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COLLECTIVE DOSE AS A PERFORMANCE MEASURE FOR OCCUPATIONAL RADIATION PROTECTION PROGRAMS: ISSUES AND RECOMMENDATIONS

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Executive Summary

Collective dose is one of the performance measures used at many U.S. Department of Energy (DOE) contractor facilities to quantitatively assess the objectives of the radiation protection program. It can also be used as a management tool to improve the program for keeping worker doses "as low as reasonably achievable" (ALARA). Collective dose is used here to mean the sum of all total effective dose equivalent values (defined in Title 10 of the Code of Federal Regulations (CFR) as 10 CFR 835, Occupational Radiation Protection) for all workers in a specified group over a specified time. It is often used as a surrogate estimate of radiological risk. In principle, improvements in radiation protection programs and procedures will result in reduction of collective dose, all other things being equal. Within the DOE, most frequently, a single collective dose number, which may or may not be adjusted for workload and other factors, is used as a performance measure for a contractor. Without such adjustments, collective dose is too simplistic to be valid as an ALARA management tool and performance measure. In practice, a single, unadjusted number is only appropriate for intragroup trend analyses. Even when the number is more facility- or building-specific, it is found that a cursory analysis is inappropriate since facility workloads and working conditions vary, and collective dose may go up when radiation protection improves, or even go down when attention to radiation protection is reduced. This may occur as the result of a change in the amount of work or in the experience level of employees, or from programmatic decisions to delay or accelerate work for financial reasons. Furthermore, collective dose is subject to "gaming," that is, it can be affected by deliberate actions that either do not improve radiation protection or even increase risk. Examples of gaming include inflating pre-job collective dose estimates so that actual performance looks good by comparison, performing low-dose work in the near- term while postponing high-dose work, doing less work, excluding particular workers from monitoring programs, increasing detection thresholds (lower bioassay frequency, higher TLD frequency), and increasing reporting levels so that small doses and intakes are not recorded and reported. In its analysis of gaming, this report identifies contractor actions involving operations, radiation protection, and collective dose, that should be rewarded or penalized, or are neutral, including examples where the contractor takes the best course of action but collective dose increases. A survey of DOE sites and Field Office representatives shows that collective dose is used as a performance measure by most DOE sites, as described in DOE Order 210.1. Many sites indicated difficulties with the collective dose measure, especially if it was not adjusted for workload. Based on the literature review and the comments received during discussions with contractor and Field Office representatives, this report recommends expressing a collective dose performance measure as collective dose per unit work accomplished for it to be effective as an ALARA management tool and performance measure. The report recommends estimating the collective dose on a job-by-job basis, often during the development of the Radiological Work Permit (RWP). This report proposes, as an alternative performance measure, the ratio of the sum of the actual doses received during all radiological work for that year divided by the sum of all collective dose estimates required for the RWPs before each project or task is initiated. The recommended goals of the program include not exceeding the estimated collective dose in a specific percentage of the projects or tasks or ensuring that the collective dose resulting from each project or task falls within a selected range, such as within 20 percent of the original dose estimate.

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1.0 Introduction

The purpose of this report is to evaluate the use of collective dose as a performance measure for ALARA programs at U.S. Department of Energy (DOE) sites.

Performance measures are used to quantitatively assess progress toward achieving a pre-determined goal. Most performance measures can be grouped into six general categories: effectiveness, efficiency, quality, timeliness, productivity and health and safety (TRADE 1995). Performance measures used at DOE facilities encompass all these areas. DOE Order 210.1 states that the contractor will identify, monitor and analyze data that measure the environment, safety and health (ES&H) performance of facilities, programs and organizations (DOE 1995). The intent of DOE Order 210.1 is not to be prescriptive but rather to guide contractors to develop performance measures that are meaningful and useful for enhancing performance. DOE Guidance document DOE G 120.1-5 provides guidelines for the development of performance measures. The *Radiological Control Manual* (*RadCon Manual;* DOE 1994) provides a list of examples of radiological performance goals or performance indicators.

Collective dose is one of the performance measures used at many nuclear facilities to quantitatively assess the objectives of the health and safety program. It can also be used as a management tool to improve the program for keeping worker doses "as low as reasonably achievable" (ALARA). Collective dose is the sum of all total effective dose equivalent values for all workers in a specified group over a specified time. It is often used as a surrogate estimate of radiological risk. If all factors of the workplace are kept constant, including the number of workers, and the amount and type of work, then a reduction in collective dose means a reduced radiological risk, which subsequently points to an improvement in the health and safety program. Under a linear, no-threshold dose-response model for stochastic risk from exposure to ionizing radiation, the risk of cancer and heritable ill-health is proportional to collective dose.

Many DOE contractor facilities have a collective dose performance goal that is established as part of the contract. At some sites, if the contractor meets or exceeds the performance goal, the award fee for the contractor will be greater. Penalties can result from not meeting the performance goal. Thus, the contractor has incentive to ensure that the collective dose performance goal is met, and it is possible that both DOE and the contractor may focus too intensely on the numerical performance goal, and not on the underlying process of improvement. In this case the contractor may not appropriately focus on using collective dose as an effective ALARA management tool.

The *RadCon Manual* attempts to address the inappropriate use of collective dose by indicating that radiological performance goals are intended as a measure of and a motivation for improvement, not an end in themselves (DOE 1994). The *RadCon Manual* states that the collective dose goal should be based upon planned activities and historical performance. The

performance indicators listed in the *RadCon Manual* were not intended to be viewed narrowly as numerical goals, but to be used as tools to assist management in focusing their priorities and attention. The indicators can reveal a site's degree of success in controlling radiological exposures to ensure that they are ALARA.

In principle, improvements in radiation protection programs and procedures will result in reduction of collective dose, all other things being equal. In practice, workloads and working conditions vary, and collective dose may go up when radiation protection improves, or even go down when attention to radiation protection is reduced. This may occur as the result of a change in the amount of work, in the experience level of employees (as more experienced employees retire, and new employees are hired), and programmatic decisions to delay or accelerate work for financial reasons.

The validity of using collective dose as a performance measure and as an ALARA management tool depends on the process used to select a collective dose goal and the methods used to determine whether that goal has been met. As with all performance measures, a poor choice of collective dose goal, or inadequate evaluation methods for the collective dose performance measure may not result in any improvement of the radiation program being evaluated.

Even if the process and methods discussed above are valid, collective dose is subject to "gaming," that is, manipulating the numbers or work loads to ensure that the collective dose performance goal is met, while not paying real and close attention to maintaining doses ALARA. For example, to reduce collective dose, sites may postpone high-dose work, monitor fewer workers, or raise detection and reporting levels.

To evaluate the use of collective dose as a performance measure for ALARA programs at DOE sites, this work set four objectives:

- describe the current use of collective dose as a performance measure to determine what strategies are being used across the DOE sites to ensure that there is a correlation between the collective dose performance measure and the ALARA program;

- describe the current use of collective dose as an ALARA management tool across the DOE sites;

- identify contractor actions involving operations, radiation protection, and collective dose that should be rewarded, or penalized, or are neutral; and

- describe the types of systems or methods that are being used to establish collective dose performance measures that provide a clear indication of a site's success in maintaining exposures ALARA.

These goals are accomplished in the following sections by: 1) providing a summary of references related to performance measures and collective doses, 2) discussing the use of collective dose as a performance measure, 3) discussing the use of collective dose as an ALARA tool, 4) surveying the current uses of collective dose at DOE and non-DOE contractor facilities, 5) summarizing the views of contractor and Field Office representatives who were contacted during this study, and 6) recommending a method for using unit-work assessments for collective dose to improve a contractor's radiation protection program.

It was not an object of this report to review contractors' collective dose records, assess their ALARA programs and ALARA status, or determine whether and to what extent contractors engaged in gaming. Because contractor and DOE personnel volunteered information, their identities have been separated from their statements. Conclusions and recommendations of this report are based on a literature review, interviews with contractor and DOE Field Office representatives, discussions with other radiation protection professionals, and the authors' analysis and professional judgment.

2.0 Review of Literature on Performance Measures and Collective Dose

Current regulations, guidance and recommendations were reviewed to understand the requirement for use of performance measures as they relate to ES&H. In addition, a literature search was performed of published information regarding the use of collective dose as a performance measure.

Through the Training Resources and Data Exchange (TRADE), the DOE has developed the manual, *How to Measure Performance: A Handbook of Techniques and Tools* (TRADE 1995). The handbook can be used to assist in the development, use, evaluation and interpretation of performance measurements. Although it does not specifically discuss collective dose, it discusses the general process of developing performance measures, describes the data tools used for performance measures, and provides case studies of the use of performance measures.

A Guide to Reducing Radiation Exposure to As Low As Reasonably Achievable (ALARA) (Kathren et al. 1980) states that "the success of applying [the ALARA concept] is often measured not by what is done, but by how it is done. ...[T]he success of a mature ALARA program will be measured by many factors... ALARA programs will therefore include numerical goals, although compliance with numerical standards is not *prima facie* evidence that the ALARA concept has been embodied in a health physics program." Kathren et al. go on to state, "As a minimum, the following four measurements of ALARA are recommended:

- mean individual dose equivalent for penetrating dose to the whole body
- statistical distribution of mean individual dose
- cumulative [i.e., collective] penetrating dose equivalent
- mean individual dose equivalent by location and job classification."

