6

PNL-2678
UC-11

# Use of Benefit-Cost Analysis in Establishing Federal Radiation Protection Standards: A Review

L. E. Erickson

October 1979

Prepared for the U.S. Department of Energy
under Contract EY-76-C-06-1830

W. N. Thomasson, Project Monitor
Office of Technology Impacts

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

PNL-2678

Battelle

## NOTICE



PACIFIC NORTHWEST LABORATORY
*operated by*
BATTELLE
*for the*
UNITED STATES DEPARTMENT OF ENERGY
*Under Contract EY-76-C-06-1830*

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy $____*; Microfiche $3.00

| *Pages | NTIS Selling Price |
|---|---|
| 001-025 | $4.00 |
| 026-050 | $4.50 |
| 051-075 | $5.25 |
| 076-100 | $6.00 |
| 101-125 | $6.50 |
| 126-150 | $7.25 |
| 151-175 | $8.00 |
| 176-200 | $9.00 |
| 201-225 | $9.25 |
| 226-250 | $9.50 |
| 251-275 | $10.75 |
| 276-300 | $11.00 |

PNL-2678
UC-11

# USE OF BENEFIT-COST ANALYSIS IN ESTABLISHING FEDERAL RADIATION PROTECTION STANDARDS: A REVIEW

Prepared by L. E. Erickson

October 1979

Prepared for the
U.S. Department of Energy
Assistant Secretary for Environment
Office of Technology Impacts
under Contract No. EY-76-C-06-1830

W. N. Thomasson, Project Monitor

Pacific Northwest Laboratory
Richland, WA 99352

## ACKNOWLEDGMENTS

This paper was prepared as part of a project sponsored by the Office of Technology Impacts (OTI), Office of the Assistant Secretary for Environment, U.S. Department of Energy. Neill Thomasson, the project monitor for OTI, provided helpful comments.

Helpful comments on various parts of a draft of this report were also provided by Bruce Wachholz of the Office of Technology Impacts, U.S. Department of Energy, and by D. L. Hessel, C. L. McDonald, R. F. Foster, and P. L. Hendrickson of Battelle's Pacific Northwest Laboratory.

Suresh Malhotra and Michael Morrisey of Battelle's Human Affairs Research Centers prepared a draft of the review of approaches to valuing lives saved, which forms the bulk of the chapter on "Valuing Health and Safety Benefits." Their work was sponsored by the Office of Standards Development of the U.S. Nuclear Regulatory Commission. The Commission required that the following disclaimer be included with acknowledgment of this support:

# SUMMARY

This paper complements other work which has evaluated the cost impacts of radiation standards on the nuclear industry. It focuses on the approaches to valuation of the health and safety benefits of radiation standards and the actual and appropriate processes of benefit-cost comparison.

A brief historical review of the rationale(s) for the levels of radiation standards prior to 1970 is given. The tolerance dose concept was prevalent in the early recommendations of the National Council on Radiation Protection and Measurement (NCRP) and the International Commission on Radiological Protection (ICRP). The nonthreshold assumption and the philosophy that actual radiation exposures should be "as low as practicable" (ALAP) have governed the radiation standards-setting process since World War II.

Using this ALAP philosophy, the Nuclear Regulatory Commission (NRC) (formerly AEC) established numerical design objectives for light water reactors (LWRs) in Appendix I to Title 10 of the Code of Federal Regulations, Part 50 (10 CFR 50). The process of establishing these numerical design criteria for ALAP below the radiation protection standards set in 10 CFR 20 is reviewed. Before Appendix I to 10 CFR 50 was finalized in 1975, the Environmental Protection Agency (EPA) was well along on the preparation of its 40 CFR 190 environmental radiation protection standards for the uranium fuel cycle. The decision process used by EPA to set these standards is reviewed and compared to NRC's approach.

EPA's standards may or may not be more stringent than NRC's. EPA's 40 CFR 190 environmental standards for the uranium fuel cycle have lower values than NRC's radiation protection standards in 10 CFR 20. However, NRC's design objectives for LWRs given in Appendix I to 10 CFR 50 provide numerical design criteria for ALAP below the 10 CFR 20 standards. EPA's environmental standards in 40 CFR 190 for the uranium fuel cycle are slightly above NRC's Appendix I to 10 CFR 50 design objectives for LWRs. The task of allocating EPA's 40 CFR 190 standards to the various portions of the fuel cycle was left to the implementing agency, NRC. So whether or not EPA's standards for the uranium

fuel cycle are more stringent for LWRs than NRC's numerical design objectives depends on how EPA's standards are implemented by NRC. Radiation standards are implemented by NRC through the technical specifications agreed upon by NRC and nuclear facilities licensees.

In setting the numerical levels in Appendix I to 10 CFR 50 and 40 CFR 190 NRC and EPA, respectively, focused on the costs of compliance with various levels of radiation control. Both agencies compared these costs to the expected dollar value of benefits associated with the respective health risk reductions. Neither agency devoted much effort to valuing these benefits, and neither agency discounted future values of health effects benefits before comparing them to the discounted future compliance costs. Steps to improve both of these aspects of the analysis are suggested.

