procedure lists the radiation controls, requirements, and restrictions for either all or a specific portion of work in a radiation zone. The purpose of the RWP is to assure an exchange of information between the zone workers and health physics/management personnel on radiological conditions at the work site. The RWP also serves as a check sheet on worker qualifications, exposure anticipated, and the type of exposure control devices and protective equipment to be used. At some facilities, the RWP system requires the signature of the individual using an RWP to indicate that he is performing work under the RWP authorization and that he has read the requirements. In addition, some facilities use the RWP signature as an entry control mechanism.

RWPs are written to maintain worker exposures ALARA. Therefore, an ALARA review is part of the RWP process. Strodl (1984) indicated that the interface between the RWP program and the ALARA program is not well defined. Typically, ALARA reviews are conducted after the RWPs are written and do not take into account the job reviews and exposure-reduction decisions made during the development of the RWP. Strodl provides a method to integrate the ALARA review and RWP-issuing process into a single process which will take into account the daily ALARA decisions made by radiation protection technicians (RPTs) and health physics supervisors. An integrated RWP/ALARA system flowpath developed by Strodl is shown in Figure 6.1. At step 5, the RWP Supervisor makes the decision as to whether an ALARA review is required (unless the dose estimate for the job exceeds an established limit which automatically requires an ALARA review). If the RWP Supervisor determines that an ALARA review is not necessary, the ALARA Coordinator will still review the RWP and can overrule him and require that an ALARA review be completed. Figure 6.2 presents an ALARA checklist developed by Strodl for use by the ALARA Coordinator. Strodl listed the following advantages of the RWP/ALARA system.



(a) - The ALARA Coordinator will review all RWPs exempted for detailed ALARA review by the Health Physics Supervisor and can overrule the Health Physics Supervisor.

FIGURE 6.1. Integrated RWP/ALARA System Flowpath

Source: Adapted from Strodl, W. R. "Integrating the ALARA and RWP Processes." Radiation Protection Management, Vol. 1, No. 2 (January 1984), pp. 25-34.

GUIDELINES FOR ALARA REVIEW

1. PREPARE WORK PROCEDURES

- Delete unnecessary work.
- Plan access to and exit from work area.
- Provide for communication.
- Remove sources of radiation.
- Decontaminate.
- Work in lowest radiation level.
- Perform as much work as possible outside radiation areas.
- State requirements for standard tools.
- Consider special tools (remote handling, extensions, etc.).
- Identify radiological holdpoints.
- Minimize discomfort of workers.
- Consider potential accident situations.
- Use temporary ventilation systems.
- Perform work inside disposable containments.
- Provide for visual identification of workers.
- Drain/flush systems.
- Ensure equipment isolation.

2. CHECK TEMPORARY SHIELDING

- Lead blankets, bricks, or sheets.
- Shield work under water.
- Use a shielded container during movement.
- Shield nonparticipating personnel.

3. REHEARSE AND BRIEF WORKERS

- Dry runs.
- Use photographs.
  Brief workers.
- Review workers' exposure status.

4. PERFORM WORK

- Keep excess personnel out of radiation areas.
- Supervisors and workers keep track of radiation exposures.
- Evaluate use of fewer workers.

FIGURE 6.2. Sample ALARA Checklist Used by ALARA Coordinator

Source: Strodl, W. R. "Integrating the ALARA and RWP Processes." Radiation protection Management, Vol. 1, No. 2 (January 1984), pp. 25-34.

- Individuals most familiar with job and radiological conditions (RPTs and supervisors) are performing the initial ALARA review.
- ALARA Coordinators can concentrate on tasks with high-exposure potential.
- ALARA is returned to working level and recognized as an implementation of good health physics practices and work habits.

Protective Clothing and Respiratory Protection. The proper use of protective devices is important to maintaining exposures ALARA. When engineered systems fail or the optimization of dose control is not adequate to provide the desired protection, protective devices may be used to supplement the physical protection. Two of the most common and effective devices are protective clothing and respiratory protective devices.

Administrative procedures should define when these devices are required. Normally, protective clothing is required when an area with actual or potential surface or airborne contamination is entered. Respiratory protection may be required; whenever the integrity of the radioactive material containment is threatened; when the work activity may result in the release or resuspension of radioactive contamination into the air; or if, during the course of the work, there is a high potential for airborne contamination. It should be noted that it may not be ALARA to require wearing respiratory protection where the potential for dose from internal emitters is small compared to any expected increase in external exposure that may be incurred due to additional time needed to perform the work. Additional risk due to heat stress, poor vision, poor communication, or other factors, also needs to be weighed against the possible benefits of avoiding internal exposure.

Access Control System. A system for regulating access to controlled areas shall be established to ensure that no inadvertent radiation exposures occur and that casual exposure is minimized. Regulation of access may combine engineered features and procedural 'controls, as well as physical barriers and posting. Typically, a graduated control system is used in which the sophistication of the control is determined by the hazard potential. The minimum control permitted is the demarcation and appropriate posting of the radiological controlled area. The level of control may progress to physical

barriers with continuously manned access points, and barriers with failsafe interlocks to prevent access when radiation sources are exposed. Each area for which administrative controls have been established should be periodically surveyed to ensure that the controls are adequate and that exposures are maintained ALARA.

Control and Accountability of Radioactive Material. The best method of controlling radiation exposures is by maintaining control of radioactive materials. Generally, the better the materials are confined, isolated, shielded, and otherwise controlled, the less the potential for occupational exposure. Control should be continuous, from the time radioactive materials first enter or are made at the site until the time the materials are no longer the responsibility of the site.

Administrative procedures should be used to control all events involving radioactive materials, including a review before receiving or manufacturing the materials. This review will assure that the site is authorized to possess the type and quantity of material in question and should include a safety review to determine whether the facility can safely handle the new material. This review should result in identifying the safety measures, precautions, and devices needed for adequate storage and use of the material at the facility.

To maintain accountability of materials, periodic inventories at critical process points should be implemented. Inventories can 1) fulfill requirements, 2) prevent the diversion of materials, 3) maintain quality control of the facility process, and 4) lead to the discovery of problems (leaks) at an early stage. Procedures should call for an immediate investigation when changes in the expected inventory are observed.