The 1980 ALARA report identifies intragroup and intergroup dose comparisons. A single, annual collective dose number for a DOE site is an intragroup comparison that requires historical data for the group. Intergroup comparisons may be smaller breakdowns of work within a site or across sites. The report cautions against applying the same standards for comparisons without examining "the relative achievements" of each group, including the amount of work done. Both inter- and intragroup comparisons are examples of trending. The 1980 report stresses that ALARA goals (and therefore performance measured against those goals) must "relate to specific characteristics of operations or programs." As a measure of goal attainment, the report cautions that "doses alone are worthless if they do not correctly relate a real condition to a desired condition." The important question is whether "an accomplished goal resulted from planned or known actions..." Many of the concerns of the 1980 ALARA report concerning dose measurement and dose interpretation have been resolved by the use of total effective dose equivalent, a quantity not in use at the time.

For dose interpretation, Kathren et al. recommend considering the following factors in the interpretation of dose data as a measure of ALARA programs:

- Is the same population being used?
- What is the effect of new employees or members of the population?
- Has the distribution of doses changed because of any new members?
- How did doses change with time?
- Are any dose reduction techniques related to large changes in average dose?
- Did changes in dose result from planned actions or did they occur by chance?
- How confident are we that the observed change is real?

It is clear that the 1980 ALARA report recognized the pitfalls in using collective dose (called "cumulative dose" in that report), as an ALARA performance measure.

In "Practical Quantitative Measures of ALARA," Kathren and Larson (1982) amplify the recommendations of the 1980 ALARA report (Kathren et al. 1980). Many of the dose quantities in this 1982 paper have problems that are resolved by using TEDE and collective TEDE, and in several instances two or three of their proposed quantities may be covered by one effective dose equivalent quantity. Their recommendations are still valid today if modern quantities are used. In particular, their recommendation to assess "dose equivalent for a given production level" explicitly requires adjustment for amount of work performed. They also recommend evaluating "incurred dose equivalent by specific job task." Additionally, Kathren and Larson propose "[collective] dose equivalent per hour worked" as a method of normalizing collective dose. They recognize that quantitative performance measures must be assessed "by work location, job classification, and task, because these may vary as a result of changes in job assignment over the reporting period."

The Health Physics Manual of Good Practices for Reducing Radiation Exposure to Levels that Are As Low As Reasonably Achievable (ALARA) (Munson et al. 1988) discusses the use of collective dose as a goal in the ALARA program, but does not specifically describe the use of performance measures. The 1988 manual recommends that both individual and collective effective dose equivalent be evaluated because collective dose for an activity can increase while the average dose is reduced. It also makes the point that optimization of the individual doses should be part of the ALARA program in order to ensure that doses are as far below the regulatory limits as is reasonably achievable, thus minimizing health effects. This in turn minimizes the collective dose since collective effective dose is the sum of all the individual effective doses.

The report of the National Council on Radiation Protection and Measurements (NCRP) on collective dose, *Principles and Application of Collective Dose in Radiation Protection* (NCRP Report No.121, NCRP 1995) states that collective dose is a way to assess radiological risk, but does not discuss using collective dose as a performance measure. The NCRP report indicates that the assumption of a direct proportionality between the risk incurred and the radiation dose over the range of doses and dose rates of concern is implicit in the concept of collective dose. The

assumption is made that the response to radiation is both linear and time independent and any incremental dose above background, no matter how small, carries with it a proportionate risk of a specific stochastic effect or group of effects. NCRP Report No. 121 further states that although the assumption of "linearity without a threshold" is justified for radiation protection purposes, it should be recognized that at low levels of individual exposure the risk estimates are uncertain by a factor of two or more in either direction and a threshold in the dose response relationship cannot be excluded, nor can the possibility that the risks are underestimated at low doses be excluded. Despite this potential, NCRP Report No. 121 recommends that all doses should be included in calculations of collective dose and that there is no conceptual basis for excluding any individual doses, however small, from the collective dose calculation, although there may be some practical limitations to this procedure.

For NRC licensees, there are no regulations that specifically require an ALARA program that includes a collective dose performance measure. However, all nuclear power licensees do track collective dose, and this number is used by both the licensees and the NRC to provide indications of the effectiveness of the ALARA program. The NRC *Inspection Manual*, Chapter 83728 ("Maintaining Occupational Exposures ALARA") asks inspectors

> "as a minimum [to] consider the total annual collective dose (person-rem) for the facility. Determine whether that collective dose is increasing or decreasing and whether it is higher or lower than the collective dose for other facilities of the same type and generating capacity. Consider reasons for increases or higher-than-average doses and discuss licensee's plans in relation to relatively high doses or upward dose trends."

In addition, inspectors are asked to ensure that there is a means of tracking progress toward the ALARA goals and objectives and to take action on the findings. *NRC Inspection Manual*, Chapter 83728, also states that "facility goals might include a total annual collective dose (person-rem) value..." (NRC 1991a). These statements are also echoed in NRC *Inspection Manual*, Chapter 83100 ("Occupational Exposures During SAFSTOR and DECON"), for decommissioning facilities (NRC 1991b).

The Institute of Nuclear Power Operations (INPO), an industry-sponsored organization, evaluates U.S. nuclear power plants and sets goals for excellence in operations. One of the performance indicators that INPO monitors is collective radiation dose. Collective radiation dose at U.S. nuclear power plants has trended downwards since 1980. At boiling water reactors (BWRs), the collective radiation dose fell from a median of 859 person-rem for 1980 to 235 person-rem for 1996. At pressurized water reactors (PWRs), the collective dose fell from a median of 417 person-rem for 1980 to 126 person-rem for 1996. The nuclear industry has set performance targets for the year 2000. These include a collective annual dose of 215 person-rem at each BWR and 110 person-rem at each PWR[1].

[1]from Nucleonics Week, April 3, 1997

3.0 Collective Dose as a Performance Measure

Guidance is available on choice and use of performance measures at DOE facilities. However, prescriptive information is scarce on the use of specific measures, such as collective dose and on the best use of specific measures. For this reason, this section summarizes the guidance on performance measures and provides a discussion of the use of collective dose as a specific performance measure.

3.1 Performance Measures

Most performance measures can be grouped into six general categories: 1) effectiveness, 2) efficiency, 3) quality, 4) timeliness, 5) productivity and 6) safety. Although the category of most significance for collective dose performance measures is safety, other categories also apply.

Performance measures are used to quantitatively assess a product, service or process. The TRADE document (TRADE 1995) states that performance measurement is not simply concerned with collecting data associated with a predefined performance goal or standard. Rather, it is better thought of as a tool to help understand, manage and improve operations.

Performance measures are composed of a number and a unit of measure. The measure is always tied to a goal or an objective. Performance measures may be represented by single-dimension units (such as number of person-rems for collective dose), or they may be multidimensional, which provides more information than the single-unit performance measures. The determination of the units is very important to determining if the measurement is meaningful and can be used to improve the product or service that is being assessed.

The effective use of a performance measure is a process with multiple steps that ultimately ends in a feedback loop. The first step is to identify process that is being measured. In this case, it is the process of performing work that results in a radiation dose to the worker, as well as the method used to determine what the radiation dose is.

The second step is to identify the critical activity to be measured. In the simplistic approach, this means that the radiation dose is measured for all workers and totaled for the whole facility. A more complex approach would involve measuring the collective dose by building, project, or task. A more complex approach is more time-consuming, but it also provides a greater depth to the information that is obtained.

The third step in designing a performance measurement process is to establish the performance goals or standards. The goals or standards are used to interpret the results of measurements and gauge the success of a management system. A simple example may be to reduce collective dose by 5% for the same work conducted the previous year. A more complex, yet more valid, goal would be a reduction of collective dose that is tied to the amount of work that is performed in radiation areas and to the intensity of the radiation.

The fourth step is to establish performance measures. An example of a simple measurement would be to compare last year's collective dose to this year's collective dose for a particular group. A more complex, yet more valid, performance measure would be required to compare this year's collective dose with the collective dose for the last three years, correcting the total for the amount of work and the type of work performed in each year.

The fifth step in the process is to identify the responsible parties and to collect the data.

The sixth step is to analyze the data. The analysis process involves converting the raw data into the same units in which the performance goal is expressed and displaying them in an understandable form.

Step seven is to compare actual performance to goals. For the simple example, this means determining the collective dose for all of the radiological workers and comparing the number to the previous year's collective dose.

The eighth step is to determine if any corrective actions are necessary. Corrective actions may be required, depending on the magnitude of the variation between measurements and goals (for example, determining how radiation protection measures can be improved to reduce collective dose). If corrective actions are necessary, the next step would be to make the changes to bring the performance back in line with the goal. The actual determination of the corrective action is part of the quality improvement process, not the performance measurement process.

The ninth and last step is to determine if new goals are needed. If the performance goal is not met, the process should be reevaluated to determine if the performance goal is not realistic, if it is not measuring the process accurately, or if quality improvements are needed. Any corrective actions that are determined during this evaluation should be implemented. If the performance goals are then met, it should be determined whether new goals are needed to further challenge the improvement of radiation protection. Thus, the process of goal development is restarted.

For the process to be meaningful in most facilities that use collective dose as a performance goal, a more complicated system is necessary to incorporate the changing workloads, the changes in processes, or the improvements in technology. Section 3.2 describes the various ways collective dose can be effectively used as an ALARA tool and points out how it can be misused.

3.2 The Use of Collective Dose as A Performance Measure

When used as a performance measure, reducing collective dose is the basis for reducing radiological risk for the next period of performance (NCRP 1995). Six factors have been observed to affect the use of collective dose as an effective performance measure: cost-effectiveness, amount and variability of work, type of work and of materials used, timing of work, level of experience of workers, and unforeseeable accidents.