A major portion of the paper is devoted to a review and critique of the available methods for valuing health and safety benefits. All current approaches try to estimate a constant value of life and use this to value the expected number of lives saved. This paper argues that it is more appropriate to seek a value of a reduction in risks to health and life that varies with the extent of these risks. Additional research to do this is recommended.

CONTENTS

## FIGURES



## TABLES

## INTRODUCTION

This paper was prepared as part of a project, sponsored by the Technology Assessment Division of the Office of Technology Impacts of the U.S. Department of Energy (DOE), to evaluate the impacts of radiation standards on the nuclear power industry. Other parts of this project have: 1) explored ways of estimating the costs to the industry of complying with radiation standards (Schulte et al. 1978) and 2) surveyed the costs and impacts of radiation standards on the nuclear reactors (McDonald 1979). It was concluded from these other parts of this project that the differences among the NRC, EPA, and industry estimates of compliance costs were small enough that these differences would not significantly alter radiation standards selected using benefit-cost analysis. Because of this, the effort reported in this paper to examine the methods of valuing the benefits of radiation standards and of performing the benefit-cost tradeoffs was initiated.

The purposes of this paper are 1) to develop an understanding of how benefit-cost analysis has been used in establishing radiation standards, 2) to identify areas where improvements in this use of benefit-cost analysis can and should be made, and 3) to develop a better understanding of the rationale(s) behind the current radiation standards established by the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA). This work may be useful to DOE in interacting with NRC and EPA in the process of developing future radiation standards.

Many environmental, health, and safety regulations have been developed in the last decade. This has also been an active period in the development of Federal radiation protection standards, and much of this paper focuses on this recent period. However, the basic philosophy for the establishment of radiation standards dates back a few decades. Therefore, a short chapter summarizing this historical background is included before turning to the development of the current Federal radiation standards by NRC and EPA.

While it is widely accepted that radiation standards should be "as low as practicable," it is also widely recognized that in order to determine what level of radiation standards meets this rule, the costs of controlling radiation must be balanced against the health and safety benefits of doing so. However, implementation of this philosophy has been hindered by the difficulties in measuring these benefits. Therefore, a major chapter of this paper is devoted to reviewing issues and literature related to valuing health and safey benefits. This provides the basis for the recommendations given for improvements in the process of establishing Federal radiation protection standards.

## CONCLUSIONS AND RECOMMENDATIONS

Occupational radiation protection standards were established long before public radiation protection standards. When public limits on radiation exposures were set, a percentage of the previously established occupational limits was often used. The occupational limits were first established at a radiation level believed to be too low to cause any immediately observable biological reactions in individuals working with radiation.

In the 1940s, when the seriousness of the delayed biological effects of large doses of radiation were recognized, the conservative assumption that no threshold for biological effects existed was adopted. Once the nonthreshold assumption was established, it was recognized that radiation standards that would eliminate all health risks could not be established unless all operations that might cause some exposure were terminated. At this time, recommendations of the National Council on Radiation Protection and Measurement (NCRP) and the International Commission on Radiological Protection (ICRP) began to be based on the pholosophy that actual radiation exposures should be limited to levels which were "as low as practicable" (ALAP).

Comparing benefits and costs of additional controls thus became a necessary part of establishing radiation standards consistent with the ALAP philosophy. However, the process of doing this has remained largely a qualitative comparison. NRC, EPA, and others have conducted detailed analyses of 1) the costs of achieving additional reductions in radiation doses through the use of various radiation control devices and 2) the radiation dose reductions expected to occur. While the health and safety benefits of reduced radiation risks have been estimated, little attention has been devoted to the assessment of the value of the benefits associated with the reductions in risks of radiation-induced disease. Both EPA and NRC have selected constant monetary values for these benefits, but their numerical values differ, and neither is based on as thorough a scientific foundation as the cost estimates.

Administratively, NRC (formerly AEC) followed the recommendations of the NCRP and ICRP in establishing radiation protection standards for the public

(10 CFR 20) along with the admonition that actual exposures be controlled to the ALAP level below these standards; numerical guidelines for design objectives for Light Water Reactors (LWRs) to achieve this ALAP level were later specified in Appendix I to 10 CFR 50. EPA, on the other hand, apparently established its standards f40 CFR 190) at the level that they thought were ALAP.

While NRC reported establishing their numerical design objectives for LWRs using benefit-cost analysis, and EPA reported establishing their environmental standards for the uranium fuel cycle (UFC) using cost effectiveness analysis, there is little difference between their approaches. The philosophy that radiation doses to the public should be maintained at a level which is "as low as practicable" seems to govern the decision process for all the regulatory agencies and advisory bodies involved.

The key difficulty in implementing the philosophy that radiation releases should be "as low as practicable" has been the quantification and valuation of the benefits of reduced risks to health and life. Current approaches to valuing health and safety benefits all try to estimate a single "value of life." These approaches use 1) observed behavior on risk/dollar tradeoffs to get implicit values, 2) explicit value statements, and 3) estimates of future earnings foregone to get productivity measures of the value of life. This paper argues that it is more appropriate to speak of the "value of changes in risks to health and life" and that both the "value of life" and the value of changes in risks to health and life vary with the extent of these risks. [See pp. 55-56, and 37-38) Therefore, research is recommended to estimate the value of changes in risks to health and life as a function of several variables rather than to estimate the value of life as a constant.