Adequate control of the materials must be maintained until their final disposition is completed. Depending on the facility, this point may be that at which another authorized facility takes responsibility for the materials. If the materials are disposed of on the facility site, perpetual controls may be required.

Administrative Exposure Limits. As stated in NCRP Report No. 91, "In the control of occupational exposure, the application of the dose limits

specified here are not sufficient in themselves" (NCRP 1987). Administrative exposure controls should thus be established to provide a level of control well below regulatory limits. These are contractor-adopted administrative exposure controls which, when exceeded, indicate abnormally high or unexpected exposures that are still below regulatory limits. Administrative exposure controls are normally established at some fraction of the regulatory limits. They are valuable in alerting personnel to trouble spots where exposures may not be optimized.

Operating Systems. Administrative controls should be extended to assure that engineered systems are operating as designed. Each system's functions should be reviewed to verify design criteria both before and after the process is placed on line. Reviews should then be performed at reasonable intervals to maintain continued assurance of system functions. These reviews may include performance checks of detection and measurement devices, tests of interlock functions and warning systems, tests of the differential pressure and flow of ventilation systems, and particulate and/or iodine removal efficiency tests of filters. These are only a few of the many operational system tests that may be necessary for ensuring the control of radiation exposures.

6.1.4 Planning and Preparation

A basic necessity for keeping occupational exposures ALARA is continual vigilance for means to reduce exposures. One focus for this vigilance is the planning of tasks that will take place in a radiation zone. The objective of planning is to ensure that all factors that may influence the adequate and efficient performance of a task are recognized and that appropriate skills, training, and resources are available. Careful planning and preparation for work activities may reduce the radiation exposure received, because work will be performed more efficiently and less time will be spent in a radiation zone. The areas of planning and preparation that are of primary importance to the ALARA program are training personnel, scheduling work, briefing and debriefing workers, and documenting and analyzing historical data and work experiences.

Training Personnel

Training personnel in the concept of ALARA can be beneficial to facility operations and to the protection of the workers. Training in the ALARA concept and in ALARA techniques is necessary to ensure an understanding of ALARA and its importance to the individual and to management, and should be included in the contractor's regular training program. Even though ALARA ideas and concepts are interspersed with the individual's specific training, one separate section of the training program should be directed specifically to ALARA. All radiation workers should understand the meaning of ALARA, its importance to plant operations, the risks involved in radiation work, the contractor's program to optimize radiation exposures, and the individual's responsibility for minimizing his own exposures. Weedon (1985) described the importance of providing positive ALARA training to radiation workers.

Contractors may employ a training specialist or training staff. The training staff should work closely with the health physics staff to ensure the correct communication of ALARA concepts. The extent and frequency of training and periodic retraining should be based on the complexity of the tasks and the hazards involved.

The use of mockup equipment and dry-run practices may be a valuable asset in increasing worker efficiency and in identifying problem areas in performing maintenance work, thus increasing the ratio of productivity to exposure received or reducing the time required to complete the work.

The training program should be established and defined in a formalized training document that includes a policy statement, staff responsibilities, training procedures, and lesson plans. Management should review and approve the training program and provide for its periodic review.

Scheduling Work

The orderly planning of a group of tasks may result in more efficient work than if each individual task is considered separately, thus decreasing work time, decreasing maintenance costs, and lowering radiation exposures. The effective scheduling of work activities, with input supplied to the scheduling engineer by the health physics staff and those responsible for ALARA, can be extremely valuable in achieving ALARA goals.

Work should be scheduled based on the following guidelines:

- Schedule hazardous operations to be carried out when few persons are around.
- Make use of dose reduction practices (less time, greater distance, shielding).

Use the optimal number of persons to perform work in radiation areas (eliminate casual observers).

Ensure that adequate resources (equipment, tools, and procedures) are available to perform the work.

Scheduling ALARA reviews of incoming jobs can become a problem for the ALARA staff during busy work periods (e.g., outage at a nuclear power plant). Britz, Clancy, and St. Laurent (1985) revised their work order tracking system to include an entry that asks whether an ALARA review will be required. This modification should help ALARA and radiation protection staffs identify jobs requiring an ALARA review early enough to prepare for any overload conditions.

McArthur et al. (1984) identified the importance of using planners and schedulers who have had ALARA training and who are involved with the facility's ALARA program. Problems such as inadequate health physics personnel to handle issuing RWPs, to perform general or specific radiation surveys, or to adequately monitor jobs have been observed when untrained planners and schedulers scheduled too many jobs for the same time period.

Briefing and Debriefing

The RWPs discussed earlier are useful in planning and carrying out work in radiation areas. However, RWPs are limited in the amount of information they can provide. Personnel briefings should be held before radiation work is performed to supplement the RWP information and to ensure that those involved in the work understand where and how it is to be done and what the radiation protection requirements are. Upon the completion of a task, a debriefing of those performing the work may be valuable in identifying problems encountered, techniques for improving the future performance of similar tasks, and techniques for further reducing exposures.

Documentation

Historical data and work experiences should be documented and maintained as a library of valuable data for use in planning future radiation work and in tracking high dose jobs, especially those which are repetitive. Building on past experience may assist in keeping exposures ALARA. As a minimum, the following information should be provided:

- specific job performed (including location)
- the original dose estimate for completing the job and how it was calculated

  resources required
- precautions taken
- persons performing the work (name and title)
- problems encountered

  solutions to problems

  abnormal occurrences
- time required for job
- number of persons required

  individual and total dose for job.

Historical data may be used to perform a statistical analysis of the reliability and frequency of required maintenance work on process equipment. The results of this analysis may be used in dose projections (e.g., annual dose projections) or as a basis for a justification to replace equipment or processes with more reliable ones.

6.2 EMERGENCY OPERATIONS

All users of radioactive materials or radiation-generating machines should develop an emergency preparedness program to assure that adequate response is available in the event of accident or abnormal occurrence. The DOE requirements for an emergency preparedness program are found in DOE 5500.3 (DOE 1981), DOE 5500.1A (DOE 1987b), and DOE N5500.2 (DOE 1987c).