3.2.1 Cost-Effectiveness

The first factor that affects the collective dose performance goal is cost-effectiveness. To be a meaningful measure of contractor performance, cost-effectiveness of collective dose reduction must be considered (Arrow et al. 1996). The "R" in ALARA is "reasonably," with economic, social and technological factors being taken into account. For example, for NRC licensees, as long as individual doses are kept within individual dose limits, collective dose reduction should not cost more than $2000/person-rem for workers (NRC 1995). While the DOE has not put a dollar value on averting a person-rem, the value of $2000/person-rem is consistent with extensive recent work on the cost of many life-saving interventions (Baum 1994; ICRP 1989; NRPB 1993; Oregon Health Services Commission 1991; Oregon Department of Human Resources 1993; Puskin and Bunger 1996; Tengs et al. 1995).

If included as a contractual measure, a dollar value per unit collective dose avoided should be agreed upon by contractor management and site DOE management.

3.2.2 Amount and Variability of Work

The second factor that affects the collective dose performance goal is the amount and variability of the work. The greater the amount of work that involves radioactive material, the higher the anticipated collective dose. Because the amount of radiological work varies markedly each year for some contractors, the evaluation of the performance goal should take into consideration the anticipated quantity of radiological work. A procedure should be established for varying the performance goal during the year for those facilities where the work level or the scope of major projects may vary significantly during the year. There should never be an incentive to turn down work or to postpone work for the sole purpose of meeting established performance measures. However, postponing work, if it decreases dose ("delay for decay"), may demonstrate optimization of dose to workers.

3.2.3 Type of Work and Nature of Material in Process

A third factor that affects the collective dose performance goal is the type of work and the nature of the material being worked on. Routine work is more easily adapted to a program for reduction of the collective dose. However, work that varies over time, such as a cleanup project that is multi-year with no two years being identical, is more difficult to adapt to a program of reducing annual collective dose. In addition, a new project involving higher exposure rates than in previous years will also increase the collective dose.

3.2.4 Timing of Work

The fourth factor that affects the collective dose performance goal is the timing of the work. In some cases, incurring more collective dose during the current year in order to reduce overall collective dose in the future is the correct choice. Examples of this would include performing

decontamination of systems or components or remodeling a laboratory or facility to provide for extra shielding to reduce worker doses. In many cases, this type of work can be anticipated before the performance goal is set. However, it is important to realize that for such years, the collective dose performance goal may be increased over what it was during previous years.

3.2.5 Experience of Workforce

The fifth factor is the experience of workers. In most cases, reductions in collective dose can be seen by using the most highly qualified and experienced persons. In some cases, however, experienced workers may depart, retire or approach the administrative control limits, and other less experienced workers may have to be trained to complete the work. In these cases, there needs to be a close examination of whether higher-than-predicted collective doses are a result of less experience or less-than-adequate training or preparation.

3.2.6 Unforeseeable Accidents

The sixth factor affecting the collective dose is unforeseeable accidents. The contractor should be rewarded for correcting the hazard caused by the accident, even while being penalized for the conditions or actions that led to the accident. If the contractor is penalized for cleaning up after the accident, then the incentive may be to delay removing the hazard in order to meet the collective dose performance measure.

3.3 Rewards and Penalties: Incentives for the Contractor to Take the Best Course of Action

The current award fee system of rewards and penalties that are contractually set with DOE provides rewards for contractors that achieve the collective dose goals written into the contract. In some cases, penalties are assessed for not meeting the goals.

Ideally, any use of collective dose as a performance measure should be an incentive for the contractor to "do the right thing." However, it became clear during the course of this project that the award fee system may cause the contractor to view the measurement of collective dose more as a means to demonstrate that it has met the goal and is eligible to collect a financial reward than as a means to improve the ALARA program and thus reduce collective dose. A radiological protection program that has as its main goal to ensure that the collective dose goal is met may come into conflict with the objective of the ALARA program. For example, if the contractor determines that some additional dose should be incurred in the near term to reduce collective doses in the long term, there may be a conflict between doing the "right thing" (incurring the additional dose now) and meeting the collective dose goal that was set in the contract.

Table l lists factors that should be considered when setting up the incentive program for a contractor's radiological protection program. These factors are based on a review of the literature and discussions with contractors and DOE field personnel. If not appropriately applied, the

collective dose performance measure will not reduce radiological risks. Reasons for incorrect use of the collective dose performance measure may include 1) the contractor either knowingly or unknowingly focusing on the numerical goal in order to obtain a greater award fee, 2) either or both parties (DOE and the contractor) not fully comprehending the variables that need to be considered in setting the performance measure and inappropriately evaluating the performance against the goal, or 3) the contractor assuming that the collective dose performance goal must be reduced every year without any consideration of the variability in type or amount of work. Collective dose as a performance measure is only meaningful when it is compared to realistic nominal goals and stretch goals that have been set using unbiased methods in the light of historical experience.

Consideration should be given to contractor actions involving operations, radiation protection, and collective dose, that should be rewarded, penalized, or have no impact on radiation protection (see Table 1). Such actions (both rewarded and penalized) include

- managing collective dose per unit work accomplished
- optimizing the timing of receiving collective dose and offsetting worker dose with public dose
- making reasonable expenditures to avert dose
- optimizing impact of workforce training and experience on collective dose
- balancing equitable distribution of individual doses with needs for particular skills
- optimizing impact of foresight and work scope
- postponing work
- improving or manipulating worker participation in personnel monitoring programs, and improving or manipulating detection thresholds of monitoring programs
- improving or manipulating recording and reporting of personnel monitoring results
- setting realistic and challenging collective dose goals.

It is important to bear in mind that a contractor may take the overall best course of action but nonetheless incur an increase in collective dose because of overriding non-radiological considerations. Implementation of the incentives in Table 1 would improve radiation protection, even though a simplistic measure such as unadjusted annual collective dose at a site may increase.

Table 1. Incentives for Improving Radiation Protection

Contractor should be rewarded for:	Contractor should neither be rewarded nor penalized for:	Contractor should be penalized for:
Doing more work but incurring less than proportionately more collective dose, e.g., doing twice as much work for 1.5 times as much dose	Doing more work and incurring proportionately more collective dose, e.g., doing twice as much work for twice as much dose	Doing more work and incurring disproportionately more collective dose, in the absence of extenuating circumstances (say, national defense needs), e.g., doing twice as much work for 3 times as much dose
Deciding to incur some collective dose in the near-term to reduce overall collective dose in the long-term (the annual time-scale may not be long enough) - In particular, choosing an alternative with the lowest collective dose from among documented alternatives, even if it is incurred sooner rather than later, should be rewarded.	Incurring collective dose for accident recovery *after* the penalty has been assessed	Increasing collective dose to the public to decrease collective dose to workers when the increase to the public exceeds the decrease to workers by a factor of X (where $X = 0.02$ based on the ratio of individual dose limits for the public and for workers, i.e., [0.1 rem/year]/ [5 rems/year])
Decreasing collective dose to workers at a cost of less than $2000 per person-rem	Decreasing collective dose to workers at a cost equal to $2000 per person-rem	Decreasing collective dose to workers at a cost of significantly more than $2000 per person-rem
Reducing collective dose by using the most highly qualified and experienced persons	Increasing collective dose due to departure or retirement of experienced personnel	Increasing collective dose due to inadequate training or preparation of workers
Reducing collective dose through additional training of workers and improvements to the training program	Increasing collective dose because some workers neared the DOE administrative control level (2 rems/y) and other, less experienced workers had to finish the work	Decreasing collective dose by "burning out" selected skilled, experienced workers (above the DOE administrative control level of 2 rems/year)

Table 1. (Cont.)

Contractor should be rewarded for:	Contractor should neither be rewarded nor penalized for:	Contractor should be penalized for:
Foreseeing and forestalling events that the contractor can control or mitigate that lead to the avoidance of collective dose	Experiencing events beyond the contractor's control that add to collective dose, including change of work scope that is beyond the contractor's control (such as discovery of an unsuspected problem)	Allowing avoidable or foreseeable accidents that add to collective dose
Postponing work if it ultimately decreases collective dose ("delay for decay" may be the right choice) ***provided other risks are not increased by the delay***		Postponing or not performing radiological work simply to avoid collective dose in a given year
Improving participation in worker monitoring programs and/or more sensitive dose and bioassay measurements	Increasing collective dose due solely to improved participation in monitoring programs and/or more sensitive measurements	Decreasing collective dose due solely to reduced participation in monitoring programs and/or less sensitive measurements
Improving recording and reporting of personnel monitoring results	Increasing collective dose due solely to improved recording and reporting of personnel monitoring results	Decreasing collective dose due solely to reduced recording and reporting of personnel monitoring results
Achieving "challenge" or "stretch" collective dose goals - even if the goals are higher than in previous years as a result of additional work or other programmatic changes	Achieving nominal collective dose goals or maintaining the same level of goals in a program where there is no variation in the amount or type of work	Setting non-challenging collective dose goals, i.e., overestimating collective dose in advance of a job to make subsequent performance look better

4.0 Collective Dose as an ALARA Management Tool

Collective dose can be used as an ALARA management tool, in order to assist in the reduction of dose to the individual workers. The *Health Physics Manual of Good Practices for Reducing Radiation Exposure to Levels that Are As Low As Reasonably Achievable (ALARA)* (Munson et al. 1988) discusses the use of collective dose as a goal in the ALARA program. This report indicates that while the most common index or measure for evaluation of ALARA goals is the average individual effective dose equivalent (the total effective dose equivalent for all exposed personnel divided by the number of persons exposed), that both individual and collective effective dose equivalents should be evaluated. This is because average individual doses can be distorted by one or a few extraordinarily high exposures. In addition, the size of the population can be distorted by including workers with a low exposure potential, such as administrative and stockroom personnel.

Measurements and trend analysis of collective dose per unit work can be more meaningful than a simple analysis of collective dose alone. According to Munson et al. (1988), evaluating effective dose equivalent by job classification or by type of work can be revealing from the standpoint of ALARA goal achievement.

