87
10/14/78
25 exp to XTIS

MASTER

UCID- 17925

Lawrence Livermore Laboratory

DEVELOPMENT OF RADIOLOGICAL PERFORMANCE OBJECTIVES
INTERIM RESULTS:
TRADE-OFFS IN ATTITUDES TOWARD RADIOACTIVE WASTE

MASTER

John W. Lathrop, Ed.

July, 1978

DEVELOPMENT OF RADIOLOGICAL PERFORMANCE OBJECTIVES,
INTERIM RESULTS:
TRADE-OFFS IN ATTITUDES TOWARD RADIOACTIVE WASTE

Lawrence Livermore Laboratory

July, 1978

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

1.0 Introduction

Lawrence Livermore Laboratory is developing a methodology for the generation of radiological performance objectives for the regulation of radioactive waste. Interim reports describing this work [1, 2] have been produced, and a final report will become available by November, 1978. As explained in [1] and [2], in order to measure the risk associated with radioactive waste it is necessary to ascertain public opinion concerning the relative significance of the different possible health effects of radiation, and public attitudes towards uncertainty.

Lawrence Livermore Laboratory has directed Decisions and Designs, Incorporated (DDI), to elicit such views from various members of the public. The purpose of this note is to give a brief account of some of the views so far obtained, provide some interpretation of these results, and briefly demonstrate how these results can be used to guide the drafting of regulations. Section 2.0 describes the views to be elicited and the procedure used in the elicitation. Section 3.0 presents some of the preliminary results. Section 4.0 contains comment and interpretation of these results and how they may be aggregated to produce a risk index for society. Section 5.0 briefly demonstrates how that risk index can be used in an example regulatory decision problem. Finally, Section 6.0 outlines work yet to be completed in the RPO development effort.

While this note is intended only as a brief update of interim reports [1] and [2], in order to orient the reader who has not read those reports, we include an extremely cursory review of the main points of the radiological performance objectives task:

1

109

The purpose of the task is to develop radiological performance objectives (RPO's) for guidance in the drafting of regulations for nuclear waste management. Those RPO's must be based on a risk index, a single number which describes the overall risk represented by a given waste management repository. This index has three essential purposes:

- (1) To order alternative repository designs in terms of their degree of risk. A description of the risk of a repository involves several uncertain measures which must be combined into a single index before one repository can be identified as less risky than another.
- (2) To identify efficient repository designs in terms of the least risk possible for a given expenditure.
- (3) To measure the reduction in risk afforded by a proposed regulation or change in regulation, so that that reduction can be compared with the cost of achieving it.

The methodology being exercised to produce this risk index is decision analysis (see [3]). The basic advantages of this methodology over others are:

- (1) It provides a formally correct way to include attitudes toward uncertainty in the evaluation of the uncertain impacts of a waste management repository. This feature can be used to assure that regulations concerning uncertain impacts are consistent with regulations on certain or routine impacts.
- (2) It incorporates the relevant social values in a structured, self-consistent manner that allows the measurement and use of values external to the NRC.
- (3) It reduces large amounts of very complex risk analysis information into progressively more simple summary indices, and finally into a single risk index, in a manner that is consistent with the values measured.

This memo should provide some insight into the "nuts and bolts" of how the decision analytic methodology employed in this task fulfills the purposes and achieves the advantages listed above.

2.0 Public Values in a Risk Index for Radioactive Waste

Many approaches to measuring risk have concentrated on the potential fatalities associated with an activity and on the probabilities of occurrence of those fatalities. This ignores, however, the many other deleterious consequences that are of public concern and the fact that the circumstances and timing of a death (or some other consequences) may alter its perceived importance. Categorizations of the consequences of a radiation dose which appear to be of public concern, and some circumstances in which the dose might arise, are outlined in Figures 2-1 and 2-2.

In order to determine the relative significance of these effects, value judgments have to be made. Since in this context the source of such values should be the public, DVI has been sounding key segments of public opinion in these matters. The spectrum of effects is large and complex, but a characterization of those effects has been established that, in some sense, spans the gamut of possible effects. It is complex enough to capture the range of concerns yet simple enough for it to be possible, within reasonable resources, to elicit the tradeoffs involved from scores of different people.

A second elicitation is the judgment of how much the government should pay to reduce these health effects, i.e., the judgment of how much we should expend to ensure adequate safety. Third, tradeoffs of the relative significance of effects as a function of the type of radiation exposure is necessary. Last, attitudes towards uncertainty are needed.