Neither NRC nor EPA discount their estimated value of the benefits. NRC annualizes costs and compares these costs to the undiscounted benefits. EPA calculates a total present value of costs and compares this to undiscounted benefits summed over a 100-year period. This paper argues that the value of both benefits and costs should be discounted to get a valid benefit-cost comparison. (See pp. 32-34.)

The process of setting radiation standards could be improved in the short run by making better use of benefit-cost analysis or some other formal decision analysis procedure (Erickson et al. 1978). This should include using value of life estimates derived from explicit statements or implicit in observed risk/dollar choices for as similar risk levels and changes in risk as possible and discounting both benefit and cost values in the same way. Data similar to the low probability-high consequence events currently relevant in public radiation standards-setting are likely to be scarce, however.

To further improve the radiation standards-setting process in the future, the following types of research are recommended:

1. Focus on determining the "value of changes in risk to health and life" as a functional relationship of several variables rather than the current approach of attempting to determine the "value of life" as a constant.
2. Use surveys to obtain direct responses on how much people would be willing to pay for additional reductions in risk to their health and safety.
3. Explore the issues of intertemporal comparisons of benefits and costs, including such questions as the discounting of genetic effects and the influence of irreversibility on the present value of future benefits and costs.

Such issues must always be addressed, at least implicitly, in setting health and safety standards; the recommended research would allow more explicit treatment of them.

## HISTORICAL BACKGROUND

### OCCUPATIONAL EXPOSURE STANDARDS

Over most of its history, radiation protection has been concerned primarily with occupational rather than public exposures (Taylor 1973, p. 1). Radiation protection standards for the public have been frequently derived as fractions of the previously established occupational limits. Therefore, this section reviews the historical development of occupational exposure standards.

The imnediate biological effects of radiation were noticed almost as soon as x-rays were discovered by Roentgen in 1896 (Parker 1977). Attempts to avoid exposures large enough to produce the immediately observable effects began soon after this. Skin erythema (reddening of the skin similar to sunburn) was the most imnediately observed biological effect. In the 1920s, it was reported that the amount of radiation necessary to cause this effect was about 400-650 roentgens (R) per year; this was called the threshold erythema dose (TED) (Kustner 1927).

This kind of threshold evidence formed the basis for the 1934 "tolerance dose" recommendations for radiation workers issued by the National Council on Radiation Protection and Measurement (NCRP) and the International Commission on Radiological Protection (ICRP). Their recomnendations were about 5% (0.1R/day) and 10% (0.2R/day) of the reported TED levels, respectively (Taylor 1973, p. 7). These levels were apparently intended to protect radiation workers from <u>any</u> biological effects of occupational exposure to radiation, although some (e.g., Wintz and Rump 1931) cautioned that "the tolerance dose is never a harmless one." Parker (1977, p. 22) claims that "the issue is a semantic one, because in comnon English parlance, tolerance implies a capacity to accept a pain detriment, whereas the medical usage specifically refers to ability to endure effects without showing unfavorable effects."

In the 1940s, the serious delayed biological effects of large doses of radiation were recognized (e.g., March 1944). The possibility of delayed somatic carcinomas (cancers) and genetic effects led to the current view that the potential delayed consequences were too great to continue to assume that a threshold or tolerance dose existed.

In 1949, the NCRP circulated a draft report recommending a Maximum Permissible Dose (MPD) of 0.3 rem/week, below which they further recommended that radiation exposures be kept "as low as practicable" (ALAP). The final version of this report was issued as NCRP Report Number 17 in 1954. This report claimed to be the first radiation protection guidance to assume that any level of radiation exposure may have some risk of biological effects associated with it. While the terminology and the numerical radiation standards have been modified since that time, this report was the first statement of the modern philosophy of radiation protection.

Once it was recognized that the only way to insure that no risk resulted from radiation was to ban all activities that might result in some exposure, it was seen that radiation protection criteria could not depend only on physical and biomedical considerations. Thus, value judgments balancing the risks associated with any degree of radiation exposure and the benefits associated with the activity that would entail this level of exposure were first recognized as an indispensable part of the process of establishing radiation protection criteria.

In 1956, two reports were issued that provided a better understanding of the genetic effects of radiation. These reports by the British Medical Research Council (MRC) and the National Academy of Sciences (NAS) prompted the NCRP to lower their recommended numerical values for MPD in 1957 from 0.3 rem/week to 5 rem/year for individual radiation workers and 10% of this (0.5 rem/year) for individuals in the genera? population (NCRP Report Number 39, 1971).

PUBLIC EXPOSURE STANDARDS

During the 1950s and early 1960s public concern about fallout from nuclear weapons testing caused a shift in emphasis from occupational to public radiation standards. During this period also, the Federal Radiation Council (FRC) was formed (in 1959; Public Law 86-373) to provide a consistent Federal policy on human radiation exposure limits. Beginning in 1960 the FRC adopted Radiation Protection Guides (RPGs) which were based on a qualitative balance between the net benefits from commercial activities involving radiation and the risks associated with radiation exposure (FRC 1960). These RPGs were generally consistent with the recommendations of the NCRP (1954 and 1957) and ICR? (1959) but were approved by the President for the guidance of Federal agencies and, thus, had greater legal force than the NCRP and ICRP recommendations.

