

# ornl

ORNL/M-4231

RECEIVED

MAR 13 1996

OSTI

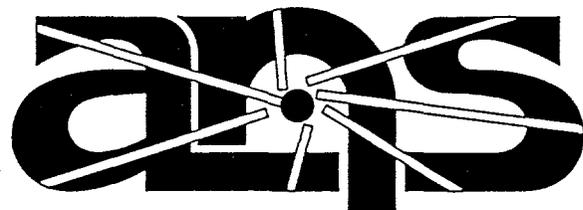
OAK RIDGE  
NATIONAL  
LABORATORY

MARTIN MARIETTA

## Advanced Neutron Source Reactor Zoning, Shielding, and Radiological Optimization Guide

J. L. Westbrook  
J. R. DeVore

August 1995



Advanced Neutron Source

MANAGED BY  
MARTIN MARIETTA ENERGY SYSTEMS, INC.  
FOR THE UNITED STATES  
DEPARTMENT OF ENERGY

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

**ADVANCED NEUTRON SOURCE REACTOR  
ZONING, SHIELDING, AND RADIOLOGICAL  
OPTIMIZATION GUIDE**

J. L. Westbrook  
J. R. DeVore

Date Published—August 1995

Prepared by  
OAK RIDGE NATIONAL LABORATORY  
Oak Ridge, Tennessee 37831-6285  
managed by  
LOCKHEED MARTIN ENERGY SYSTEMS, INC.  
for the  
U.S. DEPARTMENT OF ENERGY  
under contract DE-AC05-84OR21400



## CONTENTS

LIST OF TABLES .....	v
ACRONYMS AND INITIALISMS .....	vii
ABSTRACT .....	ix
1. INTRODUCTION .....	1
2. NUCLEAR INDUSTRY APPROACH TO RADIOLOGICAL CONTROL .....	3
3. ANS APPROACH TO RADIOLOGICAL CONTROL .....	5
4. DOSE AND DOSE RATE CONSTRAINTS .....	7
5. DERIVATION OF THE RADIOLOGICAL ZONING SCHEME .....	9
6. ACCESS CONTROL REQUIREMENTS .....	13
7. PROPOSED ANS RADIATION ZONES .....	15
8. GENERAL GUIDELINES FOR THE ASSIGNMENT OF RADIATION ZONES .....	17
9. ALARA CONSIDERATIONS FOR AOOs AND ACCIDENTS .....	21
10. SPECIFIC GUIDELINES FOR ZONING AND SHIELDING .....	23
11. METHODS FOR THE OPTIMIZATION OF RADIATION PROTECTION .....	27
12. SPECIFIC ANS AREAS ALREADY IDENTIFIED AS BEING OF ALARA CONCERN .....	31
REFERENCES .....	33
APPENDIX A: ANNUAL DOSES OF INTEREST AND DOSE RATES THAT MAY PRODUCE THEM .....	35
APPENDIX B: SHIELDING EXAMPLE .....	37
APPENDIX C: TWO EXAMPLES OF THE APPLICATION OF OPTIMIZATION .....	39
APPENDIX D: DISCUSSION OF THE U METHOD VERSUS THE DELTA METHOD ..	43
APPENDIX E: ZONING, SHIELDING, AND OPTIMIZATION REVIEW CHECKLISTS .	47



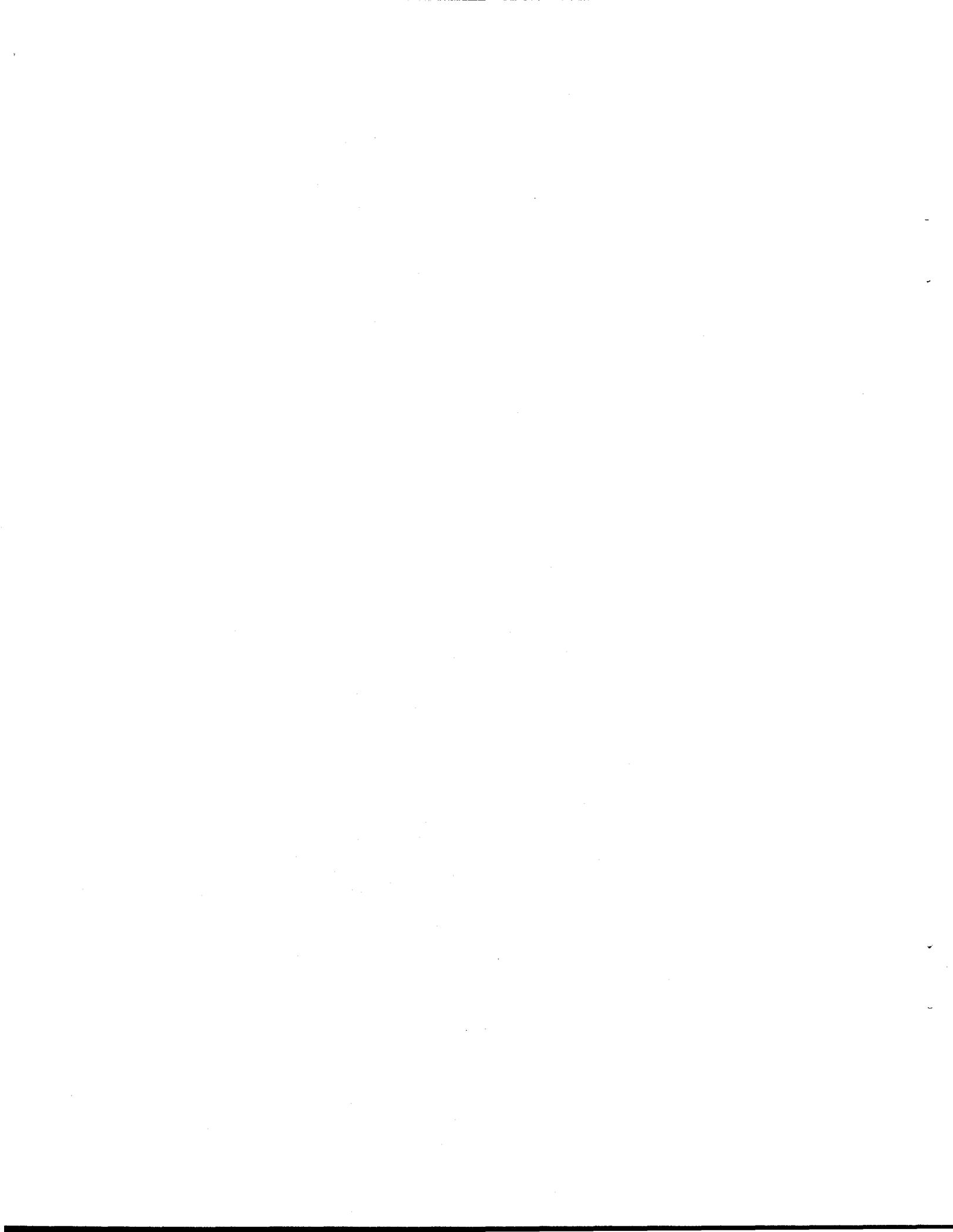
## LIST OF TABLES

Table		Page
1	Regulatory limits and objectives for occupational radiation workers .....	7
2	Administrative limits and objectives for occupational radiation workers .....	7
3	Regulatory limits for occupational nonradiation workers and the public .....	8
4	Definitions of radiological and related areas requiring controls .....	10
5	ANS radiological zones—external dose rate .....	15
6	ANS radiological zones—surface contamination potential .....	15
7	ANS radiological zones—airborne radioactivity .....	16
8	Considerations in zoning and in estimating doses by area, task, and work group .....	17
9	Application of Zones 1–4 when occupancy is uncertain .....	23
10	Reactor building areas and hot cell preliminary dose rates .....	24



## ACRONYMS AND INITIALISMS

ALARA	as low as reasonably achievable
ALI	annual limit of intake
ANS	Advanced Neutron Source
AOO	anticipated operational occurrence
BEIR	Biological Effects of Ionizing Radiation (Committee)
CFR	Code of Federal Regulations
DAC	derived air concentration
DOE	Department of Energy
FHC	fuel handling cell
ICRP	International Commission on Radiological Protection
LMES	Lockheed Martin Energy Systems, Inc.
MOP	member of the public
MSL	main steam line
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
RB	reactor building
RBA	radiological buffer area
RCM	Radiological Control Manual
RED	responsible engineering designer
TBD	to be determined
Y-12	Oak Ridge Y-12 Plant



## ABSTRACT

In the design of major nuclear facilities, it is important to protect both humans and equipment from excessive radiation dose. Past experience has shown that it is very effective to apply dose reduction principles early in the design of a nuclear facility both to specific design features and to the manner of operation of the facility, where they can aid in making the facility more efficient and cost-effective. Since the appropriate choice of radiological controls and practices varies according to the case, each area of the facility must be analyzed for its radiological impact, both by itself and in interactions with other areas. For the Advanced Neutron Source (ANS) project, a large relational database will be used to collect facility information by system and relate it to areas. The database will also hold the facility dose and shielding information as it is produced during the design process. This report details how the ANS zoning scheme was established and how the calculation of doses and shielding are to be done.



## 1. INTRODUCTION

In the design of major nuclear facilities, it is important to protect both humans and equipment from excessive radiation dose. Past experience has shown that it is very effective to apply dose reduction principles early in the design of a nuclear facility, both to specific design features and to the manner of operation of the facility. Doing so can also aid in making the facility more efficient and cost-effective.

Since the appropriate choice of radiation controls and practices is different for each case, each area of a facility must be analyzed for its radiological impact, both by itself and in interactions with other areas, for normal, upset, and accident conditions. As a result of this analysis, a set of information is compiled about each area. Communication of this information in an appropriate tabular or graphical form is accomplished by assigning one or more radiological zones that are part of a predefined set to each area of the facility. The information conveyed in this manner is expected to aid in the resolution of the following concerns:

- Shield designers require a knowledge of what the expected dose rates in the different areas are so as to allow the determination of the correct shielding thickness.
- The layout of equipment for future operation, maintenance, inspection, calibration, and testing requires a knowledge of what areas are acceptable for personnel occupancy or for activated or contaminated equipment movement or storage.
- Systems designers need to know what integrated dose their equipment is likely to receive and where to locate radiation sensitive equipment.
- Radiation protection personnel want to be able to look at the facility from a total plant point of view, especially with regard to intermittent, unfamiliar, or special operating states.
- Radiological considerations must be integrated with the many other requirements that are involved in determining the plant layout.

This report is written to establish the zoning requirements for the areas within the Advanced Neutron Source (ANS), to establish a procedure for making zone classifications, and to suggest a procedure that ANS designers should use for optimizing their designs from a radiological viewpoint. In the sections that follow, a discussion of approaches to radiological control, details of how the ANS zoning scheme was established, and how the calculation of doses and shielding are to be done are given. Some example calculations are also given. All the areas discussed below should be addressed in system radiological reviews, but the discussion of the performance of such reviews is beyond the scope of this document.



## 2. NUCLEAR INDUSTRY APPROACH TO RADIOLOGICAL CONTROL

In the design of nuclear power plants (the most recent U.S. examples being the standard boiling water reactor and pressurized water reactor designs), initial estimates of dose rates and occupancy requirements can be based on the operating experience of existing similar plants in the United States and around the world. From these and from other experience at existing facilities, resulting doses and required shielding thickness can be calculated. However, the many unique features of the ANS and the uncertainty of source terms for much of the equipment do not allow for such initial estimates to be made with the same degree of confidence. Hence the process of arriving at sound estimates of dose rates and occupancy requirements for the ANS is expected to be much more iterative than it is for power plants and to require a much more careful study of the interactions between areas, given that some of these will be completely new.

The Clinch River Breeder Reactor Plant project staff, who also had to confront the problem of lack of a similar experience model, took the following approach in conceptual design. They set a total annual dose goal for the plant and then allotted fractions of it to the various systems and operations. Each cognizant engineer was to try to subdivide his allotments and to design his system(s), operations, and areas so as not to exceed his allotment. Regulatory Guide 8.8 (Ref. 1) was used as a guide to good design choices. The then-current 10 CFR 20 exposure limits and maximum permissible concentrations for air and liquids were used; specific limits included 500 mrem/year to unrestricted areas and 100 mrem/week and 2 mrem/h to general access areas. Other specific shielding criteria were adopted and applied. A standard set of radiological zones tied to these limits and to control requirements was established to aid in area classifications for specifying shielding and radiological controls and thus in aiding decisions regarding accessibility. Cost-benefit analysis was also used to help in decision making.

Once the five main blocks of information—dose allotments, zoning assignments, the results of cost-benefit analysis, source terms, and time-access (occupancy) requirements—had been produced, the engineers could proceed with the detailed design of systems and components. There was to be some readjustment of dose allotments based on continuing review of the design, as source terms were refined and as some allotments or suballotments were found to be too large or too small.



### 3. ANS APPROACH TO RADIOLOGICAL CONTROL

The Clinch River approach was considered for use in the design of ANS, but there is a significant difficulty in producing an annual dose goal. Existing reactors, both power-producing and research, are comparable in only limited ways to ANS, so their dose would have been difficult to scale up or adjust to the proposed operation of ANS. Thus, although the Clinch River iterative approach will eventually be followed, starting at the completion of the conceptual design stage, the initial estimates are to be mostly prospective. That is, source terms and occupancy information are to be used to calculate raw dose rates and the resulting doses. Basic dose and dose rate constraints as discussed below will be applied, and any necessary shielding and controls will be added. A zoning scheme will be used to help represent the dose rates produced in an area with sources and the dose rate limits for areas in which access would be required. Then the dose(s) associated with each system, operation, and area will be examined together with the others to see which produces the highest dose and which might be the best candidate application of dose reduction features or measures. The iterative process, including cost-benefit analyses and dose allotments, will essentially have begun at this point. Completion will occur at the point that the design is finalized, just prior to the start of construction.