The report form used by the DVI investigator as an aide-memoir in the procedure of eliciting views from the public is enclosed here in the Appendix. (Note that the investigator filled out these forms during each interview. This was done to ensure that the questions were presented in a standardized manner.) Several assumptions about the preference structures have been made, and these are implicit in the form in which the views were sought. These include:

- (a) The relative importance of different health effects is independent of the levels of those effects or of the levels of any other health effects.
- (b) The relative importance of different health effects does not depend on whether the exposure is occupational or non-occupational, nor on the time at which the exposure occurs, even though the significance of a particular health effect may well depend critically on these circumstances of dose.

Figure 2-1. Categorization of Health Effects.

Figure 2-2. Categorization of Types of Radiation Exposure.

That is, if a fatal cancer is felt to be 50 times worse than a non-fatal cancer, that 50:1 value does not change with the numbers of cancers or other health effects involved. Nor does it change with the circumstances of the dose: a current fatal cancer is 50 times worse than a current non-fatal cancer and a future fatal cancer is 50 times worse than a future non-fatal cancer. Analytic approximations of this kind are essential if public values are to be incorporated into a risk measure. Justification of these approximations is contained in [1].

As can be seen from a study of the Appendix, when interviewing people the investigator first set this project in context and then endeavored to discover whether the subject had any general views on nuclear energy.

The relative importance of different health effects as perceived by the subject was discovered by first ranking the five typical effects (as specified on the card) in order of seriousness. Then for each adjoining pair on this list, the subject was asked how many cases of one effect was as bad as one case of the effect above it in the list. As a cross-check, the first and third and second and fifth effects were independently assessed in this way. Where there was inconsistency, the subject was asked to modify his assessments until they were consistent and he was satisfied that they represented his judgments. (Many of the subjects felt that a range of numbers, rather than a single number, would adequately represent their judgments of relative harm. This effect will be discussed in the final report of this study; in this note we will just present single numbers for the tradeoffs.)

Next the subject was asked how much money he felt the Government should be prepared to spend to prevent one case of a particular health effect. This was done for two different effects, again as a cross-check. The difference in importance of these effects, depending on the circumstances of the radiation dose that caused them, was then assessed by concentrating on one particular effect (a fatal cancer). First, the time dependency was investigated by asking how many deaths one thousand years from now were as bad as a death thirty years from now and a similar trade-off was made between deaths ten and one thousand years into the future.

The next step was to explore the occupational/non-occupational question. Again restricting attention to fatal cancers, the subject was asked how many such cancers caused by radiation to workers who knew and accepted the risk they were running, was as bad as a single fatal cancer inflicted on a member of the public.

Last, attitudes to uncertainty were explored by asking for indifference judgments between one sure death (fatal cancer) and a 1% and 50% chance of some number of deaths.

3.0 Some Preliminary Results

One of the sets of people interviewed was the advisory group, whose members were selected because of their knowledge of the problems of radiation and the respect that they enjoy in the community at large. This group of thirteen people was composed of eight members of the National Council on Radiation Protection Working Group on Acceptable Risk (Nuclear Waste), three members of a relevant government agency (not NRC), and two recognized authorities in fields relevant to nuclear safety. Their judgments (kept anonymous) are presented in Tables 3-1 to 3-5. The tradeoffs between health effects have been presented in Table 3-1 by expressing the significance of each effect as a multiple of the significance of the least important effect. Notice that this does not give any meaning to the absolute numbers in that table; it is only the ratios between effects that can be compared between subjects.

Table 3-2 presents judgments as to the amount of money that the Government should expend (in today's dollars) to avoid an instance (statistical) of one of these effects. The underlined figures in this table were obtained by direct elicitation (adjusted by the subject for consistency where necessary), while the other figures are inferred from Table 3-1.

Tables 3-3 and 3-4 present the tradeoffs as to the circumstances of the dose causing the effects. Table 3-3 deals with the time at which the dose is received and Table 3-4 with whether or not the exposure is occupational. Questions were only asked about one health effect, namely, a fatal cancer. Our methodology assumes that these tradeoffs between the circumstances of a dose will be the same no matter which health effect is considered; where this assumption was tested, it was shown to hold.

Subject No.	Quick Death	Fatal Cancer	Nonfatal Cancer	Mental Subnormal	Sterility
1	100	200	10	1,400	1
2	1	12	3.0	2.0	1.4
3	30	430	110	36	1
4	60	60	1	15	10
5	90	20	1	30	2.0
6	13	11	1.4	20	1
7	52	100	26	120	1
8	23,000	28,000	100	33,000	1
9	250	160	1	52	7.5
10	16	18	5.5	25	1
11	48	77	1	24	3.1
12	43	36	12	8.3	1
13	11,000	33,000	1,100	67	1

Table 3-1. Relative Importance of Health Effects.