While these RPGs were consistent with the NCRP (1957) recommendation that exposures to individual members of the public be limited to 0.5 rem per year (10% of the occupational limit), they went on to recommend that this be achieved by limiting whole-body exposure of average population groups to 0.17 rem per year. This assumed that "the majority of individuals do not vary from the average by a factor greater than three" (FRC Report No. 1, 1960). These RPGs were also consistent with the ICRP (1959) recommendation that the average exposure of the gonads of the population should not exceed 0.17 rem per year from conception to age 30. The FRC further recommended that every effort be made to encourage the maintenance of radiation doses "as far below this level as practicable" (FRC 1960).

The FRC (1964) also introduced the term Protective Action Guides (PAGs). The numerical values for the PAGs were higher than for the RPGs because the PAGs were aimed at acute, unplanned releases of nuclear material such as nuclear fallout from bomb testing or power-plant accidents rather than chronic, routine releases such as from normal operation of nuclear facilities. The PAGs assumed that introduction of nuclear material into the environment had already occurred and were intended to provide guidance as to when to institute countermeasures to reduce the exposure of the population to these radioactive materials, either directly or through the food chain (FRC Report No. 5, 1964).

The philosophy that radiation risks should be balanced against the reasons for accepting exposure led to "acceptable risk" values, which varied according to the extent of the reasons for accepting these risks and the costs of controlling them; again, the PAGs were higher than the RPGs. During Congressional hearings on the PAGs, Dr. Paul C. Thompkins, Executive Director of the Federal Radiation Council, stated that these recommendations provided the American public with "ample, not just adequate protection" (p. 91); evidently he felt that the benefits of the standards exceeded the costs. While **it** is clear that a qualitative balancing of benefits and risks was considered important in the establishment of PAGs and RPGs, no formal benefit cost analysis or other formal decision analysis techniques were attempted.

The first nuclear power plants began to operate during this period of concern about protection of the public from radiation exposure due to fallout from nuclear weapons testing. Also during this period the Atomic Energy Commission (AEC) established "permissible levels of radiation in unrestricted areas" in 10 CFR 20.105 and "limits on radioactivity in effluents to unrestricted areas" in 10 CFR 20.106 and Appendix B to Part 20. The AEC in 1960 affirmed the 1957 recommendation of the NCRP that the maximum dose to individuals in the genera1 population, that is in the unrestricted areas, should be limited to 0.5 rem per year (10 CFR 20.105). The NCRP had chosen this figure because **it** was 1/10 of the "annual permissible occupational dose (5 rems) for the whole body, head, trunk, active blood-forming organs, or gonads" (NCRP Report No. 43, p. 117, emphasis added). This is the same level adopted by the Federal Radiation Council in 1960.

Detailed tables of maximum permissible concentrations (MPCs) of radioactive isotopes in air and water effluents from LWRs are contained in Appendices B and C to 10 CFR 20. These tables were abstracted from recommendations of the NCRP (1959) and ICRP (1959). These recommendations were in turn related to the overall maximum permissible dose recommendations through a series of complex dose calculations. These calculations estimated the total doses resulting from various isotopes in air breathed and water ingested (internal emitters) based on biological information on how long each isotope would stay in the body and in what organs **it** might be deposited. In adopting these NCRP and ICRP recommendations, the AEC made the conservative assumption that effluents from power plants might be directly breathed or ingested by the public.

In summary, while the radiation standards existing at the beginning of the nuclear power age were not developed using benefit cost or other formal decision analysis approaches, some qualitative comparison of benefits and risks was involved. Further, there was general agreement on the numerical standards. Both the AEC and FRC standards generally agreed with the NCRP and ICRP recommendations.

# NRC'S APPROACH TO NUMERICAL GUIDELINES FOR ALAP FOR LWRs (APPENDIX I TO 10 CFR 50)

As discussed in the previous chapter, in the 1960s the AEC had adopted many of the same numerical standards recommended by the NCRP and adopted by the FRC. However, it was not until December of 1970 that the AEC firmly established the ALAP philosophy that actual radiation exposure of individuals in unrestricted areas should be as far below the numerical limits established in 10 CFR 20.105 and 10 CFR 20.106 as practicable. This means "as low as is practicably achievable taking into account the state of technology, and the economics of improvement in relation to benefits to the public health and safety and in relation to the utilization of atomic energy in the public interest" (10 CFR 20.1 and 10 CFR 50.34a). At this time the AEC began to focus on design objectives for nuclear power reactors as an approach to insuring that exposures of individuals in unrestricted areas be kept as low as practicable (10 CFR 50.34a and 10 CFR 50.36a).