Munson et al. (1988), points out that the logical extension of evaluating effective dose equivalent by job category is to evaluate the incurred effective dose equivalent by specific job task. For example, changing a light bulb over a pool-type reactor may be a high-dose task because of the location of the bulb or the manner in which the task is performed. This job could be defined as a unit of work, and an analysis of this unit of work (for example, a time-motion study with the emphasis on dose incurred while performing the task) could be used to reduce the amount of dose received by the worker. This is especially significant for work processes that are repetitive. If a work process is repetitive, then unit work can be defined and individual doses can be measured and summed to yield collective dose per unit work. Analysis of trends in collective dose per unit work can identify anomalies that affect worker efficiency and can indicate the effectiveness of specific ALARA actions.

Measurements of collective dose for a group of workers over a given time period often do not take into account any variations in schedules or the amount of work performed. Thus, this is another complexity that needs to be examined in order to optimize collective dose.

To understand the concept and usefulness of determining the collective dose per unit work, consider the example of a facility where the work is highly repetitive. The radiation workers train extensively on mockups before beginning a project, and a group of workers or a team is usually dedicated to the particular project for the duration of that project. As the radiation workers begin a project, it is possible to collect records that reflect team members' work assignments, time worked per day, days worked per month (one month is the unit of time for measuring collective dose and the amount of work performed). Likewise, it is easy to determine the number of times a task is performed during the month. The group's collective dose for the month is simply the sum

of the individual doses of the group members. It is important to determine the specific workers in the group and the number of work units over exactly the same time period as the dosimeter measurement period.

During the course of the project, the collective dose per unit of work (per task) can be tracked month-by-month to indicate meaningful trends. For example, a downward trend in the collective dose might be expected as the workers develop slightly more efficient techniques and improve teamwork. If the trend levels off and a new ALARA action is taken that renews the downward trend, it can be a clear indication of the effectiveness of the action. An upward trend may occur if a significant problem arises that decreases worker efficiency.

Some interesting trends have been observed at such a facility. One project was being conducted on the day shift only, and a baseline collective dose per unit of work had been established. In order to increase production, additional workers were trained and a second shift was added. The number of tasks performed during the month more than doubled, and the collective dose per task decreased markedly. Investigation revealed that the second shift was significantly more productive. The reason was that workers were rarely interrupted. The day shift, on the other hand, was frequently interrupted due to visitors, managers, auditors, etc., and these interruptions decreased their efficiency. Reviewing the comparative data led management to curtail visitors and other noncritical interruptions. This ALARA action was very effective because it increased efficiency and decreased collective dose.

Similarly, individual dose data were correlated with specific work assignments so that anomalies could be easily detected. For example, if a new worker received an unusually high dose for the month for a job that was normally low dose, it could mean that training was not adequate or that the worker was doing work other than what was assigned. The workers' tasks were also videotaped for training and ALARA engineering purposes, and time-and-motion studies were conducted during that portion of the work with the highest dose rate. Both the dose rate data and the videotapes were studied to improve equipment, techniques, and procedures. This study facilitated the design of remote-handling tools, job-specific shielding, and a streamlined procedure.

For this facility, the data for collective dose per unit work can be plotted as shown in Figure 1. Trends from month-to-month are clearly apparent. The increase in the second month (December) was largely due to lower-than-average production because of holidays and vacations. A downward trend through April was from increased productivity; the increase in May was from elevated background radiation caused by radioactive components not being promptly removed from the workplace. The downward trend though September was due to effective ALARA actions. Figure 1 clearly shows when investigations are needed and when corrective actions have been effective. The ALARA goal for the program is also shown; the data suggest the goal for next year should be lowered to provide a continuing challenge.

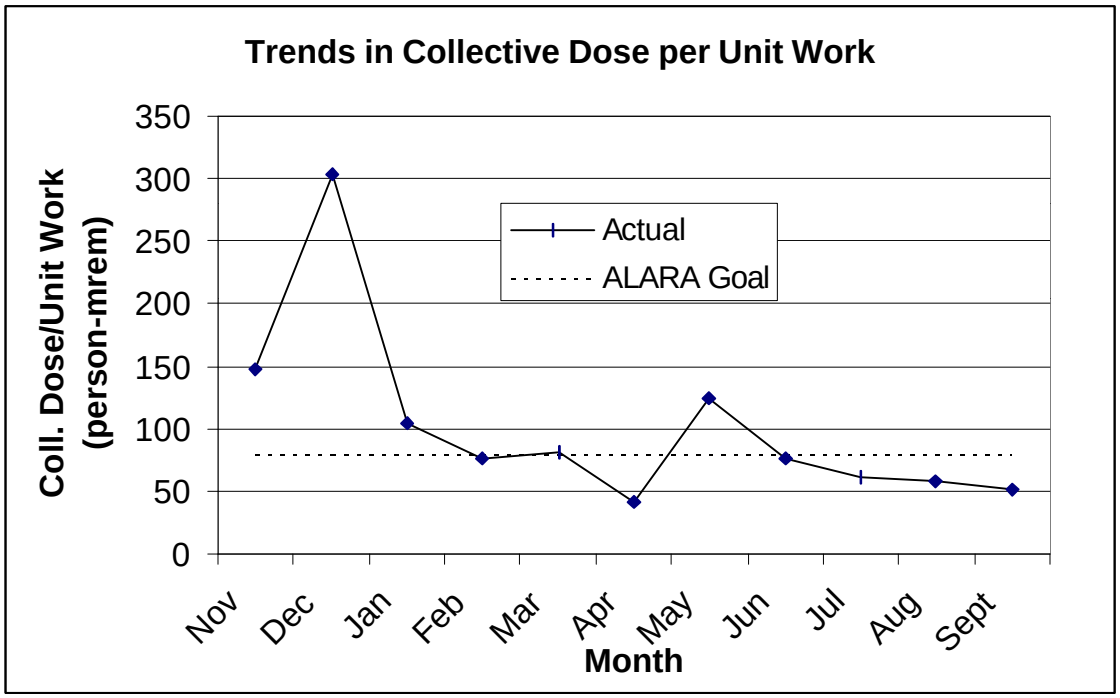

Figure 1. Time Trends in Collective Dose (person-millirems) per Unit Work at a DOE Site - The ALARA goal was 80 person-mrem/unit work.

The plots showing monthly collective dose per unit work are provided to the facility's ALARA Committee and to the managers and supervisors. Managers can correlate collective dose trends with other trends that affect their teams. For example, an inefficient or disruptive worker could be identified and removed from the team. Inefficiencies due to lack of parts or supplies could be identified and adjustments made to prevent such shortages. The ALARA Committee and the Radiation Safety Department can focus extra attention on any upward trends in collective dose and bring additional resources to bear on the problem. Successful ALARA actions, indicated by downward trends, can be expanded to foster further worker efficiencies and reduced collective dose.

This example of collective dose per unit work depends on a repetitive work cycle to obtain consistent, useful data. Because many DOE sites conduct highly varied work, it may be concluded that collective dose per unit work cannot be measured. In order to find examples of repetitive work where collective dose per unit work can be measured, it may be necessary to examine individual tasks or radiological work permits, such as the Radiological Work Permit (RWP) for a high-efficiency particulate air (HEPA) filter exchange. The example may apply to only a few workers and a relatively small collective dose, but if the dose rates for the work are high, the analysis can lead to effective ALARA actions.

5. 0 Survey of Collective Dose Usage at DOE Contractor Facilities

Information was collected from 13 DOE sites (listed in Attachment 1) and non-DOE sites to determine whether collective dose is used as a performance measure and if and how the sites use the results of measuring collective dose to make improvements to ALARA programs. Of the 13 DOE contractor facilities contacted, detailed information was received from nine and is presented here. Most of these facilities tracked collective dose; however, some facilities did so only for internal use (i.e., using the information to improve radiation protection at their site), while others tracked collective dose solely as a performance measure to be reported to the DOE Field Office. Some facilities have set collective dose performance goals that did not change during the year, while other facilities have collective dose performance goals that varied during the year depending on the work load or other factors. The methods that are used to track collective dose as a performance indicator are discussed below.

Sections 5.1 and 5.2 deal specifically with the methodology used by each of the contractors. Section 5.1 focuses on those facilities that had fixed performance goals that did not vary during the year. Section 5.2 discusses the methods used by contractor facilities that had collective dose performance goals that varied. In two cases, facilities were changing from a fixed to a variable collective dose performance goal. In those cases where enough information was available regarding the new method of determining the collective dose, both the old and new methods are discussed. For each facility, it is clearly stated whether the performance goals are tracked as an internal measure, an external measure, or both. These findings are summarized for nine contractors using collective dose (in one form or another) in Table 2. Other contractors did not use collective dose as a performance measure. Section 5.3 summarizes the contractors' comments about the usefulness of collective dose as a performance measure. Recommendations for the appropriate uses of collective dose as performance measurements are found in Section 8.

5.1 Fixed Performance Goals

DOE contractor "A" sets specific annual goals that are based on the collective dose in response to a DOE requirement. The annual goal is based on the collective dose for the previous 3 years. In order to meet expectations, the collective dose must be maintained within 5 percent of the previous 3-year running average for collective doses. To exceed the expectations of the goal, the collective dose must be reduced by at least 10% of the 3-year running average or below a specified control level. Contractor "A" indicated that the types of facilities and projects that it has can cause significant variability in the collective dose total from year to year. However, their performance objective also includes the statement that "any actual or anticipated significant change in workloads (interpreted to be an increase or decrease of 10% or more) that would affect radiation doses will be brought to the attention of [the contractor] and the DOE, and appropriate adjustments will be made [to the annual goal]." Since this facility routinely has significant changes in their workload, they document the changes and make adjustments to the annual collective dose goal. The collective dose performance measure, which is one of 40 performance measures that they use, is used primarily to meet DOE requirements.