Subject No.	Quick Death	Fatal Cancer	Nonfatal Cancer	Mental Subnormal	Sterility
1	<u>100</u>	200	10	1,400	<u>1</u>
2	<u>20</u>	<u>240</u>	60	40	28
3	<u>7</u>	<u>100</u>	25	150	4
4	<u>360</u>	360	<u>6</u>	90	60
5	<u>810</u>	180	<u>9</u>	270	18
6	<u>360</u>	300	38	540	<u>25</u>
7	150M	<u>300M</u>	77M	370M	<u>2.9M</u>
8	10B	<u>12B</u>	43M	14B	<u>500</u>
9	<u>3.5M</u>	2.2M	<u>15</u>	740	100
10	<u>330</u>	360	<u>110</u>	510	<u>22</u>
11	<u>380</u>	610	<u>8</u>	190	24
12	<u>8.6M</u>	7.2M	2.4M	1.6M	<u>200</u>
13	<u>1M</u>	<u>3M</u>	100	6	<u>1</u>

Table 3-2.

dollar values for preventing one instance of the effect occurring 30 years from now, as a result of a non-occupational risk.

(Thousands of dollars, except: M = million

B = billion)

Underlined figures are direct judgments. Other figures are implied using Table 3-1.

Subject No.	30 Years From Now	1,000 Years From Now	10,000 Years From Now
1	1	1	1
2	30,000	1,000	1
3	100,000	1,000	1
4	100	33	1
5	16	1.6	1
6	1	10	12
7	10	1	1
8	5,000	5	1
9	1.2	1.1	1
10	1	1	1
11	50	1.5	1
12	14	1.4	1
13	25,000	100	1

Table 3-3.

Relative importance of fatal cancers occurring at different times.

<u>Subject No.</u>	<u>Non-Occupational</u>	<u>Occupational</u>
1	1	1
2	1.2	1
3	5	1
4	2	1
5	5	1
6	1.4	1
7	10	1
8	4	1
9	1.4	1
10	5	1
11	12	1
12	5	1
13	3	1

Table 3-4.

Relative importance of occupational vs. non-occupational fatal cancers.

Finally, Table 3-5 presents attitudes toward uncertainty. Recognizing that many people do not view the expected number of a particular health effect to be an adequate risk measure (in that one death for sure may be judged worse than, say, a 1% chance of one hundred deaths), the subjects were asked for their own views on uncertainty. Specifically, they were asked how many deaths occurring with a 1% probability were as bad as one death occurring for sure, and the same question was asked when the probability was 50%.

4.0 Comment and Interpretation

These results are of interest just as they stand. For example, Table 3-1 shows that, contrary to the usual assumptions, some people do not view death as the principal cause for concern about the effects of radiation. Note that subject 1 feels that a mutation leading to mental subnormality is fourteen times as significant as a quick death. However, our more specific aim here is to exercise the methodology being adopted in this study for measuring risk.

As indicated in [1], the data on judgments collected from members of the public are to be used to construct a risk index for a nuclear waste repository. This involves the following steps:

(a) Construction of a value function.

In our representation of the consequences of a radioactive waste repository, every eventuality can be described by just twenty variables. These are the numbers of cases of the five different health effect measures of Figure 2-1, for non-occupational exposure in each of the three possible time periods (near future, during deposition - effects caused in the first two thousand years and effects caused after the first two thousand years) and for occupational exposure in the deposition phase. The value function for a single person is merely a weighted sum of these twenty variables, weighted according to the tradeoff assessments that he gave.

(b) Construction of a utility function.

The next step is to create a utility function for each individual which captures his attitudes towards uncertainty and his judgment as to the relative importance of consequences of different

NUMBER OF FATAL CANCERS
OCCURRING WITH PROBABILITY X,
JUDGED EQUIVALENT TO
ONE SURE FATAL CANCER

Subject No.	X = 1%	X = 50%	Coefficient of Uncertainty Aversion
			Corresponding to 1% Response*
1	100	2	0
2	100	1.9	0
3	700	2	.010
4	200	3	.0080
5	500	3	.010
6	100	2	0
7	100	2	0
8	35	10	-.053
9	100	1.9	0
10	250	4	.0090
11	100	2	0
12	120	1.5	.0032
13	1,000	4	.010

Table 3-5. Attitudes Toward Uncertainty.

*This variable will be explained in Section 4.

severity. This is essentially a modification of the scale of the value function, designed so that an uncertain situation can be evaluated by its expected utility, the expectation over the utilities of the possible outcomes (as opposed to the expected value, the expectation over un-rescaled values of the possible outcomes). This utility function incorporates aversion or preference for uncertainty in a logically self-consistent manner, as explained in [3].