While these new paragraphs to 10 CFR 50 provided qualitative guidance for those applying for licenses to build and operate nuclear power plants, they did not provide numerical criteria for determining when design objectives and operations met the ALAP requirement, In fact, prior to this time no one had thought that numerical criteria corresponding to ALAP were necessary; rather, numerical limits were established, along with the admonition that below these limits radioactive effluents and exposure of individuals to radioactivity be kept "as low as practicable" (ALAP). In 1971 the AEC announced its intentions to establish such numerical criteria for ALAP to provide more concrete design objectives for LWRs. Hearings began in 1972 and the decision was released in 1975 after the establishment of the Nuclear Regulatory Commission (40 FR 19439). While the NRC announced the decision, all of the hearings were conducted and testimonies received by its predecessor, the AEC. This chapter focuses on the development of the NRC's numerical criteria for ALAP as given in Appendix I to 10 CFR 50.

ENVIRONMENTAL STATEMENT (WASH-1258)

On June 9, 1971, the AEC published its proposed numerical guidance for ALAP for LWRs in the Federal Register. These proposed guidelines were about 1% of the previously established FRC Radiation Protection Guides for the general public. These guidelines were design objectives which were intended to provide "reasonable assurance" that exposures of persons in unrestricted areas would be less than or equal to 5 millirem per year per person for any organ or the whole body as a result of liquid, gaseous, and particulate emissions. Beyond these design objective guidelines, the AEC left applicants the option of demonstrating that other techniques or technology could be used to insure this (Section II-C of the draft Appendix I to 10 CFR 50). The AEC produced an Environmental Statement on this proposed rule-making action which is a key source of information on the thinking behind these proposed standards for ALAP for LWRs (WASH-1258, July 1973).

These proposed guidelines for ALAP for LWRs provided for action by the Atomic Energy Commissioners in the event that the "estimated annual quantities or concentrations of radioactive material in effluents are likely to exceed a range of 4 to 8 times the design objective quantities" previously noted (Section III-B of the draft Appendix I to 10 CFR 50). Should this occur the Commission would take "appropriate action to assure that such released rates are reduced." Thus, Appendix I does not establish rigid standards for radiation exposure to the public; rather, it provides numerical design guidelines for ALAP for LWRs below the previously established permissible levels of radiation in unrestricted areas (10 CFR 20.105).

The AEC recognized that the level of radiation dose which is "as low as practicable" depends on the balancing of costs of the incremental reductions in radiation dose against the benefits of reduced risks to human life and health and that both costs and benefits "should be expressed in commensurable units such as dollars." However, a formal benefit-cost analysis was not conducted because they felt that it was not possible to value the benefits of reductions in risks to human life and health (WASH-1258, p. 1-27).

The AEC staff reviewed the technical alternatives for rad-waste control and determined both the costs and the resulting radiation exposure levels associated with these technical alternatives. As one might expect, they found that successive increments of reduction in radiation exposure could be achieved at increasing increments of cost (Table 1-3 and Table 1-4 on pp. 1-34 and 1-32, respectively, and Section 8 of WASH-1258).

While a formal comparison of the costs of reducing radiation risks with the benefits of reducing such risks was not performed, it does appear that the benefit values ranging from $10 to $980 per man-rem reported in the hearings (WASH-1258, Vol. 1, pp. 1-28) did influence the AEC staff's recommended numerical ALAP guidelines. Consider, for example, the guidelines for liquid effluents (WASH-1258, Vol. 1, pp. 8-4 to 8-8). According to the dose calculations of the AEC staff for the technical alternatives considered, both boiling water reactors (BWRs) and pressurized water reactors (PWRs) were found to be capable of meeting the ALAP guidelines at a cost of less than $800 per man-rem for all but one of the combinations of alternative sites and cooling options. (The one exception to this genera1 statement is a PWR at a seashore location.) When these same numerical guidelines for liquid effluents are applied to gaseous effluents (WASH-1258, Vol. 1, pp. 8-9 to 8-13), the staff found that BWRs could essentially meet these guidelines at a cost of less than $700 per man-rem. PWRs could not meet this same gaseous effluent ALAP guideline at a cost anywhere near this range for any of the alternative sites considered. However, the AEC staff reported that preliminary data showed that a significant fraction of the radioactive iodine from LWRs was in organic forms that would permit the thyroid doses estimated to result from ingestion of locally-produced fresh milk to be significantly reduced. If these estimated thyroid doses could be reduced enough, it appears from the AEC staff calculations that there would be PWR alternatives that could meet the ALAP guidelines within the range of costs noted earlier (WASH-1258, Vol. 1, pp. 1-53 to 1-54).

In addition to this rough benefit-cost comparison that seems to have influenced the AEC's guidelines, a design objective guide value of 1% of the

Radiation Protection Guides applicable to individual members of the public may have sounded conservative, and was also consistent with the precedent of establishing new radiation standards by reference to previously established radiation standards. Both, the FRC and the AEC had originally based their standards for individual members of the public on the NCRP and ICRP recommendations. (FRC's Radiation Protection Guides appear as Federal Radiation Council Reports Numbers 1 and 2, and the AEC standards for individual members of the public appear as 10 CFR 20.105.)

EPA provided comments to the draft Environmental Statement on the proposed Appendix I to 10 CFR 50. In these comments, EPA made two general claims: 1) the cost of rad-waste treatment had been in some cases overestimated by the AEC, and 2) the risks of radiation exposure and health effects resulting from such exposure had been in some cases underestimated by the AEC. However, the EPA did not challenge the rationale behind the establishment of the guidelines for ALAP in Appendix I to 10 CFR 50 (WASH-1258, Vol. 3, pp. 254-309). Also, comments by the Atomic Industrial Forum did not dispute the general rationale or approach to the problem of establishing ALAP guidelines but did differ with some of the particulars of the calculations (WASH-1258, Vol. 3, pp. 96-110).