Although the primary objectives of an emergency preparedness program are to control an accident and to mitigate its effect, implied in those objectives is the need to maintain radiation exposures within the radiation protection standards and ALARA. Emergency actions and activities should therefore be evaluated to ensure that ALARA considerations have been included.

A formalized emergency plan should provide the basis of a rapid, effective emergency response. The emergency plan shall address the following areas (DOE 1981):

- organization and assignment of responsibilities
- emergency response support and resources
- emergency response level plans
- notification methods and procedures
- emergency communications
- public education and information
- emergency facilities and equipment
- accident assessment
- protective response
- radiological exposure control
- medical and health support
- recovery and reentry planning and post-accident operations
- exercises
- radiological emergency response training
- memoranda of understanding and letters of agreement.

Radiological exposure control methods as they relate to emergency planning and ALARA are discussed in this section. DOE 5500.3 (1981) indicates that facilities shall ensure that guidelines and means for controlling radiological exposures are established for emergency workers. The discussion of radiological exposure control methods is divided into emergency organization, emergency equipment, emergency implementing procedures, and training and exercise.

6.2.1 Emergency Organization

Because an emergency may require that established exposure limits be exceeded, a responsible person should be onsite at all times with the authority to approve emergency radiation exposures in excess of the limits. This

responsibility usually rests with the emergency director (i.e., person responsible for onsite activities in an emergency) after consultation with the most senior health physicist on staff. Some facilities have a graded-type of responsibility. For example, the senior health physicist would be able to authorize dose extensions up to a certain percent above limits (e.g., 25%) at which time the emergency director would have to approve the extension.

6.2.2 Emergency Equipment

Facilities should have adequate radiological monitoring equipment and supplies to support emergency workers. Locations of equipment and supplies should be considered. Generally, equipment and supplies should be located in emergency facilities to eliminate accessibility problems because of radiological conditions in other parts of the facility. The following is a list of typical radiological monitoring equipment and supplies that should be available to emergency workers in-plant:

- protective clothing
- respiratory protection (full-face respirators and self-contained breathing apparatus)
- decontamination supplies
- radiation posting signs and step-off pads
- portable radios for communication between in-plant teams and the controlling emergency facility
- personnel dosimetry (TLDs, film badges, self-reading dosimeters)
- portable survey instruments
- instrument check sources
- air sampling equipment.

6.2.3 Emergency Implementing Procedures

Because normal radiological control procedures may not be sufficient during an emergency, additional procedures addressing emergencies shall be developed. In accordance with DOE 5500.3 (DOE 1981), specific procedures shall be developed for emergency worker radiation protection and control,

and emergency worker decontamination. Key information that should be included in these procedures follows.

Procedures shall identify onsite emergency exposure guidelines that are consistent with DOE 5480.11 (DOE 1988) and U.S. Environmental Protection Agency (EPA) emergency worker and lifesaving activity protective action guidelines as defined in EPA 52011-75-001 (EPA 1980). Emergency exposure guidelines should also be provided for performing assessment actions, providing medical treatment, performing personnel decontamination, and providing ambulance service. As discussed in Section 6.2.1, procedures should also identify who has authority to authorize exposures exceeding normal exposure limits and emergency limits.

In order to achieve dose control for emergency workers, current personnel dose information shall be available and maintained. The capability to process dosimeters and have the information promptly available on a continuous basis should exist and be described in a procedure. Special control dosimeters may be necessary to provide real time exposure measurement, e.g., total dose meters and alarming dose/dose rate meters. A reliable dosimeter distribution system and record system should also be available. Records on respiratory protection mask fits should be available.

Procedures should include a discussion on the preparation and dispatch of in-plant teams (e.g., search and rescue teams, repair and damage control teams). Team size should be limited to the minimum number to safely perform the job. One of the team members should be an RPT because of the changing nature of radiological conditions in the facility during an emergency. Teams should be briefed by health physics supervisory personnel prior to dispatch. Procedures should discuss key items that should be covered in the briefings. These include:

- radiological conditions at the work site and in-transit to the site
- need to closely monitor individual exposures
- exposure limits
- means and frequency of communications with emergency facility
- protective clothing requirements.

Some facilities write emergency RWPs for each emergency job, which would contain much of the information listed above. In this case, a briefing

should still be held to provide last-minute information and answer any questions the team members may have. After returning from the assigned job, teams should be debriefed to obtain updated information on radiological conditions in-plant.

6.2.4 Training and Exercise

Facilities shall establish emergency response training programs for all employees and employees with emergency response responsibilities in accordance with DOE 5480.11 (DOE 1988) and DOE 5500.3 (DOE 1981). Training of emergency workers in the area of radiological exposure control should be based on the procedures discussed in Section 6.2.3. Formal classroom training should be performed annually. In addition, emergency exercises should be conducted annually to test worker reactions to a realistic accident scenario.

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APPENDIX

PERFORMANCE OBJECTIVESAND CRITERIA FOR TECHNICAL SAFETY APPRAISALS

APPENDIX

This appendix reproduces entirely the Radiological Safety Section as Contained in Performance Objectives and Criteria for Technical Safety Appraisals Revision 1, which was developed specifically for the Technical Safety Appraisal program from material found in Standard Lines of Inquiry for Functional Appraisals of Field Offices. The latter document was prepared in April 1984 by Mr. E. J. Vallario, U.S. Department of Energy, Office of Nuclear Safety, and was based on many years of experience in assessing the radiological safety programs of the DOE. Both documents have been revised and upgraded numerous times as a result of field experience to provide clarification and interpretation of wording and to assure inclusion of all elements necessary for an adequate evaluation of both the content and performance of a radiological safety program.

REVISION I

* RADIOLOGICAL SAFETY SECTION AS CONTAINED
IN

PERFORMANCE OBJECTIVES AND CRITERIA FOR TECHNICAL SAFETY APPRAISALS

OFFICE OF THE ASSISTANT SECRETARY
FOR
ENVIRONMENT, SAFETY, AND HEALTH
U.S. DEPARTMENT OF ENERGY

MAY 1987

*DERIVED FROM 'STANDARD LINES OF INQUIRY FOR FUNCTIONAL APPRAISALS OF FIELD OFFICES 1984" – A REFORMAT

RP. Radiological Protection

1. Organization and Administration
2. Internal Audits and Investigations
3. Radiological Protection Procedures and Posting
4. External Radiation Exposure Control Program
5. External Dosimetry (routine and accident use)
6. Internal Radiation Exposure Control Program
7. Internal Dosimetry
8. Fixed and Portable Instrumentation (normal and emergency use)
9. Respiratory Program
10. Air Monitoring
11. Radiological Monitoring/Contamination Control
12. ALARA Program
13. Records

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RP. 1 ORGANIZATION AND ADMINISTRATION

PERFORMANCE OBJECTIVE

Facility organization and administration should ensure effective implementation and control of radiological protection activities within the facility.