(c) Aggregation of utility functions from different subjects.

To establish a utility function which represents public opinion, individual utility functions must be aggregated. There are many difficult methodological issues here which have not yet been fully resolved; these will be addressed in the final reports on this study. For exemplification of our methods here, however, we shall use an approach involving a weighted sum of utilities. The weights are adjusted so that the contribution to overall utility from a single instance of the most significant effect (in the judgment of any subject) is the same across subjects.

(d) Calculation of risk index.

The risk index can now be calculated by multiplying the utility for any particular outcome (i.e., a set of values for the twenty descriptive variables) by the probability of that outcome and summing over all probability-outcome products.

To carry out the calculations outlined above, we must first calculate the value function for each subject. For example, consider subject number 5. Arbitrarily setting to 1 the weight associated with his most significant effect (Quick Death), his weights for Fatal Cancer, Non-Fatal Cancer, Mental Sub-Normality, and Sterility cases are (from Table 3-1) .22, .011, .33, .022, respectively. Relative to a non-occupational health effect 30 years from now, the weights for subject 5 of an occupational health effect, an effect 1,000 years from now, and an effect 10,000 years from now are (from Tables 3-3 and 3-4) .20, .10, and .062, respectively. Thus, the value function for subject 5 is:

$$\begin{aligned}
 v_5(\underline{x}) = & x_{11} + .22x_{12} + .011x_{13} + .33x_{14} + .022x_{15} \\
 & + .20x_{21} + .044x_{22} + .0022x_{23} + .067x_{24} + .0044x_{25} \\
 & + .10x_{31} + .022x_{32} + .0011x_{33} + .033x_{34} + .0022x_{35} \\
 & + .062x_{41} + .014x_{42} + .00069x_{43} + .021x_{44} + .0014x_{45},
 \end{aligned} \quad (1)$$

where x_{ij} is the number of health effects of type j caused by radiation exposure type i , for:

$i = 1 :$	30 years, non-occupational	$j = 1 :$	Quick Death
$= 2 :$	30 years, occupational	$2 :$	Fatal Cancer
$= 3 :$	1,000 years from now	$3 :$	Non-Fatal Cancer
$= 4 :$	10,000 years from now	$4 :$	Mentally Sub-Normal Child
		$5 :$	Sterility

The next step is to fit a utility function to each subject's judgments about uncertainty. The general form for this function to be used in this study is a simple rescaling of the value function. For the k^{th} subject:

$$\begin{aligned}
 u_k(\underline{x}) &= 100 \frac{1 - e^{-a_k v_k(\underline{x})}}{1 - e^{-100a_k}}, & a_k \neq 0 \\
 u_k(\underline{x}) &= v_k(\underline{x}), & a_k = 0.
 \end{aligned} \quad (2)$$

This function is normalized to be zero when $x_k(\underline{x})$ is zero, and to be 100 when $v_k(\underline{x})$ is 100. The single parameter, a_k , is fitted in this case to each subject's 1% uncertainty response as reported in Table 3-5. That parameter is the person's coefficient of uncertainty aversion. If a_k is negative, $u_k(\underline{x})$ is convex downward (on $v(\underline{x})$) and so models aversion to uncertainty. That is, such a function will discount uncertain outcomes to reflect the attitude of a person who would, for example, prefer 10 fatalities for sure to a 5% chance at 200 fatalities. A positive a_k indicates preference for uncertainty. A zero a_k indicates indifference to uncertainty, where all a person cares about is the expected value of the outcome. These values for a_k are listed in the last column of Table 3-5. For subject number 5, then:

$$u_5(\underline{x}) = 100 \frac{1 - e^{-.01v_5(\underline{x})}}{1 - e^{-1}} \quad (3)$$

Note that, of the thirteen people reported on here, six are averse to uncertainty, six are indifferent to uncertainty, and one prefers uncertainty (among choices of equal expected value).

The third step is to aggregate these utility functions across people to achieve a single, group utility function. The method employed in this memo for calculating an aggregated utility for a group of subjects involves adding utility functions across subjects. This ensures that a scenario giving just one instance of the health effect viewed as most significant by each subject has the same effect on the public utility. This property holds because of the way the utility and value functions have been constructed. Using the Table 3-b and Equation (2), we can define the aggregate utility function, $U(\underline{x})$:

$$U(\underline{x}) = v_1(\underline{x}) + v_2(\underline{x}) + 158(1 - e^{-0.01v_3(\underline{x})}) + 181(1 - e^{-0.008v_4(\underline{x})}) \\ + \dots + 368(1 - e^{-0.0032v_{12}(\underline{x})}) + 158(1 - e^{-0.01v_{13}(\underline{x})}). \quad (4)$$

One criticism of this aggregation scheme is that it may seem to give unequal influence to the views of various subjects. Any method for aggregating values will have some difficulties. The problem is a classic one in the field of social choice (see [4] and [5]). The method for aggregation of utility functions that will be recommended in the final report on this study may differ from the simple sum used here. The final aggregation method is currently being developed for Lawrence Livermore Laboratory by Stanford Research Institute, International.