NRC OPINION (DOCKET NO. RM-50-2)

While it is based largely on the recommendations of the NRC (formerly AEC) staff, the NRC Opinion that was issued at the time of the announcement of the Commission's decision on Appendix I of 10 CFR 50 provides a clear statement of the philosophy of radiation protection underlying this section of the code. (Commission Opinion, Docket No. RM-50-2, May 5, 1975; a summary appears in 40 FR 19439-19443.) Here the Commission makes clear that the standards in 10 CFR 20 for protection against radiation remain unchanged by this decision. These radiation protection standards of the Commission are based on the Radiation Protection Guides of the Federal Radiation Council, which are in turn based on the parallel recommendations of the NCRP and ICRP. The Commission expressed the belief (p. 6) that "any biological effects that might occur at the low levels of these standards have such low probability of occurrence that they would escape detection by present day methods of observation and measurement." Thus, rather than lowering the standards given in 10 CFR 20.105, the Commission was subscribing to the general principle previously recommended by the NCRP and ICRP that, within the established radiation protection standards, radiation exposures to the public should be kept "as low as practicable," where the meaning of this term is defined in 10 CFR 50.34a as previously noted. Appendix I to 10 CFR 50 is intended to provide the guidance of the Commission regarding compliance with this ALAP philosophy in the design of LWRs.

The key provisions of Appendix I to 10 CFR 50 may be summarized as follows:

- The estimated annual dose from radioactive materials in liquid effluents to any individual in an unrestricted area should not be more than 3 millirem to the total body or 10 millirem to any organ.
- The annual dose of radioactive materials from gaseous effluents to any individual in an unrestricted area should not be more than 5 millirem to the total body or 15 millirem to the skin.
- The annual total dose from radioactive iodine and radioactive material in particulate effluents should be not more than 15 millirem to any organ.
- If any additional rad-waste equipment can be added to reduce the exposures to the general population within 50 miles of the reactor at a cost less than or equal to $1,000 per total body man-rem and $1,000 per man-thyroid rem, then these devices should be added. (Section II, Appendix I to 10 CFR 50, 40 FR 19442.) It was not specified what year's dollars were to be used or how these costs were to be calculated. These dollar values were originally intended to be interim values, but currently there are no plans to change them.

The primary focus of the ALAP numerical guidelines for LWRs was the protection of near neighbors of the reactor. However, the Commission felt that the provision for the addition of more rad-waste equipment when this could be done at a cost of less than $1,000 per man-rem protected the general public more effectively than these exposure guidelines (Commission Opinion, pp. 52 and 53). The Commission also expressed the opinion that the exposures resulting to an individual in unrestricted areas near a cluster of nuclear power plants could not under these ALAP guidelines receive more than 5% of the radiation standards specified in 10 CFR 20, and that actual doses would normally be appreciably less than this (Commission Opinion, p. 63).

While the NRC regulatory staff suggested that a cost-benefit balance in terms of dollars was a useful way of determining when radiation doses to the general public met the ALAP criteria, they were reluctant to select a dollar value for man-rem reductions in population dose (WASH-1258). The NRC staff did calculate the cost of reductions in population dose on a dollar per man-rem basis, but they left to the Commission the decision of a dollar value of a man-rem reduction on population dose and the extent to which this should be given weight along with other considerations in the ALAP ruling (Hearing transcripts, pp. 3472-73 and Comnission Opinion, p. 86). The Commission's selection of $1,000 per man-rem follows the lead of the Consolidated Utility Group (Commission Opinion, pp. 86-88). This figure was selected to be slightly larger than the range of values cited in the Final Environmental Statement (WASH-1258) and in the hearing transcripts (Commission Opinion, p. 87).

In the section discussing the selection of the numerical values themselves, the Commission was apparently influenced by the testimony of Dr. Walton A. Roger on behalf of the Consolidate Utility Group (Commission Opinion, pp. 64-76). Dr. Roger used $1,000 per man-rem for the value of the benefits of reducing radiation risks. The Commission appears to have used this benefit value along with the cost per man-rem calculations of the NRC staff to reach their numerical values for Appendix I and also to establish a basis for evaluating additional rad-waste equipment beyond these values.

Another factor which probably influenced the Commission's decision on these numerical values was the belief that most operating LWRs already met the ALAP numerical guidelines (Commission Opinion, p. 114). Further, these are design objective guidelines, and operating flexibility is provided in addition to them (Commission Opinion, p. 105). The Commission would not take action against licensees violating these guidelines unless they were violated by a rather large amount, as discussed earlier. Thus, these guidelines are not absolute operating limits. The combination of the operating flexibility written into Appendix I and the Commission's belief that most operating LWRs already met the ALAP guidelines suggests that the Commission must have thought that compliance with the promulgated ALAP guidelines would not mean much change in design or operating practices on the part of the nuclear industry.

