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# DOE STANDARD

## APPLYING THE ALARA PROCESS FOR RADIATION PROTECTION OF THE PUBLIC AND ENVIRONMENTAL COMPLIANCE WITH 10 CFR PART 834 AND DOE 5400.5 ALARA PROGRAM REQUIREMENTS

-- VOLUME 1--
DISCUSSION

**DRAFT**
**U.S. Department of Energy**
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A. Introduction

The admonition to keep exposures as low as is reasonably achievable (ALARA) has been the traditional position of the radiological protection community for several decades. The International Commission on Radiological Protection (ICRP) in Publication 26 (1977) recommended that ALARA be a formal procedure as part of a system of dose limitations consisting of three parts:

> (1) **Justification** No practice [causing exposures of persons to radiation] shall be adopted unless its introduction produces a positive net benefit (practices should not cause more harm than they do good);
> (2) **Optimization** All exposures shall be kept as low as is reasonably achievable, economic and social factors being taken into account; and
> (3) **Dose limits** The dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances.

The National Council on Radiation Protection and Measurements (NCRP) subsequently made similar recommendations. The ICRP system of dose limitations has been adopted almost universally and DOE has implemented the recommendations through Orders and regulations, such as DOE 5400.5, DOE 5480.11, and 10 CFR Part 835. The regulation 10 CFR Part 834, among other things, implements these ICRP/NCRP recommendations as applied to the general public and the environment through rulemaking. This guidance will focus on the recommendation that all exposures shall be kept as low as is reasonably achievable, economic and social factors being taken into account.

The Department of Energy's 10 CFR Part 834 "Radiation Protection of the Public and the Environment," that reiterates and strengthens a long standing requirement for DOE activities to maintain all exposures at levels that are as low as is reasonably achievable (ALARA) below the appropriate dose limits. The rule 10 CFR Part 834 specifically requires the application of the ALARA process for radiation protection of the public and environment.

It may be assumed that any activity implemented by the Department has been reviewed by the government and provides a net benefit, that is, **justification**, and this will not be addressed further in this guidance. Exposures of individuals will be managed in a manner that will ensure compliance with the appropriate **dose limit** for the individuals, regardless of the cost for doing so, thereby ensuring that the risk of radiation-induced health effects are acceptably low for individuals. **Optimization**, which considers the collective dose to the entire exposed population from radiation sources (presumed, for radiation protection purposes, to be proportional to the number of radiation-induced health effects) and cost or detriment of measures that would reduce the dose below applicable dose limits or dose constraints, provides a basis for judging the reasonableness of the selection of a particular radiological protection system after considering several alternative systems. The following guidance is intended to be consistent with the ICRP recommendations and to supplement other Federal regulations, that also are intended to be consistent with the ICRP and NCRP recommendations.

B. Purpose

The purpose of this document is to provide guidance for implementing and complying with the ALARA [1] requirements of 10 CFR Part 834 for the development and application of a program to keep radiation exposures of the public and releases of radioactive material to the environment from DOE activities as low as is reasonably achievable, that is, an

[1] ALARA means "As Low As is Reasonably Achievable" which is an approach used for radiation protection to manage and control exposures (both individual and collective to the work force and to the general public) and releases of radioactive material to the environment so that the levels are as low as is reasonable taking into account social, technical, economic, practical, and public policy considerations. As used in 10 CFR Part 834, ALARA is not a dose limit, but rather a process which has the objective of attaining doses as far below the applicable limit of this part as is reasonably achievable.

ALARA program[2]. ALARA applications to radiation protection may be reflected in decision-making on the selection of the optimum design of a process system, or performance criteria for the features or components of the system, or on the selection of operating modes or other parameters that can effect the exposure of members of the public to radiation. The selection may be achieved through a logical process that considers both benefits and detriments. This is the ALARA process[3]. ALARA decisions require consideration of a broad range of technical and societal factors. The rule requires that the bases for the ALARA decisions be documented.

Doses to the public from residual radioactive material must be maintained as low as is reasonably achievable below the primary dose limits. The rule requires all activities that release radioactive material or cause exposure of the public to radiation to be assessed under the ALARA process. The ALARA process must be applied no matter how small the dose. However, in this guidance DOE has established a graded level of control and oversight to ensure that doses to the public are low and assessments are both beneficial and cost effective. The guidance describes a detailed "quantitative" process, a "qualitative" criteria, and guidance on when each should be applied. Both approaches require full documentation.

The degree of control, treatment, processing, remedial action, or other method of limiting doses to workers and to members of the general public should be determined by implementing a process that identifies and considers all factors important to the decision-making. ALARA, as applied by DOE, is not a level or limit to be achieved in controlling radiation exposures or doses, but rather a process that will be used to ensure that appropriate factors are taken into consideration in arriving at a decisions that could affect protection against radiation.

This guidance identifies a number of factors that should be considered and presents a logical sequence for considering the factors important to decision making and references a number of techniques what may be used to quantify some of the factors. The guidance recognizes the difficulties in ascertaining quantitative evaluations of alternative options using tools, such as cost-benefit analyses, and acknowledges that decisions must inevitably involve a great deal of technical and managerial judgment, whatever system is used. Much of the discussion in this guidance focuses on cost-benefit analysis and optimization but it is recognized that other decision-making tools such as multi-attribute utilility analysis may also be useful particularly where non-quantifiable factors or attributes are concerned (see Volume II, Section F).

C. Goal

The ALARA process is a decision-making tool with the goal to maximize the total benefits of the radiological protection[4] provisions for a DOE activity that is likely to expose members of the public to ionization radiation. This occurs when the cost of radiological protection plus the cost of the detriment are minimal. The procedure for attaining the minimal cost condition is called "optimization." This guidance describes and discusses necessary elements of an ALARA program and is intended to help persons in making decisions on radiation protection by providing a method for selecting the optimum radiological protection alternative from among several candidate alternatives. The use of site-specific and activity-specific

[2] ALARA program means the set of design specifications, operating procedures, techniques, monitoring and surveillance programs, records, and instructions used to implement the ALARA process.

[3] ALARA process means a logical procedure for evaluating alternative operations, processes, and other measures, designed to reduce exposures to radiation and emissions of radioactive material into the environment, taking into account societal, environmental, technological, economic, practical, and public policy considerations to make a judgment concerning the optimum level of public health protection.

[4] The term radiological protection, is used in this document in the broad sense in that it includes, among other things, the design and operation of those processing components whose function is to remove radioactive material from waste streams which become part of the effluent releases to the environment or to constitute other sources of exposure of members of the public.

factors are encouraged in evaluations used in the ALARA process. The resources allocated to the ALARA process detail or scope of the associated analyses should be commensurate with potential benefits.

> The goal of the ALARA process is to identify, from among several candidate alternative radiological protection systems, the system that would result in the minimal overall cost and maximum benefit.

D. ALARA Requirements in 10 CFR Part 834

The principal ALARA requirements in 10 CFR Part 834 are contained in § 834.104:

**§ 834.104 ALARA considerations**

**§ 834.104(a) An ALARA Program must be established to control and manage releases of radioactive material to the environment and exposures of members of the public to radiation at levels as low as is reasonably achievable.**

1. ALARA program.

DOE contractor or operating organization at each DOE facility (where activities routinely involve radiation or radioactive materials) is required, by 10 CFR Part 834, to have an ALARA program that addresses the impact of the operations on the public and the environment[5]. ALARA programs may be integrated into Environmental Radiological Protection Program (ERPP) plans or may be a separate document that is included by reference in the ERPP[6]. Whether included in the ERPP by reference or integrated into an ERPP plan, the ALARA program must address each activity on the site that can cause exposures of members of the public to radiation.

The amount of effort that can justifiably be put into an ALARA program or evaluation depends on the potential magnitude and likelihood of radiation exposures to individuals and the general public in the vicinity of the site. The admonition in § 834.5(a) that the content of the ERPP should be commensurate with the complexity and hazard of the DOE activity also applies to the ALARA program (that is, a component of the ERPP). For example, an activity that makes use of encapsulated radiation sources, where there is essentially no likelihood of releasing source material, would only require addressing possible contamination from ruptured sources and potential external exposure. In contrast, if the activity included recovering the source material from ruptured capsules and re-encapsulation, the potential exposure pathways for inhalation and ingestion would also have to be addressed in the ALARA program. This is discussed in Section H.

The ALARA program must be reviewed and approved (separately, as part of the ERPP plan) by the appropriate DOE Program or Field Office and contained or summarized and referenced in the DOE-approved ERPP plan. The ALARA program should be reviewed by the DOE contractor or operating organization as necessary, but at least every 3 years, to identify: (1) changes that have occurred in the facility, operations, or activities that might have altered the relative importance of the releases or exposures; (2) alternatives to the operations or activities that were not considered previously; and (3) operational information on the performance of the selected equipment or process that could alter the decision on choice among alternatives. Consideration should be given to providing an in-house audit system to evaluate the effectiveness of the ALARA program and to ensure that improvements are implemented to strengthen it, if justified.

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[5] ALARA requirements for workers are contained in 10 CFR Part 835. However, ALARA programs for protection of the public and environment must also consider worker protection.

[6] The ALARA Program documentation and ERPP plan may also be incorporated into an integrated systems management plan.

A quality ALARA program must be fully documented and all information supporting ALARA-based decisions available to the public. The Department encourages public involvement in the process as well as coordination with appropriate external regulators that may be involved in related activities. This can be accomplished through existing site advisory groups, through the NEPA process or other public involvement programs that are currently being implemented in support of DOE actions.

**§ 834.104(b) An ALARA Program shall address:**

**§ 834.104(b)(1) a statement of commitment to use the ALARA process.**

2. ALARA policy statement.

Among other things, the ALARA program should include: (1) a policy statement and commitment from management to the ALARA philosophy and process[7]; (2) a designated organizational responsibility, authority, and structure for implementing the ALARA Program; (3) a systematic evaluation of the activities at the site to identify those activities that are responsible for the releases of radioactive material and the exposures of the public and workers; and (4) a procedure by which the operations or activities will be analyzed to determine whether they are being performed in a manner that will ensure that the radiological impacts are ALARA. The Environmental Radiation Protection Program (ERPP) plan should include a statement by the responsible manager committing to establish and to implement the ALARA process for activities that are sources of exposures to ionizing radiation. It is also important that the organizations commitment to ALARA be known to the public and is recommended that the policy statement be made part of the public record

The importance of the ALARA process to DOE activities is reflected in the number of occasions the use of the ALARA process is required in 10 CFR Part 834, that is, in every instance where exposures to radiation can occur, except where an ALARA determination was part of the rulemaking process in arriving at a dose standard, such as some of the NRC and EPA regulations or Federal guidance. The success of an ALARA program is dependent upon the acceptance and backing of the management responsible for the DOE activity that causes the exposure to radiation.