CRITERIA

1. Organizational responsibilities for radiological protection are clearly defined.

2. Staffing and resources are sufficient to accomplish assigned tasks.

3. Appropriate responsibilities are assigned to facility management personnel for such matters as:

   - minimizing personnel radiation exposure
   - minimizing the contamination of areas, equipment, and personnel
   - reducing solid radioactive waste volumes

4. Responsibilities and authorities for each radiological protection technician position at the facility are clearly defined and sufficient to control work activities to protect employees.

5. Personnel clearly understand their authority, responsibilities, accountabilities, and interfaces with supporting groups.

6. Radiological protection requirements are actively administered by facility management and supervision and adhered to by plant personnel.

7. The radiation protection manager has direct access to the facility manager and has sufficient authority to perform his duties effectively.

8. Managers and supervisors observe radiological protection activities to ensure adherence to company policies and procedures and to identify and correct problems.

*9. Inspections and audits utilizing DOE 5482.1B, Section 10, are scheduled and performed by contractor safety personnel independent of the operation to determine the effectiveness of the radiological protection program to identify problems and to initiate necessary corrective action's.

10. Auditable reports of inspections, audits, and resulting corrective actions taken, are maintained.

11. Procedures approved by facility management are in place to implement the radiological protection program and are updated periodically.

12. Radiological protection problems are documented and evaluated. These evaluations are reviewed for trends, and actions are taken to correct the causes.

13. Facility managers are aware of trends with regard to occupational radiation exposures, solid and liquid radioactive waste, contamination and radiation levels and the number and location of radiation and contaminated areas within their facility.

14. Radiological protection personnel are actively encouraged to develop improved methods of meeting radiation protection objectives and goals.

15. Indicators of radiological protection performance are established and periodically assessed to enhance radiological protection effectiveness.

RP.2 INTERNAL AUDITS AND INVESTIGATIONS

PERFORMANCE OBJECTIVE

The internal audit program for both routine operations and unusual radiological occurrences should provide adequate performance assessments.

CRITERIA

Internal Audits

1. The internal audit program complies with DOE Order 5482.1B, Section 10 and DOE Order 5480.18, Chapter XI.

2. All radiation protection program elements are audited (i.e., procedures, records, routine survey program, internal and external dosimetry, instrumentation, calibration, etc.)

3. The internal audit is conducted by individuals knowledgeable in radiation protection but independent of the program of being audited.

4. Internal audits are conducted on a specified frequency, at least every 3 years.

5. Internal audits are documented.

6. Management is aware of findings and recommendations from the internal audit and assures appropriate followup action.

Accidents/Incidents

7. Procedures for investigation and documentation of accidents and incidents are documented.

8. Investigations of incidents and accidents consider such factors as

   a. The frequency of such losses to control.

   b. Operations or workers that are "frequent repeaters" of such incidents.

9. An attempt is made to determine and correct the cause of even minor incidents. Upper management shows support of efforts to eliminate even "minor" incidents.

10. Management response to incidents is positive. There is adequate followup, including additional training of workers to keep all employees informed of the types of incidents that are occurring to enhance their safety consciousness or awareness.

11. More serious accidents are investigated thoroughly and documented and publicized appropriately. Closeout procedures are in place.

12. Management is willing to stop work if necessary to ensure that any corrective action is taken to preclude repetition of the accident.

13. Corrective action includes consideration of engineering design changes, if warranted, to preclude repetition of the accident.

14. There is evidence of adequate pre-job planning to reduce or minimize the potential for an accident.

15. There is documented evidence of training of workers in the high-risk jobs to promote a safety awareness attitude.

16. Unusual Occurrence Reporting and Accident Investigation and Reporting is consistent with DOE 5000.3 and DOE 5484.1.

RP. 3 RADIOLOGICAL PROTECTION PROCEDURES AND POSTING

PERFORMANCE OBJECTIVE

Radiation protection procedures for the control and use of radioactive materials and radiation generation devices should provide for safe operations and for clearly identifying areas of potential hazards.

CRITERIA

Procedures

1. The radiation protection documentation system has a hierarchially arranged'system that allows the tracing of DOE Order requirements:

   - From the Orders to policy
   - From policy to contractor standards and controls
   - From contractor standards and controls to procedures

2. The contractor has a written policy on radiation protection (including ALARA).

3. Radiation protection standards, procedures, and controls have recognizable or formal technical bases for limits, methods, and personnel protection standards. They include sound radiological requirements such as those recommended in American National Standards Institute (ANSI) and National Council on Radiation Protection and Measurements (NCRP) documents.

4. Radiation work procedures (permits) are used for all radiation area work. These procedures are approved by health physics staff and contain adequate provisions for:

   - protective apparel
   - work limitations
   - job descriptions
   - radiological conditions
   - special instructions

5. Radiation protection procedures are adequately documented and updated periodically. This includes, but is not limited to:

   - facility posting
   - developing and maintaining all radiation protection records
   - reporting unusual radiation occurrences
   - operating radiation-generating equipment
   - using radiation monitoring instruments
   - using radiation sources (e.g., reference and calibration)
   - tracking personnel medical evaluation
   - reporting radiation exposures

- using protective clothing
- responding to radiological emergency events
- survey and monitoring
- counting room equipment and procedures
- instrument maintenance and control control

6. Procedures and standards and controls program have a documented approval system. Those who generate and those who use the program both concur in the procedures.

7. The procedures and standards and controls program elements have specific intervals for review and/or revision. There is a tracking scheme to ensure that the required reviews and revisions occur.

8. The procedures and standards and controls program elements are maintained in a centralized historical file. There is a designated period of time that such files must be maintained.