A large relational database system (called the ANS Buildings and Site Planning Database) will be used to collect information by system and relate it to areas. This information includes sources, dose rates, zone assignments, occupancy requirements, requirements for access for operation, maintenance, inspection, testing, calibration, radiation surveillance, and interaction between areas (e.g., transportation of casks between areas). This database will also hold the dose and shielding information as it is produced.



#### 4. DOSE AND DOSE RATE CONSTRAINTS

The basic dose limits for occupational workers are from 10 CFR 835 (Ref. 2). At this time, however, the Department of Energy (DOE) Radiological Control Manual (RCM) and DOE Order 5480.11 (Ref. 3) are also in force. The basic requirements of 5480.11 are covered in 10 CFR 835 and the RCM, so there are virtually no separate 5480.11 requirements to invoke. Some of the requirements of DOE documents mentioned above are also incorporated by reference into DOE Orders 5480.30<sup>4</sup> and 6430.1A.<sup>5</sup> Dose limits and other applicable requirements of 10 CFR 835 and the RCM<sup>6</sup> (and DOE orders, as applicable) are given in Tables 1 and 2. Lockheed Martin Energy Systems (LMES) and ORNL control levels in force at present are given also, since they are useful as indicators of representative operational limits or controls.

**Table 1. Regulatory limits and objectives for occupational radiation workers**

Description	Limit
Nominal statutory limit	5 rem/year
DOE administrative control level (RCM)	2 rem/year
Design dose limit for new facilities	500 mrem/year
Design <u>objective</u> for new facilities (areas not continuously occupied)	"20% of the applicable dose limits," i.e., 1 rem/year
Design <u>objective</u> for new facilities (areas of continuous exposure, 2000 h/year occupancy)	0.5 mrem/h

**Table 2. Administrative limits and objectives for occupational radiation workers.**

Description	Limit
LMES administrative control level	1.5 rem/year
1995 ORNL ALARA <sup>a</sup> goal	0.650 rem/year
Other ORNL limits (requires radiation work permit and other permission to exceed them)	100 mrem/week 20 mrem/day 200 DAC-h/year <sup>a</sup> 4 DAC-h/week
Objective for frequently occupied areas (ORNL)	0.5 mrem/h
Airborne radioactivity concentrations outside radiological areas (ORNL)	"Well below 10% of a DAC"

<sup>a</sup>ALARA = as low as reasonably achievable; DAC = derived air concentration.

The basic dose limits for members of the public (MOP), which would include visitors to ANS, are from DOE Order 5400.5.<sup>7</sup> These dose limits and other applicable requirements of 5400.5 are

also given in Table 3. The doses given in the tables are the total effective dose equivalent, that is, the sum of the annual external dose equivalent and the internal committed effective dose equivalent incurred in the corresponding year. In addition, doses to occupational workers and MOP are required to be kept as low as reasonably achievable (ALARA) (835, 5400.5, 5480.11, 5480.30, 6430.1A, RCM), no matter what the regulatory and administrative limits are.

**Table 3. Regulatory limits for occupational nonradiation workers and the public**

Description	Limit
Occupational nonradiation worker	5000 mrem/year
Nominal limit for control purposes	100 mrem/year
Member of the public, regulatory limits:	
Dose, controlled area	100 mrem/year
Dose, uncontrolled area	
All DOE sources, total	100 mrem/year
All DOE sources (airbornes only)	10 mrem/year
Dose, within 80 km of the site, accidents (siting purposes)	25 rem to the whole body, 300 rem to the thyroid

Doses to on-site personnel are to be evaluated for postulated accident conditions. For siting purposes, 10 CFR 50, Criterion 19, states that for the control room, the dose to personnel under accident conditions shall not exceed 5 rem whole body or its equivalent to any part of the body over the duration of an accident. The time period is commonly taken to be 30 days. (This figure is used as a nominal dose here for workers in the facility after a serious accident for which on-site postaccident response activities are necessary.)

Maximum container dose rates for shipping are 100 mrem/h at contact and 10 mrem/h at 1 m. However, for on-site handling purposes, the dividing line between contact-handled and remote-handled radwaste (including containers) is 200 mrem/h.

## 5. DERIVATION OF THE RADIOLOGICAL ZONING SCHEME

Radiological zones are designations that indicate the degree of radiological hazard associated with an area. The three basic aims for the ANS zone scheme are given below.

- It should accommodate the three radioactive hazard conditions that may need to be represented: external dose rate, potential for surface contamination, and potential airborne radioactivity.
- It should accommodate all status situations that might be encountered: normal operation; shutdown; maintenance, inspection, calibration, and testing; anticipated operational occurrences; and accidents, including the design-basis accident. (For convenience, normal operation, shutdown, maintenance, inspection, testing, calibration, and like expected status modes of the reactor facility or of a particular component or system will all be designated as "normal operation".)
- It should accommodate the range of dose the various dose receivers might experience: personnel, monitors, and equipment.

These aims can be further defined as follows. As noted in the Introduction, a zoning scheme can be set up so that each zone is tied to given dose or dose rate limits or to control requirements; this can be extended to cover, although in a more general way, surface contamination and airborne radioactivity conditions. It can also be set up to indicate equipment qualification requirements. Because the radiological conditions in an area may vary according to whether the reactor is operating or not, whether a given system is operating or not, or whether an operation is being performed or not, the zone assignment for the area may change as normal conditions change. In addition, the radiological conditions may change if there is an anticipated operational occurrence (AOO), an upset condition, or undesirable event that is likely to occur at least once during the life of the plant. Other changes in zones could occur if an accident (an event with significant adverse consequences that is not expected to occur, but may nevertheless credibly occur, during the life of the plant) were to happen. As also noted in the Introduction, the zones are intended to be an aid to specifying shielding and radiological controls and in making decisions regarding layout, accessibility, traffic, line routing, and other operational planning concerns. Therefore, zoning a given area may involve the assignment of multiple zones, each with its associated conditions, access requirements, etc.

Because of the various potential uses of the zones, the zoning scheme adopted should be as flexible and comprehensive as possible. Table 4 gives the definitions of the radiological and related areas for which controls must be provided in one form or another.

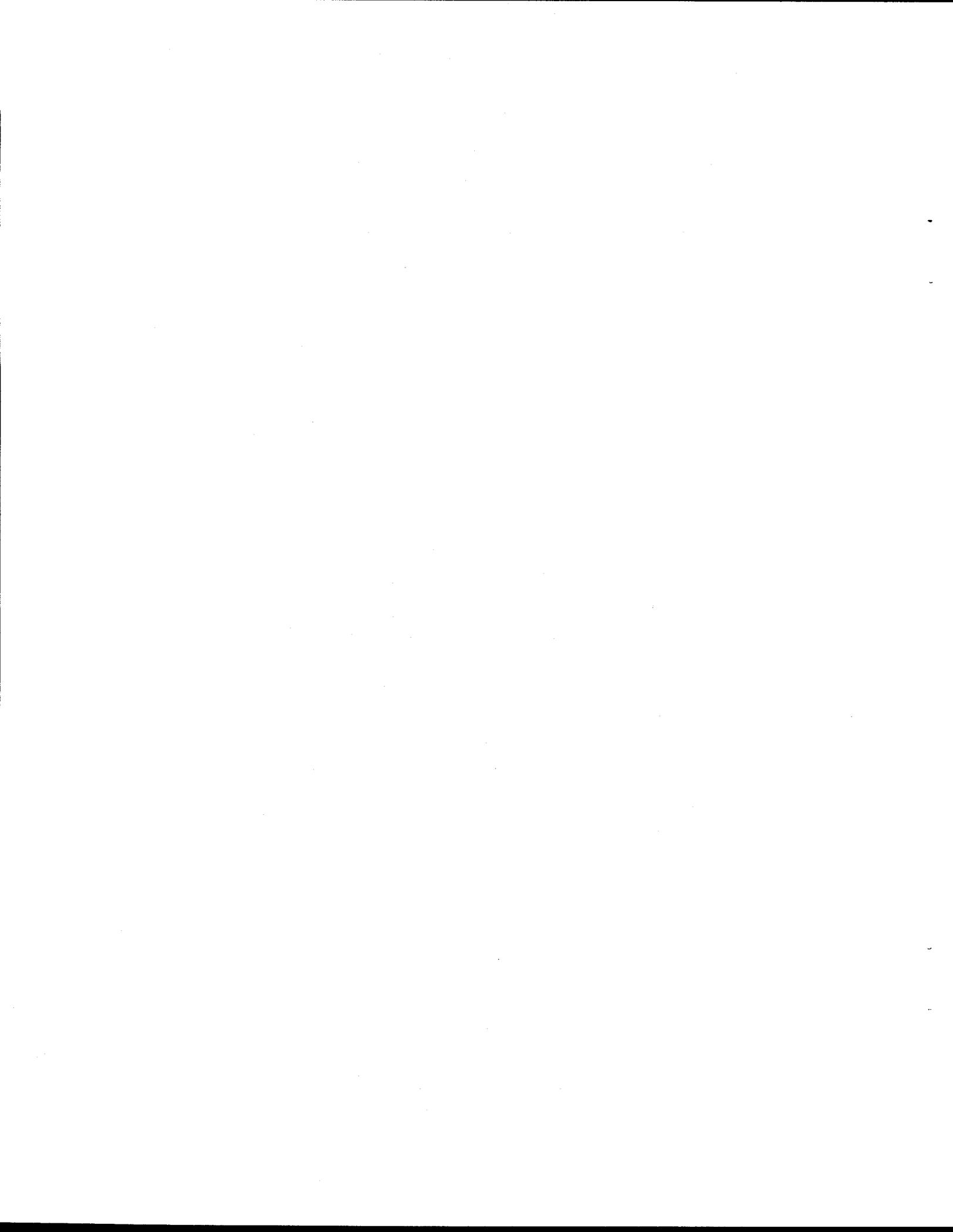
The definitions in the above tables are from 10 CFR 835 and one of its implementation guides, G-10 CFR 835/G1,<sup>8</sup> except for the definition for the radiological buffer area, which is from the RCM. "Contamination" is defined similarly (i.e., as cutoff levels) for workplace surfaces in Appendix D of 10 CFR 835, in Table 2-2 of the RCM, and in Attachment 2 of 5480.11. However, the total limit for the transuranics is lower in 5480.11 than it is in the other two documents. A level is given for tritium in the RCM but is "reserved" (i.e., TBD) in 10 CFR 835. The surface contamination values to be used for design on ANS are the 10 CFR 835 values with the addition of the RCM tritium values. For the free release of objects from controlled areas (although it does not use this term), 5400.5 gives the same values as the other three documents, except that it does not mention tritium and its transuranic values are "reserved."

**Table 4. Definitions of radiological and related areas requiring controls**

Area	Definition
Controlled area	Any area to which access is managed to protect individuals from exposure to radiation or radioactive materials. Individuals who enter only a controlled area without entering radiological areas are not expected to receive a total effective dose equivalent of more than 100 mrem in a year. There may be more than one controlled area within a site boundary.
Radiological buffer area (RBA)	An area established within a controlled area to provide a secondary boundary to control the spread of radioactive material contamination or the exposure of personnel to external radiation. The requirement for such an area is based on protecting individuals who do not have radiological worker training from inadvertent exposure to radioactive material or radiation fields at levels at which such training would be required. RBAs should be established as buffer areas for entrance or exit between contamination, high contamination, or airborne radioactivity areas, except that no RBA is needed for the latter areas if they are completely contained within contamination areas.
Radiological area	Any area within a controlled area (but not considered to be part of the controlled area) that qualifies as a radiation area, high radiation area, very high radiation area, contamination area, high contamination area, or airborne radioactivity area. The boundaries of any of the three radiation areas, when the area is permanent, should be the physical barriers (e.g., walls or fences) that prevent access to the area except at designated access points.
Radiation area	Any area accessible to individuals in which radiation levels could result in an individual's receiving a deep dose equivalent of more than 5 mrem but less than or equal to 100 mrem in 1 h at 30 cm from the source or from any surface that the source radiation penetrates. During transportation of radioactive material emitting radiation at levels that meet the criteria for a radiation area, if it is not possible for a physical barrier to be established at the 5-mrem/h level, the exterior of the material package or container shall be labeled as a radiation area, and the individual transporting the material is responsible for communicating the radiation hazard.
High radiation area	Any area accessible to individuals in which radiation levels could result in an individual's receiving a deep dose equivalent of more than 100 mrem but less than or equal to 500 rad in 1 h at 30 cm from the source or from any surface that the source radiation penetrates. High radiation areas should be located within radiation areas, if practical.
Very high radiation area	Any area accessible to individuals in which radiation levels could result in an individual's receiving a deep dose equivalent of more than 500 rad in 1 h at 1 m from the source or from any surface that the source radiation penetrates. A physical barrier(s) should be provided to prevent personnel access to the area while the radiological conditions creating the very high radiation area exist.