The last step is to apply the utility function of Equation (4) to measure the risk of a repository. The risk index of a repository is simply the expected utility of the uncertain outcomes caused by the repository. That is, the risk of repository D_q , $R(D_q)$, is:

$$R(D_q) = \sum_i p(\underline{x}_i | D_q) \cdot U(\underline{x}_i), \quad (5)$$

where $p(\underline{x}_i | D_q)$ is the probability that the set of health effects $\underline{x}_i$ will occur given that repository D_q is built. This risk index is on an arbitrary scale, so it is not possible to provide units for it. But it has been calculated in such a way that (i) any other repository with the same value for the risk index should be viewed as equally bad by our group of subjects, and (ii) any repository with a higher value for the index is more risky (and conversely any repository with a lower value is less risky) than the repository we have been considering.

We can, however, interpret the value of this risk index in terms of a repository of a standard (although unrealistic) kind. Imagine a repository, D_0 , which is absolutely safe, in the sense that no health effects of any kind occur at any time, except for a one in a hundred thousand chance of a number of quick deaths to workers during the deposition phase. What is the number of such deaths produced by this hypothetical repository such that its risk index is equal to the risk index of the repository being evaluated? That number represents a rescaling of the risk index in more meaningful terms: equivalent current occupational fatalities, $\hat{x}_{21}$. In mathematical terms, $\hat{x}_{21}$ is such that:

$$R(D_0(\hat{x}_{21})) = R(D_q) \quad (6)$$

or:

$$10^{-5} \cdot U(0,0,0,0,\hat{x}_{21},0,0, \dots,0) = \sum_i p(\underline{x}_i | D_q) U(\underline{x}_i) \quad (7)$$

or:

$$\hat{x}_{21} = U^{-1}[10^5 \sum_i p(\underline{x}_i | D_q) U(\underline{x}_i)], \quad (8)$$

where U^{-1} is the inverse function of U into its x_{21} argument, all other arguments zero.

In order to illustrate this evaluation procedure, we will step through a hypothetical numerical example, evaluating a repository, D_q , characterized by the very simple (and purely hypothetical) probability distribution given in the D_q columns of Table 4-1. [It is simple since in reality there will be a joint probability distribution over all 20 variables for each repository. In fact this example may create some confusion which we ought to attempt to avoid. It is normal when thinking of risk to consider the chances that a particular event has of occurring, such as the probability that a meteorite

Probability that this Particular Set of Consequences (or Scenario) will Occur	Repository D _q		Repository D _s *	
	Scenario A	Scenario B	Scenario C	Scenario D
	A 10 ⁻⁶	B 10 ⁻⁸	C 10 ⁻⁵	D 10 ⁻⁹
Occupational Effects				
Quick Death	0	2	4	10
Fatal Cancer	3	5	6	30
Non-Fatal Cancer	2	10	4	20
Mentally Sub-Normal Child	4	20	1	5
Sterility	10	25	6	25
Non-Occupational Effects				
During Deposition				
Quick Death	0	1	0	4
Fatal Cancer	0	2	1	8
Non-Fatal Cancer	1	5	1	6
Mentally Sub-Normal Child	2	6	0	1
Sterility	3	10	1	7
In the First 2,000 Years				
Quick Death	0	1	0	0
Fatal Cancer	0	6	0	20
Non-Fatal Cancer	3	10	0	15
Mentally Sub-Normal Child	10	25	0	5
Sterility	20	50	0	22
After 2,000 Years				
Quick Death	0	0	0	0
Fatal Cancer	20	30	1	50
Non-Fatal Cancer	20	40	1	40
Mentally Sub-Normal Child	100	70	0	10
Sterility	30	100	0	45

Table 4-1. Characterization of the Consequences of Two Alternative Repositories.

*To be discussed in the next section.

will hit the repository. The probabilities in Table 4-1 however are attached to whole scenarios of possible events that may befall a waste repository; these will be compounded of several different events, each with their consequent health effects. Thus, even with only a few events possibly occurring in each of the different time phases very many scenarios will result. To keep the example simple, however, we have only included two such scenarios for each repository described in Table 4-1; but we stress that this does not imply that we are imagining some one event (with probability 10^{-6} or 10^{-8}) which will causally lead to all the effects listed in one of the columns in Table 4-1.]