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| A commitment by management is necessary for implementing an ALARA program. |

**§ 834.104(b)(2) a description of the means to be used to implement the ALARA process.**

3. ALARA process.

A cost-benefit analysis is a key component of the ALARA process. By differentiating a cost-benefit equation, setting it equal to zero, and solving for certain conditions, one can identify operating parameters that will optimize the activity with respect to benefits that occur when the overall costs are minimal. Major factors in the ALARA process include:

- o identifying and quantifying the sources of radiation;
- o defining possible candidate radiation protection systems (including treatment of waste streams) that would reduce the exposure or doses;
- o quantifying the economic factors (cost of systems, operations, maintenance,...);
- o quantifying exposures and doses to individuals and to populations in the vicinity of the DOE activity;
- o estimating the health risk and identifying non-health detriment; and
- o selecting one of the candidate radiation protection systems as ALARA.

[7] In addition to the policy statement that should be reaffirmed on a regular basis, management should consider incentive programs for individuals that suggest ALARA related improvements in process operations or even in the implementation of the ALARA program as part of their commitment to ALARA.

There is no single best procedure for implementing the ALARA process for all DOE activities; rather, it depends on the characteristics of the activity, the site, and the potential doses involved. The ALARA process is discussed further in Sections G and H.

When a new facility is being contemplated, the ALARA program should be employed in the selection of processes, design of the facility, and setting operating parameters and procedures. Early consideration of alternatives permits the maximum flexibility in the selection of design options. When a new DOE activity is being designed, the initial source term ("base case") to be characterized. This is the source term that would result from the least radiation protection system that would permit operation. The condition that the base case must satisfy is that the radiation dose to the most exposed persons (workers or members of the public) must be within the appropriate dose limit. This base case system subsequently will be used as a basis for comparison of the cost effectiveness of more sophisticated and costlier alternative systems. The base case or some of the alternatives cases may or may not be a practical design candidate because of possible environmental or other impacts that may be judged to be undesirable, or unacceptable, but these considerations would be evaluated at a later point in the decision-making.

When the ALARA application is for an established, on-going, activity or facility, that is, retro-fitting, the practical alternatives are likely to be much more limited because back-fitting is considerably more costly (frequently by a factor of 2 to 3, or more) than the cost of the original design features and the alternatives are generally limited to practical modifications of the facility structures and possible operational procedures.

The ALARA process can be most effective when it is applied in the design of new facilities that have potential for exposing workers and members of the general public.

4. Identifying and quantifying the sources of radiation.

A logical starting point for an ALARA cost-benefit analysis is to identify and characterize all anticipated radiation source terms, that is, sources of ionizing radiation that can occur from the DOE activity. The source evaluation should quantify all parameters germane to the estimation of potential direct exposures of the workers and members of the public and internal exposures due to inhalation, ingestion, or absorption of radioactive material released to the environs by the DOE activity.

For operational facilities, the "base case" source term, that will be used to compare with all alternative radiation protection systems, must be characterized is that which currently exists. The data obtained from effluent monitoring and environmental surveillance required by 10 CFR Part 834 could be a valuable source of data for the effort to define existing source terms from an ongoing activity and can provide exposure pathway and source data. The monitoring and surveillance data also may verify the adequacy of analytical models for dispersion of radioactive material in the environs and exposure pathways used to evaluate exposure conditions and dose estimates. Careful evaluations of facility design and operating conditions and measurements at a variety of locations in and around the facility or activity may also reveal radiation sources and release and exposure pathways not previously identified or anticipated.

For facilities that are in the design stage, the base case is a radiation protection system that will meet the dose limits for postulated dose to the maximally exposed member of the general public.

The ALARA program should indicate how the activities and operation of the facility will be systematically analyzed to identify existing and potential radiation sources and pathways for discharges or leakage of radioactive material can be released to the environment where members of the public could be exposed.

5. Defining possible candidate radiation protection systems.

When the amount, physical characteristics, and location of the radiation sources are known, process systems can be designed to reduce the exposures of the workers and the public from the sources. For new facilities, or those being designed, source characterization would likely be based on component performance data supplied by the manufacture, the design engineers, data from other installations that have used similar components, or even laboratory tests. For operating facilities, the source characterization can be based on the results of survey, monitoring, and environmental surveillance data with supplemental studies or measurements, as necessary.

Assuming that the sources of radiation and exposures are sufficient to justify the effort, several candidate system design and operating options that would result in a range of release or exposure conditions and costs should be identified for each radiation source of exposure. Ideally, the design options would include several process technologies, combinations of process components, and operating conditions ranging from the most rudimentary (base case) to the most technologically sophisticated system. The ALARA process will identify the most favorable of the candidate design and operating options.

The performance of the components of the radiation protection systems for reducing the exposures and associated doses should be estimated for each candidate system and option so that the modified source term, before and after treatment, can be estimated. Consulting engineers, operators, and designers of other nuclear (and non-nuclear) facilities can provide extremely valuable data on alternative systems and components, cost, maintenance, and operating experience, particularly where the characteristics of the streams or processes are similar. A data-base of information from DOE and other facilities can be extremely valuable in applying the ALARA process. Therefore, it is recommended that facilities and sites completing ALARA analyses that may be of interest to other sites or operations make the material available. The cost of establishing and maintaining such a data base could be recovered in savings from a few applications. Data should include system descriptions, performance and cost characteristics. If such data are provided to EH-41, EH will make it available DOE-wide.

It is very important that several candidate process or radiological protection design options, or combinations thereof, be evaluated because the ALARA process can only choose the best system from among those that have been defined and evaluated.

6. Quantifying the economic factors (costs).

Two primary components to the cost associated with a radiological protection system are (1) the system cost, that is, purchasing, installing, operating, and maintaining the equipment and (2) the cost of the potential health effects, that is, costs associated with the exposure of people and any other direct or indirect cost resulting from exposures to radiation--whether the consequences are real or imagined. In ALARA applications, one is interested in the cost of providing various degrees of radiation protection for persons who are anticipated to be exposed to sources of radiation caused by the DOE activity and how they change with alternative systems. These analyses identify the candidate system with the least total cost; hence, the optimum system. System costs are discussed in Section E.

7. Quantifying exposures and doses to individuals and to populations in the vicinity of the DOE activity.

The doses to occupationally-exposed individuals and to maximally exposed individual members of the general public are important because there are specific dose limits that have been promulgated and must be met, if the activity causing the exposures is to be permitted. The appropriate dose limit for an individual worker or member of the general public must be met regardless of cost. Doses to workers are regulated by 10 CFR Part 835. ALARA requirements for workers also are addressed in that rule and associated guidance.

The health detriment to the exposed population from an activity that causes exposures to radiation is assumed to be proportional to the collective dose, that is, in units of person-rem, to the population from direct exposures to the radiation and from ingestion, inhalation, or absorption of the radioactive material released to the environment.

The magnitude of a dose to individuals or populations will depend upon the radiation source geometry, quantity, type and energy of radiation emissions, exposure modes, population distribution, location of the receptor with respect to the source location, duration of exposure, quantity of radioactive material released, dispersion by natural forces, lifestyle of the receptors, potential exposure pathways, and other parameters. Some of these parameters are discussed in Section E.2.

There are no promulgated limits for collective dose from a DOE activity. As will be seen, if the health-detriment or health benefit can be quantified, a cost of the detriment or benefit may be postulated for cost-benefit purposes. The collective dose is presumed to be a surrogate for the potential health impact on the population exposed to the radioactive material.

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| It is necessary to comply with the appropriate (individual) dose limit to any member of the public, whatever the cost to do so. However, it is the collective dose that is used in the cost-benefit analysis to select a radiation protection system. |

8. Estimating and identifying health and non-health detriments and benefits.

a. Health detriment.

Serious health effects, such as cancer and genetic diseases, can be induced be exposures of humans to ionizing radiation. The effects have been observed only among populations subjected to doses greater than about 10 rad delivered at a high dose rate. Whether these health effects occur at lower dose rates or by chronic exposure at low dose rates has not been determined owing to the logistic problems attendant to large epidemiological studies and to incomplete knowledge of the mechanisms of radiation-induced cancer causation. Thus, it is necessary to speculate on the risk of induced health effects at dose levels that do not exceed the dose limits for workers and for members of the public. For radiation protection purposes, DOE assumes that there is a proportionality between dose and risk (the probability of radiation-induced health effects) at dose levels encountered in the work-place and in the environment[8].

The importance of quantifying the detriment (risk) or benefit (risk reduction) is that by doing so, one can place a value on the amount of resources that may be committed for a radiation protection system to avoid a radiation-induced serious health effect. This is discussed in Section F.3.

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[8] DOE is in the process of completing review of dose to risk conversion factors including the recommendations of BEIR V, BEIR IV, UNSCEAR 88, and ICRP Publication 60 (1990) in order to recommend a general value to use to compare effective dose equivalent to health effects in environmental analyses. In the interim, a factor of 5 fatal cancers per 10,000 person-rem may be used for doses in the range of, and below, the DOE dose limit. The value is within the range of values that the new data would suggest and equivalent to the value used by EPA in recent regulations (EPA 1989). The ICRP recommendations include life-shortening as a significant factors of health-detriment. The ICRP-60 recommendations have not received consensus acceptance among Federal agencies.

The analyses conducted to support the ALARA process should consider all health detriments and benefits associated with the various alternatives evaluated. For example, one alternative control technology might reduce the collective dose by þx person-rem (detriment averted) but could significantly increase the risk to workers. The technology might also create a very hazardous waste that could increase the public risk and present difficult disposal problems. All of these and similar factors must be considered in the ALARA assessment. Reasonable measures should be taken to mitigate any additional risks caused by the technology.

b. Non-health detriments.

Non-health effects can also be experienced from activities that involve actual or potential exposures to radiation. Some of these are real and associated with environmental considerations, such as temperature, noise, humidity, and other comfort considerations. Others are psychological or political in nature, such as aversion to radiation at any level, or anti-nuclear agenda. Additional confounding factors complicate the rationale, that is, cost or other impacts and benefits may be accrued to a population other than the one receiving the exposure. It could include costs for purchasing property or other expenses to avoid litigation or demonstrations from "stakeholders." Unlike the health detriment, the non-health detriment is not linearly related to dose, and might not be related to dose levels at all! On the other hand, the costs of non-health detriments are real and can be quantified--at least in retrospect.

Because it is difficult to anticipate the cost of non-health detriments and the cost may not even be related to collective dose, they are difficult to include in a cost-benefit analysis and other decision-making techniques such as multi-attribute analyses may be useful. Non-health (or non-human) detriments are discussed in Section F.4.

