

**An Approach to Determining the
Monetary Value of Collective Dose for Occupational Exposures**

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1. Background

A common technique used to determine which of several potential approaches to a radiological problem is best is cost-benefit analysis. Cost-benefit analysis seeks to determine the option with the minimum total cost where total cost is the sum of the monetary cost of the option and the monetary value of the collective dose. This requires that a monetary value of a unit of collective dose be established.

There are a number of problems associated with developing a monetary value of a unit of collective dose. One is that it requires establishing a value that is equivalent to establishing a monetary value for a human life, a complex and subjective undertaking that has not been satisfactorily addressed (and, perhaps, never will be). Another problem is accounting for the aversion that people have to the increased risk as the doses increase. Also, it is necessary to account for the non-health related detriment to an organization as the allowed exposure of their employees is used. For these reasons, there is no “right” answer to this problem; there is not even a consensus answer on how to approach the problem on calculating the monetary value of collective dose. At best there are answers that are defensible in that no one can think of a better way to do it. Therefore, the approach discussed below is an acceptable approach to determining a monetary value of unit collective dose, but is not a required approach.

The general approach taken to develop the monetary value of collective dose is to divide the problem into two parts and to approach each part separately. The two parts are the detriment related to potential health effects and the detriment not related to health. For flexibility of operations, a formula is developed for a single worker category, and a formula is developed for a value that would be appropriate for a group consisting of workers from several categories.

The development discussed in this review makes the resultant values appropriate for occupational exposure, and they may not be appropriate for exposures involving member of the public.

2. Acceptable Approach

This section presents the formulae to be used in calculating the monetary value of collective dose without explanation. A discussion of the bases for the formulae is given in section 3.

2.1 For a Category of Worker

For a single category of worker (for example, HPTs), an acceptable approach to determining the monetary value of collective dose (in dollars per man-rem) is to use the sum of \$4,000 and 2/3's of the average replacement cost for that category of workers. That is,

$$V_{UCD}(\text{category}) = \$4,000 + (2/3) R_{\text{org-cat}}$$

where,

$$V_{UCD}(\text{category}) = \text{value of unit collective dose for a category (dollars/man-rem)}$$

$$R_{\text{org-cat}} = \text{replacement cost in dollars for a member of an organizational category}$$

For example, if it cost \$39,000 to replace an HPT, the value of HPTs would be \$4,000 + 2/3(\$39,000) or \$30,000/man-rem.

It is up to the implementing organization to determine the average replacement cost for a category of worker. Ordinarily, this cost should include a consideration of the training cost, the cost of salary during the training period, relocation expenses, etc. However, there are various other factors that cannot be readily valued, such as effect on schedule and success of the project due to the loss of use of an experienced worker, or future claims against the company by a worker for health related effects due to dose received.

2.2 For an Organization with Several Categories of Workers

An acceptable approach for determining the monetary value of unit collective dose (\$/man-rem) is to use the sum of \$4,000 and two-thirds of the dose-weighted replacement cost for plant staff members. This dose-weighted replacement cost is calculated by first determining the fraction of the total organizational dose received by worker category for those categories that received significant exposure, and then multiplying these fractions by the average expected replacement cost for workers in each category, and then summing the products.

$$V_{ucd} = \$4,000 + 2/3 \sum_{org-cat} w_{org-cat} R_{org-cat}$$

where

V_{UCD} = monetary value of collective dose (\$/man-rem)

org-cat = categories of workers receiving significant dose (for example, operators and HPTs)

$w_{org-cat}$ = ratio of collective dose received by a category to the total collective dose for all categories used in the calculation

$R_{org-cat}$ = replacement cost for a worker in a given category

The value, once obtained, is to be applied to all individuals who do work for the organization, including contractors.

Example:

Suppose that almost all of an organization's collective dose is received by three departments: operations, maintenance and radiation protection. Assume that over a period of time long enough to damp out any short term anomalies that operations received 4.53 man-rem, maintenance received 5.11 man-rem and radiation protection received 3.50 man-rem, for a total of 13.14 man-rem. The weighting factor operations is then 0.34 (i.e., 4.53/13.14); for maintenance, 0.39; and for radiation protection, 0.27. Assume that the expected average replacement cost of individuals within the three organizations

are \$70,000 for operations, \$18,000 for maintenance, and \$40,000 for radiation protection. The dose-weighted replacement cost is then $(0.34)(70,000)+(0.39)(18,000)+(0.27)(40,000)$. Taking 2/3's of this value and adding it to \$4,000 yields \$31,747 or rounded to \$30,000 / man-rem.

3. Discussion

3.1 General Approach Taken

The general approach taken to determine the monetary value of collective dose is to divide the value into two parts: a part representing the health related detriment and a part representing the non-health related detriment. This is the basic approach recommended by PNL-6577, *Health Physics Manual of Good Practice for Reducing Radiation Exposure to Levels that are As Low As Reasonably Achievable* (see reference 1). As used here, the health related detriment is calculated using the so-called "human capital" approach adjusted for risk aversion due to higher doses; that is, people's increasing reluctance to accept additional risk (dose) as their level of risk (dose) increases. The non-health related detriment is based on the replacement cost for a worker if he can no longer do his job due to having a dose approaching the *de facto* limit (1.5 rem/year).