In 1997, Contractor "B" used one collective dose value for all radiological activities in the laboratory as a performance goal. The goal was based on the previous year's performance goal. This performance goal is in the DOE contract and is, therefore, a DOE requirement. The activities at this facility vary from year to year and a variety of different types of work are performed. The contractor's representative stated that with a single collective dose number, it was practically impossible to identify where improvements in radiation protection could be made. Therefore, Contractor "B" does not use this performance goal to improve its ALARA program because the radiological control staff have been unable to use the single-number performance goal for the purpose of reducing doses to workers. The contractor has found that the variation in collective dose between subsequent years can be quite large as a direct result of the variation in the amount and type of work performed during a specific year. For instance, the collective dose during 1997 appeared at mid-year to be twice as high as it was originally estimated from 1996 doses because of additional work performed after the goal was set. For this contractor, the use of a single-number collective dose performance indicator is not useful in keeping doses ALARA. Therefore, the contractor has investigated the use of a different type of measurement that would use radiological work permits for work unit assessment. This methodology will be discussed further in Section 5.2.

Contractor "C" indicated that their performance goal was developed with assistance from the DOE Field Office, specifically to reduce FY96 collective dose by 25%, normalized for increased work in radiation areas. However, both the contractor (and, apparently, the Field Office) are rethinking the usefulness of this particular performance goal although they are now committed to this performance goal for the remainder of FY97. Contractor "C" is planning to make future goals, in agreement with DOE, that relate to a job-by-job assessment. In addition, Contractor "C" plans to use collective dose as an internal measure only for radiological program improvement and to ensure that the collective dose does not become a performance measure in the next contract with DOE.

Contractor "D" has a two-tiered performance goal, set as a DOE requirement. First, the collective dose is not to exceed 85% of the 2-year running average of the collective dose at the Contractor "D" facility. Second, the collective dose is not to exceed 95% of the 5-year running average of the collective dose for two other facilities, which are also run by the same contractor organization but are located in another state. No explanation was provided for basing the collective dose performance goals on work at other facilities. Contractor "D" stated that any actual or anticipated significant change in workloads (defined to be a change of 10% or more) that would affect radiation dose would be brought to the attention of the contractor's organization and the DOE Field Office as soon as possible, and an appropriate change made to the goal.

5.2 Variable Performance Goals

Contractor "E" used collective dose as an internal performance indicator for many years. However, it is now also a part of their contractual agreement and is routinely reported to the DOE Field Office along with 130 other performance indicators. Initially, the contract with DOE specified a single number for the collective dose performance goal. Because Contractor "E's" operations vary so much during the year, Contractor "E" opted for a variable collective dose performance goal that changes during the year. This system is based on a single "baseline" goal, which is an estimate of the lowest collective dose that the facility anticipates from maintenance and routine monitoring. It is the minimal collective dose expected to maintain the facility with no special projects. To this collective dose, the contractor then adds the collective doses expected from the projects that are anticipated during the year. If the new work is canceled before the collective dose is incurred, the contractor subtracts the estimated collective dose for that project from the collective dose total. If the new work is in excess of the original estimate, they add an estimate of the collective dose for the new work to the total collective dose estimate. The contractor representative indicated that they do not use the collective dose estimate in their ALARA program because as a single number, it was too simplified. The representative thought that a collective dose for each separate facility at the contractor's site would have been more useful for application to the ALARA program.

Contractor "F" uses a single-number collective dose performance measure, but has quarterly review meetings in which they reevaluate their status and adjust the number as appropriate. The collective dose performance measure is written into their contract with DOE, although it is also used as an internal measurement. Although it is one of a number of performance measures set in their contract, they find it to be the most important. For this contractor, the collective dose goal is based primarily on ALARA reviews. The radiological protection group evaluates each job to estimate whether the doses are defensible. Then, the results of the analysis are further reviewed by DOE and the radiation control manager. In the past, the radiation control manager has taken the liberty of further reducing the collective dose estimate in order to make it a "more challenging" goal before finalizing it with DOE. Each quarter, both the contractor and the DOE Field Office representative reevaluate the progress towards meeting the collective dose goal. If the work has been changed, the goal is adjusted as necessary. In addition, if the process required to do the work has changed (for example, from a robotic application to something that requires a "hands-on" approach), the contractor would propose an increased collective dose performance goal. The DOE Field Office allows the increased goal if there is a reasonable documented basis for the change. However, in some cases, the actual dose incurred during the repair rather than the estimate has been added to the collective dose performance goal. This may occur when a piece of equipment required repairs that had been previously unanticipated. This contractor views the collective dose performance measure as very important.

Contractor "G" has a variety of performance measures, including collective deep dose and collective shallow dose, that are a part of its contract with DOE. Contractor "G" tends to consider the collective dose as more of an internal performance measure. Contractor "G" was

unique among the facilities contacted in this study because they do not have a set "goal" for collective dose. At the end of the year, the DOE Field Office reviews all the performance measures and any explanations for why there were deviations (if there were deviations) from the previous year. The Field Office then determines if the measures and explanations are adequate. For example, one year the contractor exceeded by 50% the collective dose from the year before as a result of some cleanup and waste-management activities. However, they were able to justify the increase to the satisfaction of the DOE Field Office.

Contractor "H" sets an internal goal for collective dose each year and communicates this goal to the DOE Field Office. The goal is also discussed in the formal ALARA meeting that is held each year, which both the contractor and the Field Office representatives attend. The goal is set for each quarter, and if new work or complications in the previously planned work arise, the contractor adjusts the collective dose goals and informs the DOE Field Office. Contractor "H" has very low collective doses and thought that the collective dose measurement had little value except for trend analysis.

Contractor "I" indicated that although it did track the collective dose from year to year, the number was not used as a means of indicating where improvements were required, or as a mechanism to highlight where changes needed to be made in order to keep doses ALARA. Instead, because they have very low collective doses (less than 2 person-rem for the whole year), the facility concentrates on "trigger levels" on specific projects as the major factor to ensure the reduction of doses in the ALARA program. Each project is appraised for potential "triggers," such as an estimated collective dose greater than 500 mrem. Other triggers are the potential for accidental overexposure or the use of a new procedure.

One contractor (Contractor "B"), which previously used a single number for the collective dose goal, has changed the collective dose performance measure so that it can be used to improve the management of radiological work. This approach is based on the concept that collective doses that can be accurately estimated can be better managed. If there is a high level of certainty regarding the source of the dose, then the contractor can be more effective at reducing unnecessary exposure. A system has been devised and to being used that will use RWPs for work unit assessment. The current system establishes a performance measure based on a comparison of the estimated (projected) collective dose before the work begins and the actual measured collective dose on each RWP, using the following equations:

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} = \frac{\sum_{i=1}^{n} w_i \left(\frac{A_i}{E_i} \right)}{\sum_{i=1}^{n} w_i}, \qquad (1)$$

where

$\bar{x}$ = the weighted average actual-to-projected collective dose ratio
w_i = the weighting factor for the *i*th ratio of actual to projected collective dose
$x_i = A_i/E_i$ = the *i*th ratio of actual to expected collective dose
A_i = actual collective dose on the *i*th RWP
E_i = estimated collective dose on the *i*th RWP.

If $w_i = E_i / E_t$ (where E_t = the sum of all estimated collective doses), Equation (1) simplifies to

$$\bar{x} = \frac{\sum_{i=1}^{n}\left(\frac{E_i}{E_t}\right)\left(\frac{A_i}{E_i}\right)}{\sum_{i=1}^{n}\left(\frac{E_i}{E_t}\right)} = \frac{1}{E_t}\sum_{i=1}^{n} A_i . \qquad (2)$$

In order to improve the process for making collective dose estimates, the goal is to keep

$$\text{lower-bound (e.g., 0.8)} < \frac{\sum_{i=1}^{n} A_i}{E_t} < \text{upper-bound (e.g., 1.2)} . \qquad (3)$$

The collective dose estimates that fall between these bounding values would meet the performance measure goal. Those outside the bounds would not meet the goal.

The effectiveness of this approach can be seen more clearly with a specific, real example. If the collective dose estimate, E_i, in the RWP for a HEPA filter exchange is 1.2 person-rem and the actual measured collective dose, A_i, for the job is 1.1 person-rem, then

$$\frac{A_i}{E_i} = \frac{1.1}{1.2} = 0.917 \qquad (4)$$

The ratio is within the desired bounds, and it indicates that the estimated collective dose was slightly overestimated. This information can provide a basis for the estimator to be slightly less conservative and more accurate in future estimates. The ability to accurately estimate collective doses will lead to a better understanding of the dose components, improved management of radiological work, and reduced collective dose. This approach is based on the following assumptions: 1) if there is a significant change in the scope of radiological work which changes the assumptions used to develop the performance ranges, they can be renegotiated by the contractor and the DOE Field Office, 2) only those activities requiring entry into Radiation Areas, High Radiation Areas and Very High Radiation Areas are included, 3) only those activities with

an estimated dose for an individual greater than 100 mrem or an estimated collective dose greater than 500 mrem will be included and 4) supplemental dosimetry will be used to track the doses for this indicator of collective dose.

Contractor "B" identified the following benefits of such a system: 1) ownership of the performance measure would be shared by both the radiological control organization and the operational organization, 2) the measure would be based on work actually performed and not on proposed work that is planned for the future, and 3) the measure will encourage real ALARA measures to be taken to reduce dose to the workers. The primary disadvantage is that since individual workers may work under many different RWPs, the thermoluminescent dosimeter (TLD) or dose of record cannot be used; instead, the readings from the personal ionization chambers (such as a pencil dosimeter) would be used to track dose on day-to-day activities and these readings are rarely equivalent to the TLD readings.