Table 4 (continued)

Area	Definition
Contamination area	Any area where contamination levels are greater than the values specified in Appendix D of 10 CFR 835 (except that Table 2-2 of the RCM will be used for tritium) but less than or equal to 100 times those values. These values will also be used for the free release of objects from controlled areas.
High contamination area	Any area where contamination levels are greater than 100 times the values specified in Appendix D of 10 CFR 835 (except that Table 2-2 of the RCM will be used for tritium). If practical, high contamination areas should be located within contamination areas, and permanent barriers should be used.
Airborne radioactivity area	Any area where the measured concentration of airborne radioactivity, above natural background, is or is likely to exceed 10% of the derived air concentration (DAC) values given in Appendix A or C of 10 CFR 835. Permanent barriers should be used whenever practical.
Hot spot	Any localized source of radiation or radioactive material, normally within facility piping or equipment, that results in radiation levels that exceed the general area radiation level by more than a factor of 5 and are greater than 100 mrem/h on contact. The purpose of posting it is to identify to the worker the significant localized sources of radiation in accessible areas frequented by workers; thus, hot spots need not be posted in high radiation areas with general area dose rates greater than 1 rem/h or in very high radiation areas.
Hot particle area	Undefined as such, but the RCM implies that any area known to have had hot particles is ipso facto a radiological area and must have additional controls. A hot particle is a small bit of radioactive material that can produce a high localized dose and "may not be detected during normal personnel monitoring at exit areas."



## 6. ACCESS CONTROL REQUIREMENTS

The major access control requirements associated with the areas defined above are listed below. Note that in addition to the access controls, 10 CFR 835 requires air sampling for areas in which an individual might receive 2% of the annual limit of intake (ALI) in a year (corresponding to a committed effective dose equivalent of 100 mrem) and real-time air monitoring for normally occupied areas where an individual is likely to be exposed to more than a DAC or "where there is a need to alert potentially exposed individuals to unexpected increases in airborne radioactivity levels." Appendix A shows some correspondences that were taken into account in the consideration of an ANS zoning scheme.

For high radiation areas where dose rates are such that a person could receive a whole-body dose of 1 rem in 1 h at 30 cm from the source or from any surface that the radiation penetrates and for very high radiation areas, at least one of the following shall be provided:

1. Control devices on each access point that function automatically to prevent entry, that permit entry only if the dose rate is reduced to 100 mrem/h or less, and that prevent use or operation of the radiation source while personnel are present.
2. A control device that energizes conspicuous visible or audible alarm signals so that the individual entering the area through a failed control device is aware of the radiation level and so that radiation protection or operational personnel are aware of his entry.
3. Locked entryways, with positive control over the area when access is required.
4. Control devices that automatically generate audible and visible alarm signals to alert personnel in the area before use or operation of a radiation source in time for them to evacuate or to activate a secondary control device to prevent use or operation of the source.
5. Continuous direct or electronic surveillance that is capable of preventing unauthorized entry.
6. Additional measures to preclude entry into areas while the dose rate exceeds 500 rad/h.

Physical controls should not unduly impede passage toward emergency exits or evacuation routes (including the control barriers of item 3 above).

Entrance to and exit from an RBA or contamination area shall be made through a specified control point(s). The number of control points should be minimized. A control point may be temporary or permanent depending on the degree of access required. The main access control point should be located on the (or a) major route into the outer radiological boundary(-ies) [i.e., the entry(-ies) into the containment, the guide hall, etc.].

Weekly inspections of the physical controls for high and very high radiation areas should be made.

Successful completion of the appropriate level(s) of radiation worker training shall be required for unescorted entrance to RBAs or to radiological areas (RCM, ORNL Health Physics Manual). For example, DOE Radiation Worker I training is required (with few exceptions) for entry into RBAs and radiation areas with no contamination; Radiation Worker II, a longer training course, is required for entry into all other areas. Thus, access control measures and points should be planned with this in mind.



## 7. PROPOSED ANS RADIATION ZONES

On the basis of the data, definitions, and control requirements given previously, the radiological zones to be used for design and operational planning purposes were chosen. These are shown in Tables 5, 6, and 7. Every assigned radiological zone is to consist of an external dose rate number (i.e., 1 through 11) and may also have a contamination letter or airborne radioactivity letter or both, depending on the potential for contamination. For example, an RBA established for contamination control in which the maximum dose rate was 0.1 mrem/h would be given the zone designation 2a. A radiation area with a maximum dose rate of 30 mrem/h and a high potential for significant surface and airborne contamination might be given the designation 6c.

**Table 5. ANS radiological zones—external dose rate<sup>a</sup>**

Zone	Control range	Rationale
1	0.0–0.05 mrem/h	Free MOP access
2	0.05–0.25 mrem/h	Free nonradiation worker access
3	0.25–2.5 mrem/h	
4	2.5–5.0 mrem/h	
5	5.0–20.0 mrem/h	Radiation area
6	20–100 mrem/h	Radiation area
7	100–1000 mrem/h	High radiation area
8	1–10 rad/h	High radiation area
9	10–100 rad/h	High radiation area
10	100–500 rad/h	High radiation area
11	≥500 rad/h	Very high radiation area

<sup>a</sup>Small hot spots do not affect the zoning; dose rates are those above background. Zones 3 to 6 are the areas of greatest health physics interest. Zones 7 to 11 are primarily for equipment qualification and accident use and have very limited or no personnel access.

**Table 6. ANS radiological zones—surface contamination potential**

Zone	Control range
None	No potential
a	Buffer area—low potential (low concentrations if contamination occurs)
b	1–100 × 10 CFR 835, Appendix D, limits, potential or actual (contamination area)
c	≥100 × 10 CFR 835, Appendix D, limits, potential or actual (high contamination area)

**Table 7. ANS radiological zones—airborne radioactivity**

Zone	Control range	Rationale
None	$\leq 0.01$ DAC	Virtually no potential
A	0.01–0.10 DAC	Low potential, low level (respirator or air suit use not likely)
B	0.1–1.0 DAC	Light control range (respirator or air suit use likely, air sampling or monitoring)
C	1–10 DAC	Medium control range (respirator or air suit used required, other strict clothing requirements, air monitoring)
D	$\geq 10$ DAC	Strict control range (the most stringent personnel protection measures)

## 8. GENERAL GUIDELINES FOR THE ASSIGNMENT OF RADIATION ZONES

The radiation zone designations are to be applied and used according to the following guidelines.

First, in general, the maximum dose rate and the maximum contamination and airborne levels for the area are to be used for purposes of calculating shielding and personnel and equipment doses. However, in cases where this is clearly not warranted (such as when the maximum dose rate is applicable to one side of a room while personnel are occupying an area of much lower dose rate on the other side), exceptions such as using the average dose rate may be made if justified.

Second, in the absence of specific information regarding dose rates, contamination levels, or airborne radioactivity levels in an area, the radiological zone designation for that area shall be applied as appropriate in shielding design and in the calculation of personnel doses based on expected occupancy of the area. The zone designation may also be used for the planning of radioactive materials movement, the evaluation of requirements for equipment qualification, the determination of necessary radiation protection measures, and operational planning. Appropriate zone designations should be applied as necessary to the operational condition being addressed. Some of these considerations appear in Table 8.

**Table 8. Considerations in zoning and in estimating doses by area, task, and work group**

### *Area*

- What system(s) or component(s) are in or affect this area?
- What control measures or features are required for this area?
- Where in the area is the source(s) located?
- Where are readouts, control panels, and other must-access points located in the area?
- What types of entry are required for this area (e.g., rad surveillance, maintenance)?
- For how long is each type of entry required?
- How often is each type of entry required?
- How many people will enter for each type of entry?
- What are the interactions of this area with other areas?
  - Through what other areas does the worker pass to get to this one?
  - What areas does the worker enter after passing through this one?
  - What communications are available in this area (e.g., telephone)?
- Is this area used for laydown, storage, in situ maintenance, remote operations, etc.?
- What shielding is present in and enclosing this area?
- What are the predicted radiation levels in this area?
- Do radiation levels vary substantially within the area and are there any hot spots?
- What training and authorization are required to enter this area?

### *Task*

- What type(s) of workers perform this task?
- What training and authorization are required to perform this task?
- What tasks are associated with this one (e.g., movement of a cask associated with refueling)?
- What support services are associated with this task (e.g., fixed and portable ventilation)?

Table 8 (continued)

Personnel

What type(s) of worker (work group) is required for each entry?

What other duties does this worker or work group perform?

Systems and Components

What parts of a system or component are potentially radioactive (e.g., activated) or contain radioactivity?

What are the operational, maintenance, inspection, calibration, and testing modes of this system or component?

What are the failure modes of this system or component, and which ones result in AOOs or accidents?

What is the possible operating state(s) of the rest of the facility when this system or component is operating: normally shut down; shut down for maintenance, inspection, calibration, testing, etc.; or malfunctioning in such a way as to have a radiological impact?

Is a system or component dedicated or shared?

Can maintenance be done on one component or system while the other is operating?

Third, in planning for postaccident actions, particular attention should be paid to the presence of hot spots in areas through which personnel may need to pass. This is particularly true of hot spots created by penetrations, since these may not be small localized areas, but may be conical extensions out the penetrations. The area that is immediately outside a penetration's line-of-sight cone but may experience a high dose rate due to scattering off the sides of the penetration should be considered also, along with the area that is not in the line of sight of the penetration and sees no direct scatter off the sides of the penetration. This latter area may experience a dose rate that is significant (that is, beyond what comes through the shield wall) from scatter of the direct and penetration-scattered radiation off the opposite and surrounding walls.

To understand the reason behind this, suppose that the dose rate at a point 10 ft. away from a wall along the centerline of a penetration is 2.4 mrem/h and that the dose rate at a point 4 ft below it is a factor of 6 lower, or 0.4 mrem/h. If the second point is at head level, then the zone for the general area (a worker standing on the floor) might be based on the 0.6 mrem/h, except for a platform up at centerline level, where the zone would be based on the 2.4 mrem/h. Both the area and the platform would be Zone 3 and would be considered to be accessible for extended periods of time since the resulting doses would be low. However, in an accident, if the dose rate at the first point were 72 R/h, then (assuming that the spectrum was about the same and the source geometry had not changed significantly) the dose rate at the second point would be 12 R/h. Both points would be in the same zone, in this case Zone 7. However, the difference in allowed accessibility times would be very significant: An occupancy of only a few minutes would even be considered for the first point, but an occupancy of almost half an hour would be possible in the area of the second point without an on-site postaccident worker's receiving more than the nominal 5 rem. Thus the use of the higher zones when planning postaccident access should be done with care.

Fourth, preliminary ALARA determinations (that is, preliminary decisions based on evaluations of the necessity of reducing dose resulting from work on a particular task, or in a certain area, or by a specific work group) are to be done using the zone designations. The

preliminary determinations are to be regarded as pointers to operations, layouts, or measures whose initially proposed designs or conceptions need to be reconsidered.

Obviously, an initial rough dose estimate resulting from a worker's presence in an area can be found by multiplying the top dose rate for an area by the number of hours he is assumed to do normal operational work there in the time period (usually a year) over which the estimate is to be made. If such an estimate is made for each worker who may enter the area, the highest individual dose due to work in the area can be determined as well as which work group would have this most exposed member. The sum of the estimates made for all workers by work group shows which work group will receive the most dose from work in the area. Finally, the sum over all work groups gives the total dose estimate for the area.

The rough estimates above will be refined as the design proceeds, of course. However, these estimates may not include all of the dose or may not give a complete picture of the dose. First, the estimates above are for normal operation and do not include AOOs. Estimates of doses due to AOOs should be made and added as information regarding AOOs that affect the area become known. Second, it is of interest to know what dose is attributable to what task, not only to what work group or area. So separate sums will have to be made over workers on a task, whatever their work group and whatever the areas in which the task is assumed to take place; again, the highest individual dose, the work group having the most exposed member, and which work group will receive the most dose from work on the task can be determined. Note that it is easier to look at dose due to maintenance alone, or testing alone, etc., by examining task doses than it is by examining area doses; this is particularly useful when one is trying to decide where it makes radiological sense to devote resources to increase reliability.