9. Selecting one of the candidate radiation protection systems as ALARA.

In some cases, adequate information will be available to permit a cost-benefit analysis to quantify elements important in the decision-making process. In other cases, the information might not be available or a quantitative cost-benefit analysis might not be practical to aid in a decision-making process involving ALARA exposures--in that case, the decision must be based almost entirely on subjective judgment.

Put in the simplest terms, the radiation protection system selected by the ALARA process is the one that results in the maximum benefit and the minimum cost--both of which occur with the same system if the detriment is health effects only. The prime factors important for making ALARA decisions is the cost differential between candidate radiation protection systems and the attendant differential collective dose. The mathematical derivation of the optimization is presented in Section G.1.

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| In the simplest case, the optimum system is that system with the least **total** cost--including the monetary cost assigned to the health detriment. |

**§ 834.104(b)(3) a process for documenting ALARA decisions**.

10. Records.

The DOE contractor or operating organization is required to record the ALARA evaluations and other activities and information that were considered in the decision-making for selecting the alternative radiological protection option judged to be ALARA and the rationale leading to the selection. (See § 834.401 for specific record requirements.) The ALARA program should specify procedures by which ALARA records are kept current, complete, and readily available for use. The records should be organized in a manner such that appropriate sections can be readily located to demonstrate compliance with the ALARA requirements. The records should facilitate coordination and cooperation with other organizations in

sharing information on analyses, performance of equipment, costs, operations, maintenance, identity and technical evaluations of alternatives, and other facets of interests.

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| There is much to be gained by creating a data base for cost and performance information for process systems and components. NRC licensees and regulators as well as DOE contractors and National laboratories are likely contributors to such a data base. |

**§ 834.104(b)(4) a training program for the staff on implementation of the ALARA process.**

11. Training.

The ALARA program should describe, or reference, a training program to ensure the availability of appropriate staff capabilities to provide the necessary analyses and evaluations. The ALARA process applications require evaluations of exposures and doses to individuals and populations, dispersions of radioactive material in the environment, cost-benefit and other economic evaluations, engineering evaluations of equipment performance and source determinations, and applications of other disciplines. It would be unusual to find staff personnel capable of performing all of the evaluations necessary for ALARA applications. Consequently, training should be made available to staff to provide the necessary knowledge and skills.

**§ 834.104(c) The ALARA process must include documentation of the societal, environmental, technological, economic, and public policy factors considered in decision-making, where exposures to radiation from DOE activities can occur, and must include:**

**(1) the maximum dose to members of the public;**
**(2) the collective dose to the population;**
**(3) doses to workers;**
**(4) applicable alternative processes such as alternative treatments of discharge streams, operating methods, or controls;**
**(5) doses for each alternative evaluated;**
**(6) cost for each alternative evaluated;**
**(7) an examination of the changes in cost among alternatives; and**
**(8) societal and environmental (positive and negative) impacts associated with alternatives.**

The elements of the ALARA process that must be recorded have been discussed. No specific format or other constraint is required by 10 CFR Part 834.

**§ 834.104(d) Public exposure resulting from radiation, release of radioactive material, or other radiological contamination from a DOE activity shall be deemed to comply with ALARA requirements if the activity is evaluated and conducted in accordance with an ALARA program approved by the Department.**

**§ 834.401 Records.**
**(a) Records must be maintained to document compliance with the requirements of this part.**

Records of individual and collective dose estimates should be maintained to document estimated doses to members of the public who are likely to receive doses from DOE activities owing to their location or due to exposure pathways during normal operations and unusual occurrences. The administrative information to be documented and maintained should include:

(1) records of actions taken to implement the ALARA process in regulating exposures to individuals and members of the public, including the actions required for this purpose by § 834.104 such as records of cost-benefit or other analyses, and other factors that were considered important to the ALARA decision-making process; and

(2) records of actions taken to implement the "best available technology for radioactive effluent control" (BATREC) selection process in regulating liquid discharges, including records to document the analyses and factors that were considered to be important, including alternative processes, for the BATREC selection process.

12. Compliance.

In addition to the requirements above, the rule requires application of the ALARA process in most activities addressed in the rule. The exception is where an activity is regulated by a rule wherein dose or other limits were based on an ALARA determination. In that case, simply complying with the dose limit constitutes ALARA. Requirements do not originate in guidance documents, such as this one. Rather, they are specified in DOE Orders and rules as well as those of other Federal, State, and local agencies.

Demonstration of compliance with the ALARA requirements of 10 CFR Part 834 may be provided by:

(1) A documented current description of the site ALARA program, reviewed and approved by the appropriate Program Office[9] and a statement of commitment to implement the ALARA process;

(2) A documented current ALARA program describing procedures by which the individual ALARA evaluations and judgments will be made and the documentation of the procedures;

(3) A description of the training program provided to ensure staff capabilities to perform ALARA evaluations; and

(4) Records of all formal ALARA evaluations and decisions, including the rationale for the ALARA judgments, indicating that the ALARA program is being implemented. The records should demonstrate that sufficient information was assembled and considered to support the ALARA decisions.

The ALARA program should identify general areas to be considered in making ALARA decisions: societal, technological, economic, and public policy considerations. A checklist of more common specific factors may be helpful. As a minimum, the checklist should include the eight specific items listed in § 834.104(c).

The rule 10 CFR Part 834 requires that contractors report to DOE line management and EH when certain reporting limits are exceeded, such as a collective TEDE of 100 person-rem in a year.

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| Whether the ALARA analyses is quantitative or qualitative, it is essential that the analyses and decision be documented. |

E. Evaluations and Assumptions

1. Cost of radiation protection systems.

Cost projections for candidate radiation protection (including treatment systems) that alter the radiation source and operating cost may be expressed in terms of annual cost or total cost over the lifetime of the facility. Total cost for a facility or process typically should include, but not be limited to:

(a) the system (capital) cost
- equipment and piping (description and quantity),
- labor (installation and operation), and
- other material;

(b) the annual charge on capital (to the extent that this cost is applicable to Federal agencies);

[9] If the description of the ALARA program in the EPIP is sufficiently detailed, the ALARA program approval requirement may be satisfied through the approval of the EPIP. However, if the EPIP is not approved, program offices may opt to approve an ALARA plan.

(c) the operation and maintenance (O&M) cost, that is,
- a selected fraction of total capital equipment and piping cost,
- expendable material cost,
- electrical or other power cost,
- processing cost,
- collection and disposal cost,
- contingency allowance,
- the type of activity being considered, and
- transportation cost; and

(d) the health detriment (cost for reduction).

Cost varies with equipment specifications, regional labor availability, (perhaps) site characteristics, and (certainly) with time--owing to capital availability.

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| Standard costing methods should be used in arriving at cost estimates for the systems. |

2. Exposures and doses.

The doses to occupationally-exposed individuals (workers) and to maximally exposed individual members of the general public are important because there are specific dose limits that have been promulgated and must be met, regardless of cost, if the activity causing the exposures is to be permitted. The primary dose limit is based on the sum total dose from all exposure modes and sources with few source-specific exceptions (see § 834.101(a)(2)(i)-(v)). The primary dose limit for members of the public from all exposure modes is 100 mrem in a year. Dose limits for individuals are generally specified in a standard, that is, a regulation or Federal Act, or published in Federal guidance signed by the President and is generally selected on the basis of presumed health risk to the individual that is deemed acceptable, feasibility of compliance, cost-benefit considerations, or arbitrary selection.

Several supplemental dose limits that are source-specific or exposure-specific have been promulgated, that is, from drinking water, from airborne sources, from fuel-cycle activities. Thus, there may be multiple dose limits appropriate for an individual depending, in some cases, upon the exposure mode (direct exposure, ingestion, inhalation or absorption), the receptor status (occupationally exposed worker or incidentally exposed member of the public), and the source of the exposure (fuel cycle activity, exposure media such as drinking water, airborne source, and others).

Because the primary dose limit is applicable to all sources and pathways, DOE requires that dose constraints for single sources be a fraction of the primary dose limit. DOE applies a dose constraint of 30 mrem in a year be used for any single source or practice, § 834.102(a)(1).

If a DOE activity is subject to a dose limit that was promulgated on the basis of cost-benefit considerations, and if it can be demonstrated that the dose from the activity is within that dose limit, a cost-benefit (or any further ALARA analysis to demonstrate that the exposures or resulting dose from that exposure mode are ALARA) will not be required for the part of the exposure subject of that dose limit.

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| The maximum dose to individuals must be quantified to verify compliance with appropriate primary and supplemental dose limits. |

a. Exposure location.

The magnitude of potential doses to individuals is dependent, among other things, on their location during exposure. The location of the maximally exposed individual will depend on the amount and characteristics of the radioactive source, the release mechanism (that is, through a stack, elevated vent, building leakage, rakes ...), the site dispersal modes (that is, wind-roses, natural water ways, ...) and exposure modes (that is, direct exposure, intake of foodstuff, ...). If the DOE-activity can cause the release of airborne radioactive material, the location of the maximum potential exposure for that pathway is likely to be where the annual maximum time-integral of the air concentration exists. For example, the location of the highest annual average air concentration as a function of distance from the point of discharge may be determined by analytical modeling of meteorological data using joint wind-direction, wind-speed, and stability roses.

The location of maximum potential dose is not necessarily where the highest concentration occurs. While the location of the maximum time-integral of the air concentration can be determined, the location might be uninhabited and no person would be exposed. Further, it is unlikely for an individual to occupy any location for very extensive periods of time. Few people live in one location all of their lives. About two decades of living in one house is more likely [10]. The doses at locations where there are homes, schools, and work locations, should be evaluated. Therefore, even if people did occasionally occupy that location, adjustments for exposure duration would be necessary to estimate dose. However, it is also important to recognize that for collective dose assessments, the length of time at a given location is not as important as the total time people spend at a given location. That is, the collective dose associated with one person at a given point for 30 years is same as 3 people each spending 10 years at the location.

The distance of the maximally exposed individual from the point of discharge of the radioactive effluents can be taken as the location of the individuals home, work-place, school, or other location where the individual remains for substantial periods of time. Doses to the maximally exposed individual from exposures to radioactive material in a waterways might depend on the concentration at the nearest location where access to the waterway is likely to occur.

Although it is desirable (and recommended) to evaluate doses in a realistic manner, it is possible (and permissible) for economic savings to be realized to assume (conservatively) that the exposure of an individual occurs at the site-boundary in the predominant wind direction. The advantage is that it is not necessary to collect data on actual locations of individuals. In this case, potential exposure pathways identified in the rule should be evaluated to confirm that greater potential doses are unlikely to occur at a location beyond the site boundary. This approach is less acceptable for estimating collective dose than for individual dose because overestimating doses can result in biased results and poor decisions.