The nature of the collective dose performance measures at the nine DOE sites responding to this survey are summarized in Table 2.

5.3 Comments Received from Contractors

The contractors contacted for this study were asked to provide their opinions on the usefulness of collective dose as a performance measure, and whether they thought it was meaningful, misleading, or subject to "gaming." The contractors were asked what they would like to do to improve the use of collective dose as a performance measure. In addition, the contractors were asked for the problems, pitfalls and shortcomings of using collective dose as a basis to improve the ALARA program.

Two contractors indicated that they liked the collective dose performance measure. One contractor noted that they have a mechanism to justify any legitimate increases in the collective dose (that might result from additional work loads, etc.). Moreover, because it is combined with about 30 or 40 other performance measures, it does not weigh heavily in meeting the terms of the contract. According to the other contractor, the collective dose performance measure worked well for them because they had the flexibility to change the collective dose goal, based on the amount of work actually performed at the facility and on any variations there might be in the types or amounts of work required. Having used this process for two full years (this is the third), they have been able to reduce the collective dose goals in both years. This contractor credits much of the success to congenial and helpful DOE Field Office personnel.

Table 2. Nature of Collective Dose Performance Measures at Nine DOE Sites.

Site	Nature of Performance Measure: Collective Dose Is...
A	A required performance measure. One collective dose number based on average over past three years; can adjust the goal if workload changes.
B	A required performance measure. One collective dose number for all activities, based on previous years performance goal, was not allowed to adjust goal based on workload changes.
C	A required performance measure. One collective dose number, based on previous years performance goal (goal was to reduce collective dose by 25%, normalized for increased work in radiation areas).
D	A required performance measure. Two tiered goal based on 1) collective doses from previous two year average and 2) five year average from other facilities run by contractor; can adjust the goal if workload changes.
E	A required performance measure based on a single baseline goal for estimated work for the current year; goal can be adjusted up or down if workload changes.
F	A required performance measure based on a single number estimated for work to be conducted during the year; goal can be adjusted if workload changes.
G	A performance measure. However, rather than a specific goal that must be reached, performance is evaluated at the end of the year and deviations must be justified.
H	Not required as a performance measure. Contractor sets an internal goal and communicates goal to DOE Field Office; adjusts goal as workload changes
I	Not required as a performance measure. Contractor tracks collective dose annually.

The other eight contractors did not like the collective dose performance measure, basing their judgment either on the way it was administered at their facility or on its general formulation.

One facility located the major problem with the collective dose performance indicator in its being administered as a single number for an annual goal. Thus, there was a lack of ownership among the various groups at his facility. For example, if more work comes into the facility, the administrative arm of the company welcomes it, but the radiological control group is held responsible as the collective dose exceeds the original goal as a result of the increased work load.

For another contractor facility, the collective dose performance measure seemed too much of a simplification. This facility has a large number of smaller individual facilities; thus, it seemed that using a performance goal for collective dose for each facility would be more meaningful than

combining it into a single number. The contractor representative held that "you can't globalize ALARA, it must be measured customer-by-customer." At this facility, the collective dose has routinely dropped every year, but only part of this decrease is due to the ALARA program. The rest is due to a decrease in operations. Using only one number thus conflates both issues, so that it is hard to tell if the reduced collective dose is due to improvements in the ALARA program or if there is a reduction in the amount of work performed.

One contractor indicated that the collective dose performance goal methodology does not work very well for non-production facilities because the amount of variation that is encountered in the work levels between calendar quarters is often fairly large. This same contractor representative specifically commented on the use of a single number for the performance goal. He indicated that they had used the single-number approach, but that it did not work well because their operations varied extensively during the year. The single-number approach left them with the problem of explaining to the Field Office that the goal had been determined and written into the contract before either a program was canceled and far less dose than anticipated was actually received, or because a new program, previously unanticipated, was started. He termed their experiment with a single-number collective dose goal "disastrous."

The representative at another facility thought that collective dose goals would work well for routine operations. However, for facilities that are intensively into decommissioning or cleanup-type work, which are one-time jobs that will probably never be repeated, it does not make as much sense. This representative thought that the concept of ALARA and collective dose were being used as a "counting widget" tool by administrators, when they had never really been meant for that purpose. The contractor representative also said that collective dose by itself does not provide much information. Despite seeing a relatively high collective dose at one site and a lower one at another site, unless the activities that were taking place at each site were examined, no one could tell which site had the best ALARA program.

Another contractor termed the use of a single-number collective dose goal "really dumb." For his facility, both the contractor and DOE agreed that it had not been a good idea, and they were currently searching for a replacement performance measure.

Yet another contractor representative thought that the use of collective dose for anything other than trending purposes was "rather stupid."

One contractor thought that using an annual collective dose for the entire facility left things too wide open for "gaming." This contractor thought it was more appropriate to make estimates of the collective dose for a specific project, or for similar types of projects, and to document the assumptions that go into each aspect of the estimate. Thus, if some changes to the project scope occur, the estimates can be easily reviewed and reworked as appropriate. He likened the process to one of making cost estimates. If additional work was required on the project, the cost estimate would be revised, as would the collective dose estimate. This would require contractors and DOE to look at similar types of projects and group them. However, they would need to look not

only at similar types of work, but also at the radiation levels for each job. For instance, a job requiring 40,000 hours of work with only 1000 hours in a radiation area is clearly not the same as a job requiring 40,000 hours of work with 30,000 hours in a radiation area. The second part of the analysis would be to address exposure levels: a job requiring 1 hour of work in a 100-mrem-per-hour field is quite different than one requiring 50 hours of work in a 2-mrem-per-hour field.

6.0 Collective Dose: Views Held by DOE Operations Offices

In an effort to provide a balanced picture on the use of collective dose as a performance measure at DOE sites, a total of 18 representatives at 10 Field or Operations Offices (Attachment 2) were contacted to obtain information on the use of collective dose as a performance measure at their sites and to solicit opinions on the usefulness of collective dose as a performance measure. Eight of these offices provided detailed information that is summarized here. Each site representative was asked whether collective dose was meaningful, could be misleading or was subject to gaming. Opinions on improved methods for using collective dose as a performance measure were solicited. This section summarizes the information obtained from the site representatives.

6.1 Use of Collective Dose as a Performance Measure at DOE Sites

Collective dose is used as a performance measure for contractors at Site Representative 1's site, and incentive fees are associated with meeting a specified reduction in collective dose. There is one Integrated Management (IM) contractor and a number of subcontractors under the IM. Currently, the contractors report collective dose on a consistent basis with few variations or anomalies. When anomalies occur, the contractor and DOE Field Office review the abnormalities to determine why they occurred and what action, if any, is needed.

At Site Representative 2's site, external dose is the main concern and collective dose is used as a performance measure.

Collective dose is not used at Site Representative 3's site. The site is currently in a work-intensive phase because remediation activities started recently. The Field Office has worked with its contractor to develop weighted dose related to amount of work performed. No incentive fees are tied to performance measures; the contractor is paid a fixed fee.

The contractors under Site Representative 4 are directed to have specific performance indicators, and collective dose may be one of the indicators. In some cases, the collective dose performance number is normalized to workload. Collective dose used as a performance measure is not currently a monetary goal, but it has been in the past.

A 5-year running average for collective dose was originally established as a performance measure for the contractor of Site Representative 5. The five-year time span was shortened to three years because earlier years were work-intensive with very large collective doses. The current allowance for fluctuation in collective dose is 20%, a change from the former goal of 5%. The contractor informs the field office of changes in work and explains how this will affect dose. Performance measures are often evaluated on a good/better/excellent scale based on either levels or reduction reported. Dose assessments are performed in the June/July and December/January time frames. Sometimes, financial incentives are tied to meeting performance measures.

Collective dose is used as a performance measure for the contractors of Site Representative 6. Contractors report collective dose on a consistent basis. When anomalies occur, they look at individual doses and determine the reason for the change. Personnel and area monitoring are the key issues in the safety program. Total dose and internal and external exposures are measured at the site and used for assessing ALARA goals. Skin, deep, neutron, tritium and eye doses are collected and tracked monthly

At Site Representative 7's site, collective dose is used only as a general tracking indicator of performance. Internal, external, and individual dose performance indicators are measured for six discrete facilities and an aggregate dose is calculated for the site. One facility has an incentive fee attached to the goal of achieving ALARA by reducing collective dose by 25%. The site has developed Radiological Performance Indicators (RPI), similar to OSHA's radiological indicators, to track contractor performance. The RPIs allow the site to better track funds and ALARA performance.

Collective dose is used as a performance measure for Site Representative 8's one contractor. A single annual total dose number is used which is negotiated between the DOE Field Office and the contractor. ALARA goals are set to achieve a percentage reduction (estimated at 5%) in the collective dose each year. The number is negotiable during the year when new work scope is added or some unforeseen event occurs. The contractor actively tries to provide a measure that is meaningful as well as applicable to its ALARA program. The contractor makes an effort to achieve ALARA and notifies DOE when dose estimates and work changes may affect collective dose.

6.2 Site Representatives' Views on Use of Collective Dose as a Performance Measure

When asked about the usefulness of collective dose, one site representative provided the following: The essential matter in planning work is to focus on the question, "Is what I'm doing worth the rem received?" Often, the work performed is essential for remediation or maintenance and operations. Collective dose used as a performance measure sometimes prohibits answering this question. It is often used to encourage reductions in dose from year to year without consideration of the work that needs to be performed. Contractors should focus on meeting ALARA goals *and* getting the work done. There is a strong need for a "leading" indicator, which is currently impossible given the time delay in getting data. One site is trying to avoid the lag-time problem by getting dose estimates from a newly developed computer tracking system. The goal is to have real-time data on a facility basis and to track performance against historical data. This information can be tied into work plans and schedules, with the goal of avoiding any 10 CFR 835 violations. Incentive fees attached to performance measures can lead to a "bean counting" mentality.