The Commission stressed that while compliance with the provisions of Appendix I automatically means that the behavior of the licensee would be judged acceptable, the converse is not true. That is, if the licensees did not comply with the provisions of Appendix I their behavior would not necessarily be unacceptable (Commission Opinion, p. 124). These individuals would be free to demonstrate compliance with the philosophy of ALAP by the use of benefit cost analysis in their own applications for license (Commission Opinion, p. 142).

Although the ALAP terminology has been replaced by ALARA (as low as reasonably achievable), this change in terminology does not affect the substance of the foregoing discussion.

# EPA'S APPROACH TO ENVIRONMENTAL RADIATION PROTECTION STANDARDS FOR NUCLEAR POWER OPERATIONS (40 CFR 190)

The Environmental Protection Agency (EPA) was established in December of 1970 and assumed many responsibilities for protection of the environment from other Federal agencies. In the radiation protection area the EPA assumed the broad guidance responsibilities of the former Federal Radiation Council and the more explicit responsibility of establishing generally applicable radiation standards for the environment from the Atomic Energy Commission. Reorganization Plan No. 3, which established the EPA and transferred these responsibilities, defined these generally applicable environmental standards as "limits on radiation exposures or levels, or concentrations or quantities of radioactive material outside the boundaries of locations under the control of persons possessing or using radioactive material."

Under this authority the EPA, on May 10, 1974, announced its intent to propose standards for the uranium fuel cycle. On May 29, 1975 the EPA published in the Federal Register these proposed standards along with some discussion of the rationale for them; the Draft Environmental Statement on the proposed action was also issued at this time. Public hearings were held March 8-10, 1976, and the Final Environmental Statement was released on November 1, 1976. The final version of the standards was published in the Federal Register on January 13, 1977.

## EPA'S PROPOSED STANDARDS

The EPA's proposed environmental radiation protection standards for nuclear power operations are shown in Table 1. These standards were intended to supplement the existing Federal Radiation Protection Guidelines limiting maximum exposure of the general public by providing "more explicit public health and environmental protection from potential effects of radioactive effluents from the uranium fuel cycle during normal operation" (40 FR 23420). Revisions of the Federal Radiation Protection Guidelines themselves were postponed because EPA believed that a detailed examination of each major activity contributing to public radiation exposure was required prior to such

TABLE 1. EPA's Proposed Standards for Normal Operations of the Uranium Fuel Cycle

| | | |
|---|---|---|
| A. | Individual Dose Limits | |
| | 1. Whole body | 25 mrem/yr |
| | 2. Thyroid | 75 mrem/yr |
| | 3. Other organs[a] | 25 mrem/yr |
| B. | Limits for Long-Lived Radionuclides | |
| | 1. Krypton-85 | 50,000 Ci/GW-yr |
| | 2. Iodine-129 | 5 mCi/GW-yr |
| | 3. Transuranics[b] | 0.5 mCi/GW-yr |
| C. | Variances | |
| | At the discretion of the regulatory agency (licensor) for temporary and unusual operating circumstances to insure orderly delivery of electrical power. | |
| D. | Effective Dates | |
| | Two years, except 1983 for krypton-85 and iodine-129 | |

(a) Any human organ except the dermis, epidermis, or cornea.
(b) Limited to alpha-emitters with half-lives greater than one year.

Source: EPA, 1976, Vol. I, Table 8, p. 70 and 40 FR 23421.

revisions. The numerical values of these EPA standards are about a factor of 20 lower than the existing Federal Radiation Protection Guidelines and NRC's 10 CFR 20 standards.

These proposed EPA standards were the first to include limitations on long-lived fission and activation products defined as those whose half-lives are greater than one year (40 FR 23421). The standards for long-lived radionuclides focus on limiting the quantity discharged, while the standards for short-lived effluents concentrate on the maximum individual annual dose rate (EPA, 1976, Vol. I, p. 69). The standard of 75 mrem/yr to the thyroid was chosen "to reflect a level of biological risk comparable, to the extent that current capability for risk estimation permits, to that represented by the standard for dose to the whole body" (40 FR 23422).

Responsibility for the establishment of radiation protection standards for nuclear power operations rests with EPA, but responsibility for their implementation and enforcement rests with NRC. This division of responsibilities between EPA and NRC posed a potential source of tension between the two agencies. However, EPA expressed the opinion that the guidance for design objectives provided by NRC in Appendix I to 10 CFR 50 would provide "an appropriate and satisfactory implementation of these proposed environmental radiation standards for the uranium fuel cycle with respect to light water cooled nuclear reactors utilizing uranium fuel" (40 FR 23423).

The EPA followed the NCRP, ICRP, FRC and NRC in assuming a linear non-threshold dose-effect relationship. They also agreed that acceptance of such an assumption implied that radiation protection standards cannot be established by merely attempting to minimize the health effects of radiation. Thus, the EPA states that their proposed standards "generally represent the lowest radiation levels at which the agency has determined that the costs of control are justified by the reduction in health risk" (40 FR 23421). Such a balancing approach was seen as necessary because "there is no sure way to guarantee absolute protection of public health from the effects of a non-threshold pollutant, such as radiation, other than by prohibiting outright any emissions" (40 FR 23421). EPA termed this balancing approach "cost effectiveness" analysis.