Posting

9. The technical criteria, and dose rate and/or levels, for defining radiation, high radiation, very high radiation, contamination, and airborne radioactivity areas are established, documented, and consistently applied.

10. Radiation levels are established and documented for when areas are to be barricaded and marked to prevent inadvertent entry and when areas are to be physically locked to preclude unauthorized entries.

11. Current radiation work permits (radiation zone entry permits) meeting the requirements of the facility are posted at entrances to work areas. They reflect actual working conditions. Out-of-date work permits removed in a timely manner.

12. Results of radiation surveys of radiation areas are posted at the entrance.

13. Airborne activity areas are posted to alert personnel to possible respiratory protection requirements.

14. DOE required forms are posted in all facilities.

15. Only trained, authorized personnel handle radioactive materials.

16. Areas where radioactive materials are handled or stored are clearly and accurately posted.

17. Entrance to areas where radioactive materials are used or stored is restricted based upon established criteria.

Source Control

18. Inventories of stored radioactive materials specify locations, quantities, and characteristics, and are current and periodically audited.

19. Procedures are in place to adequately control, label, handle, ship, and receive source material. They do address ALARA principles.

20. Natural, depleted, or enriched uranium and natural thorium is stored and processed separately from highly toxic alpha emitters.

21. Containers used for storage provide at least one barrier of containment. More if warranted.

22. An inventory is maintained of source material, which is audited by management.

23. Leak checks are performed on all sources including calibration sources in accordance with ANSI N54.2.

Radiation Generating Devices

24. The radiation field around radiation generating devices and radioactive material has been well characterized (type, energy, and dose range known).

25. Operating procedures, interlock procedures, and warning signs are posted at radiation-generating machine operating consoles and in target areas.

26. ANSI N43.2 and N54.3 are utilized, as appropriate, in establishing radiological safety programs for radiation generating devices.

27. Fail-safe interlocks are used, tested, and documented on radiation generating devices, and barriers are adequately used to ensure the safety of operators and other personnel.

28. Set-points to activate interlocks or other safety systems (i.e., beam shutters, warning lights, etc.) associated with radiation generating devices are defined.

29. A sufficient number of warning lights are installed so that at least one light is visible from occupied areas adjacent to the x-ray machine and from all avenues of approach to such area.

30. The shielding design limit for x-ray machines - the dose rates in adjacent areas to ALARA - dose rates are allowed in these adjacent areas are defined.

31. Area radiation monitoring systems are used for radiation generating devices.

32. Remote and local readout provided for radiation generating devices have visible and audible alarm capacity.

33. Specialized inspections and surveys of machines are performed periodically and documented.

RP. 4 EXTERNAL RADIATION EXPOSURE CONTROL PROGRAM

PERFORMANCE OBJECTIVE

External radiation exposure controls should minimize personnel radiation exposure.

CRITERIA

1. Effective exposure control methods are in use, which include:

   - Accurate and timely radiation level information for planning, determining the boundaries of radiation and high radiation areas, and posting entry requirements. The boundaries of these areas are clearly identified and posted (see Posting **RP.3).**

   - "Hot spots" are clearly posted.

   - Radiation work permits or similar controls to control exposures associated with specific jobs (see RP.3 - Procedures)

   - Controlling personnel exposures in work areas involving high exposure rates by a combination of special tools, shielding, timekeeping, and monitoring of accumulated exposure.

   - Routing personnel traffic through lower exposure rate areas; and establishing waiting, staging, and office areas in low background areas.

   - Controls to protect personnel from transient high radiation levels such as those involved in moving radioactive materials.

2. Proper controls are used to minimize exposure to the skin and eyes, **e.g.,** by use of protective clothing and equipment.

3. The radiation exposure reduction program includes the following whenever collective personnel exposure is expected to be significant:

   - planning for the work

   - work scheduling that provides for completion of exposure reduction efforts prior to and during work and that ensures the order of work provides the lowest exposures

   - job goals based upon estimates made using facility and industry experience

   - job goals that are realistic but stringent enough to encourage improvements

4. Specific job-related exposure reduction efforts are incorporated into work procedures, including the following, where appropriate:

   - use of temporary or permanent shielding;
   - use of special tools;
   - flushing and decontamination, as appropriate;
   - pre-operational and post-operational briefings of personnel;
   - specialized training and "dry runs" on mock-up equipment;
   - use of auxiliary lighting and a working environment with comfortable temperature and humidity and adequate space, where feasible;
   - adequate communication capabilities;
   - assignment to the job site of the minimum number of personnel needed to perform the work

5. Analysis of current practices and comparison with industry-wide exposure controls are ongoing actions to achieve minimum exposures.

6. Exposure trends are monitored and actual exposures are compared to established ALARA goals (see RP. 12). Actions are initiated to correct a problem or adjust the goals as appropriate.

'Note: Portions of RP.3, "Postings and Procedures"; RP.8, "Instrumentation"; RP. 11, "Radiological Monitoring/Contamination Control"; and RP. 12, "ALARA" may apply to this section on external exposure control.

RP. 5 EXTERNAL DOSIMETRY (ROUTINE AND ACCIDENT USE)

PERFORMANCE OBJECTIVE

The routine and accident personnel dosimetry programs should ensure that personnel radiation exposures are accurately determined and recorded.

CRITERIA

Routine Dosimetry

*1. The program appropriately incorporates the requirements of ANSI Standards 13.5-1 97.2, N13.7, N319-1976, N323-1975 and DOELAP Standard for personnel dosimetry systems.

2. Dosimeter (whole body and extremity) calibration facilities and procedures are adequate to cover the range of exposures, energies, and type of radiation anticipated.

3. Technical criteria and dose rate levels for assignment of extremity and personnel dosimeters are established and documented.

4. Procedures to identify workers for whom monitoring is required and the frequency with which their dosimeters are processed are available and are technically based.

5. Personnel who enter radiologically controlled areas wear appropriate dosimetry devices capable of accurately measuring whole-body and/or extremity exposures from the types of radiation present.

6. Whole-body exposures dosimeters are worn in the proper' location and manner to measure the highest whole-body exposure.

7. Extremity dosimetry devices are worn when performing work where extremity exposures are likely to be significantly higher than whole-body exposures.