The representative also stated that ALARA is important but it can be a subjective measure. No one performance measure can give enough information to definitively show whether the work performed is better or worse than it should be. It is important to have a committee that works

diligently with the contractor, particularly in the planning stages of a project. Open, realistic, and challenging dialog between the ALARA committee and the contractor is essential to success.

One site representative did not like using collective dose as a performance measure and stated that is served only as a statutory requirement and was not used to help meet ALARA goals or reduce risk. The site representative felt that using collective dose as a performance measure led to gaming, and the contractor would try to get the necessary reductions in collective dose by going after the easy reductions, which often would have been addressed without an incentive fee attached to the performance measure. The method of calculating collective dose has sometimes resulted in the contractors using creative accounting to produce a lower number. The contractor could also "pad" the numbers by including many workers who were exposed minimally into the same collective dose calculations with a few highly exposed individuals. The resulting collective dose can then meet the reductions defined in the performance measure, enabling the contractor to receive an incentive fee even when one or several individuals received large doses or exceeded their individual limits. This site representative felt that collective dose has become a subjective measure, susceptible to manipulation depending on how the contractor adds up the number.

The site representative also stated that no incentive fees should be awarded for obtaining a low collective dose since this should be part of the contractor's program for ensuring worker and public health protection. ALARA goals should be set at reasonable yet protective levels. Proper use of resources, particularly workers, should be considered when evaluating performance. Reduction of dose should be looked at on a project basis to consider the differences in expected dose generally associated with the variability of the work performed. Certain projects naturally have higher exposure conditions associated with them then other projects, thus increasing the potential for dose. Other projects may be very well defined and operated so that dose is reduced so significantly that further reduction would be difficult and costly to achieve with little or no risk reduction.

Another site representative expressed mixed feelings regarding the use of collective dose as a performance measure. At this site, external dose is the main concern and the work can be assessed by workload so that the contractor does not get credit for reducing dose when less work is being performed. Although the contractor wanted to have an incentive fee tied to reduction of dose, the site representative did not think that the contractor should "be rewarded for doing their job". Radiation safety is the key goal and this routinely involves the ALARA committee adjusting goal limits appropriately. The contractor may be hesitant to set goals too low since it may result in not being able to meet the target. Instead, contractors often ask for a goal they know they can meet. The Field Office would rather see them set a challenging goal and then ask for allowances if conditions change and it looks as if they may have underestimated the dose. As long as the dose values can be accounted for and ALARA conditions defended, allowances can be made. It is more productive and protective if stringent limits are set and, when appropriate, exceptions for this limit allowed on a case-by-case basis.

The emphasis should not be on collective dose but on meeting ALARA. This can be best judged with a combination of qualitative and quantitative measures. Incentive fees should not be applied to meeting a collective dose performance measure. The ALARA committee should work with the contractor, line management, and manufacturing to set challenging yet work-reflective ALARA goals.

One site representative thought that a collective dose performance measure is meaningful and provides the contractor with a good overall measure and goal. It is always present in the contractors' thinking when trying to reduce dose and works as a good incentive for the workers. It serves to promote good staff knowledge of dose reduction as an important goal.

One site representative stated that collective dose as a performance measure is useless when it isn't thoroughly and critically reviewed. This representative felt that the contractors set the collective dose performance measures at easily achievable levels that are not meaningful to ALARA or improving safety. The representative said that the contractors are just trying to meet goals, and that the safety culture suffers from this approach. Financial incentives are attached to meeting the different performance levels. This is not an appropriate way to improve safety or meet ALARA, according to this representative. An annual monetary award should not motivate the contractor's management style. The contractor should create a safety culture that promotes ALARA and achieving the best work while reducing exposure to workers. This approach fits into the concept of Integrated Safety Management. If any financial incentives are used, it should be from the perspective of taking away money when a job is performed poorly. In reality, this is similar to the approach of using contract renewal as a motivation for enhanced job performance. If a contractor does a lousy job, they should worry about possibly losing work or their contract. The contractors are not playing any number games, they just set levels at non-challenging levels.

Another site representative stated that having a single collective dose number can be a useful tool to use for radiological control oversight. For example, one facility that has a high annual collective dose was able to identify a number of weaknesses int the radiological control program and to focus on correcting those weaknesses. This made it easier for the site representative to assess improvements in the radiological control program. However, there can be drawbacks in using collective dose as a performance measure. If the contractor states that there will be a 25% reduction in collective dose based on expected activities for a year, poor pre-job estimates that inflate the doses can be used to make performance look better than it actually was. The site representative thought that a better performance measure was to look at the contractors' planning for radiological work and assess the results after the work was completed.

As stated by one site representative, collective dose used as a performance measure has been helpful, but requires proper evaluation and communication between the site representative and the contractor. The field office works with the contractor to understand what work is being performed and how that will affect collective dose. Incentive fees can be used as a positive mechanism for encouraging the contractor to work harder to get dose reductions, but there is room for improvement. As is the current practice, when trying to set goals, the contractor is

working with dose data that has a 1-year lag for the goals they set. Difficulties often arise when assessing performance measures according to the good/better/excellent rating. There is no incentive, for example, to do better than the National Emission Standards for Hazardous Air Pollutants NESHAPs requirements because the numbers are so low that an excellent rating is always achieved, even though there is likely room to improve. ALARA program features are considered but not directly linked to collective dose. In fact, a performance measure has been defined as "management support of ALARA" but this measure is too subjective to be of much use.

This site representative thought that financial incentives can be positive. Improvements can be made to get better, more up-to-date data by which to set challenging yet reasonable reductions in dose. Connecting dose with the work type and amount seems logical. The key to successful reductions in doses at the site are good communication with the contractor, which is best achieved over time, and an understanding of the work being performed including how changes in work scope will effect dose. Any changes in operations or working conditions should be brought to the attention of the Field Office so dose projections can be evaluated and opportunities to reduce dose can be identified.

One site representative suggested that a better performance measure than collective dose would be to look at how good their planning is for radiological work and then estimating dose for smaller segments of work than an entire site's operation for a year. One problem at a large site is tracking the estimators and the estimates. The work scope fluctuates so that the system needs to track collective dose for each job, update and modify the projected dose for each period of time, and, at the same time identify any problems that may be arising. This site representative would rather see good dose estimates than have a true system of performance measures based on collective dose.

This site representative also believed that dose could be tracked by job where there are identifiable tasks for which the dose can be projected. Such projections must be reviewed and adjusted at least annually. In the annual report, a contractor should identify where the number went up or down and why. A time-series graph of collective dose during the year should be useful as long as there is an explanation for bumps or changes in the doses.

This site representative also made a variety of observations:

- Analyzing collective dose numbers by facility within a site can help focus resources, but such numbers are not useful as a performance measure.

- Tracking collective dose may be too labor- and resource-intensive to be justified by the benefit of improvements in radiation protection resulting from its use.

- Unless an automated system is already in place to track all collective dose, sites may need to establish projected collective dose thresholds, below which tracking collective dose is not justified and therefore not undertaken.

- Tracking of collective dose on a task basis may be impractical for sites where RWPs are not used for many jobs.

- The main problem with the use of collective dose per unit work, which has been looked at by several contractors at one site, is in using one or more pocket dosimeters for the job – and then having to rely on their measurement of the dose. TLDs are not exchanged often enough to base collective dose tracking on the dose of record. Collective dose per unit work would have to be tracked with the pocket dosimeter. Usually, pocket dosimeters are used in a specific area, independent of the job that is being performed. Electronic personnel dosimeters for the dose of record would solve this problem.

- To track collective dose by job, RWPs need to be written for jobs, and not just areas. However this is not always done. One Management and Integration (M&I) contractor is working towards basing the RWPs and dosimeter readings on a particular job rather than on a work area.

One site representative stated that collective dose can be a good performance measure only if conditions don't change. Collective dose never captures the real dose and is not a function for good radiation control. Reductions in collective dose do not always correspond to the contractor's improving conditions. One example is the drop in dose received by workers taking samples since over time workers became more adept at their work and it took less time in the exposure area. A good performance measure should capture the work being performed. For example, during the remediation phase, the dose naturally increases. The contractor should not be expected to reduce dose from one year to the next when the work is completely different over those two years. Out of a shear lack of any other options for measuring dose, one site decided to try a new measure of tracking dose per RWP. Although this value would capture to some extent the amount of work done, the contractor still had legitimate concerns that it did not capture all aspects of working conditions, such as the type of radiation and controls. Although the dose per RWP is not a perfect measure, this site representative held that it is better than a non-weighted value such as collective dose. Tracking collective dose should only serve the purpose of indicating change because it is too subjective to be used to make such broad statements, such as, "We reduced radiation exposure at the site."

Another site representative stated that collective dose reduction should not be part of the agreement with the contractor. A dose weighted according to work type and intensity would be a better performance measure for assessing ALARA and dose reduction than the current method of using collective dose. A measure similar to dose per some indicator that captures the amount and type of exposure would be best. It would be beneficial to DOE nationally if all the sites and laboratories could brainstorm and share ideas on how best to capture dose concerns and meet

ALARA requirements. Coming up with measures that were used the same way at all of the sites would help in comparing the sites. It is currently difficult to compare one site to another since the performance measures used are not equivalent.

Two DOE site representatives stressed that the approach to contractor incentives should be focused on Integrated Safety Management, not quantitative, single numbers such as collective dose.