> In estimating anticipated doses for ALARA purposes, "realistic" parameters should be used. The goal should be to ensure that the estimated doses will not substantially underestimate the doses. To the extent practicable, the estimates should address anticipated doses to actual people, rather than maximum doses to hypothetical persons.

b. Receptors.

For most ALARA applications, the use of "average" or typical characteristics for evaluating potential doses to exposed populations are recommended. Irrespective of the age or the gender of the persons exposed, average doses to organs or tissues, average risk coefficients, and typical values for food and drink intakes and metabolic parameters for "reference

[10] An EPA survey found that about 95% of the population live in a particular residence less than 30 years. The mean duration was about 7 years per residency.

man" should be used[11]. ALARA evaluations should be expressed in terms of total effective dose equivalent (TEDE), that is the sum of the EDE from external exposures and the committed EDE from radionuclides taken into the body during the same exposure time-interval. There may be special circumstances where age or gender issues may be important considerations and the use of "reference-man" or other standardized assumptions may not be applicable.

For assessing compliance with individual dose limits or dose constraints, where there is considerable uncertainty in the location and characteristics of the maximally exposed individual or it is difficult to identify the single individual who receives (or is likely to receive) the highest dose, the average dose to the "critical group [12]" may be evaluated.

c. Collective doses.

Collective dose to the public is simply the product of the average dose and the number of exposed persons. It is important to the decision-making process that collective dose estimates be representative so that comparisons of alternatives can be accomplished without bias. Although the use of conservative dose estimates may be acceptable for screening assessments to determine if quantitative ALARA assessments are needed, average or representative dose estimates are needed for actual optimization assessments. The problem, therefore, is determining the average dose(s) and the number of persons that receive the dose.

To illustrate one calculational method for estimating collective dose, S, consider the release of radioactive material to the atmosphere. Various analytical models, generally in the form of diffusion equations, may be used to estimate the dispersion of the material at various distances from the source. The potential exposure conditions, e.g., integrated air concentration, as a function of distance and direction from the source can be valuated. The population distribution of persons at the same distances and directions must be determined. Within each direction-sector, a series of radial increments (say, distances $X_i \pm \Delta X$) can be defined and representative (average) doses estimated for the centerline of the radial increment. The potential dose at distance, $X_i$, can be taken as the average dose, $H_i$, for all persons, N, located within the radial increment defined by $X_i \pm \Delta X$. The incremental collective dose $\Delta S = N_i \times H_i$. Similarly, additional incremental collective dose values are estimated for all radial increments in that quadrant from the source until the next increment contributes less than about 5% of the total collective dose in that sector out to that distance or about 50 miles (86 Km) from the point of release or about 50 miles beyond the site-boundary. This process is repeated in all other sectors (each usually corresponding to one of the 16 wind directions of the wind rose generated from joint wind-speed and stability class), in the case of site-specific meteorologic data. The sum-total of the incremental collective doses from all sectors is the collective dose, S, for the release. **Figure 1** illustrates this example.

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[11] It is noted that DOE recommends the use of the linear dose to risk assumption and average parametric assumptions for planning purposes and for evaluating potential exposures for use in the ALARA process and other environmental evaluations. However, these assumptions may not be applicable or appropriate when assessing the risks from actual exposures or the effects of exposures to accidental releases or conducting scientific studies (e.g., epidemiology). For instance, in assessing possible health-effects that might be associated with an actual exposure, the magnitude of the exposures might be much greater than the dose limits selected for radiation protection purposes and beyond the dose range where a linear relationship might reasonably be expected to apply. At very high doses (beyond threshold dose values), non-stochastic health-effects might be expected and these are not related to dose in a linear manner. Further, when quantitative estimates of risk are evaluated in epidemiologic studies, it might be appropriate to consider the exposed group and determine if specific age, gender, or other factors are important in making the risk assessments.

[12] For purposes of this guidance, the "critical group" may be considered to be individuals in the general vicinity of a DOE activity, facility, or site from which radioactive material is released or other sources of exposure occurs, which have relatively homogeneous physical and lifestyle characteristics that are likely to result in the maximum dose (and presumably the highest risk) compared to other groups in the exposed population. For example, the critical group might be infants who ingest milk from cows pastured on land in the predominant downwind direction from a facility which releases radioiodine to the atmosphere. Another critical group might be fishermen who ingest a substantial amount of fish taken from a local waterway downstream of a facility that releases radionuclides in liquid effluent.

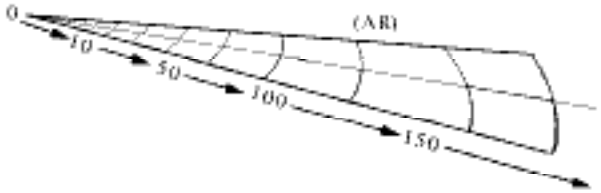


**Figure 1 An Illustrative Reference System for Use in Collective Dose Estimates for Airborne Releases of radioactive Material.**

Around the release point, O, consider 16 equal sectors of 22.5 degrees, each centered on the points of the compass corresponding to a wind direction. [Meteorological data are usually collected and presented as wind roses with joint wind-speed, wind direction, and stability class.] Divide each of the sectors into radial increments, þR, 1 mile in length for the first 10 miles, 5 miles in length from 10 to 50 miles, and 25 miles in length from 50 to 150 miles. Calculate the potential doses (internal and external), H, for the center of each of the radial sectors, and determine the product of the centroid dose and the number of persons, N, within the radial sector. The collective dose is the sum of the products from all radial increments in all sectors.

In the example above, the radial increments selected at various distances in a sector should be relatively small at locations where the concentration is decreasing rapidly with distance and larger at locations where the concentration is decreasing more slowly. This is necessary because the approximation is made that the average dose to all persons in the incremental radial sector will be the dose calculated for the mid-point of the sector. For example, the radial increments might be no more than a mile apart out to about 10 miles, no more than about 10 miles apart out to 50 miles, and (if estimates beyond this distance is needed) 25 miles apart out to 150 miles. When the release includes short-lived material, adjustments for decay in route may be required. The collective dose associated with the use of each alternative radiation protection system is needed for a cost-benefit analysis. Unless the characteristics (other than the magnitude) of the source term is altered by the various systems, the collective dose will be proportional to the source term and the collective doses will be readily determined by ratios.[13] Deposition of the airborne source on ground-level surfaces may be estimated using similar analytical models and estimated deposition velocities.

When evaluating collective dose for release of property, defining the representative receptor is difficult. In comparing alternative actions collective doses estimates should consider the expected or likely use of the property. Where data are available, for key parameters, models may use probabilistic assessment techniques to establish the average or representative dose for computing the population doses. However, these dose estimates may not be acceptable for demonstrating compliance with the individual dose limits.

The collective dose to the exposed population is required to evaluate the potential risk of serious radiation-induced health effects to the public and to identify the optimum radiological system among several alternatives. Actual, and projected, population distributions in the vicinity of the DOE activity or site are needed for this estimate. For practical

[13] Examples of situations where collective dose may not be proportional to source term include control systems that selectively affect certain radionuclides. For example, a containment facility may be used to delay releases for a period of time sufficient to significantly deplete (through decay) short-lived radionuclides. Such a control system may also increase worker dose while reducing public dose. Both public and worker doses must be assessed.

reasons, such as availability of data, relatively small source term, limitations of dispersion data, the availability of the population distribution might be limited to a distance of 50 miles from the point of release. Releases of radioactive material to a surface waterway also may be evaluated using readily available analytical models, data on water usage, and the population data for activities involving the waterway and shoreline.

Analytical models may be used for evaluating atmospheric, waterway, and other dispersal modes to estimate collective doses to populations as well as doses to individuals. In the case of airborne releases, exposure evaluations may assume sector-averaging and radial increments with the dose calculated at the center of the radial sectors and applied to the number of persons in that area. For releases to waterways, the method of release, such as through rakes or conduits, will determine the initial dispersal conditions. The location of wells, water intakes for water processing plants, fishing, swimming, boating, shoreline, and other activities will be an important parameters. In waterways, the dispersion is generally much more limited than releases to the atmosphere and evaluations of collective doses may generally require summations out to greater distances than for atmospheric releases. For example, discharges to a river may have few and very limited pathways of exposure within 50 miles (80 km) of the site. However, at some greater distance, say 70 miles, a major drinking water system may extract water from the river. Potential collective doses associated with releases that might effect the system may be the major detriment associated with the alternative control systems. Therefore, unlike atmospheric releases where collective doses beyond 50 miles are not essential or significant to ALARA decisions, in this example, potential receptors 70 miles from the site are likely to be important to the decision making process. Although in most instances, such situations are not expected to occur when evaluating releases to the air, the 50 mile practical geographical-based truncation of collective dose should be used cautiously. The truncation of collective dose calculations should occur only when there is a reasonable expectation that the additional calculations will not provide information important to the ALARA decision.

d. Limiting doses.

When necessary, both individual and collective doses can be limited by restricting one, or more, of the exposure parameters, such as the intensity of the radiation source or shielding; distance from the source; duration of exposure; constraints on the intake of locally produced food or water.

F. Detriment and Monetary Equivalent.

1. Dose, risk, and health detriment.

The principal radiological benefit of the process system is the reduction of the dose to the individuals with the highest exposures and the collective dose to the exposed population. For radiation protection purposes, dose is presumed to be a surrogate for risk. The risk of serious health effects is assumed, for radiation protection purposes, to be linearly proportional to the effective dose equivalent for all values of dose, greater than background. The health detriment (risk of contracting radiation-induced cancer or serious hereditary disease) to the exposed population from an activity that causes exposures to radiation is assumed to be proportional to the collective dose to the population from: (1) direct exposures to the radiation external to the body; and (2) internal exposures (material taken into the body by ingestion, inhalation, and absorption). Even though the number of potential radiation-induced health effects within a population are assumed to be proportional to the collective dose, there is no promulgated limit for collective dose.[14]

The magnitude of a dose, whether to individuals or collective dose to a population, will depend upon the radiation source geometry, quantity, type and energy of radiation emissions, exposure modes, population distribution, location of the receptor with respect to the source location, duration of exposure, quantity of radioactive material released, dispersion by

[14] However, a value of 100 person-rem in a year has been selected by DOE for reporting purposes. This is not a collective dose limit or, as used in 10 CFR Part 834, but merely a reporting requirement.

natural forces, lifestyle of those exposed, potential exposure pathways, and many other parameters. If the health-detriment can be quantified, a cost of the detriment may be postulated for cost-benefit purposes.