Because the numbers in Table 4-1 are purely hypothetical, these example calculations will only use the values of the first five subjects. The first step in evaluating repository D_q is the calculation of $v_k(x_i)$ for each subject and each scenario. Using Equation (1), subject 5 is found to have values of 4.0 for Scenario A and 9.0 for Scenario B. Similar calculations for each of the subjects result in the figures for the value functions displayed in the D_q rows of Table 4-2. Now the utility for each subject for each scenario can be calculated, using functions of the form of Equation (2) with the parameters a_k given in Table 3-5, and the arguments v_k of Table 4-2. These utilities are displayed in the D_q rows of Table 4-3.

Now the group utility for each scenario can be calculated, using the aggregation method adopted for this report, by simply taking the row sums of Table 4-3. This yields a utility of 142.1 for Scenario A, and 198.4 for Scenario B. It may seem that subject number 1 has been given a greater weight because of that person's larger utility values in Table 4-3, caused largely by that person's lack of time discounting and occupational risk discounting. However, what matters to any analysis is not the absolute value of the utilities, but the differences between alternative options. Now note that in fact, if Scenario A were being compared with Scenario B, subject 1 would have a difference in utility between the two that is less than that of two of the five subjects.

Now the risk index for repository D_q , $R(D_q)$, can be calculated by simply taking the expected utility:

$$10^{-6} \cdot 142.1 + 10^{-8} \cdot 198.4 = 1.44 \cdot 10^{-4}. \quad (9)$$

		Subject No.				
		1	2	3	4	5
Repository D_q	Scenario A	119.5	5.3	1.2	6.5	4.0
	Scenario B	127.9	17.2	5.8	23.2	9.0
Repository D_s	Scenario C	2.45	9.32	7.67	11.94	5.89
	Scenario D	37.76	49.17	38.61	60.79	21.90

Table 4-2. Evaluation of the Value Functions for Each Subject and Each Scenario, Repositories D_q and D_s

		Subject No.				
		1	2	3	4	5
Repository D_q	Scenario A	119.5	5.3	1.9	9.2	6.2
	Scenario B	127.9	17.2	8.9	30.8	13.6
Repository D_s	Scenario C	2.45	9.32	11.70	16.56	9.04
	Scenario D	37.76	49.17	50.72	69.96	31.09

Table 4-3. Utility Values for Each Subject and Each Scenario, Repositories D_q and D_s

As explained before, this index is useful in that it can rank repositories in terms of risk, but it cannot scale risk or changes in risk in meaningful terms. To do that involves the assessment of equivalent current occupational fatalities (or some other single dimension), using the reference repository D_0 as presented before. It turns out that, for a scenario in which there are 12 occupational fatalities but absolutely no other health effects of any kind, the group utility is 14.2. A reference D_0 with a 10^{-5} chance at that scenario (and no other accident scenarios) would have a risk index of $1.42 \cdot 10^{-4}$, approximately equal to $R(D_q)$. Consequently, the equivalent current occupational fatalities measure for D_q is 12 with a probability 10^{-5} .

Note that the expected number of fatalities for repositories D_q and D_0 differs. For repository D_q , it is $23 \cdot 10^{-6} + 47 \cdot 10^{-8}$, i.e., $2.35 \cdot 10^{-5}$; for the standard repository D_0 it is $12 \cdot 10^{-5}$. The risk indices are the same, however, indicating that despite the expectation that the standard repository will produce over five times the deaths of the other repository, they are evaluated as equally dangerous by this group of subjects. The reasons for this are: (a) effects other than fatalities are held to be very significant, (b) occupational deaths are not thought to be as serious as non-occupational deaths, and (c) the subject's are not indifferent between prospects at different probabilities but the same expected result (as indicated by Table 3-5).

A risk index constructed in the way outlined above can now be used to compare repositories as to risk, or to determine whether a proposed repository exceeds a pre-determined risk level. When rescaled in terms of equivalent current occupational fatalities (or any other single dimension), the risk index can be used to measure the magnitude of a risk reduction brought about by a proposed regulation in terms that can be meaningfully compared with the incremental cost of the regulation.

5.0 An Example Decision Analysis of a Regulatory Decision

The previous sections have presented some preliminary data and explained the simple math that goes into the evaluation process. This section will step through a brief hypothetical example to illustrate how the risk index can be used in regulatory decisions.