7.0 Discussion

Each of the sites that were reviewed in this study have a collective dose performance goal that is contractually set with the DOE Field Office, with two exceptions. The exceptions have extremely low collective doses during the year, but still provide the DOE Field Office with the data and information for tracking collective dose from year to year. However, only two of the contractors contacted indicated that they use the collective dose measurement that they report to DOE as an ALARA management tool.

DOE Field Offices, and to some extent contractor administrative offices, use collective dose measurements, along with a number of other measurements (such as injuries and lost work days) as an analog for risk in tracking the radiological protection organization's commitment to safety. Because the collective dose is often used as just one indication of the commitment to safety, the oversight agencies or administrative organizations understandably find it effective to reduce the results to the "bottom line." However, most Field Office representatives indicated that they prefer not to put as much emphasis on collective dose, but also consider aspects such as work planning, dose tracking and meeting ALARA goals for measuring radiological control performance.

The radiological protection organizations (based on conversations with contractor representatives) commonly find that unless there are methods in place to vary the collective dose goal based on the workload, the collective dose number did not have much meaning. The collective dose estimate that was part of the performance measure was found to relate more to the type and amount of work performed during the year rather than to any safety commitment. The radiological protection organizations also found that a single collective dose number is appropriate only for trending purposes and, in most cases, does not work as an ALARA management tool to assist in reducing doses.

The reality is that the radiological protection organization is often locked into a two-tiered system of using collective dose. First, it needs to respond to the contractual requirements for achieving the collective dose goal; second, it needs to ensure that the collective dose can be used to make improvements in health and safety techniques in order to enable the reduction of dose to workers. Some contractors indicated that in order to achieve the second goal, a more appropriate use of collective dose would be to examine or track the collective dose by facility or by job, thus providing more distinct feedback for planning and conducting future jobs in that or similar facilities.

In order to meet the needs of both DOE and the contractors' radiological protection organizations, an approach similar to that discussed for Contractor "B" in Section 5.2 may be appropriate. This would involve estimating a collective dose on a job-by-job basis. Usually, this would occur when the RWP is developed. Then, the actual collective dose that is received during the job would be determined. The performance measure would indicate the accuracy of collective dose estimates. This approach would alleviate the problems with variations in the amount of

work performed during the year as a result of new work being received or current projects being canceled. It also would provide a better means for using the collective dose estimates as an ALARA tool.

The total collective dose estimated for each project or task, as well as the assumptions that went into the estimation of the collective dose, would be determined. The dose estimates would be based on previous work that was similar in procedures, dose-rate levels and work areas. As each task or project is executed, if the assumptions on which the estimated collective dose is based prove to be in error, they can be reviewed and revised, with commensurate changes in the collective dose estimate. At the end of the project or task, the total collective dose received would be summed and compared to the original or revised estimate. The goal of the radiological protection program would be not to exceed the estimated collective dose in a specific percentage of the programs or tasks. An upper limit could be placed on the number of projects exceeding their collective dose estimates and the fraction by which they exceed the estimate. This would provide the DOE Field office with a single number to assess, and provide the contractor with the detailed information that they need to improve the ALARA program.

The primary disadvantage of this system is that since individual workers may work under many different RWPs, the TLD or dose of record cannot be used. Instead, the readings from the personal ionization chambers would be used to track dose on day-to-day activities (readings that are rarely equivalent to the TLD readings).

8.0 Findings, Conclusions and Recommendations

Collective dose is used here to mean the sum of all total effective dose equivalent values (defined in Title 10 Part 835 (10 CFR 835) of the Code of Federal Regulations, in Occupational Radiation Protection) for all workers in a specified group over a specified time. It is often used as a surrogate estimate of radiological risk. In principle, improvements in radiation protection programs and procedures will result in reduction of collective dose, all other things being equal.

8.1 Findings

Collective dose is one of the performance measures used at many DOE contractor facilities to quantitatively assess the objectives of the radiation protection program and to meet the requirements in DOE Order 210.1. DOE Field offices and, to some extent, contractor administrative offices, use collective dose measurements, and a number of other measurements (such as injuries and lost work days) as an analog in tracking the radiological protection organization's commitment to safety. Collective dose can also be used as a management tool to improve the program for keeping worker doses ALARA. Within the DOE, most frequently a single collective dose number is used as a performance measure for a contractor and may or may not be adjusted for workload and other factors.

In the literature, and among DOE contractors and DOE employees, there was the widespread belief that collective dose, if it has any value at all, is only one of many parameters to consider when assessing radiological protection programs.

However, based on information obtained in this study, collective dose is not considered by most contractors to be useful as an effective ALARA management tool since it is usually reported as a single number for all the contractors' facilities. For many organizations, the collective dose was found to relate more to the type and amount of work performed during the year rather than to the ALARA program.

8.2 Conclusions

Conclusion 1. Without adjustments for workload and other factors, collective dose is too simplistic to be valid as an ALARA management tool and performance measure.

- In practice, a single, unadjusted number is only appropriate for intragroup trend analyses.

- Even when the collective dose number is more facility- or building-specific, it is found that a cursory analysis is inappropriate since facility workloads and working conditions vary, and collective dose may go up when radiation protection improves, or even go down when attention to radiation protection is reduced. This may occur as the result of a change in the amount of work, in the experience level of employees, and in programmatic decisions to delay or accelerate work for financial reasons.

- Many sites indicated difficulties with the collective dose measure, especially if it was not adjusted for workload.

Conclusion 2. Collective dose is subject to possible "gaming," that is, it can be affected by deliberate actions that either do not improve radiation protection or even increase risk. Examples of gaming include inflating pre-job collective dose estimates so that actual performance looks good by comparison, performing low-dose work in the near-term while postponing high-dose work, doing less work, not including workers in monitoring programs, increasing detection thresholds (lower bioassay frequency, higher TLD frequency), and increasing reporting levels so that small doses and intakes are not recorded and reported.

This conclusion was supported by both DOE and contractor interviews. It was outside the scope of this project to document the existence of and/or the extent of such gaming within the DOE complex.

8.3 Recommendations

Recommendation 1. Express the performance measure as collective dose per unit work accomplished. In order to meet the needs of the oversight organizations and a contractor's radiological protection organization, this report recommends, at a minimum, expressing a collective dose performance measure as collective dose per unit work accomplished.

Recommendation 2. Project collective dose on a job-by-job basis. This report recommends prospectively estimating the collective dose on a job-by-job basis (often during the development of the RWP).

Recommendation 3. Use the weighted average, actual-to-projected collective dose ratio as an alternative performance measure. This report recommends, as an alternative to Recommendation 1, the ratio of the sum of the actual doses received during all radiological work for that year divided by the sum of all collective dose estimates required for the RWPs before each project or task is initiated (see Section 5.2).

- This weighted average, actual-to-projected collective dose ratio establishes a performance measure based on a comparison of the estimated (projected) collective dose before the work begins and the actual measured collective dose on each RWP.

- The goal of the radiation protection program is to stay within the estimated collective dose in a specific percentage of the programs or tasks.

- An upper limit is placed on the number of projects exceeding their collective dose estimates and the fraction by which they exceed the estimates.

- This performance measure provides a DOE Field Office with a single number to assess and the contractor with the detailed information that is needed to improve the ALARA program.

- The recommended goals of the program include not exceeding the estimated collective dose in a specific percentage of the programs or tasks or ensuring that the collective dose resulting from each program or task falls within a selected range (e.g., within 20% of the original dose estimate for that project or task).

- A threshold of collective dose, below which no tracking is done, may be needed for small projects.

Recommendation 4. Consider contractor actions as well as collective dose. Collective dose is only one aspect of a radiological protection program. Consideration should be given to contractor actions involving operations, radiation protection, and collective dose. Such actions could be rewarded, penalized, or seen to have no impact on radiation protection (see Table 1). These contractor actions might include

- managing the collective dose per unit work accomplished

- optimizing the timing of receiving collective dose, and offsetting worker dose with public dose

- making reasonable expenditures to avert dose

- optimizing the impact of workforce training and experience on collective dose

- balancing the equitable distribution of individual doses with needs for particular skills

- optimizing the impact of foresight and work scope

- postponing work

- improving or manipulating worker participation in personnel monitoring programs, and improving or manipulating detection thresholds of monitoring programs

- improving or manipulating the recording and reporting of personnel monitoring results

- setting realistic and challenging collective dose goals.

It is important to bear in mind that a contractor may take the overall best course of action and nonetheless incur an increase in collective dose because of overriding nonradiological considerations.

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Appendix A

List of Sites or Contractors Contacted

Appendix A: List of Sites or Contractors Contacted

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INEEL	Will Nees	(208) 526-8648
LANL	Paul Hoover	(505) 665-4691
LLNL	Dave Myers	(925) 422-5143
Nevada Test Site	Leonard Sygitowicz	(702) 295-5888
Oak Ridge:		
ORNL	Jerry Hunt	(423) 576-5117
Y-12 Plant	Rhonda Bogard	(423) 574-3539
Pantex	Roby Enge Jerry Martin	(806) 477-4435 (806) 342-9995
PNNL	Dave Higby	(509) 376-3057
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Appendix B

List of DOE Operations and Field Offices Responding to Survey

Appendix B: List of DOE Operations and Field Offices Responding to Survey

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	Paul M. Neeson	(708) 252-2258
	John Neuhoff	(630) 252-2492
	Berline S. Moore	(630) 840-4197
	James A. Buchar	(630) 252-2402
Idaho	Kenneth R. Whitham	(208) 526-4151
Nevada	David A. Hall	(702) 295-0157
Oakland	Michael J. Cornell	(925) 422-0138
Oak Ridge	Mark S. Robinson	(423) 576-7471
	Harold J. Monroe III	(423) 576-9439
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