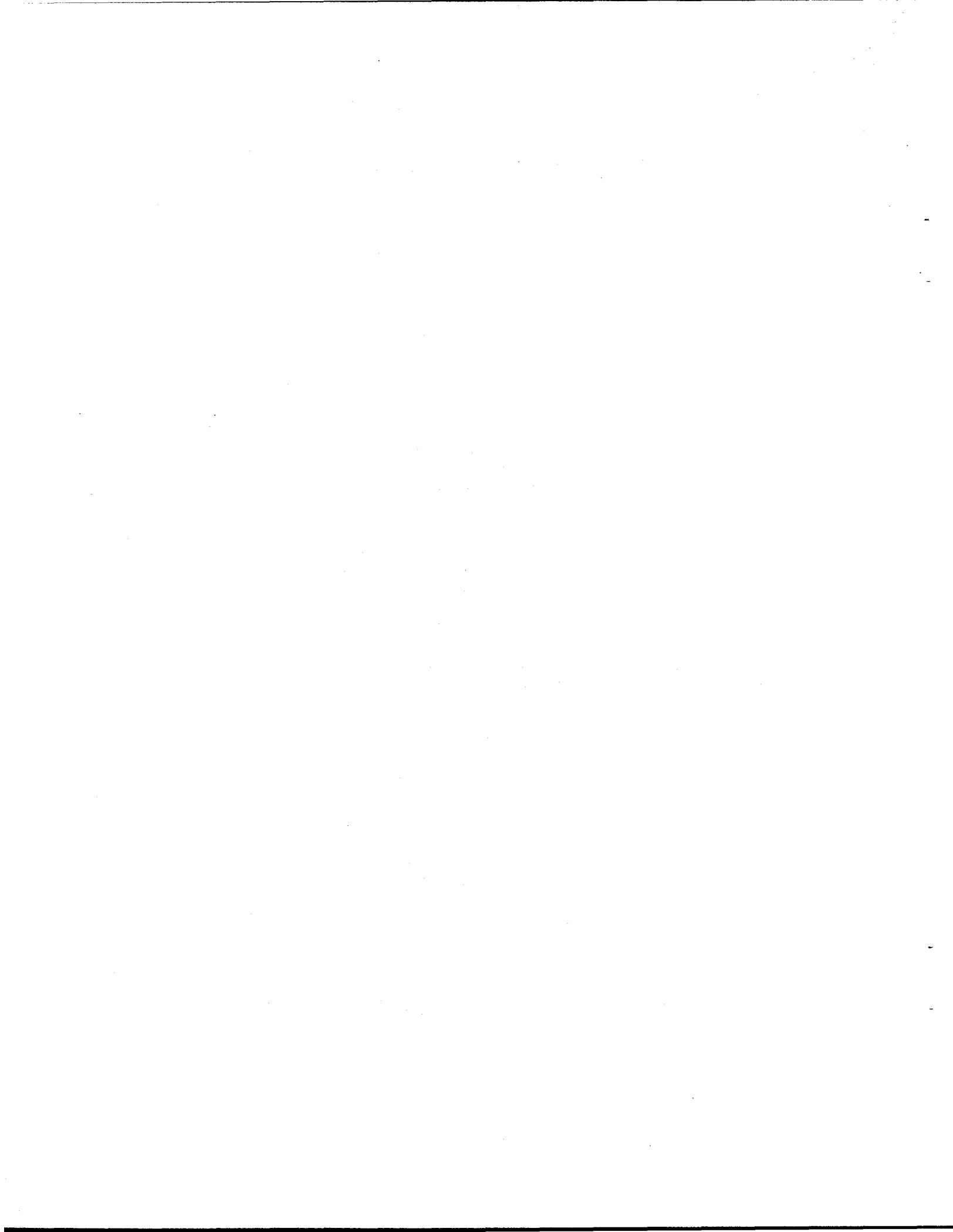


## 9. ALARA CONSIDERATIONS FOR AOOs AND ACCIDENTS

ALARA determinations (including optimization) are to be based on the estimates of dose for both normal operation and AOOs. However, dose estimates for these two conditions for an area, task, or work group will generally have to be considered separately when preliminary ALARA determinations are made. First, the AOO will generally not occur yearly, so the time period of the estimate for an AOO may not be the same as that for the corresponding area(s) or work group(s). Second, the AOO dose may not be attributable to a given task; that is, an AOO may occur in association with a given task but may also be an occurrence unconnected with a task. Recovery from an AOO may have to be considered to be a task or a series of tasks in itself. Third, changes made to reduce AOO dose may increase normal operational dose or vice versa, and other factors may render such changes more undesirable for one state or the other.

After separate consideration, the dose estimates for an AOO will have to be added to the corresponding normal operation doses in some way. This would be for purposes such as obtaining the collective dose over the lifetime of the plant for a particular task or component; estimating the total annual and total lifetime doses for the facility; and refining ALARA determinations that will help decide resource allotments. For example, if an AOO is assumed to occur every 10 years, then the dose estimate for a single occurrence could be divided by 10 and the result added to the annual normal operations total to give an annual average. Alternatively, the AOO single-occurrence estimate could be added to each year in which it is assumed to occur; this might be appropriate for an AOO that occurred in connection with a major outage that occurred less often than once a year, when the aim was to determine if dose would be a limitation that would force more workers to be used in such an outage. In any case, the basis for a sum would have to be clearly stated when the sum was taken in a different manner from the standard way that will be agreed on during the process of design. Dose estimates for areas, tasks, and work groups under accident conditions must also be made. However, because accidents are unlikely and because only one, if any, would occur in the life of the facility, these dose estimates will, of course, not be added to the facility total. Here, the individual doses are of most importance, and the sums will be taken only for the purpose of estimating the number of each type of worker needed for various tasks, particularly repeated ones.

Additionally, ALARA evaluations will not be done for accidents as they will be for normal operations and AOOs. The philosophy behind this is that since accident dose is only potential and is very unlikely to be received, resources should be applied to preventing accidents only until the probability is reduced to an acceptable level [the magnitude(s) of which is discussed elsewhere in ANS documents] and to mitigating accidents only until the estimated dose is reduced to the nominal allowed level (e.g., 25 rem to a person at the site boundary or at any point beyond that up to 80 km away). Then, any remaining resources should be applied to reducing anticipated doses, that is, to doses resulting from normal operations and AOOs. It follows that ALARA evaluations for accidents would be done for the purpose of evaluating competing choices, not for the purpose of determining what dose(s) below the nominal levels would be cost-beneficial to achieve as in the normal operation and AOO case. Note that, on the other hand, accident conditions often dictate features (e.g., for filtration or shielding or extra pumps) that would otherwise not be required and that optimization is not to be applied to the inclusion of such features.



## 10. SPECIFIC GUIDELINES FOR ZONING AND SHIELDING

In many cases, there is no choice as to whether to provide shielding or not because the unshielded dose rate is so high that no occupancy by workers or sensitive equipment is possible. In other cases the choice is not clear since the dose rate is tolerable if the occupancy is not too high. Then the question arises as to how much shielding is enough. Sometimes the dose to sensitive equipment is more limiting, and, if so, the maximum dose rate can be calculated based on the expected lifetime of the equipment. However, it is usually the case that the dose rate to workers is more limiting. In that case, once the design objectives listed in Tables 1–3 have been taken into account, an ALARA determination of the appropriate thickness of shielding must be made.

Where there is substantial uncertainty as to the occupancy of nonradiological areas, Zones 1–4 may be applied as follows and as given in Table 9. The meaning of “frequent” is deliberately left flexible here, but it will probably be defined to be the range “once per day to once per week.” For example, note that an entry made twice a week for 10 min each time would result in a maximum Zone 3 dose of  $2.5 \text{ mrem/h} \times 2/\text{week} \times 50 \text{ week/year} \times 10 \text{ min}/60 \text{ min/h} = 42 \text{ mrem}$ , or less than one-tenth of the design objective of 500 mrem for occupational workers; this would be relatively small for a radiation worker but a large fraction (42%) of the DOE limit of 100 mrem/year for an unbadged worker.

**Table 9. Application of Zones 1–4 when occupancy is uncertain**

Example situation	Zone application
Members of the public may enter the area (e.g., casual visitors and non-ORNL service workers such as vending machine changers)	Zone 1 0.0–0.05 mrem/h
Nonradiation workers and occasionally non-ORNL service workers may enter the area (e.g., short-term research visitors, telephone repairmen, and ORNL workers not expected to enter radiological areas)	Zone 2 0.05–0.25 mrem/h
Routine but not continuous radiation worker access and infrequent and brief access by nonradiation workers	Zone 3 0.25–2.5 mrem/h
Routine but moderately infrequent radiation worker access and fairly restricted access by nonradiation workers	Zone 4 2.5–5.0 mrem/h

General recommendations for preliminary zone assignments for design purposes for various systems and pieces of equipment in reactors are as given below. These have been adjusted somewhat from several American National Standards Institute (ANSI) radwaste standards. For comparison, note that the ANSI/American Nuclear Society (ANS) zones for external dose rate only are as follows: I, 1.0 mrem/h; II, 2.5; III, 15; IV, 100; and V, greater than 100 mrem/h (e.g., see Table 4 from “Occupancy Time Dose Rate Classifications,” ANSI/ANS 55.6).<sup>9</sup>

- a. The need for personnel to enter zones greater than 20 mrem/h and the time they spend there should be limited.

- b. Radwaste and other processing areas required for routine access should be in zones less than 20 mrem/h. Frequently occupied control areas should be at less than 1 mrem/h, and any remote control areas should be located in zones less than 20 mrem/h. Except for elements that must be located at the equipment or in equipment cells, instrumentation shall be located in areas of 20 mrem/h or less, in particular, instrument transmitters and flow elements in piping systems. Required lubrication addition, chemical addition, and hydraulic fluid fill points should be in areas less than 2.5 mrem/h.
- c. Pipe runs containing unprocessed liquid wastes (excluding low-level wastes such as detergent wastes) shall not be routed through zones less than 15 mrem/h unless they can be shielded to below the zone upper limit.
- d. Fuel handling equipment shall be designed such that the operator will generally not be exposed to a whole-body radiation dose rate greater than 2.5 mrem/h from an irradiated fuel assembly, control component, or both, with the pool at normal operating water level. However, for intermittent brief periods, higher dose rates may be tolerated, subject to acceptability of the total dose for the operation.
- e. Nonradioactive valves and equipment should be located in zones less than 20 mrem/h.

Other specific recommendations from Ref. 10 are given in Table 10 . An example of how dose estimates might be done is given in Appendix B.

**Table 10. Reactor building areas and hot cell preliminary dose rates<sup>d</sup>**

Area/cell	Operating condition	Personnel access <sup>b</sup>	Dose limit (mrem/h) <sup>c</sup>
<u>RB 1st floor</u>		<u>User/Research</u>	
General area	All normal	No time limit	0.25
<u>RB 2nd floor</u>		<u>User/Research</u>	
General area	All normal	No time limit	0.25
<u>RB 3rd floor</u>		<u>Operators</u>	
General area	All normal	No time limit	0.25
<u>Reactor pool</u>			
(a) Over	Reactor at power Refueling Pool filled	Limited Limited	<5 <100
(b) Edge	Reactor at power Refueling Pool filled	No time limit Limited	1
(c) Pool shaft	Reactor shut down with pool drained	Limited	<100
(d) Pool shaft	Reactor shut down with pool drained and fuel handling cell drained to minimum safe level	Limited	<100

Table 10 (continued)

Area/cell	Operating condition	Personnel access <sup>b</sup>	Dose limit (mrem/h) <sup>c</sup>
<u>Spent fuel storage pool</u>	No fuel handling	Limited	<5
(a) Over	Refueling	Limited	<5
(b) Edge	No fuel handling	No limit	0.25
	Refueling	Limited	<5
<u>Fuel handling cell, external</u>			
(a) Operating station	FHC operations	Limited	<5
(b) Others	FHC drained MSL	Limited	<100
<u>FHC internal</u>	Operations	Not accessible	>5000
	Maintenance	Limited	<100
<u>Hot cell external</u>	Operations	Limited	<5
<u>Hot cell internal</u>	Operations	Not accessible	>5000
	Maintenance	Limited	<100
<u>Heat transfer water pools</u>			
(a) Over	Normal operations	Limited	<5
(b) Edge	Normal operations	No limit	0.25
(c) Cell	Maintenance with cell drained	Limited	<5
<u>RB subpile room</u>			
	Reactor at power	Limited	<100
	Reactor shut down with fuel	Limited	<5
	Reactor shut down without fuel	Limited	<5

<sup>a</sup>This table was taken essentially as is from Ref. 10; however, there are several instances in that document where 0.2 and 2 are used instead of 0.25 and 5 mrem/h respectively. The changes were made by the original author (B. S. Maxon) but not officially transmitted in a memorandum. The changes are included here since this table is preliminary and is used mainly for illustration and since the changes are consistent with this document.

<sup>b</sup>For radiation areas with dose rates over 0.25 mrem/h, access time shall be limited as necessary in order to assure that individual operator weekly, quarterly, and annual exposure limits and ANS total man-rem annual exposure limits are not exceeded. The design and operating goals shall assure that the individual operator exposure does not exceed 0.5 rem.

<sup>c</sup>A dose rate limit of 0.25 mrem/h may be exceeded in local areas for limited time intervals.



## 11. METHODS FOR THE OPTIMIZATION OF RADIATION PROTECTION

The optimization method to be used for the ANS project is that given in ICRP 37 (Ref. 11), summarized as follows. ICRP 37 uses the term "practice" to mean an operational approach, a measure, or a feature that is taken or incorporated for the purposes of radiation protection. The principal equation is

$$B = V - (P + X + Y),$$

where

- B = net benefit from the introduction of the practice,
- V = gross benefit (e.g., monetary or fuel savings, knowledge gained),
- P = sum of all production costs except radiation costs,
- X = cost of a selected level of radiation protection,
- Y = cost of detriment for that level of radiation protection.

To maximize B, which is the goal of optimization, we must maximize V and minimize the cost term  $P + X + Y$ . Note that this does not necessarily mean that each of P, X, and Y is at its minimum, but that their sum is a minimum. Note that X strictly applies only to features that contribute to or affect radiation protection, such as a shield wall or a health physicist's time. "Detriment" usually means harmful potential health effects resulting from radiation exposures; it may also include detrimental effects due to societal attitudes or other nonpecuniary impacts. Y does not typically include harmful potential effects resulting from conventional occupational hazards involved in the operation, which are included in P. These must be considered, of course, if their probability is significantly increased or decreased by the introduction of the practice, that is, if a radiological feature or measure affects them. As noted above, optimization specifically does not apply to design for and response to design-basis accidents, where regulatory or design limits apply, but to normal operations and AOOs. So optimization is used in the range of doses less than the regulatory limits and often in the range below administrative limits. In this range we make the usual assumption that risk is proportional to dose [e.g., as in BEIR V (Ref. 12)].

To apply the equation above to a real situation, we must identify the variables involved. If  $\phi$  is a variable representing a level of protection (such as shielding thickness, ventilation rate, exposure time, etc.), then ideally we can optimize B as a function of  $\phi$ . This means that the value of  $\phi$  should be chosen that makes B a maximum. It is easiest to find this value if (1)  $\phi$  is a variable expressible in a simple equation form and (2) only X and Y are functions of  $\phi$ , that is, if V and P are independent of  $\phi$  and we simply minimize  $X + Y$ . These conditions do not always hold true. There may also be limiting conditions that restrict the range of  $\phi$  — for example, that the maximum individual dose that an occupational worker may receive in a year is 5 rem or that because of space limitations the maximum thickness of a shield is 3 ft.