2. Quantifying the risk of radiation-induced serious health effects.

Studies of data concerning the tissue-specific doses, site, and lethality of cancers have been used to select a set of tissue weighting factors that are used to provide the risk-based dose system used by DOE wherein the weighted doses (relative to the risk of total-body dose) to the various tissues may be summed to and expressed as effective dose equivalent dose (EDE) units. When dose from radiation sources include the EDE from sources external to the body and the committed EDE from sources taken into the body, it is termed the total effective dose equivalent (TEDE). The relationship between dose, expressed as total effective dose equivalent (TEDE), and radiation-induced fatal health effects (generally cancers) has been estimated to be to be about $5 \times 10^{-4}$, that is, 500 fatal health effects per million person-rem for an adult population; and about $6 \times 10^{-4}$, that is, 600 fatal health effects per million person-rem for the general population. It is further assumed that there is no threshold for dose, below which there are no radiation-induced stochastic health effects.

Data used to derive quantitative risk values for radiation-induced serious health effects are generally based on human exposures to high levels of radiation delivered at high dose rates, such as the survivors of the nuclear weapons in Japan, radium dial painters, and the use of radiation to diagnose and treat a variety of illnesses. There is no data from exposure of humans to quantify the dose-to-risk (or health-effect) relationship for doses in the regime that ranges from "background" exposure levels to doses at the limits selected for members of the public or for workers. Most authoritative organizations that have quantified radiation-induced risks caution that the values are applicable to doses of 10 rads or greater. DOE believes that it is prudent to be consistent with Federal guidance and use the linear no-threshold assumption. DOE applies the concept for radiation protection purposes and for comparing and evaluating radiation protection alternatives for protection of the public and the environment for ALARA or other purposes.

3. Monetary considerations for reduction in collective dose.

ALARA analyses require the comparison of many unlike factors such as collective dose, control costs, and so forth. For the purposes of quantifying and comparing such factors it is necessary to express them in like terms, that is, a common denominator. Although any unit of comparison can be effectively used in multi-attribute analyses like the ALARA process, one commonly used unit is cost. In such situations, the factor or attribute of interest (that is, collective dose), should be expressed in terms of a monetary equivalent.

Consistent with the assumptions of a linear relationship of health-effects with dose, it is generally assumed that the monetary value of a unit of collective dose, þ, is independent of the magnitude of the individual doses comprising the collective dose--provided that the dose to individuals are within the appropriate dose limit.[15] In 1973, the Atomic Energy Commission (AEC) assumed a constant value þ = $1,000 for a rulemaking (Appendix I of 10 CFR Part 50). At that time the Atomic Energy Commission did not attempt to derive a value for the monetary worth of a unit of population collective dose using first principles. Attempts to rationalize the value of using willingness to pay insurance premiums, commitment of resources for highway safety, cost of medical treatment for cancer, hospitalization cost, loss of years of life expectancy, loss of earnings, gross National product statistics, costs of worker replacement, and other indicators, have been considered over the several decades since the need was identified. An AEC literature search in the early '70s found values for þ ranging from about $10 to $1,000 per person-rem.

[15] However, there are situations where varied monetary equivalent values have been applied that are dose-dependent.

The Nuclear Regulatory Commission has since reevaluated the monetary equivalent value that was used in Appendix I of 10 CFR Part 50[16] and issued regulatory analysis guidelines that recommend $2,000 per person-rem as the current monetary equivalent value for converting collective dose to dollars. DOE also completed evaluations to determine the appropriate monetary conversion factors for collective dose[17] and on the basis of these analyses, the Department recommends that the monetary equivalent for a collective dose used in DOE ALARA evaluations should be between $1,000 and $6,000 per person-rem. For most applications, the $2,000 per person-rem recommended by the Commission is acceptable for DOE application. However, because of the uncertainty in the values, it is recommended that detailed ALARA evaluations use the range for comparing alternatives. Others have suggested significantly lower values[18] on the basis of single analyses and others have suggested a greater range of values.[19] After a broad review of the literature, the Department believes that its recommended range is appropriate. DOE evaluations to support ALARA analyses should apply monetary equivalents for a person-rem in the range from $1,000 to $6,000 with the nominal value of $2,000.

For comparison, that one person-rem represents a potential risk of 5 in 10,000 ($5 \times 10^{-4}$ fatal cancers per person-rem), the recommended range ($1,000 to $6,000 per person-rem) would equate to a range of $2,000,000 to $12,000,000 per hypothetical radiation-induced cancer deaths averted.

The monetary value of a unit of collective dose is assigned the symbol þ. The results of the ALARA (optimization) process is not very sensitive to the value selected for þ, but the value should not combine health and non-health effects in the same coefficient.

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[16]NUREG-1530, "Reassessment of NRC's Dollar per person-rem Conversion Factor Policy," U.S. Nuclear Regulatory Commission, December 1995.

NUREG/BR-0058, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," U.S. Nuclear Regulatory Commission, November 1995.

[17]"Estimating Costs for Man-rem Exposures;" U.S. DOE, Office of Waste Management; M.H. Chew & Associates, Inc.; April 1996.

[18] The Health Physics Society, in March 1993, issued a "Position Statement" on "Radiation Dose Limits for the General Public, Part II" wherein they concluded that "...the societally defined, statistical value of dose avoided is approximately...$40 per person-rem avoided... and ...a maximum...$200 per person rem."

[19] The rationale discussed here, that is, the willingness to commit resources to avoid a radiation-induced serious health effect, is only one of several rationales used to select a value for þ. Others have been suggested based on many vastly different considerations, such as: willingness to buy insurance; resources spent to reduce deaths from highway accidents; the gross national product-to-population ratio; litigation costs; loss of earnings; pain and suffering; hospital cost data;cost of replacing workers; etc. More recent articles have suggested values ranging from about $50 to $36,000 per person-rem for the value of þ. However, review of these estimates reveal that they frequently do not differentiate between þ and ß factors. That is, the considerations are not based on the health effects alone, but are heavily weighted with non-health considerations.

By assigning a monetary value to the willingness to avoid a serious health effect, one can express the health detriment in monetary terms, for example, Y = þS, where S is the collective dose of the exposed population[20]. It is recommended that þ be assigned a value in the range $1,000 to $6,000 per person-rem with the nominal value being $2,000.

4. Non-health detriment.

There are non-health detriments, some of that may be introduced into a cost benefit that are not readily expressed prospectively in monetary terms and are not linearly related to collective dose, for example, political considerations, comfort considerations for workers, design or operating decisions made to avoid possible losses of environmental amenities. Non-health components generally are not proportional to collective dose and may not be related to actual dose at all, for example, increased risks in industrial safety, dose-aversion, political factors.

The monetary equivalent of non-health detriment is generally given the symbol beta, ß, and can be assigned a monetary value ($) or assigned weighting factors through multi-attribute analyses or similar techniques, or simply recognized as a factors to be considered intuitively in the final selection of the radiological protection system. In some applications, the ß coefficient is a complex function of potential individual doses and may be indicated symbolically as $ßþ_j N_j f(H_j)$. If ß is the monetary coefficient of other (non-health) factors of detriment, N the number of individuals receiving a dose of H rem in a year. The value for ß is much more difficult, a priori, to estimate than þ because it can include considerations such as the cost of a State or Federal agency laying on requirements beyond those that can be rationalized by health risk evaluations in order to obtain a required permit or other approval. Additional confounding factors complicate the rationale, such as costs or impacts and benefits may be accrued to a population other than the one receiving the exposure. It could include costs for purchasing property or other expenses to avoid litigation or demonstrations from interested or affected parties. Other techniques (such as multi-attribute utility analyses) can permit some of the less quantifiable factors, such as comfort considerations or other environmental factors, to enter into the decision making process. Retrospectively, such (non-health) costs can be estimated (it is the difference in cost between the optimum system based on radiological protection and the system selected) and the cost difference should be determined and included in the records of ALARA decisions. When ALARA evaluations are based on the combined doses to workers and to members of the public, the values of þ selected for the two groups generally should not differ substantially; however, the ß factors might be quite different.

Although non-health components of the detriment are very real, and should be recognized and quantified to the extent that one can do so, the methods used in quantification or other method for introducing them in the decision-making process are variable and will not be discussed in this guidance. However, several methods, may be found in the literature (see listed references appended to this report) and should be considered.

[20] In some countries, e.g., the United Kingdom, several values of þ are assumed to apply depending on the fraction of the dose limit the individuals in the exposed population encounter. Such applications are not necessarily a denial of the "linear-theory" of health effects, but rather reflect (1) the importance which the UK authorities assign to the risk at low levels of exposure and (2) their desire to avoid doses which approach the dose limits. The NRPB (UK) has suggested use of a several values for þ, each applied to a fraction of the collective dose based on a range of individual doses and whether the individual is occupationally exposed or exposed as a member of the general public. The range of values for þ, from lowest to highest dose in the UK application, range from about $34 to $170 for members of the public and from about $70 to $1,700 for occupational exposures.

In some cases, adequate information is available to permit a cost-benefit analysis to quantify elements important in the decision-making process. In other cases, the information might not be available or a quantitative cost-benefit analysis might not be practical to aid in a decision-making process involving ALARA exposures--in that case, the decision must be based almost entirely on subjective judgment.

G. The ALARA Process

1. Optimization equations.

a. Total detriment.

The total detriment includes all deleterious effects, that is, health effects and non-health effects. These include real and imagined effects, perceived effects, anxiety, risk aversion, and any others associated with the radiation source. The total cost, that is, the monetary equivalent of the total detriment (Y), can be written:

Eqn. 1

$$Y = S + \beta + N f(H)$$

Owing to the complexity of valuating the non-health detriment, this guidance will not attempt to address them as part of the cost-benefit analysis (except retrospectively), but will focus on the health-detriment. Thus, Equ. 1 becomes:

Eqn. 2

$$Y = S$$

Two components of detriment are the assumed radiation-induced health effects, that may be expressed in monetary terms through the use of the coefficient þ ($/person-rem) and a non-health coefficient ß ($/person-rem) that is related to societal considerations. Many ß "terms" are not predictable and can be strongly dependent on such factors as the local attitude toward radiation.[21]

[21] The non-health component may be determined by ascertaining the total cost of the completed radiation protection system and subtracting the cost of the radiation protection system with only those features which can be justified considering only the health-effect detriment rather than the total detriment. This difference should be included in the records of ALARA applications as well as the rationale for the non-health costs.

b. Cost-benefit (optimization) application.

Mathematically, the net benefit of an activity may be expressed in the following manner:

Eqn. 3

$$B \; V \; (P \; X \; Y)$$

where:

B is the net benefit of the activity;
V is the gross benefit of the activity;
P is the basic production costs;
X is the cost of achieving a selected level of protection;
Y is the cost of radiation detriment resulting from the activity at the selected level of radiation protection.