8. Personnel exposure histories are readily available to those who are responsible for exposure control (e.g., health physics and operational supervisors).

9. Adequate field surveys of work locations are performed and documented to determine when routine and special dosimetry are needed..

10. Personnel decontamination equipment, supplies, and procedures are properly stored and routinely inventoried.

11. A quality control program is implemented and documented to evaluate dosimetry program performance which includes intercomparison studies and laboratory validation procedures.

12. Correction factors or other appropriate methods are employed to ensure exposures from the types of radiation present and high and low energy gammas are accurately recorded in rem.

13. Dosimeter operations are performed by and results interpreted by qualified personnel.

14. Records of personnel exposures and methods of determining exposures at the facility are permanently maintained and retrievable.

15. The amount of error (error range) in the dose measurements from personnel and extremity dosimeters using are documented.

16. The minimum detection levels of personnel and extremity dosimeters for gamma, beta, and neutron radiation for the primary sources of radiation that exist within the facility are documented.

17. The contractor participated or plans to participate in the Department of Energy Laboratory accreditation Program (DOELAP) to test its dosimeter.

18. Actions have been taken to correct deficiencies identified by participation in DOELAP.

19. If appropriate, skin dose is measured and procedures for doing so documented.

20. A procedure for estimating the dose from a lost dosimeter is available.

21. Visitors to radiation areas are monitored to determine any exposures. Exposures are reported in accordance with DOE 5484.1.

Nuclear Accident Dosimetry (ANSI N13.3)

22. Fixed and personnel nuclear accident dosimeters meeting the criteria of DOE 5480.1A, Chapter 11 are available if sufficient quantities and kinds of material to potentially constitute a critical mass as defined by DOE 5480.5, are present and excessive exposure of personnel to radiation from a nuclear accident is possible.

23. Performance of the personnel nuclear accident dosimeter has been documented and verified by participation in an intercomparison program (e.g., Oak Ridge National Laboratory).

24. Personnel dosimeters worn in radiation areas are adequate to cover the range, of exposures and energies anticipated from an accident.

25. If neutron dosimetry is not used, there is documented supporting evidence to justify the use of neutron to gamma ratios to determine neutron exposure.

26. Procedures, models, and methods are in place to characterize the source terms involved in accidents.

27. In the event of an accident, backup dosimetry or instrumentation systems exist for the determination of personnel dose.

RP. 6 INTERNAL RADIATION EXPOSURE CONTROL PROGRAM

PERFORMANCE OBJECTIVE

Internal radiation exposure controls should minimize internal exposures.

CRITERIA

1. Engineered controls are used when feasible to prevent the intake of radioactive material. Examples are:

   - Ventilation systems are balanced to ensure that air flow is toward areas of higher contamination.

   - Portable filtration systems are used to control airborne contaminants.

   - Containment structures, such as tents, are used to protect personnel working in adjacent areas.

   - Unique fittings are used for the plant breathing air system.

2. Accurate and timely airborne radioactivity survey information is available for determining the boundaries of airborne radioactivity areas, posting entry requirements, and minimizing internal exposure to workers during work activities. The boundaries of these areas are clearly identified and posted.

3. Accurate and timely contamination survey information is available for determining boundaries of contamination areas, posting entry requirements and minimizing internal exposure to workers during work activities. The boundaries of these areas are clearly identified and posted.

4. Radiation work permits or similar controls are used to control personnel entry into areas where airborne radioactivity exists or where radioactive material may become airborne due to work being performed.

*5. A respiratory protection program complying with ANSI Z 88.2 defines responsibilities and requirements in the following areas (see PP.2):

   - training
   - control and use of respirators
   - mask and fit testing
   - breathing air purity

6. The number of areas where respiratory equipment is required is minimized.

7. Monitoring data is used to perform trend analysis appropriate corrective action is taken whenever there are significant numbers of positive in-vivo and/or in-vitro counts observed, or when air concentrations are elevated even though the observed levels are less than regulatory limits.

8. Eating, drinking, smoking, and chewing are not permitted in contaminated or potentially contaminated areas.

9. Procedures and resources are available to perform dose calculations when significant internal exposures occur.

Note: Portions of RP. 3, "Posting and Procedures"; RP-7, "Internal Dosimetry"; RP.IO, "Air Monitoring"; RP.11, "Radiological Monitoring/Contamination"; RP.12, "ALARA", and PP2 (for respiratory protection) may apply to this section on internal exposure control.

PERFORMANCE OBJECTIVE

The internal dosimetry program should ensure that personnel radiation exposures are accurately determined and recorded.

CRITERIA

1. The technical criteria employed to determined which employees are included in the bioassay program, and the frequency of, bioassay are documented and are consistent with ANSI N343, ANSI N13.30 (draft), and ALARA practices.

2. The types of routine monitoring of workers (in-vivo and/or in-vitro) are appropriate for the radionuclides present.

3. Personnel who perform work in radiologically controlled areas where a potential for airborne radioactivity exists are monitored for internal deposition of radioactivity as follows:

   - at least annually
   - prior to performing radioactive work, after initial employment, and upon termination of employment
   - whenever it is suspected that personnel breathed high airborne radioactivity
   - periodically for those workers who have the highest potential for breathing high airborne radioactivity
   - following personnel contaminations, unless exempted by the radiological protection manager or his designee

4. Procedures for the internal dosimetry program are documented and updated periodically.

5. Trigger points to instigate an investigation of an intake or supposed intake are established and technically based.

6. A quality control program, including the use of internal audit samples, is employed by the contractor.

7. A radiation dose to organs is computed following an intake. If doses are calculated for some intakes but not for others, a technical basis for deciding which intakes require dose calculations is established.

8. Procedures are employed to prevent cross contamination of (indirect) bioassay samples.

9. Particle size and solubility of airborne contaminants to which a worker has or may have been exposed are determined.

10. The contractor has a documented policy on work restrictions as a result of internal exposure (i.e., to permit dose assessment and/or for temporary or permanent work restrictions).

11. The frequency and timeliness of in-vitro and/or in-vivo bioassay and notification of field personnel of results is appropriate for the radionuclides present and the nature of the operations.