However, if (as frequently happens)  $\phi$  can be taken to be a function of the dose incurred S (as represented in the ICRP formulation), if X and Y are functions of  $\phi$  (and thus S), and if V and P are assumed to be more or less independent of S, then we can differentiate B with respect to  $\phi$  and set the result equal to zero to obtain the equation given below.

$$d/d\phi(B) = d/dS(dS/d\phi)(B) = d/dS(dS/d\phi)(V - P + X + Y) = 0$$

$$\frac{dS}{dX} \frac{d\Phi}{dS} = \frac{dS}{d\Phi} \frac{dY}{dS}$$

$$\frac{dX}{dS} = - \frac{dY}{dS}$$

Alternatively, one can also differentiate in terms of  $d/dS = (d/d\phi)(d\phi/dS)$  if that is applicable or convenient. However the differentiation is done, the point is to find the value of  $S$  or  $\phi$  such that

$$U = B - (V - P) = X + Y = \text{minimum} ,$$

where  $U$  is the "optimization function." By giving the minimum value of  $X + Y$ , this value of  $S$  or  $\phi$  thus gives the maximum value of  $B$  when  $V$  and  $P$  are effectively constant with respect to variations in  $S$  or  $\phi$ . This value of  $S$  or  $\phi$  is said to optimize the problem, within the assumptions for the level of protection.

Note that  $B$ ,  $V$ ,  $P$ ,  $X$ , and  $Y$  can be functions of more than one independent variable; then the equation would have to be differentiated in terms of each variable. Since this can get quite complicated, simplifying assumptions should be made where appropriate.

The special case where only  $X$  or only  $Y$  can take on different values is "cost-effectiveness analysis," as ICRP 37 points out. Here  $X$  is fixed while  $Y$  takes on different values, or  $Y$  is fixed while  $X$  takes on different values. This could happen if one is trying for the best dose reduction one can get for a fixed number of dollars or for the greatest dollar reduction one can get if the dose reduction has to be at least a certain amount. This is not complete optimization in the sense of optimizing on all important variables but can certainly serve to examine feasibility or to find a maximum possible value under limiting conditions.

For calculating  $X$ , the cost of a given level of radiation protection, we have to consider, in general, both the initial capital cost and the operating cost, as given below.

$$X = X_c + X_o \tau ,$$

where

$X_c$  = initial capital cost,

$X_o$  = operating cost rate (in units corresponding to  $\tau$ ),

$\tau$  = design life or operating time (months, years, etc.).

Note that if  $X_o$  is not constant, we have

$$X = X_c + \sum_n X_{o,n} ,$$

with  $X_{o,n}$  then in the same units as  $X$  and  $X_c$ . For simplicity, in the discussions that follow we will use  $X$  for  $X_c + \sum X_{o,n}$ .

Similarly, for calculating  $Y$ , the cost of the detriment corresponding to the given level of radiation protection, we have to consider, in general, both the initial dose cost (for installation or removal, as the case might be) and the dose cost to operate (for maintenance, inspection, etc.). Thus we have the equation given below.

$$Y = Y_i + Y_a \tau ,$$

where

$Y_i$  = initial dose cost (e.g., in man-rem),

$Y_a$  = dose cost rate to operate (in units corresponding to  $\tau$ , e.g., man-rem per year),

$\tau$  = design life or operating time (months, years, etc.).

Note that if  $Y_a$  is not constant, we have

$$Y = Y_i + \sum_n Y_{a,n} ,$$

with  $Y_{a,n}$  then in the same units as  $Y$  and  $Y_i$ . For simplicity, in the discussions that follow, we will use  $Y$  for  $Y_i + \sum Y_{a,n}$ .

For cases in which the operating time or life of the facility or design feature is long, say more than a year, we should use the concept of the "time value of money," as is usual in engineering economics. Two ways this can be done are to discount costs using present worth analysis and to annualize costs using a capitalized cost approach. ICRP 37 recommends the latter. It is assumed that the reader is acquainted with these concepts.

$$Y = \alpha S = Y_i + Y_a \tau = \alpha(S_i + S_a \tau) ,$$

with the  $S$  variables being the doses corresponding to the  $Y$  values defined earlier.

As ICRP 37 notes, not all optimizations involve continuous functions of one or more common parameters. Often, there will be several different options (alternatives) in which  $X$  and  $Y$  appear as single-valued terms. If  $P$  and  $V$  are the same for each alternative (not always true) and  $Y$  can be expressed as  $\alpha S$ , we have for any two alternatives

$$B_1 - B_2 = [V_1 - (P_1 + X_1 + Y_1)] - [V_2 - (P_2 + X_2 + Y_2)] ,$$

$$B_1 - B_2 = -(X_1 + Y_1) + (X_2 + Y_2) ,$$

$$B_1 - B_2 = -(X_1 + \alpha S_1) + (X_2 + \alpha S_2) .$$

Thus, for  $B_1 \geq B_2$ , we must have

$$X_1 + \alpha S_1 \leq X_2 + \alpha S_2 .$$

Clearly, in this case we can simply find  $U_n = X_n + \alpha S_n$  for each alternative  $n$  and choose the one corresponding to the smallest sum. Note that we would never actually have to find a value for  $B$ ,  $P$ , or  $V$  under these assumptions.

Where P and V differ between alternatives, those components of them that are different (e.g., in maintenance terms not involving radiation exposure or radioactive systems) can be added appropriately to  $X_n + \alpha S_n$ , so that

$$V_1 - (P_1 + X_1 + \alpha S_1) \geq V_2 - (P_2 + X_2 + \alpha S_2).$$

(Even here, however, it might be argued that if nonexposure P items vary in cost with the level of protection, they are properly included in X, not P. Obviously, all such differences should be included appropriately in the analysis.)

Another popular method, which we may call the "delta" method since the difference in subtraction is often represented by delta, can be used when there is no continuously varying common protection parameter and there are different protection options not necessarily defined by a single parameter. This formulation is the cost-effectiveness ratio rather than the cost-benefit ratio, as ICRP 37 points out. The equation used is then the one given below, where the subscript 2 refers to the more dollar-costly and (by inference) the less dose-costly option.

$$-(X_2 - X_1)/(S_2 - S_1) \leq \alpha.$$

However, this method is apparently looking at doses and costs "at the margin," and, as ICRP 37 points out, this method occasionally gives nonunique answers. (See Appendix D for a discussion of this.) It is therefore generally better to use the B or U formulation above (one has to do virtually all the same calculations either way, except for the ratio).

Note that when there is only one (new) option to be considered and the B or U formulation is used, the implied other option is the status quo, whereas with the delta formulation, the status quo X and S are typically the bases subtracted from the option X and S respectively.

The values of \$2000 and \$10,000 for  $\alpha$  were approved in 1993 by the ORNL ALARA Steering Committee and reaffirmed in 1994. These may change with time, so any value used should be checked for currency. The value \$2000 applies for most occupational workers and all members of the public, while the value of \$10,000 applies for radiation workers who are approaching or potentially will approach a regulatory or administrative limit (such as the DOE's 2-rem administrative control limit).

Examples of optimization analysis are given in Appendix C.

## **12. SPECIFIC ANS AREAS ALREADY IDENTIFIED AS BEING OF ALARA CONCERN**

### **Personnel Access to Instruments in the Beam Room**

With the higher flux that will be produced at the ANS, access to the instruments in the beam room may have to be restricted through the use of time or distance limitations since there would not be room for a great deal of shielding.

### **Changeout of the Deuterium in the Cold Source**

The deuterium in the cold source will become tritiated over time and must be changed out periodically. This presents problems of how best to tap the cold source and to transfer the deuterium to the detritiation plant for treatment and storage.

### **Operation of the Positron Source**

The positron source uses activated material in the form of tiny spheres. To present the best geometry, the spheres are spread out in the source on a flat pan. However, this means that they must be removed from the reactor irradiation capsule, conveyed to the source chamber, spread out for use, and poured out of the pan into a collection device when spent. All of this must be done remotely. This presents problems in control of the spheres and retrieval of any that escape in the process.

### **Refueling**

Some tritiated heavy water may be carried over into light water in an open pool, thus resulting in airborne tritiated water through evaporation. Also, the refueling operation is still not defined well enough for the radiological hazards to be clear (such as the position of the workers during fuel movements).

### **Hot Machine Shop and Decontamination Facility**

The hot machine shop and equipment decontamination facility on elevation 133'-8" are intended for the repair of activated and contaminated equipment and the decontamination of contaminated equipment respectively. Outside the hot machine shop, the floor hatches are located over a set of hot filters. These filters must be changed periodically, and it is not clear that this can be done readily without an impact on the operation and occupancy of the hot machine shop and equipment decontamination facility. The filters would be transported in casks, and there is likely to be movement of these and other casks in and near this area. The situation is particularly of interest because the filter changeouts and cask movements are most likely to take place during outages, the time when the hot machine shop and equipment decontamination facility are most likely to be in heavy use.



## REFERENCES

1. Regulatory Guide 8.8, *Information Relevant to Ensuring That Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Reasonably Achievable*, Rev. 3, U.S. Nuclear Regulatory Commission.
2. 10 CFR 835, "Occupational Radiation Protection."
3. DOE Order 5480.11, "Radiation Protection for Occupational Workers," Dec. 21, 1988.
4. DOE Order 5480.30, "Nuclear Reactor Safety Design Criteria," Jan. 19, 1993.
5. DOE Order 6430.1A, "General Design Criteria," Apr. 6, 1989.
6. Radiological Control Manual, Rev. 1, U.S. Department of Energy, April 1994 (DOE/EH-0256T).
7. DOE Order 5400.5, "Radiation Protection of the Public and Environment," Feb. 8, 1990.
8. G-10 CFR 835/G1, Rev. 1, "Posting and Labeling for Radiological Control," November 1994.
9. ANSI/ANS-55.6-1979, "Liquid Radioactive Waste Processing System for Light Water Reactor Plants."
10. Memorandum, "Application of Radiation Protection Criteria to the Design of the ANS Buildings, Refueling and Maintenance Facilities, and Equipment," B. S. Maxon to P. B. Thompson, Mar. 2, 1993.
11. "Cost-Benefit Analysis in the Optimization of Radiation Protection," ICRP Publication No. 37, International Commission on Radiological Protection (ICRP), 1983.
12. "BEIR V," *Health Effects of Ionizing Radiation*, Committee on the Biological Effects of Ionizing Radiations, National Research Council, National Academy Press, Washington, D.C., 1990.



**Appendix A: ANNUAL DOSES OF INTEREST AND DOSE RATES  
THAT MAY PRODUCE THEM**

Dose	Dose Rate
Normal ORNL background:	0.01 mR/h (90 mrem/year)
For 2000 h/year (100% occupancy):	
100 mrem/year	0.05 mrem/h
500 mrem/year	0.25
1000 mrem/year	0.5
5000 mrem/year	2.5
For 500 h/year (25% occupancy):	
100 mrem/year	0.2 mrem/h
500 mrem/year	1.0
1000 mrem/year	2.0
For 250 h/year (1 h/day):	
100 mrem/year	0.40 mrem/h
500 mrem/year	2.0
1000 mrem/year	4.0
ORNL posting level for a radiation area:	3.0 mrem/h
DOE posting level for a radiation area:	5.0
100 h/year (2 h/week, or 6 h/cycle for 15 cycles/year):	
100 mrem/year	2.0 mrem/h
500 mrem/year	10
1000 mrem/year	20
For 50 h/year (1 h/week, or 3 h/cycle for 15 cycles/year):	
100 mrem/year	2.0 mrem/h
500 mrem/year	10
1000 mrem/year	20
For 0.5 h/week ( $\approx$ 2 h/month, or about 1.5 h/cycle for 15 cycles/year):	
100 mrem/year	4.0 mrem/h
500 mrem/year	20
1000 mrem/year	40
For 4 h/year (1 h/quarter, or about 15 min/cycle for 15 cycles/year):	
100 mrem/year	25 mrem/h
500 mrem/year	125
1000 mrem/year	250
Posting for a high radiation area:	100 mrem/h
For 1 h/year:	
100 mrem/year	100 mrem/h
500 mrem/year	500
1000 mrem/year	1000

**Appendix A: ANNUAL DOSES OF INTEREST AND DOSE RATES  
THAT MAY PRODUCE THEM (continued)**

Dose	Dose Rate
For accidents:	
1 rem in 24 h	40 mrem/h
5 rem in 24 h	200
10 rem in 24 h	400
1 rem in 1 h	1.0 rem/h
5 rem in 1 h	5.0
10 rem in 1 h	10
Equipment qualification:	
$10^4$ rad in 40 years	0.25 rad/h
$10^4$ rad in 20 years	0.5
$10^4$ rad in 1 years	1.0
$1 \times 10^7$ rad in 40 years	30 rad/h
$1 \times 10^7$ rad in 20 years	60
$1 \times 10^7$ rad in 1 years	1000

## Appendix B: SHIELDING EXAMPLE

An example of the shielding process, illustrating the use of zones and shielding assumptions, is given below.

A responsible engineering designer (RED) plans to have a small filter that serves a hot cell be physically located in the cell. Preliminary indications are that the operating area outside the cell will be a Zone 6 or 7 if unshielded and the filter change area inside the cell will be a Zone 6cB or 7cB if the worker uses long-handled tools to change the filter inside the cell. The RED estimates that the operator will spend about 2 h per cycle at the operating area and that another worker—say, a millwright—will take 15 min to change the filter each cycle (to open the housing, remove the filter, put in a new filter, and close the housing). For Zone 7, this gives a maximum of  $1000 \text{ mrem/h} \times 2 \text{ h/cycle} = 2 \text{ rem/cycle}$  for the operator and  $1000 \text{ mrem/h} \times 0.25 \text{ h/cycle} = 250 \text{ mrem/cycle}$  for the millwright. Assuming that there are 17 cycles per year, this gives collective doses of 34 rem/year for the operator's work group and 4.2 rem/year for the millwright's.