To optimize radiation protection, assuming that the collective dose (S) is the relevant independent variable, differentiate Equ. (3) with respect to S and set it equal to zero, that is:

Eqn. 4

$$\frac{dV}{dS} \quad \frac{dP}{dS} \; \frac{dX}{dS} \; \frac{dY}{dS} \; 0$$

The values of V and P generally are independent of the magnitude of collective dose, S, for a given activity, that is, the gross benefit worth and the production cost of an activity generally are not affected by variations in collective dose. Thus, the components Dv/Ds and Dp/Ds are zero and the optimum condition may be written as:

Eqn. 5

$$\frac{dX}{dS} \quad \frac{dY}{dS} \quad \frac{S}{dS}$$

The optimum degree of radiation protection is obtained at a value of S such that the incremental increase in the cost of the radiation protection per unit of collective dose is equal to the incremental reduction in detriment per unit of collective dose. This is a **differential** cost-benefit equation[22] and is used to optimize radiation protection efforts and this form is best suited for applications where the exposures (and cost of the health-detriment) can be are associated with a release of radioactive material that can be described in an equation by a continuous variable.

[22] To select the optimum radiological protection system, it is necessary to define, evaluate the performance, and cost several candidate systems which range from the most rudimentary to the more technological sophisticated system. When the several candidate systems are considered, the ALARA process will identify the **optimum** system. If only two systems are evaluated, the only finding to be made is whether the change from the first system to the second system is **cost effective** or not. There is a vast difference between the two applications, with economic savings favoring the optimization. This may be obvious when considering a typical waste stream which will be discharged to the environment. The most rudimentary treatment can be expected to remove a significant fraction of the contaminant and cost relatively little. Further removal efforts will be less and less effective because there is less and less contaminant remaining in the waste stream and the more sophisticated removal components will be more and more costly. The ALARA process will indicate the choice of the several candidate systems which will result in the minimal total cost, e.g., optimization.

In most cases, exposures are not continuous variables; rather, the alternative radiation protection options result in finite incremental changes in exposures (and cost of the health-detriment). The equation may be written:

Eqn. 6

$$\frac{(X_2 - X_1)}{(S_2 - S_1)} \quad \frac{(Y_2 - Y_1)}{(S_2 - S_1)}$$

where the subscripts indicate that the candidate radiological protection systems considered and system 2 is more costly than system 1 and results in less collective dose than system 1. This expression indicates that the optimum radiological is achieved when the incremental cost of the system equals the incremental cost of the decrease in detriment.

Put simply, given that the dose to the maximally exposed individuals from all exposure modes are within the appropriate dose limits, the optimum choice is the radiation protection system with the least total cost--where the cost of the radiation detriment is included and where benefits, if quantified, could be expressed as a negative cost.

2. Procedure.

The basic question to be answered in the implementation of the ALARA process is "Have I done all that I can reasonably do to reduce the radiation doses?" Although the goal of ALARA is primarily radiation dose reduction, hazardous non-radioactive materials also might be components of the waste stream effluent or could be introduced by some of the optional treatments used to reduce the radiological components. Therefore, the risks associated with these materials should be factored into ALARA determinations. It is important to maintain cognizance of the overall impacts of any decision. The release of hazardous chemicals could be treated as a "ß-factor," or a factor in a multi-attribute analysis.

There are many methods that can be used in gathering data concerning ALARA. Many of these techniques are described in varied detail in the references provided in this guidance. Some of these determinations can range from quantified cost-benefit analysis, to qualitative evaluations such as multi-attribute utility analyses with weighing factors and scaling factors. Some may be rudimentary and based on a fundamental understanding and commitment to the ALARA principle, "common sense," or "sound judgment," rather than formal quantitative techniques--and that may be all that is required or justified. Activities that involve low doses are more likely to be based on judgmental decisions. In cases where dose increments are very low compared to the dose limits, the social and political considerations often will be the dominant factors in arriving at the ALARA decision. DOE's application of the Best Available Technology for radioactive effluent control (BATREC[23]) may be seen as a form of ALARA.

The principal difference between the ALARA process and the BATREC selection is that the ALARA process balances the cost and dose reduction and attempts to identify the least costly of several alternatives, whereas the BATREC selection places more importance on the source term (rather than doses) and less importance on achieving minimal cost. BATREC only applies to liquid effluent, but ALARA applies to all sources of radiation exposure.

[23] Reference BATREC Manual here.

3. Application.

Table 1 presents one logical sequence of specific steps might be followed in either ALARA or BATREC evaluations. A sensitivity analysis is useful in both ALARA and BAT evaluations because it can provide information on the robustness of the results. It can also identify information that is important to obtain or monitor as part of the monitoring and surveillance program.

A flow diagram of an ALARA application is presented in **Figure 2**. The figure indicates where criteria such as dose limits or dose constraints to individuals (required by 10 CFR Part 834 or other Federal or State agencies), or other requirements (such as those derived from CERCLA and RCRA) would be considered and the various options evaluated for compliance.

ALARA should be a flexible process and the evaluation efforts should be proportional to the potential benefits. The boundaries between each of the steps will not always be clear-cut: some may proceed in parallel or may need repeating. The overall impact of the alternatives considered might also control the detail and level of effort assigned to individual steps. If the difference in doses and costs associated with the various options is small, the cost of a detailed ALARA review might not be warranted. Similarly, if the difference in dose increments is large and the cost difference is small, or visa-versa, the decision of alternatives could be obvious and very detailed analyses not justified. However, when costs, doses, and other impacts vary significantly among options, more detailed analyses are needed.

Table 1 A Logical Sequence of Events Implementing the ALARA Process

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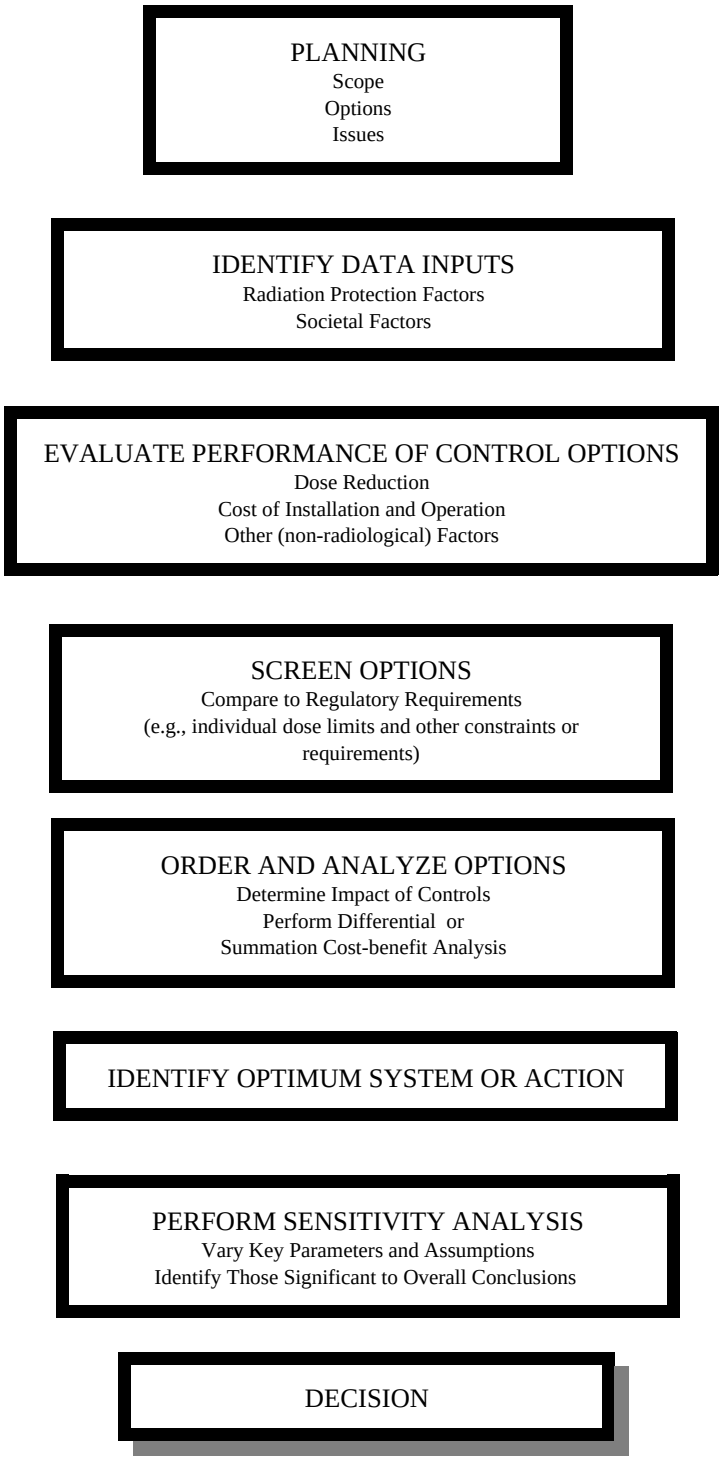
| Step 1: Define the Objective and Scope of the Issue to be Analyzed<br>State the objective of the project or proposal in terms that do not prejudge the means by which the objective is to be achieved. Specify the radiological protection factors to be included and those non-radiological protection factors to be brought into consideration. |
| Step 2: Identify Radiological Protection Options<br>Generate several options for achieving the objective: the aim is to find options that are both practicable and environmentally acceptable. This step provides a strong incentive to consider not only obvious solutions, but also innovative alternatives. It also includes the elimination of impractical options. |
| Step 3: Evaluate the Performance of the Radiological Control Options<br>Analyze these options to identify the advantages and disadvantages of each option. Use quantitative and qualitative methods when appropriate. Cost each of the options for operation, maintenance, utilities, structures, equipment, labor, and collective dose. Incorporate judgmental criteria explicitly. Identify other (non-rad) impacts and other considerations. Evaluate the impact and cost of compliance with non-rad requirements. |
| Step 4: Screen Options<br>Present the results of the quantitative analysis of factors. Present the results of the evaluation concisely and objectively and in a format that can highlight the advantages and disadvantages of each option. Do not combine the results of different measurements and forecasts if this would obscure information that is important to decision-making. |
| Step 5: Order and Analyze<br>Include consideration of all relevant factors whether treated quantitatively or qualitatively, together with judgement on relative weighing and the results of sensitively analyses to select the recommended radiological optimum. |
| Step 6: Identify Optimum Alternative<br>Select the preferred option from the feasible options. The choice will depend upon the adequacy of the radiological protection, the weight given to the environmental impacts, and associated risks and the costs involved. |
| Step 7: Perform Sensitivity Analysis<br>The robustness of the decision to select a particular alternative can be determined by varying the more important parameters and observing how the "bottom line" results are affected. If a particular parameter is seen to be capable of substantially affecting the results, the site-specific information should be scrutinized to ensure that the value of the parameter used in the study is representative for the site. |
| Step 8: Decision<br>Take account of the results of optimization and any non-radiological factors and make the decision. Scrutinize closely the proposed detailed design or operating procedures to ensure that no pollution or hazards have been overlooked. It is good practice to have the scrutiny done by individuals who are independent of the original team. Decision makers should be able to demonstrate that the preferred option does not involve unacceptable consequences to the environment. |
| Step 9: Implement and Monitor<br>Monitor the achieved performance against the desired targets, especially those for environmental quality. Do this to establish whether the assumptions in the design are correct and to provide feed-back for future development of proposals and designs. The results of the sensitivity study can provide valuable input to planning a monitoring program for the activity. |
| Throughout Steps 1 to 9: Maintain an Audit Trail<br>Record the basis for any choices or decisions through all of these stages; that is, the assumptions used, the details of evaluation procedures, the reliability and origins of the data, the affiliations of those involved in the analytical work and a record of those taking the decision. Record, if possible, the reasons for any departure from the recommended optimum. |

Figure 2. STEPS OF AN ALARA ANALYSIS



H. Factors and Issues

This guidance provides a procedure that will aid in optimizing resource allocations for radiological protection and systemize and clarify "good ALARA practices." ALARA applications are broad, ranging from day-to-day "routine" operations to those related to the design or modification of major facilities. Some useful procedures can be used to aid in deciding how much analysis is required for the ALARA evaluations.