3.2 Detriment Associated with Potential Health Effects

The approach taken to determine the detriment associated with potential health effects is a modified form of the approach taken by Hardemann *et al* of the Belgian Nuclear Research Centre as described in reference 2. The Belgian approach is a further development of an approach developed by the French at their Nuclear Protection Evaluation Centre. The reader can study the method in detail by referring to this paper.

As used here, the expression describing the health related detriment has this form

$$2 \left[\left(\frac{\text{GDP}}{\text{ACE}} \right) L_{\text{UCD}} \sum_{\text{HD-cat}} w_{\text{HD-cat}} \left(\frac{D_{\text{HD-cat}}}{D_0} \right)^a \right]$$

where

GDP = U.S. gross domestic product for 1997 which was $\$7.636 \times 10^{12}$

ACE = U.S. average civilian employment for 1997 which was 129,558,000

L_{UCD} = expected lost work time due to health effects of 1 man-rem of collective dose which is about 0.01 year

HD-cat = Hanford dose categories, which are ranges of individual doses into which the Hanford workers in 1997 fall. For this expression, these categories are

1-100 mrem: 727 people: 0.65 of total
101-200 mrem: 140 people: 0.13 of total
201-500 mrem: 172 people: 0.15 of total
501-1000 mrem: 72 people: 0.06 of total

w_{HD-cat} = fraction of the total exposure of the Hanford population in the Hanford dose category

D_{HD-cat} = the upper limit of a range of a Hanford dose category

D_0 = the upper limit of the range of doses for which there is no risk aversion, 100 mrem

a = an exponent used to express the aversion to risk as the doses increase. The value is chosen to be 1.35 which is the value used by the Belgians in reference 2; this value is midway in the value range suggested by the French, 1.2 to 1.5.

The ratio GDP/ACE gives the average output per U.S. worker for the year 1997; the value was \$58,900 or about \$60,000. In the “human capital approach” (see below), this is the value of a human life. If this is multiplied by the statistical time lost due to death per man-rem (0.01 year), then this value, \$600, is the value of the health effects per man-rem, that is, the value of productivity lost due to death per man-rem of exposure. To determine a health related value for Hanford, this basic value is adjusted for the exposure pattern for Hanford workers for the year 1997. Plugging in the values into the summed term above, the resultant value is 3.64. The adjusted value for a man-rem, based on the 1997 exposures at Hanford, is then \$2,184 or about \$2,000 per man-rem. This value, \$2,000 per man-rem, includes terms only for the economic value of life adjusted for risk aversion as the site doses increase. No account is taken for the other, less tangible, cost resulting from radiation induced death such as pain, medical costs, hardship on dependents. To take some account of these other factors, the value is doubled (this accounts for the factor of 2 in the expression) so that the final value for the Hanford site for the health-related component is \$4,000 per man-rem.

Note that spending \$4,000 per man-rem is equivalent to spending \$10,000,000 to prevent a death. This follows from ICRP 60 paragraph 83 where the nominal lifetime fatality coefficient for a worker is given as $4 \times 10^{-2} \text{ Sv}^{-1}$.

Note: Two methods have been used to determine the monetary value of a human life in an attempt to obtain a value for collective dose: the “human capital” approach and the “willingness-to-pay” approach. The human capital approach says that a persons worth is equal to his contribution to the gross domestic product (or lost wages). In fact, the base value is usually determined by dividing the gross domestic product by the national population. This is obviously a low value since it ignores other relevant factors such as medical costs, hardship on others, suffering and the value most people place on life. The willingness-to-pay approach is based on the amount people are willing to pay to reduce the probability of premature death. This is a slippery idea, and one major effort to determine it yielded values that varied by a factor of 160. Neither of these approaches provides a good answer. Nevertheless, the human capital approach is used due to the lack of anything better. Both approaches are discussed in reference 3

3.3 Non-Health Related Detriment

The expressions determining the non-health related detriment are shown in sections 2.1 and 2.2 above for both a worker from an individual worker category (for instance, a maintenance worker) and for an average worker in an organization. The implementing organization's decision whether to use one or the other in a particular case is discussed in 3.5 below.

The non-health related detriment used here is just the replacement cost per man-rem if a worker's services are lost due to reaching the de facto limit of 1.5 rem for a year. Therefore, the replacement cost or the weighted replacement cost is multiplied by a factor of 2/3 (1 rem/1.5 rem) to reduce the cost for 1.5 man-rem to the cost per man-rem.

Note that no attempt has been made to account for the potential cost of future legal actions taken by people who have diseases that they attribute to radiation exposure at Hanford.

3.4 Total Monetary Value of Collective Dose

The total value for a unit of collective dose, in accordance with the approach used here, is described by this expression:

$$V_{UCD} = 2 \left[\left(\frac{GDP}{ACE} \right) L_{UCD} \sum_{HD-cat} w_{HD-cat} \left(\frac{D_{HD-cat}}{D_o} \right)^a \right] + \frac{2}{3} \sum_{org-cat} w_{org-cat} R_{org-cat}$$

where the factors in the expression are described above.

3.5 Use of Values for a Category of Workers and for an Organization with Several Categories of Workers

It is for the implementing organization to decide if, in a particular case, it is appropriate to use values for a category of workers or a general value for an organization comprising several categories. If, for a particular case, the dose is to be shared by several categories, a general value may be appropriate. However, if most of the dose is to be taken by a single group, particularly a category with high replacement cost, it is probably in the interest of the implementing organization to use the value for the exposed worker category.