Because of the nature of these tasks and the relatively short time they take, each of these operations could and probably should be done by a single person. Thus the 2 rem and the 250 mrem can each be assumed to apply to one person (not the same person, of course). Clearly, the 2 rem and the 250 mrem are high compared to the 1-rem design objective for infrequently occupied areas, although in the operator's case the 2 rem exceeds the 1 rem, while in the millwright's case the 250 mrem is merely a large fraction of the 1 rem. So this analysis has identified these two jobs as being of concern as regards the necessity for reducing dose. The operator's position can be shielded, as would be expected for this hot cell anyway. However, it would be difficult to shield the filter during changeout, so other measures would have to be considered.

The refinement of this analysis might proceed as follows. Suppose the RED has the dose rates calculated based on preliminary assumptions about contamination in the cell and its buildup over time. It is found that the filter will reach 6 rem/h at contact, 125 mrem/h at 2 ft, and 15 mrem/h at 6 ft at the end of each cycle when capsules are opened in the cell; the 6 ft corresponds to the position of an unshielded operator standing in the operating aisle of the cell. Now, the hottest capsule to be opened in the cell produces an unshielded dose rate of 60 rem/h at contact and 100 mrem/h at 5 ft; the 5 ft corresponds to the position of the unshielded operator standing in the operating aisle of the cell. Thus shielding is needed to cut down a dose rate of up to about  $15 + 100 = 115 \text{ mrem/h}$  when the operator is working at the cell. With the occupancy assumption of 2 h/cycle, this gives a rough unshielded dose of  $115 \times 2 = 230 \text{ mrem}$  for the operator for one cycle and a total annual dose of 3910 mrem to the operator's work group over 17 cycles a year. Note that the zone is indeed a 7, but now we see that the dose rate falls in the lower range of Zone 7.

For the millwright, we have  $125 \text{ mrem/h} \times 0.25 = 32 \text{ mrem}$  for one cycle. This is conservative because it ignores any reduction in dose provided by his standing farther from the removed filter while he is putting in the new one. For 17 cycles a year, this gives a total annual dose of 544 mrem to the millwright's work group.

Regarding the operator's dose, assume that the operator's group will have a minimum of three people, based on this and other work requirements (i.e., considering all the man-hours to be worked). Even if we assumed that these three operators would take turns over the year and that they did no other work producing a significant dose contribution, the dose of  $3910 \div 3 = 1303 \text{ mrem/year}$  for this task is over the design dose objective. Let us further assume that, based on similar analyses, the operators will receive a total collective annual dose of 6200 mrem if all of the areas they work in are unshielded. This is 3910 mrem from this task, 1700 mrem total from two other tasks, and 590 mrem total from a fourth task. It is still unclear how dose should be allotted among these dose-producing tasks, but we know we need to get the collective dose down

to below  $1000 \text{ mrem} \times 3 = 3000 \text{ mrem}$ . If we regarded all of the tasks as equally likely to be done in a year, equally important, and equally susceptible to dose reduction, then we could "shrink" them in proportion to their unshielded doses. Thus, we would shield the hot cell so as to reduce the dose from the hot cell work to  $3910 \times (3000/6200) = 3910 \times 0.48 = 1892 \text{ mrem}$ . This would give a dose rate in the aisle of  $115 \text{ mrem/h} \times 0.48 = 55 \text{ mrem/h}$  and a shielded dose per cycle of  $55 \text{ rem/h} \times 2 \text{ h/cycle} = 110 \text{ mrem}$ . To ease access control restrictions, however, we may want to shield down to below  $5 \text{ mrem/h}$ , the radiation area cutoff, or even lower. If we did, then the dose reduction would, of course, be much greater.

The operator's case is relatively easy since his group has a fairly well-defined set of tasks they do and areas in which they do them, all at ANS. The millwright's case is trickier. He may do work all over ANS and indeed all over ORNL since millwrights work in an ORNL-wide division. It is usually best in such cases to assume that the worker will not spend all his time at ANS and thus will need a dose "cushion" to allow for other work. It is probably quite unlikely that the same millwright would do all of the filter changes, but, on the other hand, he may be likely to do other "hot jobs." However, if the non-ANS work he does is not likely to produce any more dose per year than the ANS work does, then we can make the simplifying assumption that he works at ANS full-time. Let us assume that, based on this and other work requirements, about six millwrights will be working at ANS at any given time. We could then plan to give a maximum of  $500 \text{ mrem}$  to an individual millwright and  $500 \times 6 = 3000$  to all six.

Now, suppose that the total estimated annual dose to the six millwrights is  $12,000 \text{ mrem}$  from all tasks they are to do at ANS, before shielding or other dose-reduction measures are applied. In the absence of other information, let us assume that we are going to try to reduce this to  $6000 \text{ mrem}$ , thus requiring a reduction factor of 2, and that, as in the operator case, all tasks are equally important and equally susceptible to dose reduction. If we apply the factor of 2 to the millwright's filter change dose, this would give  $32 \div 2 = 16 \text{ mrem}$ . We see that 32 is not a high dose and that 16 is a fairly small dose. If shielding is not practical for space and visibility reasons, it may be better to allow a dose of  $32 \text{ mrem}$  for this task and apply more than a factor of 2 to another task in which the dose is substantially higher, to obtain an overall reduction of 2. This is especially true if the filter changing sources are reliably bounded and the task is straightforward and unlikely to take more than 15 min, that is, if it is a well-characterized task.

One thing that stands out, however, that was not considered in this evaluation is contamination. If there is contamination on the inside of the cell, the millwright will not only receive an additional external dose from the contamination but also may inhale airbornes—unless he wears a respirator, which may slow down the task. Another possibility presents itself, that the filter could be moved outside the hot cell. In that case, it would probably have to be shielded, say in a locked shielded cabinet or vault. This might improve accessibility and even reduce the chances of a serious migration of radioactivity. (Note that for the millwright to enter the cell and change the filter, the cell HVAC must be turned off and the door must be opened, no different from what it would be in the filter cabinet except that the cabinet is less likely to be contaminated.)

In the example above, we were not able to achieve a resolution of the problem with regard to the filter changeout; the RED, in consultation with others, will have to rethink this. In this case, the shielding required for the operator would not be much less if the filter were moved into its own separate cabinet. However, if we did go with the factor of 3 reduction, we would have a maximum dose rate of  $55 \text{ mrem/h}$  in the cell aisle.

Also, in the example above we used the design objectives as de facto ALARA limits, but, in fact, an ALARA determination was not formally done except for the consideration of other work (and even then we did not go into specifics of the other work and thus not greatly into the details of which tasks most warranted the addition of more protective or control measures, such as shielding). An example of applying optimization to such a problem is given in Appendix C.

## Appendix C: TWO EXAMPLES OF THE APPLICATION OF OPTIMIZATION

Two examples of the application of optimization will be shown here.

### Example 1

A very simplified case involves a particulate filter having an efficiency of 99.0%. Each annual changeout costs \$600 for the filter and \$200 in total labor costs for two workers. The workers each receive 99 mrem, and the annual dose to the public from the 1% of released particulates is 10 man-rem to 10,000 people.

A new kind of filter has an efficiency of 99.6%. Each changeout would cost \$1200 for the filter and \$300 in labor costs. The workers would each receive 100 mrem, but the public dose would be 4 man-rem.

Should the new filter be used, all other factors being equal?

For the first filter, we have as the total cost (i.e.,  $U = X + Y = X + \alpha S$ , with  $\alpha = \$2000$ )

$$[\$600 + \$200] + (\$2000)[0.198 + 10 \text{ rem}] = \$21,200 .$$

For the second filter, we have

$$[\$1200 + \$300] + (\$2000)[0.200 + 4 \text{ rem}] = \$9900 .$$

Clearly, using the second filter is cost-beneficial. Note that 10 man-rem to 10,000 people is 1 mrem per person, while 4 man-rem corresponds to 0.4 mrem per person. Reducing the individual public dose from 1 mrem to 0.4 mrem does not sound like much, but remember that the airborne limit for the public is 10 mrem/year. That is interpreted by the DOE to mean that all Oak Ridge Reservation airborne emissions, not just ANS or ORNL ones, must be less than 10 mrem/year. Y-12 emissions take up a chunk of that now; so a reduction of this magnitude might well be important.

### Example 2

Consider the case discussed in Appendix B. Let us assume that the cost of the shield wall is \$650 per year (including installation and amortized over the life of the hot cell) for each 3 in. of thickness; each 3 in. provides a factor of 2 attenuation; there is an unshielded dose rate of 115 mrem/h to an operator in the operating area when capsules are present; the operator uses the hot cell for 2 h/cycle when capsules are present; and there are 17 cycles/year, for a total of 34 man-hours/year.

Additionally, assume that in the corridor outside the operating area, the unshielded dose rate is 70 mrem/h from the capsules and 10 mrem/h from the filter. About 12 people per day make an average of six round trips each down this corridor, spending 4 min per round trip. Also, there is an average of 20 people per day who make up to two round trips a week down this corridor. Finally, there is a readout panel in the corridor that shows ventilation system status; a hot cell operator records these numbers twice per 12-h shift, taking up to 20 min each time. Capsules are assumed to be present for 2 days per cycle, and the filter is assumed to be hot for 7 days per cycle. Assume the infrequently passing people always use the corridor when the capsule is present, for conservatism.

This gives a collective occupancy for the corridor as follows.  
When the capsule is in the cell:

$$\begin{aligned}(12 \text{ people})(6 \text{ trips/day})(4 \text{ min/trip})(2 \text{ days/week}) &= 576 \text{ min/week} \\ (20 \text{ people})(2 \text{ trips/week})(4 \text{ min/trip}) &= 160 \text{ min/week} \\ (2 \text{ people})(2 \text{ readings/day})(20 \text{ min/reading})(2 \text{ days/week}) &= 160 \text{ min/week} \\ \text{Total} &= 896 \text{ min/week}\end{aligned}$$

When the capsule is not in the cell:

$$\begin{aligned}(12 \text{ people})(6 \text{ trips/day})(4 \text{ min/trip})(5 \text{ days/week}) &= 1440 \text{ min/week} \\ (2 \text{ people})(2 \text{ readings/day})(20 \text{ min/reading})(5 \text{ days/week}) &= 400 \text{ min/week} \\ \text{Total} &= 1840 \text{ min/week}\end{aligned}$$

We will increase these by 10% to allow for the inevitable brief conversations in the corridor.  
This brings the weekly totals to:

With capsule:

$$(896 \text{ min/week})(1 \text{ h}/60 \text{ min})(1.1) = 16.4 \text{ h/week}$$

Without capsule:

$$(1840 \text{ min/week})(1 \text{ h}/60 \text{ min})(1.1) = 33.7 \text{ h/week}$$

With 17 cycles per year, we have hot sources in the hot cell in 17 weeks out of the year. The dose rate of  $70 + 10 \text{ mrem/h} = 80 \text{ mrem/h}$  applies for  $(16.4 \text{ h/week})(17 \text{ weeks/year}) = 279 \text{ h/year}$ , and the dose rate of  $10 \text{ mrem/h}$  applies for  $(33.7 \text{ h/week})(17 \text{ weeks/year}) = 573 \text{ h/year}$ .

Then we have, on an annual basis, for the dose rates and collective occupancies given above (including the operating area) and with  $t$  representing the thickness in units of 3 in.:

$$U = \$650t + (\$2000/\text{man-rem}) [(34 \text{ h/year})(0.115 \text{ rem/h}) + (279 \text{ h/year})(0.080 \text{ rem/h}) + (573 \text{ h/year})(0.010 \text{ rem/h})] (2^{-t}),$$

$$U = \$650t + (\$2000/\text{man-rem})(32.0 \text{ man-rem})(2^{-t}),$$

$$U = \$650t + (\$63,920)(2^{-t}).$$

Differentiating  $U$  with respect to  $t$  and setting the expression equal to zero to find the value that makes  $U$  a minimum, we have