National and international radiological protection organizations have recommended de minimis values individual and collective dose. International nuclear regulatory organizations have adopted and implemented de minimis values for individual and collective doses. The Department does not have a de minimis exposure condition for ALARA application. All DOE activities are subject to the ALARA process. However, the ALARA process should be applied in a graded manner. An admonition, in § 834.5(a), states that the content of the ERPP should be commensurate with the complexity and hazard of the DOE activity also applies to the ALARA program (that is, it is a component of the ERPP). In this guidance, DOE provides practical benchmarks and criteria for ensuring that the level of effort associated with ALARA analyses is effective.

In order to scope the effort necessary to comply with the ALARA requirements, one may start by estimating the maximum amount of resources that can be justified for reductions of the health detriment. This can eliminate considerations of options that would exceed that amount.

1. Resource allocation.

One example of an application of this admonition is to estimate the maximum resources that can be justified for health-detriment reductions. This procedure would be to: (1) estimate the source term that would cause exposures of the public; (2) estimate the potential collective dose, S (person-rem); (3) multiply the person-rem by the value of þ ($2,000/person-rem). The resulting value, S x $2,000, is the <u>maximum</u> amount of resources that could be justified for health concerns because there is no process or system that can eliminate <u>all</u> exposures. If the collective dose is from annual exposure, the $2,000S value is the maximum justifiable <u>annual</u> cost. If the collective dose is over the lifetime of the activity, the $2,000S value is the maximum justifiable <u>total</u> cost. If no process or system can be identified that could be purchased, installed, operated, and maintained within this cost constraint, no further ALARA effort is needed, other than to make the conclusion part of the record. Such a finding does not foreclose on quantitative assessments and general good management practices that may decrease doses or potential doses.

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| In applying the example described above, the source term and exposure conditions may be approximated, but in doing so, there must be some assurance that the collective dose is not substantially underestimated. |

In general, if the maximum individual dose is less than 1 mrem in a year and collective dose is less than 100 person-rem in a year, only a qualitative or semi-quantitative ALARA assessment can be justified. However, if individual doses are significant, say 10s of mrem in a year, or collective dose exceeds 100 person-rem in a year, Quantitative ALARA analyses are recommended.

2. Uncertainties.

A second basis for defining the scope of the ALARA applications is the uncertainty in the estimations of collective dose, even when using the best available analytical models for making such estimates. Evaluations of collective dose generally involve estimating a radiation source term, estimation the dispersion patterns, characterizing exposure conditions, and summing the postulated resultant doses to members of the general public over all distances (locations) and time where and when the exposures occur. It is instructive to briefly review some of the factors that contribute to uncertainties that are

germane de minimis considerations in that when uncertainties are extremely large relative to the values needed to quantify exposures and doses, it is fruitless to continue the evaluation exercise.

Source terms. It is unusual to know, exactly, the identity, quantity, and physical/chemical characteristics of the radioactive source term that is the cause of exposures of the public. Sampling, monitoring, and environmental surveillance can provide a reasonable data-base for reasonably characterizing the sources if an effort has been made to do so. Sampling. collection, analyses all have limitations and introduce their own uncertainties. In many cases, the source term can only be estimated from fragmentary information from operating experience or are completely based on speculation. Thus, the source terms are subject to considerable uncertainty.

Dispersion patterns. When radioactive material is released to the environment to be dispersed by natural forces, the concentrations generally decrease monotonically without limit until it no longer exists due to radioactive decay. The ultimate fate of the material can be postulated and analytical models can be found or developed to attempt to describe the dynamics of the dispersion between the release and the ultimate fate. There are substantial uncertainties every step of the way. The concentrations at various locations where persons will be exposed is dependent on demographic information and social profiles, that introduces yet another uncertainty.

Time-variations. Essentially all of the parameters that determine exposure or dose vary with time, for example, source terms depend on equipment performance; dispersion patterns are affected by daily, monthly, seasonal, annual, and geologic fluxuations; population numbers, locations, and life-styles that affect exposure pathways and modes vary with time.

Releases to the atmosphere. Consider a ground-level release of airborne material. As distance from the source increases, the dose rated generally decreases and one must decide how far the integration should extend. In theory, and in fact, some sources are dispersed very widely, that is, thousands of miles, or world-wide. However, the confidence in the ability of the analytical models to precisely predict the dispersion pattern, or any of the other exposure parameter necessary for collective dose estimates at distances beyond a few 10s of miles, is weak. Further, the characteristics of the source term and the inability to predict its physical fate due to, for example, deposition or re-entrainment, is another confounding factor in estimating collective dose. In view of the many uncertainties such as those discussed above, it does not appear rational to attempt to predict doses beyond a modest distance, say 50 miles, from the DOE site boundary. In most instances, collective dose integrated over 50 miles provides sufficient information necessary for the decision process and, therefore, truncation of the dose calculations at 50 miles is appropriate. Several DOE sites are very large--in some cases 10 or more miles from the release point to the site boundary. When several release points are present and they are all located at a considerable distance within the site boundary, they may be treated as a single point of release--for purposes of calculating collective dose. However, the actual release points should be used where doses to individuals are evaluated to verify compliance with appropriate limits.

DOE has no de minimis on individual dose for the purpose of integrating collective dose. However, given that collective dose is used in the comparison of alternative control systems, it is not necessary to integrate doses to infinity. Rather, a collective dose integration may be truncated when it is unlikely to significantly affect the decision process. This is expected to occur when doses are a fraction of 1 mrem in a year in most instances.

Releases to surface waterways. Releases to natural waterways generally undergo more limited dispersion than those released to the atmosphere. In both cases, the dispersion is due to mixing by eddy currents, but the natural waterways have much more finite dimensions than the atmosphere and that restricts the freedom for further mixing. Consequently, estimates of collective doses from releases to waterways may require including dose contributions beyond those associated with releases to the atmosphere. Further, if the waterway is a drinking water supply for populations, many persons may be exposed. In this event, the 50-mile distance constraint for atmospheric releases are not necessarily adequate for releases to waterways. For smaller waterways, such as creeks, rivers, or ponds, the concentration becomes uniform over cross section of the waterway in a relatively short distance and decreases with distance only as further dilution from other water sources becomes available--generally slowly. In this case, the integration of doses may be required to be extended until the next

collective dose increment to be added is less than about 1% of the total to that point. For larger waterways, such as large lakes, bays, or oceans, the dimensions are generally greater and the water has fewer dimensional constraints, and the concentration is likely to decrease at a grater rate than is the case in smaller waterways. There could be less need for calculating dose contributions at the greater distances if the concentrations in the dimensionally larger bodies of water are less than those in the smaller waterways. Site-specific conditions should be used to demonstrate that the collective dose has been adequately determined. The site of the receptor population is extremely important in these determinations. A 0.1 mrem per year dose 90 miles downstream at a water treatment system serving a large population could be the most significant source of potential collective dose.

Releases to ground water Releases to the subsurface water, that typically undergo less dispersion than releases to surface water, may or may not impact ground water quality, depending upon a number of factors, all of which contribute to overall uncertainty. These factors include:

- Depth of the aquifer or water table;
- Force that drives the released material toward the aquifer or water table;
- Pathways in the subsurface, that include physical barriers; and
- Chemical processes that enhance or retard migration.

If factors obtaining at a particular site suggest that ground water will be impacted by a release, then additional factors related to the saturated zone become significant in determining the ultimate fate of the released material, and also contribute to overall uncertainty. Such factors include:

- Transmissive properties of the hydrogeologic unit, including the hydraulic gradient, the size and dimensions of the unit, and soil particle distribution;
- Geochemical processes, that can vary significantly from one point to another in the same ground water unit, and can vary significantly over time; and
- Chemical and physical properties of the released material.

Further, understanding of the current physical conditions of the subsurface is limited as a result of the high costs of subsurface investigations. While "at surface" and "above surface" phenomena can be readily observed, all subsurface investigations are out of sight. Data from soil cores, monitoring wells, and geophysical techniques are generally taken from a small number of observation points, and extrapolated to a much larger area, or to future time periods. Extrapolation, based on models and inference, adds uncertainty, due to the lack of uniformity in the subsurface (even considering small scale investigations) and to the relatively long time periods needed to validate modelling analyses and predictions.

To these factors and sources of uncertainty, one must consider the uncertainty associated with long-term unknowns. Travel time of a conservative (that is, non-degrading) species in the ground water can typically be measured in tens of meters per year. At this rate of migration, human activities many generations into the future that one can only speculate, as well as long-term geologic phenomena, can contribute further to uncertainty.

Conceptual models of a site's subsurface conditions should be designed to identify these sources of uncertainty, and to include each source in any analyses performed--if only in a qualitative sense. Short-term (decades to centuries long) predictions of fate of releases to the subsurface should be matched with on-going monitoring of actual site conditions to reduce uncertainty, and to continually validate long-term predictions.

3. Time integrals.

Among the more difficult issues to evaluate are those that deal with very low levels of exposure from man-made sources in the environment, that is, exposures that result in individual and collective doses that are a small fraction of those from naturally occurring sources. In some activities, widespread, chronic, very low dose levels might be delivered over very long time intervals (such as several generations) to many people over a very large geographical area.

The dose from radiation sources depends on the dose rate and the duration of exposure. Possible duration of exposures to members of the public to radiation from some DOE activities could range from the duration of a cloud passage to a receptors lifetime. Estimates of the time-integrated air concentration and doses from airborne radioactive material in the cloud can be evaluated using available meteorological models describing atmospheric dispersion in the lower atmosphere for finite size clouds and for clouds of semi-infinite dimensions. Such calculations can also be used to estimate the intake of radioactive material by inhalation during cloud passage.