Suppose a new regulation is being considered that would require an increased waste packaging effort over what would happen otherwise. The point of this new regulation would be to reduce long term social risk. However, a comprehensive risk analysis might show that the new regulation has safety implications for the pre-seal phase that might be important. Suppose that the risk analysis found that the new regulation would ensure that any repository to be built would have a probability distribution over consequences like the extremely simple one of repository D_s presented in Table 4-1. If the new regulation were not implemented, the existing regulations would result in a repository like D_q in Table 4-1. It bears repeating that the actual probability distributions over outcomes to be produced in a risk analysis would be far more complex than the two-scenario hypothetical numbers of Table 4-1.

The first question to ask is: Which repository is more safe? That is: Does the new regulation increase safety? It seems like a very simple question, but an examination of Table 4-1 will show that the answer to that question must involve value tradeoffs and a particular attitude toward uncertainty. If these value inputs are not stated explicitly, then they are implicit within the judgment of which repository is safer. The new regulation does seem to reduce long term risk, but by increasing the pre-seal handling of nuclear waste, it causes an increase in short term risk. A further confusing factor is the difference in probabilities of the various scenarios. The only way to decide which repository is more safe is to reduce the risk evaluation down to a scalar (a single number), either implicitly or explicitly. That, of course, is the purpose of the risk index methodology explained previously in this note.

Applying the individual value and utility functions to scenarios C and D yields the numbers in the D_s rows of Tables 4-2 and 4-3. The utilities sum across people to 49.1 for Scenario C, and 239 for Scenario D. This leads to the risk index $R(D_s)$:

$$10^{-5} \cdot 49.1 + 10^{-9} \cdot 239 = 4.91 \cdot 10^{-4}. \quad (10)$$

This is much higher than the risk index for repository $D_q : 1.44 \cdot 10^{-4}$. This evaluation shows that, using the aggregated values of these five people, the proposed regulation decreases the overall safety of the repository. This analysis would recommend against the adoption of the new regulation.

But now suppose that we have a new regulation that does manage to decrease risk. Perhaps without the new regulation repository D_s results, and with it D_q results. Now the question becomes: Does the regulation reduce risk enough to justify its incremental cost? That question can be answered by calculating the equivalent current occupational fatalities associated with each repository. For D_q that number is 12 occupational fatalities at a 10^{-5} probability. For D_s we calculate 43 such fatalities at a 10^{-5} probability. That is a difference of 31 lives saved at a 10^{-5} probability. Similar calculations show that $12 \cdot 10^{-5}$ occupational fatalities for certain yields a risk index equal to $R(D_q)$, and $41 \cdot 10^{-5}$ such fatalities for certain yields an index equal to $R(D_s)$. Either mode of measurement yields about $30 \cdot 10^{-5}$ equivalent occupational lives saved by the new regulation. At $\$10^6$ per occupational life saved that makes the regulation worthwhile if it costs less than $\$300$ per repository to implement.

Note that the D_s repository has $12 \cdot 10^{-5}$ expected fatalities (of all types), while D_q has $2.4 \cdot 10^{-5}$ such expected fatalities, taking straight expectations without using the value model. That yields about $10 \cdot 10^{-5}$ expected lives saved by the new regulation, a number quite different from the $30 \cdot 10^{-5}$ equivalent occupational lives saved using the value model. That difference reflects the importance of non-fatal health effects, the discounting of occupational lives, and attitudes toward uncertainty.

This example may have overemphasized a "plug and crank" use of the decision analytic evaluation methodology. It should be stressed that the methodology is best used as a means for condensing very large and complex sets of risk analysis data into summary indices. These indices can provide guidance and support in the drafting of regulations in a way that can be shown to be consistent with the aggregate values of the people elicited.

6.0 Future Work

Three main sections of work remain to be completed in the course of the current contractual effort, to be completed by November, 1978. First, the final method of aggregation of values must be decided upon and implemented. Second, the data from the advisory group, the polarized group, and the general group (already collected) must be processed into risk indices in the manner described in this report, and then developed into radiological performance objectives. Finally, the entire evaluation methodology will be exercised on example repositories, described in terms of probability distributions over outcomes, in a demonstration of the interaction between the RPO work and the rest of the Lawrence Livermore risk analysis effort.

Looking beyond the current contractual period, more work needs to be done on the elicitation and aggregation of values. While the current work succeeded in eliciting values from the appropriate people, much more work needs to be done to increase the soundness and defensibility of the values elicited. The question of how to elicit well-considered and stable value information remains a central problem with any approach that seeks to evaluate social risk.