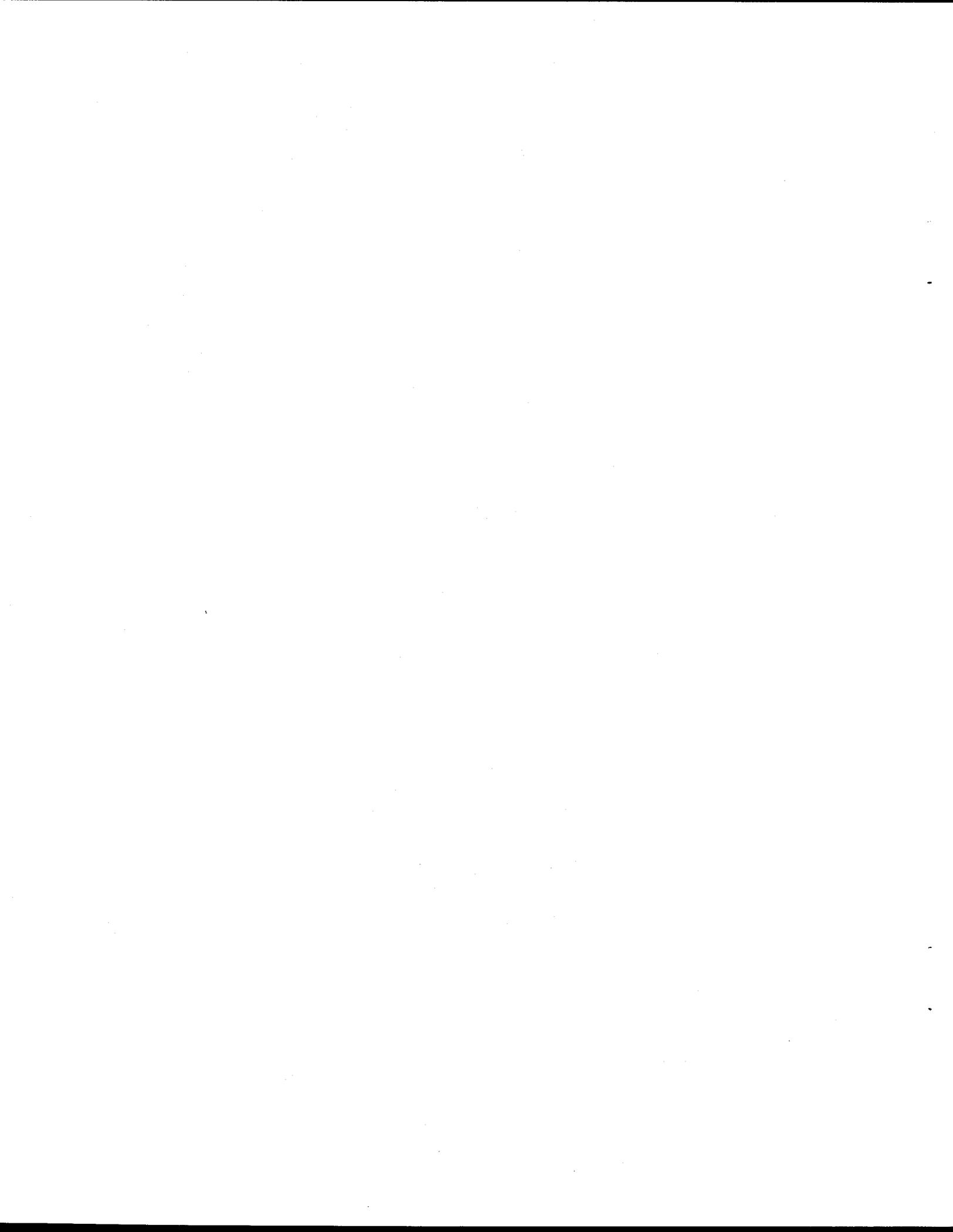
$$\begin{aligned}0 &= \$650 + (\$63,920)[(2^{-t} \cdot \log 2 \cdot (-1))], \\ 0 &= \$650 - (\$19,242)(2^{-t}), \\ 0.0338 &= 2^{-t}.\end{aligned}$$

Taking the logarithm of both sides and solving, we have

$$\begin{aligned}-1.47 &= (-t)(0.301) \\ t &= 4.89\end{aligned}$$

Thus the optimal value of  $t$  is about five units of 3 in., or 15 in. This will reduce the dose rate, and thus the doses, by a factor of  $2^5 = 32$ , to about 3.6 mrem/h in the operating area and 2.5 mrem/h in the corridor when the capsule is present and to about 0.5 mrem/h in the operating area and 0.31 mrem/h in the corridor when it is not (and the filter is hot). The individual dose per cycle in the operating area is thus  $3.6 \text{ mrem/h} \times 2 \text{ h} = 7.2 \text{ mrem}$ , and the annual collective dose for the operator work group from work at this hot cell is  $3.6 \text{ mrem/h} \times 34 \text{ h/year} = 122 \text{ mrem/year}$ . The maximum individual dose per cycle in the corridor area for a frequent passerby is  $6 \text{ trips/day} \times 4 \text{ min/trip} \times 1 \text{ h/60 min} \times [(2.5 \text{ mrem/h})(2 \text{ days/cycle}) + (0.31 \text{ mrem/h})(5 \text{ days/cycle})] \times 1.1 = 2.9 \text{ mrem}$ , and for an infrequent passerby is  $2 \text{ trips/cycle} \times 4 \text{ min/trip} \times 1 \text{ h/60 min} \times (2.5 \text{ mrem/h}) \times 1.1 = 0.37 \text{ mrem}$ ; per year, these come to 49 and 6.3 mrem respectively. Finally, the dose to an operator performing the panel readings, assuming he works a 7-day week, is  $2 \text{ readings/day} \times 20 \text{ min/reading} \times 1 \text{ h/60 min} \times [(2.5 \text{ mrem/h})(2 \text{ days/cycle}) + (0.31 \text{ mrem/h})(5 \text{ days/cycle})] = 4.4 \text{ mrem/cycle}$  and 75 mrem/year (assuming he does all the readings in one shift in a year). The collective dose to his work group, since there are two shifts per day, is thus twice the maximum annual individual dose, or 150 mrem.

Actually, the dose rates in the corridor and the operating area will likely be set lower than the rates given above, particularly considering that in this example we did not consider other work the people might be doing and that the 2.5 mrem/h in the corridor would mean that administrative controls might be applied to limit access. However, these would obviously be important considerations in an actual analysis. Further, if other work were considered and the optimized maximum (total) individual dose for the work group exceeded the implied design objective of 1 rem/year, the dose would have to be reduced even more in spite of this analysis.



## Appendix D: DISCUSSION OF THE U METHOD VERSUS THE DELTA METHOD

As was stated in the text (some of which will be repeated below for clarification), the basic equation for optimization analysis is given by the International Commission on Radiological Protection (ICRP) and is as follows:

$$B = V - (P + X + Y),$$

where

- B = net benefit (of the project, measure, feature, etc.),
- V = gross benefit,
- P = production costs, excluding any radiation protection costs,
- X = radiation protection costs excluding dose costs,
- Y = dose costs (detriment).

Again, to maximize B, which is the goal of optimization, we must maximize V and minimize the cost term  $P + X + Y$ . Note that this does not necessarily mean that any of or each of P, X, and Y is at its minimum, but that their sum is a minimum.

In the case where V and P change very little if at all when X and Y do and where X and Y are a function of the dose S (or a dose-related variable such as shield thickness), we can usually differentiate with respect to S (or the variable). This gives  $dB/dS = dV/dS - dP/dS - dX/dS - dY/dS$ , which reduces to  $dB/dS = -dX/dS - dY/dS$ . To obtain the value of dose (or the variable) which makes B a maximum, we set  $B = 0$  and solve for S (or the variable). This will be called the "U method" here, since the quantity U, the "optimization function," is defined such that  $U = X + Y$ .

On the other hand, when we have several discrete alternatives (e.g., buying a monitor versus increasing the shield thickness versus limiting the number of sources that may be moved), we see that if V and P change little if at all when X and Y do, B will be a maximum when the sum of X + Y is a minimum. Then we choose the alternative corresponding to this minimum sum. Again, the U method is applied to find the minimum sum, but here there will be a U for each alternative and the values of U will be compared to determine the smallest.

A shortcut method, which is a "cost-effectiveness analysis" rather than a "cost-benefit analysis," according to ICRP 37, considers only the cost of the measure and the dose saved. In this method, the ratio of the cost to the dose is compared to the accepted value of a man-rem; if the ratio is lower than the accepted value, the measure is deemed to be cost-effective, but if the ratio is higher, it is not. We can informally refer to this method as the "delta method" (since the change in dose is referred to as "delta dose" and the change in cost, as "delta cost"). The two methods are compared in the example below, which also illustrates a problem with the delta method.

### EXAMPLE 1

Suppose that the cost of installing a shield wall is \$300 per inch of thickness installed. A dose rate reduction factor of 10 is provided by each 10 in. of shield. Thus the first "x10" reduction costs \$300/in. x 10 in., or \$3000. The second x10 reduction costs \$3000 also. If the unshielded dose rate is 200 mrem/h, the first 10 in. reduces the dose rate to 20 mrem/h, and the next 10 in. reduces it further to 2 mrem/h. For an assumed 20-h/year collective occupancy (i.e., summed over all

workers), this gives doses of 4 man-rem/year, 0.4 man-rem/year, and 0.04 man-rem/year respectively for no shielding, 10 in. of shielding, and 20 in. of shielding. Using 1 year and \$2000/rem, should there be no shielding, or should 10-in. of shielding or 20 in. of shielding be added where there is no shielding? Also, if there is already a 10-in. shield, should an additional 10 in. be added or not? (An asterisk below denotes the best choice.)

### U Method

Adding no, 10 in., or 20 in. when there is no existing shielding:

- No shielding  $U = X + Y = \$0 + (\$2000/\text{rem})(4 \text{ rem}) = \$8\text{K}$   
 \* 10 in. of shielding  $U = X + Y = \$3000 + (\$2000/\text{rem})(0.4 \text{ rem}) = \$3.8\text{K}$   
 20 in. shielding  $U = X + Y = \$6000 + (\$2000/\text{rem})(0.04 \text{ rem}) = \$6.1\text{K}$

Adding 10 in. to an existing 10 in. of shielding:

- \* No shielding  $U = X + Y = \$0 + (\$2000/\text{rem})(0.4 \text{ rem}) = \$0.8\text{K}$   
 10 in. of shielding  $U = X + Y = \$3000 + (\$2000/\text{rem})(0.04 \text{ rem}) = \$3.1\text{K}$

### Delta Method

- \* 0-10 in.: Cost = \$3000, Dose Saved = 3.6 rem, Ratio = \$830/rem  
 YES:  $\$830/\text{rem} \leq \$2000/\text{rem}$
- 10-20 in.: Cost = \$3000, Dose Saved = 0.36 rem, Ratio = \$8300/rem  
 NO:  $\$8300/\text{rem} \geq \$2000/\text{rem}$
- 0-20 in.: Cost = \$6000, Dose Saved = 3.96 rem, Ratio = \$1500/rem  
 YES:  $\$1500/\text{rem} \leq \$2000/\text{rem}$

Both methods show that the proper choice is to add only 10 in. where there is no shielding or to add no shielding where there is already 10 in..

Notice that for 10 years' worth of dose, the seven final numbers above would change to the numbers below. This shows how the choice can change as either X or Y changes.

### U Method

Adding no, 10 in., or 20 in. to where there is no shielding:

- No shielding  $U = \$80\text{K}$   
 10 in. of shielding  $U = \$11\text{K}$   
 \* 20 in. of shielding  $U = \$6.8\text{K}$

Adding 10 in. to an existing 10 in. of shielding:

- No shielding  $U = \$8\text{K}$   
 \* 10 in. of shielding  $U = \$3.8\text{K}$

**Delta Method**

\* 0 to 10 in.:  
Ratio = \$83/rem

10 to 20 in.:      Ratio = \$830/rem

0 to 20 in.:      Ratio = \$152/rem

With the U method, we would conclude that it was best to have 20 in. of shielding, whether starting with none or with 10 in. However, with the delta method, we would conclude that while all choices were allowable, since the ratio is less than \$2000/man-rem in all three cases, adding only 10 in. was the best choice since it produced the lowest ratio. This shows that the conclusions reached can vary according to the optimization method used.

**Example 2**

Suppose the status quo involves the receipt of 1000 man-mrem over a certain period of use of the facility. Two new measures are considered, one that will cost \$500 and reduce the dose to 500 man-mrem and another that will cost \$1000 and reduce the dose to 200 man-mrem. What choice should be made? Use \$2000/man-rem.

**U Method**

Status quo       $U = \$0 + (\$2000)(1.0 \text{ rem}) = \$2000$

1st measure       $U = \$500 + (\$2000)(0.5 \text{ rem}) = \$1500$

\* 2nd measure       $U = \$1000 + (\$2000)(0.2 \text{ rem}) = \$1400$

**Delta Method**

\* 1st measure      Cost = \$500, Dose Saved = 0.5 rem, so Ratio = \$1000

2nd measure      Cost = \$1000, Dose Saved = 0.8 rem, so Ratio = \$1250

Note that in the delta method, both measures are deemed to be cost-effective, but the first is more cost-effective than the second since the first ratio is less than the second. However, in the U method, the second is the most cost-beneficial and the one to be chosen.



## Appendix E: ZONING, SHIELDING, AND OPTIMIZATION REVIEW CHECKLISTS

The following checklists are supplied for the purpose of guiding REDs and others in assigning preliminary zones, making dose estimates, having shielding and optimization analyses done, and revising zone assignments and dose estimates. The questions in Table 8 should be gone through before the checklists are filled out. No checklist is supplied for doing individual and work group dose estimates since these calculations will generally be done in the course of and after the task dose estimates are done and since it is unlikely that an RED could do the entire estimate for any but a small and dedicated work group. The RED should keep a running record of these doses in order to pool his calculations with those of other REDs. Note that to some extent, the same is true of doses associated with areas, tasks, etc.; REDs who have overlapping responsibilities for an area will generally have to pool their estimates before shielding calculations and optimization analyses can be performed.

The zone assignment guidelines refer to any that have been established for the ANS, for example, those mentioned in Table 1 and the preceding sections, "Guidelines for the Assignment and Use of Radiation Zones" and "Considerations for Shielding." The term "access times directly associated with" used with regard to occupancy for, for example, a component means that the access is for the purpose of operating, and maintaining, etc., the component itself. The term "access times not directly associated with" used with regard to occupancy for, for example, a component means that the access is for the purpose of operating, and maintaining some other piece of equipment that might be affected by the dose rate from the component. The terms "dose estimates directly associated with this component" and "dose estimates not directly associated with this component" are defined similarly.

It is intended that any additional information (such as that which does not fit in the description blanks at the beginning of each checklist) be appended at the end.

Note that, for example, components whose operation, etc., may result in significant internal doses are not covered by shielding analyses but may be identified in the production of dose estimates and may be addressed in the optimization analyses.