In estimating the doses from finite exposure durations, the annual intake of radionuclides by inhalation or ingestion should be determined and appropriate dose conversion factors used to estimate the annual (committed) dose and summed over the years of exposure. The average lifetime is about 70 years. However, it is highly unlikely that an individual would be exposed to one source for more than about 20 years, because people rarely live in one location more than about 20 years.

Most intake-to-dose conversion factors are based on 50-year time-integrals (dose commitments) after the intake. There is little error introduced by the 50-year rather than a 70 year period since very few isotopes have half-lives sufficiently long that the last 20 years would make a significant difference in the dose received.

Another time-interval that must be considered is the time-interval over which the public could be exposed. In some cases, chronic exposures presumably could occur over may years--perhaps several hundreds of years and possibly several thousands. The duration of these exposures are generally associated with applications involving very long-lived radioactive materials that are assumed to be released to the biosphere at some point in time. The scenario usually involves the assumption of a release mechanism and a fraction of the existing inventory of material into a medium such as the water supply (terrestrial or underground), and chronic exposure of the public. The results of such evaluations usually assume that a large number of people will receive relatively low doses for many generations. Such projections deserve to be examined critically to verify their credibility. Judgement on the acceptability of such doses are usually based on the dose to individuals, rather than the collective dose, but the societal impact is related to collective rather than individual dose. The dose estimate can require the summation of annual dose over a lifetime and the total exposure is assumed to continue over many generations. Further, the population density and distribution can be expected to differ substantially compared to current distributions. Lifestyles, that determine exposure modes, can also be expected to change markedly over such a time-span.

For purposes of comparing ALARA alternatives for operational systems, the lifetime of the facility generally is a basis for truncating collective dose estimates, temporally. However, where cleanup, restoration, and waste management activities are necessary, the time-frame of interest can be much longer. Where radionuclides have relatively short half-lives, decay over a few half-lives may be sufficient to determine the collective dose. For longer-lived radionuclides, integration times may be determined by the uncertainties in scenarios and due to the physical parameters affecting dose rates. Typically, it is only appropriate to do quantitative comparisons to a few hundred years, or less.[24] Although evaluating doses for periods of up to 1000 years may provide useful information, periods beyond 1000 years should not be used in quantitative ALARA assessments.

[24] Administrator of the Office of Information and Regulatory Affairs of the Office of Management and Budget, 11 Jan 1996, "Regulatory Planning and Review, -- Economic Analysis of Federal Regulations Under Executive Order 12866."

Owing to the uncertainties and difficulty in quantifying these time-related factors, it is critical that knowledgeable persons be responsible for making ALARA judgments. As an example, the time and duration of exposures to the affected individuals or population and the likelihood or probability of occurrence of the exposure scenarios evaluated in the analyses should be considered and appropriately balanced when the alternatives are weighed. It may be appropriate, for instance, to give more weight to likely near-term exposures than to plausible but unlikely future exposures. In general, it is reasonable to weight doses that are increasingly uncertain lower than those that are not. Similarly, equal collective doses resulting from individual doses that are a significant fraction of the dose limit may be considered more important than collective doses resulting from individual doses that are very small compared to the dose limit. This is recommended because the linear non-threshold dose-risk assumption is generally believed to be conservative.

The product of a very small annual dose, to a very large number of people, over a very large area, and over a very long period of time, can result in collective doses that may or may not be significant. A perspective for such exposures should be provided for lay readers.

4. Discounting cost.

One of the more controversial time-integral issues is that associated with discounting of cost when the expenditure is present and the health detriment that is being reduced is several hundred or thousands of years in the future. From strictly an economics point of view, it is rational to discount cost projections based on postulated health effects centuries and eons in the future. Assuming all conservative assumptions in quantifying potential health effects are factual, if any finite discounting is applied, the present worth would be a small, even infinitesimal, fraction of the cost of the future detriment. Because of this, and the extreme uncertainties associated with very long projections of dose, DOE recommends that quantitative assessments of collective dose to support ALARA efforts be limited to a few hundred years. This is one method of weighting present collective doses greater than those that occur in the future. Conventional discounting is not recommended for analyses hundreds of years into the future. However, without discounting, analyses of detriments over long periods are typically biased in favor of future generations at the expense of the present generation, including current radiation workers.

5. Perspectives.

A perspective should be provided for lay readers. It is useful to compare estimated collective dose values from DOE activities with the collective dose to the same exposed population from natural (background) radiation sources. One such comparison would be the time required for the exposed population to receive a comparable collective dose from natural background radiation. Similarly, risks to populations can be compared to the normal incidence of cancers (fatal and non-fatal to the same population during the same exposure time). For example, about one-third of the population will contract cancer in their lifetime, and about half of those will be fatal. There are other comparisons that also can add perspective.

Although justifiable from economic considerations, the issue of discounting (like many other factors) is a policy consideration, and currently no discounting is likely to be considered. However, perspectives are always helpful to lay readers.

6. Other factors and criteria.

In many cases, particularly where multiple contaminants in multimedia situations occur, DOE ALARA requirements must be applied along with other criteria and requirements. The ALARA process is sufficiently flexible to incorporate such criteria into the process and in many cases, these factors or criteria are already part of the process.

For example, under CERCLA regulations (40 CFR 300.430) selection of remedial actions must consider the following criteria:

**Threshold Criteria**:

Compliance with ARARs - Addresses whether a remedy will meet the applicable and relevant and appropriate Federal and state standards or whether a waiver is justified.

Overall protection of human health and the Environment - Addresses whether a remedy provides adequate protection of human health and the environment and discusses how risks are eliminated, reduced or controlled through treatment, engineered controls or institutional controls.

*Both of these criterion are addressed in the ALARA process through the consideration of dose constraints and selection of alternatives that reduce doses (risks) to as low as is reasonable. Although ARARS waiver justification is a CERCLA-specific requirement, the ALARA process may be useful in assessing the use of specific ARARs and their impacts with regard to implementable alternatives.*

**Primary Balancing Criteria:**

Short-term effectiveness - Addresses the period of time needed to achieve protection and to determine any adverse impacts on human health and the environment that may be posed during the construction and implementation period, until remedial action objectives are achieved.

Long-term effectiveness - Refers to expected residual risk and ability of a remedy to maintain reliable protection of human health and the environment over time.

Reduction of toxicity, mobility, or volume - Refers to the performance of treatment technologies.

Implementability - Refers to the technical and administrative feasibility of a remedy including the availability of materials and services to implement the alternative remedy.

Cost - Includes estimated capital and operational and maintenance costs and the net present value.

*All of the primary balancing criteria are key factors in ALARA process assessments. Although the Reduction of toxicity, mobility, or volume criterion is not addressed in detail, processes or techniques such as these that can reduce migration and possibly dose should be considered and addressed in the selection of alternatives.*

**Modifying Criteria:**

State acceptance - Indicates whether the state concurs with or opposes or has no comment on the preferred alternative.

Community acceptance - Summarizes the public's response to the alternatives.

*As noted in this guidance, the analysis of the ALARA process factors requires judgement and as a result, input from interested groups (e.g., states, cumminities, unions and so forth) may be important when considering and evaluating the ALARA factors. The impacts of such input is discuss in some of the examples in Volume II of this guidance for both CERCLA and non-CERCLA related projects.*

As noted in italics above all of these criteria are or can easily be addressed as part of the ALARA process and the CERCLA requirements to document their consideration is clearly consistent with the ALARA documentation requirements. Although some of the CERCLA criteria may not be easily quantified through a monetary equivalent in the cost-benefit analysis, they can all be address with multi-attribute utility analysis approaches. Such approaches would weight each of the criteria and then score the alternatives for each criterion. The sum of these scores may be used to rank the alternatives.

## I. Quantification of Collective Dose

As observed throughout this section, there is no de minimis for the ALARA process. Theoretically collective doses over all time and space may be considered in applying this decision-making tool. However, given that the propose of using the ALARA process is to help optimizing benefit and make good decisions balancing many factors including dose reduction, economics and social factors, collective dose calculations should be constrained by practical considerations. Extending dose calculations inappropriately to include very long time periods, very large areas or very low individual doses could bias the data and analysis and is as likely result in a poor decision as a good decision. For example, integrating doses to infinity could result in results that are biased against protection of workers but given the uncertainty in the long projects provide little additional benefit to the non-worker populations. Therefore, quantitative ALARA analyses should only be conducted within periods or spaces where the collective dose data and differences between alternatives are meaningful. Temporal and geographical boundaries should be selected with care so as to minimize bias in results and uncertainty between alternatives analyzed. With this in mind, as noted in the previous discussion:

- Integration times for quantitative comparisons should be limited to time periods for which reasonable projections and comparisons can be made. For operational activities it is generally the expected life of the facility or operation. For cleanup and waste management it is typically a period up to a few hundred years but no more than 1000 years. In special circumstance such as deep geologic disposal, quantitative analyses beyond 1000 years may be useful but in most situations analyses and data relating to such long periods should be assessed qualitatively not quantitatively.

- As a general rule, collective doses to populations need only be assessed to 50 miles from the site boundary. There may be special circumstances where larger distances may be used (e.g., a large population is located just beyond the 50 mile (80 km) radius or the dispersion is sufficiently limited that larger distances can contribute collective dose that will be significant to the analyses).

- Although the Department recommends no dose-based value for truncating collective doses, specific analyses may truncate calculations when it is determined that the continued integration will be of little or no use in the comparison of alternative controls. It is expected that any such truncation will be at doses well below 1 mrem in a year given that the median maximum individual dose associated with releases from DOE facilities is below 0.1 mrem in a year..

- The ALARA process must be applied and documented for all DOE activities. However, the Department supports a graded approach to the process. A process for assessing the maximum resources appropriate for an ALARA assessment are discussed in Section H.1.a (Resource allocation. As a general rule, quantitative assessments will not be required if potential individual doses from all alternatives assessed are less than a 1 mrem in a year and collective doses are less than 10 person-rem. Quantitative comparisons of alternatives should always be considered when individual dose may exceed 10s of mrem in a year and collective doses exceed 100 person-rem.

All of the criteria above constitute guidance not rules. The goal of any ALARA analysis is to produce data that will be useful in supporting a good decision that fairly assesses the benefits and costs associated with the alternatives being considered. Therefore, care should be taken to treat analyses of the alternatives equally and not compare conservative estimates for one alternative to realistic estimates for another. Similarly, varied uncertainties in data from different alternatives should be identified and to the extent possible eliminated or at least be clearly stated.

J. Bibliography

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