12. Procedures are established and documented to identify individuals who fail to leave routine in-vitro bioassay samples.

13. Procedures for in-vitro and/or in-vivo bioassay of visitors, if appropriate, to radiation areas are established and documented.

14. Procedures to identify workers for whom bioassay is required and the frequency is technically based.

15. The minimum detection level for in-vitro and/or in-vivo bioassay procedures are documented.

16. In-vivo counting equipnent is calibrated and maintained on an established frequency.

PERFORMANCE CRITERIA

Radiological protection instrumentation used to obtain measurements of radioactivity or personnel dosimetry should be calibrated, used, and maintained so that results are accurately determined.

CRITERIA

1. Instrumentation (normal and emergency) and instrumentation calibration are consistent with ANSI N42.17, ANSI N323, ANSI N320, ANSI N317, ANSI N43.1, and ANSI 13.10 as appropriate.

2. Instrumentation selection is based on objective criteria (such as performance standards, facility requirements, etc.). Selected instruments are acceptance tested against those criteria to ensure they are satisfactory, and results are documented.

3. Instruments are properly tested and calibrated periodically, and adequate records of servicing and calibration are maintained by the facility.

4. Technically based criteria are used to determine the frequency of calibration and tests for operation.

5. The complement (number and types) of instruments are adequate to meet the needs of both the routine and nonroutine health physics surveillance program and are appropriate for the activities and sources present.

6. Instruments have current calibration stickers with appropriate correction factors, and an adequate system for instrument recall has been established.

7. Instrument calibrations are traceable to a recognized standard.

8. The facility has adequate arrangements for decontamination of operative and inoperative instruments.

9. The calibration facility (onsite or vendor) has well characterized dose rate profiles of the full range and type of sources needed to calibrate instruments for the situations encountered in the facility, and is periodically quality control checked.

10. The instrument repair facility has adequately trained personnel and facilities to service the instruments in use in a prompt and safe manner.

11. Methods have been established to periodically test overload response, temperature sensitivity, linearity, and stability.

12. If special conditions, such as radio frequency fields, magnetic fields, etc., exist that would require special instruments, these instruments have been tested to ensure a lack of susceptibility to these factors.

13. An adequate supply of instruments that will operate up to 100 R/h is available.

14. Adequate check sources are available and used for both energency and routine instruments to ensure they operate properly prior to use.

15. 'Extendable' detectors are available for remote monitoring under accident conditions.

16. The calibration facility can calibrate the high ranges and tests for overload response and this is done periodically.

17. Procedures for workers to determine if instruments, such as hand and shoe counters, are operating are available.

18. The numbers and locations of fixed instruments are adequate to assess accident conditions (i.e., they would not be affected by elevated background radiation and the readout will be accessible during a serious emergency).

19. Fixed instruments alarm at a central location in addition to the alarm at the instrument.

21. The exact locations of fixed instruments are documented (height above floor, etc.) so that the shielding effect can be calculated from drawings and the exposure rate in nearby locations estimated in the event of a serious accident (i.e., a criticality accident).

RP. 9 RESPIRATORY PROGRAM

PERFORMANCE OBJECTIVE

The respiratory program should ensure optimum protection against-internal radiation exposures to workers.

COMMENT

The substance of this Performance Objective is now addressed in Performance Objective PP.2, Chemical Contamination. Conclusions regarding respiratory protection will be found in RP. 9 for Technical Safety Appraisals conducted prior to June 1987.

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RP. 10 AIR MONITORING

PERFORMANCE OBJECTIVE

Air monitoring systems selection, location, calibration, and maintenance should ensure reliable estimates of air activity for radiological control purposes.

CRITERIA

1. A documented, acceptable air sampling and monitoring program is in place, and is supported by sufficient studies (e.g., air flow patterns, particle size distribution).

2. Air sampling and monitoring equipment are used are appropriate for the nature of the operation and sources.

3. The nominal flow rates and sampling intervals used by the contractor for grab sampling, continuous sampling, personal (i.e., breathing zone) sampling, air monitoring, and emergency sampling are based on appropriate technical criteria.

4. Appropriate filter media are used for particulates and radio-iodines.

5. Action levels, investigation levels, and maximum permissible concentrations (MPC) used are based on appropriate technical criteria to evaluate air sampling and monitoring results and determine necessary control procedures.

6. The calibration procedures (and frequency) for the air sampling and monitoring equipment are based on appropriate technical criteria.

7. The minimum detection limits (MDL) or minimum detectable activities (MDA) for the specific radionuclides of interest. The detection levels provide optimum worker protection and are appropriate for established action levels, investigation levels, and MCP's are documented.

8. Results of breathing zone sampling are compared with area air sampling.

9. Appropriate radiation detectors are used to analyze air samples.

10. Adequate counting equipment for filters is available. The equipnent is properly calibrated and maintained. Counting procedures are available and followed by technicians. Adequate records are maintained to permit QA/QC verification of sample results. Corrections for counting losses due to absorption and/or backscatter within filters are made for alpha and beta radiation.

11. Corrections for radon daughter product interference are made.

12. Procedures for calibration of air monitors are documented. Included are source check, stability check, electronics check, and air flow calibration.

13. Routine air monitor calibrations include minimum detectable activity; energy dependence; efficiency; precision; response time; stability; alarm threshold accuracy and stability; air flow accuracy and stability; air in-leakage; and effects of temperature, humidity, and ambient pressure.

RP.II RADIOLOGICAL MONITORING/CONTAMINATION CONTROL

PERFORMANCE OBJECTIVE

The radiological monitoring and contamination control program should ensure worker protection from radiological exposures.

CRITERIA

A. Radiological Monitoring

1. A documented radiological monitoring program is in place that includes the frequency and location for radiological surveys.

2. Procedures'and criteria for completion of survey forms, acceptable survey levels, evaluation of results, and reporting of off-standard results are available.

3. Dose rate values are established for posting radiation areas and approximate dose rates are posted.

4. Documented procedures are available and training conducted to ensure that routine dose rate and contamination surveys are conducted in a manner that is consistently repeatable in terms of location, use of smears, and instrument interpretation.

5. Survey limits for breathing air are established. These limits are related to the controlled area concentration values in DOE guidance.