A second major future effort should be directed at the meshing of this evaluation methodology with the process of regulation development. This effort would be directed at taking advantage of the power of the methodology to process large amounts of information into a smaller set of decision-focused indices, so that the decision makers could have a more manageable and structured data base upon which to base their decisions.

REFERENCE

- [1] Watson, S. R., An Index of Hazard for Radioactive Waste (Revised). Interim Technical Report PR 78-10-BUR, Decisions and Designs, Incorporated, McLean, Virginia, June, 1978. UCRL #13868.
- [2] Lathrop, J. W., "Measuring Social Risk and Determining Its Acceptability," presented at Workshop on Environmental Standard Setting, International Institute of Applied Systems Analysis, Vienna, Austria, May 3, 1978. To appear in proceedings of that workshop. UCRL #81060.
- [3] Keeney, R. L., and Raiffa, H., Decisions with Multiple Objectives: Preferences and Value Tradeoffs, Wiley, New York, 1976.
- [4] Arrow, K. J. "Current Developments in the Theory of Social Choice," Social Research, Vol. 44, No. 4, Winter, 1977.
- [5] Harsanyi, J. C., Rational Behavior and Bargaining Equilibrium in Games and Social Situations, Cambridge University Press, 1977.

APPENDIX A

Decisions and Designs Inc. (W.O. 80.13)

Purpose: To find out how the people of this country feel about health dangers of radiation from nuclear waste. Gov't is sponsoring this study so decisions on how to handle nuclear waste will reflect the values and priorities of the American public.

Name _____

Date _____

Home place _____

AG _____

You were asked to participate because ET _____

-> OCCUR _____

___ (General panel:) Picked up information? Where? What?

___ (P or P panel:) How did you get interested in nuclear waste policies? How become involved in _____ group?

___ First a Q about your gen. views on nuclear energy: On the whole, do you favor or oppose nuclear energy development, or have you not yet decided? Favor_____ Oppose_____ Undecided_____

Are you undecided because you have not given it much thought or because the advantages and disadvantages seem about equal?

Little thought_____ +-- about equal_____

Though you haven't yet decided, are you presently leaning slightly toward favoring or opposing nuclear energy development?

Favor_____ Oppose_____ Neither_____

___ The rest of my Qs deal only with nuclear waste storage and health. Hope public values will also be studied in broader decisions.

___ GIVE CARD DESCRIBING HEALTH EFFECTS

These are some of the serious health effects that could result...

___ I will ask for your personal views about how bad each one is, and how much effort should go into avoiding each effect. Not techn. knowledge, so no right or wrong answers, just your opinions.

___ Unknown persons; gov't decisions; what should gov't do.

___ Consider effects on victim personally, friends, family, society; weigh all these together

___ Ask me Qs any time--change your answers any time.

At the end, your reactions to what we are doing. Ready?

Assume these radiation effects
are to people who just happen
to live in the area.

Name _____

Which of these 5 effects is worst?

§

Reasons

_____	1. (Worst)	1. _____
_____	2. <input type="text"/>	2. _____
_____	3. <input type="text"/>	3. _____
_____	4. <input type="text"/>	4. _____
_____	5. <input type="text"/>	5. _____

1-3

2-5

Suppose only 2 reasonable plans for storing rad.waste. One costs more but would save 10 more lives in the next 50 years. After that the plans are equally safe. How much more should the country pay to save 10 more lives?

Prompts:
Questions
Reasons

Death in: 30 yrs 1k yrs 10k yrs

worse

Death of: Person living in area Employee who knows risks

(pers, fam & society)

worse

One sure death = 1% chance of _____ deaths

= 50% chance of _____ deaths

100% 25 yrs from now
at one time and place

100% at different times
& places spread over
the next 50 yrs.

(equal media
exposure &
public
awareness)

Card Describing Possible Health Effects and
Presented to Elicitees

EXAMPLES OF POSSIBLE HEALTH EFFECTS OF EXPOSURE TO RADIATION

Quick death. Waste radiation causes quick death (within 30 days) to a person at age 40.

Fatal cancer. The victim gets a cancer at age 40, is somewhat ill (Minor pain and discomfort) for 3 years, then very ill for one year, then dies.

Non-fatal cancer. The victim (age 40) is moderately ill with some pain, discomfort and worry for 5 years, though functioning normally most of the time, then recovers completely and lives a normal life thereafter.

Mentally subnormal child. The radiation causes a genetic mutation in a parent who, as a result, has a child who is below normal mentally. All his/her life the child needs some special care, has to go to a special school, can only hold a paying job that is simple manual work; but can do most other routine life activities adequately. The child does not marry so there is no effect on future generations.

Sterility. The radiation causes a young woman to become permanently sterile so she can have no children, though she would like to have had children.