**Zoning, Shielding, and Optimization Review Checklist: Component**

**Component Name** \_\_\_\_\_  
**Component System** \_\_\_\_\_  
**Area of Component** \_\_\_\_\_  
**RED (or designate)** \_\_\_\_\_ **Date** \_\_\_\_\_

**Preliminary Zone Assignment**

Have the zone assignment guidelines been considered for application to the area in which this component is located? \_\_\_\_\_

Has a preliminary zone assignment been made for the area? \_\_\_\_\_

**Source Terms and Dose Rate Determinations**

Have source terms been determined for this component for:  
Normal operation (including normal leakage)? \_\_\_\_\_  
Shutdown of the component? \_\_\_\_\_  
Maintenance, inspection, testing, and calibration? \_\_\_\_\_  
Anticipated operational occurrences involving it? \_\_\_\_\_  
Accidents involving it? \_\_\_\_\_

Have direct dose rates been determined for this component for:  
Normal operation (including normal leakage)? \_\_\_\_\_  
Shutdown of the component? \_\_\_\_\_  
Maintenance, inspection, testing, and calibration? \_\_\_\_\_  
Anticipated operational occurrences involving it? \_\_\_\_\_  
Accidents involving it? \_\_\_\_\_

Have internal dose rates, where appropriate, been determined for this component for:  
Normal operation (including normal leakage)? \_\_\_\_\_  
Shutdown of the component? \_\_\_\_\_  
Maintenance, inspection, testing, and calibration? \_\_\_\_\_  
Anticipated operational occurrences involving it? \_\_\_\_\_  
Accidents involving it? \_\_\_\_\_

Have dose rates to the area around the component from other nearby contained sources been determined? \_\_\_\_\_

Have dose rates to the area around the component from other airborne or loose liquid sources been determined? \_\_\_\_\_

**Zoning, Shielding, and Optimization Review Checklist: Component  
(continued)**

Occupancy

Have access times directly associated with this component been determined for:

- Normal operation? \_\_\_\_\_
- Shutdown of the component? \_\_\_\_\_
- Maintenance, inspection, testing, and calibration? \_\_\_\_\_
- Anticipated operational occurrences involving it? \_\_\_\_\_
- Accidents involving it? \_\_\_\_\_

Have access times not directly associated with this component been determined for:

- Normal operation? \_\_\_\_\_
- Shutdown of the component? \_\_\_\_\_
- Maintenance, inspection, testing, and calibration? \_\_\_\_\_
- Anticipated operational occurrences involving it? \_\_\_\_\_
- Accidents involving it? \_\_\_\_\_

Dose Estimates

Have dose estimates directly associated with this component been determined for:

- Normal operation? \_\_\_\_\_
- Shutdown of the component? \_\_\_\_\_
- Maintenance, inspection, testing, and calibration? \_\_\_\_\_
- Anticipated operational occurrences involving it? \_\_\_\_\_
- Accidents involving it? \_\_\_\_\_

Have dose estimates not directly associated with this component been determined for:

- Normal operation? \_\_\_\_\_
- Shutdown of the component? \_\_\_\_\_
- Maintenance, inspection, testing, and calibration? \_\_\_\_\_
- Anticipated operational occurrences involving it? \_\_\_\_\_
- Accidents involving it? \_\_\_\_\_

Shielding Analyses

Have shielding analyses been done for the area in which the component is located? \_\_\_\_\_

Have shielding analyses been done for nearby areas that may affect or be affected radiologically by the component? \_\_\_\_\_

**Zoning, Shielding, and Optimization Review Checklist: Component  
(continued)**

Optimization Analyses

Have any issues or concerns been identified regarding the design of this component that may require an optimization analysis? \_\_\_\_\_

Have any issues or concerns been identified regarding the operation of this component that may require an optimization analysis? \_\_\_\_\_

Have any issues or concerns been identified regarding this component and its area that may require an optimization analysis? \_\_\_\_\_

Have any issues or concerns been identified regarding this component and any neighboring area that may require an optimization analysis? \_\_\_\_\_

Have all necessary optimization analyses been performed? \_\_\_\_\_

Other Considerations

Will those accessing the area of this component be entirely ANS or ORNL staff? \_\_\_\_\_

Will those accessing the area of this component include only occupational radiation workers? \_\_\_\_\_

Will those accessing the area of this component include occupational nonradiation workers? \_\_\_\_\_

Will those accessing the area of this component include visitors? \_\_\_\_\_

Revision of Zone Assignment

Have the zone assignments of this area and nearby areas been reevaluated in light of the estimates and analyses above? \_\_\_\_\_

Notes

**Zoning, Shielding, and Optimization Review Checklist: Area**

Area Name \_\_\_\_\_

Description of Area \_\_\_\_\_

RED (or designate) \_\_\_\_\_ Date \_\_\_\_\_

Preliminary Zone Assignment

Have the zone assignment guidelines been considered for application to this area? \_\_\_\_\_

Has a preliminary zone assignment been made for the area? \_\_\_\_\_

Source Terms and Dose Rate Determinations

Have source terms been determined for this area for:

Normal operation (including normal leakage)? \_\_\_\_\_

Shutdown (as applicable)? \_\_\_\_\_

Maintenance, inspection, testing, and calibration? \_\_\_\_\_

Anticipated operational occurrences involving it? \_\_\_\_\_

Accidents involving it? \_\_\_\_\_

Have direct dose rates been determined for this area for:

Normal operation (including normal leakage)? \_\_\_\_\_

Shutdown (as applicable)? \_\_\_\_\_

Maintenance, inspection, testing, and calibration? \_\_\_\_\_

Anticipated operational occurrences involving it? \_\_\_\_\_

Accidents involving it? \_\_\_\_\_

Have internal dose rates, where appropriate, been determined for this area for:

Normal operation (including normal leakage)? \_\_\_\_\_

Shutdown (as applicable)? \_\_\_\_\_

Maintenance, inspection, testing, and calibration? \_\_\_\_\_

Anticipated operational occurrences involving it? \_\_\_\_\_

Accidents involving it? \_\_\_\_\_

Have dose rates to this area from contained sources not in the area been determined? \_\_\_\_\_

Have dose rates to this area from areas nearby originating airborne or loose liquid sources been determined? \_\_\_\_\_

**Zoning, Shielding, and Optimization Review Checklist: Area  
(continued)**

Occupancy

Have access times directly associated with this area been determined for:

- Normal operation? \_\_\_\_\_
- Shutdown (as applicable)? \_\_\_\_\_
- Maintenance, inspection, testing, and calibration? \_\_\_\_\_
- Anticipated operational occurrences involving it? \_\_\_\_\_
- Accidents involving it? \_\_\_\_\_

Have access times not directly associated with this area been determined for:

- Normal operation? \_\_\_\_\_
- Shutdown (as applicable)? \_\_\_\_\_
- Maintenance, inspection, testing, and calibration? \_\_\_\_\_
- Anticipated operational occurrences involving it? \_\_\_\_\_
- Accidents involving it? \_\_\_\_\_

Dose Estimates

Have dose estimates directly associated with this area been determined for:

- Normal operation? \_\_\_\_\_
- Shutdown (as applicable)? \_\_\_\_\_
- Maintenance, inspection, testing, and calibration? \_\_\_\_\_
- Anticipated operational occurrences involving it? \_\_\_\_\_
- Accidents involving it? \_\_\_\_\_

Shielding Analyses

Have shielding analyses been done for this area? \_\_\_\_\_

Have shielding analyses been done for nearby areas that may affect or be affected radiologically by or interface with this area? \_\_\_\_\_

**Zoning, Shielding, and Optimization Review Checklist: Area  
(continued)**

Optimization Analyses

Have any issues or concerns been identified regarding this area that may require an optimization analysis? \_\_\_\_\_

Have any issues or concerns been identified regarding this area and any neighboring area that may require an optimization analysis? \_\_\_\_\_

Have all necessary optimization analyses been performed? \_\_\_\_\_

Other Considerations

Will those accessing this area be entirely ANS or ORNL staff? \_\_\_\_\_

Will those accessing this area include only occupational radiation workers? \_\_\_\_\_

Will those accessing this area include occupational nonradiation workers? \_\_\_\_\_

Will those accessing this area include visitors? \_\_\_\_\_

Revision of Zone Assignment

Have the zone assignments of this area and nearby areas been reevaluated in light of the estimates and analyses above? \_\_\_\_\_

Notes

**Zoning, Shielding, and Optimization Review Checklist: Task**

**Task Name** \_\_\_\_\_  
**Description of Task** \_\_\_\_\_  
**Task Area(s)** \_\_\_\_\_  
**Systems or Components Involved** \_\_\_\_\_  
**RED (or designate)** \_\_\_\_\_ **Date** \_\_\_\_\_

**Preliminary Zone Assignment**

Have the zone assignment guidelines been considered for application to the area(s) in which the task takes place? \_\_\_\_\_

Has a preliminary zone assignment been made for the area? \_\_\_\_\_

**Source Terms and Dose Rate Determinations**

Have source terms been determined for components and areas involved in this task for (as applicable):

Normal operation (including normal leakage)? \_\_\_\_\_

Shutdown? \_\_\_\_\_

Maintenance, inspection, testing, and calibration? \_\_\_\_\_

Anticipated operational occurrences? \_\_\_\_\_

Accidents? \_\_\_\_\_

Have direct dose rates been determined for components and areas involved in this task for (as applicable):

Normal operation (including normal leakage)? \_\_\_\_\_

Shutdown? \_\_\_\_\_

Maintenance, inspection, testing, and calibration? \_\_\_\_\_

Anticipated operational occurrences? \_\_\_\_\_

Accidents? \_\_\_\_\_

Have internal dose rates, where appropriate, been determined for areas involved in this task for (as applicable):

Normal operation (including normal leakage)? \_\_\_\_\_

Shutdown? \_\_\_\_\_

Maintenance, inspection, testing, and calibration? \_\_\_\_\_

Anticipated operational occurrences? \_\_\_\_\_

Accidents? \_\_\_\_\_

**Zoning, Shielding, and Optimization Review Checklist: Task  
(continued)**

Have dose rates to the areas involved in this task from contained sources not in the areas been determined? \_\_\_\_\_

Have dose rates to the areas involved in this task from areas nearby originating airborne or loose liquid sources been determined? \_\_\_\_\_

Occupancy

Have access times directly associated with this task for each area involved been determined for (as applicable):

Normal operation? \_\_\_\_\_

Shutdown? \_\_\_\_\_

Maintenance, inspection, testing, and calibration? \_\_\_\_\_

Anticipated operational occurrences? \_\_\_\_\_

Accidents? \_\_\_\_\_

Have access times not directly associated with this task for each area involved been determined for (as applicable):

Normal operation? \_\_\_\_\_

Shutdown? \_\_\_\_\_

Maintenance, inspection, testing, and calibration? \_\_\_\_\_

Anticipated operational occurrences? \_\_\_\_\_

Accidents? \_\_\_\_\_

Dose Estimates

Have dose estimates directly associated with this task been determined for (as applicable):

Normal operation? \_\_\_\_\_

Shutdown? \_\_\_\_\_

Maintenance, inspection, testing, and calibration? \_\_\_\_\_

Anticipated operational occurrences? \_\_\_\_\_

Accidents? \_\_\_\_\_

Have dose estimates not directly associated with this task been determined for (as applicable):

Normal operation? \_\_\_\_\_

Shutdown? \_\_\_\_\_

Maintenance, inspection, testing, and calibration? \_\_\_\_\_

Anticipated operational occurrences? \_\_\_\_\_

Accidents? \_\_\_\_\_

Shielding Analyses

Have shielding analyses been done for the components and areas involved in this task? \_\_\_\_\_

**Zoning, Shielding, and Optimization Review Checklist: Task  
(continued)**

Have shielding analyses been done for nearby areas that may affect or be affected radiologically by this task? \_\_\_\_\_

Optimization Analyses

Have any issues or concerns been identified regarding this task that may require an optimization analysis? \_\_\_\_\_

Have all necessary optimization analyses been performed? \_\_\_\_\_

Other Considerations

Will those performing this task be entirely ANS or ORNL staff? \_\_\_\_\_

Will those performing this task include only occupational radiation workers? \_\_\_\_\_

Will those performing this task include occupational nonradiation workers? \_\_\_\_\_

Revision of Zone Assignment

Have the zone assignments of the areas and nearby areas involved in this task been reevaluated in light of the estimates and analyses above? \_\_\_\_\_

Notes

**INTERNAL DISTRIBUTION**

- |       |                  |        |                            |
|-------|------------------|--------|----------------------------|
| 1-5.  | J. R. DeVore     | 16     | C. D. West                 |
| 6.    | R. M. Harrington | 17-21. | J. L. Westbrook            |
| 7-10. | R. L. Johnson    | 22.    | ORNL Patent Office         |
| 11.   | G. T. Mei        | 23-24. | Central Research Library   |
| 12.   | R. L. Mlekodaj   |        | Document Reference Section |
| 13.   | D. L. Selby      | 25.    | Y-12 Technical Library     |
| 14.   | H. B. Shapira    | 26-27. | Laboratory Records Dept.   |
| 15.   | C. S. Sims       | 28.    | Laboratory Records, RC     |

**EXTERNAL DISTRIBUTION**

29. T. A. Khan, Brookhaven National Laboratory, Department of Advanced Technology, BNL ALARA Center, Bldg. 703M, P.O. Box 5000, Upton, NY 11973
30. U.S. Department of Energy, ANS Project Office, Oak Ridge Operations Office, FEDC, MS-8218, P.O. Box 2009, Oak Ridge, TN 37831-8218
- 31-32. Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831