6. The contractor surveys all sealed sources (e.g., reference and calibration) on a designated schedule (at least annually).

7. Facility area monitoring readouts and alarms are adequate to inform workers of workplace radiation levels.

B. Contamination Control

1. Adequate documented protective measures are employed, where practicable, to maximize contamination control.

2. Leaks from radioactive systems are promptly contained and repaired, and affected areas are decontaminated.

3. Unrestricted radiological contamination release levels for personnel, equipment and materials, and facility surfaces are defined and comply with appropriate standards.

4. The system for unrestricted radiological contamination release (i.e., monitoring procedures, authority to release, etc.) ensure that equipment and materials removed from contaminated areas are not contaminated above release levels and are not mixed with clean items prior to a final release.

5. Contamination and dose rate limit for equipment and tools stored and used only in radiation zones are established.

6. Methods such as coffer dams, drip pans, and containments are used to minimize the spread of contamination.

7. Contaminated areas are clearly identified and have the contamination levels and the protective measures required clearly posted at the entrance.

8. Protective clothing removal procedures are posted at each contaminated area control point.

9. Contaminated or potentially contaminated areas are adequately surveyed, documented, and posted at specific frequencies, based upon the contamination levels, traffic patterns, and occupancy levels.

10. Routine contamination surveys are conducted in areas that are not normally contaminated. Frequency of those surveys is commensurate with the potential for contamination and with the significance of finding contamination in a particular area.

11. The contamination control program provides maximum accessibility to all areas with minimum use of anti-contamination clothing.

12. Sufficient quantities of protective clothing are available, and are consistently used where required.

13. Laundry procedures minimize spread of contamination.

14. Contamination control levels have been established. Controls are employed for areas, equipment, materials, tools, and other items if contamination levels exceed the established levels. Release surveys are performed by qualified personnel.

15. Operations with a high potential for release of contamination are performed in accordance with job-specific procedures that minimize the potential for release.

16. The use of equipment capable of spreading contamination, such as blowers, fans, and vacuum cleaners, is controlled to prevent the spread of contamination.

17. Radiation work permits or similar controls are used to control access to contaminated areas.

18. Procedures for use of step-off pads and the removal of protective clothing are posted where such removal is required and are consistently followed.

19. Personnel exiting posted contamination areas are required to monitor their whole body and extremities for contamination. For personnel exiting a radiologically controlled area, the degree of monitoring is based on the potential for contamination. Appropriate monitoring equipment is available.

20. Portal monitors are not used as the primary monitoring method for personnel contamination.

21. Maximum permissible personnel contamination levels (skin and clothing) have been established. Detected contamination in excess of these levels are investigated and documented as to source, probable cause, and other pertinent information. Records of these investigations are maintained and reviewed by radiological protection management for trends, and corrective action taken as necessary.

22. Facilities for decontamination are available.

23. Adequate counting equipment for swipes is available. The equipnent is properly calibrated and maintained. Counting procedures are available and followed by technicians. Adequate records are maintained to permit QA/QC verification of sample results.

RP. 12 ALARA PROGRAM

PERFORMANCE

A formally structured, auditable program should be in place with established milestones to ensure that exposures are maintained As-Low-As-Reasonably-Achievable.

CRITERIA

1. A documented ALARA program incorporating the guidance contained in DOE/EV/1830-T5 as appropriate is established and audited on a specified frequency.

2. An ALARA coordinator or other staff has been designated with specific ALARA responsibilities. These responsibilities are documented and integrated into the radiation protection program.

3. The ALARA program and its results reflect management commitment to ALARA. The radiation workers are convinced of management's commitment to ALARA. The radiation workers themselves committed to ALARA.

4. ALARA goals are established that are measurable and realistic.

5. The methods and procedures to evaluate ALARA data on a specified frequency are established.

6. The ALARA data can be used to identify operations and activities that may need extra attention.

7. ALARA reviews routinely performed prior to issuing radiation work permits.

8. ALARA is discussed in training given to radiation workers.. Specific methods are described for limiting exposure.

9. Meetings are held to discuss complex radiation work with high exposure potential. Dry runs are conducted with "cold" systems.

10. Facilities have been surveyed to locate any sources of nonproductive, low-level radiation exposure and such sources have been eliminated.

11. Trend analysis is performed by craft and facility type for both routine and repetitive operations. Management reviews these analyses on a specified frequency and takes action as appropriate.

RP. 13 RECORDS

PERFORMANCE OBJECTIVE

Records related to occupational radiation exposure should be maintained in a manner that permits easy retrievability, allows trend analysis, and aids in the protection of an individual and control of radiation exposure.

CRITERIA

1. Comprehensive records related to occupational radiation exposure are systematically generated and maintained consistent with ANSI N13.6. The records include:

   - Radiation records related to an individual, e.g., prior exposure history bioassay data, dose assessment methodology, personnel dosimetry results, etc.

   - Radiation records related to the status of work areas, e.g., radiation surveys, air sampling result, etc.

   - Records that describe the technical and administrative basis for radiation protection programs, e.g., standards, policies, procedures, methods of dose evaluations, etc.

   - Records of unusual occurrences, accidents, and incidents, e.g., investigations, corrective action, follow-up, etc.

2. Records related to occupational radiation exposure are adequate to demonstrate compliance with DOE 5480. 1B, Chapter 11 to meet the reporting requirements of DOE 5484.1A for employees and visitors, and the records retention requirements of DOE 1324.2

3. There are sufficient cross references in the records to ascertain on what data and by which technician a given personnel dosimeter or in-vitro and/or in-vivo bioassay sample was processed or measured. A given in vivo measurement? A dosimeter?

4. Records are maintained in a centralized location, protected from loss, such that the level of effort required to retrieve all the records relevant to a given incident (including field monitoring records, air sampling data, bioassay analysis, in vivo measurement, dose assessments, etc.) would be minimal.

5. Documented procedures for record maintenance, including length of storage are established for all records (e.g., instrument calibration, testing, area monitoring results, exposure history, etc.).

6. Records are used to determine ALARA programs are efficacious (i.e., dose trend analyses, etc. is performed).

7. Employees are provided with an annual report of their occupational exposure history.

8. Visitors are provided information with respect to their exposure in accordance with DOE 5484.1.

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