## FINAL ENVIRONMENTAL STATEMENT ON 40 CFR 190

In EPA's Final Environmental Statement (FES) on their "environmental radiation protection requirements for normal operations of activities in the uranium fuel cycle," EPA characterized their standard-setting method as "a process of cost effective health risk minimization" (EPA, 1976, Vol. I, p. 28). However, EPA's actual process of selecting their standards can best be understood by looking at Section V-A of the FES: "Model Projections of Fuel Cycle Environmental Impacts" (EPA, 1976, Vol. I, pp. 37-52). This section summarizes the earlier work done by EPA on "Environmental Analysis of the Uranium Fuel Cycle," which provides information both on the health effects expected to result after the implementation of various control technologies and on the cost of these technologies.

The expected future health effects are summed without being discounted over a 100-yr period, while the control costs are presented in present worth terms. EPA's Figures 3 and 4 indicate that as additional radiation control devices are added, the cost of obtaining successive increments of radiation control increases, as one would expect (EPA, 1976, Vol. I, p. 39 and p. 49). EPA notes that these costs increase more rapidly at a present value of about $3 million per GW of power capacity for the entire fuel cycle for PWRs and about $8 million for BWRs. At these cost levels the cost of reducing additional expected future health effects is roughly $500,000 per health effect avoided (EPA, 1976, Vol. I, p. 48).

This extensive analysis of the cost of controlling additional health effects of radiation is important to determining acceptable radiation exposure levels. However, an equivalent amount of effort has not been devoted to determination of a similar relationship between the health effects of radiation and the benefits of controlling these effects. EPA does state that "most current estimates of the acceptable limiting rate of investment for the prevention of future loss of life appear to fall at or below an upper limit of one-quarter to one-half million dollars" (EPA, 1976, Vol. I, p. 51). However, the sources of the benefit estimates quoted apparently already incorporated other individuals' judgnents as to the balancing of costs of control of radiation-induced health effects and the value to society of these effects. Thus, these estimates do not reflect solely the benefits of reduced risks to health and life.

Nevertheless, EPA's measure of the value of these benefits appears to be between $100,000 and $500,000 per health effect averted. All potential health effects, including cancer, leukemia, and serious genetic effects, are equally valued. EPA claims that its $100,000 estimated cost per health effect of the proposed controls on long-lived radionuclides is equivalent to $75 per man-rem. The EPA was criticized for not making more explicit the source of whatever benefit measure was used in the derivation of these standards.

Indeed, the Energy Research and Development Administration [ERDA, now The Department of Energy (DOE)] claimed that these standards were actually set on the basis of what technology was expected to be commercially available rather than by some comparison of health effects averted to the control costs (EPA, 1976, Vol. II, p. A234). Another critic pointed out that if benefit cost analysis had been used to set the standards, lower standards would exist where the costs of reducing health effects of radiation were lower.

EPA emphasized that "most of the reduction in potential health effects required by these standards comes as a result of the reduction of environmental releases of long-lived materials" (EPA, 1976, Vol. I, p. 93). (This is partly because the world population is used to calculate these health effects since the long-lived radionuclides are dispersed throughout the earth's atmosphere.) Thus, the EPA standards "impose increased control requirements principally on effluents that can deliver doses to very large populations over long periods of time, instead of in areas where short-term doses to only a relatively few individuals near facilities can occur" (EPA, 1976, Vol. I, p. 93). The principal cost impacts of EPA's standards on the nuclear industry were expected to be about 10% increase in capital costs for fuel reprocessing plants. These costs are principally to remove krypton-85 from fuel reprocessing effluents. The present value of these controls at reprocessing facilities was estimated to be "approximately $30 million, or $0.7 million per gigawatt (electric) of fuel cycle capacity served" (EPA, 1976, Vol. I, p. 95).

## COMPARISON OF NRC AND EPA APPROACHES

The previous two chapters described the NRC and EPA approaches to controlling radiation risks. The present chapter compares these approaches and identifies areas where they differ. This emphasis on the differences between them should not obscure the fact that they are basically similar: Both apparently concur with the radiation protection philosophy that has been generally accepted for the last three decades, namely, that actual radiation risks should be kept "as low as practicable" (ALAP) or "as low as reasonably achievable" (ALARA). Both also apparently accept the concept that to find the ALAP or ALARA level requires some balancing of the costs of controls and the benefits of reduced radiation risks. Both have concentrated on estimating the costs of controlling radiation to various possible levels and the health effects expected to result from these various possible levels of radiation doses. Both have devoted comparatively little attention to the question of what the benefits of reduced radiation risks to health and life are worth. Both assume that these benefits can be adequately described by a constant average dollar benefit value that does not depend on the level of radiation risks, and that is not expressed in any specific year's dollars. Beyond these basic similarities, there are some important differences which are discussed in the remainder of this chapter.

### APPLYING THE ALAP PHILOSOPHY

NRC established radiation protection standards in 10 CFR 20 and recommended that actual radiation releases be kept ALAP below these standards. In doing this they were consistent with the intent of the previously established policies of the NCRP, ICRP and FRC of calling for ALAP actual releases below the standards given or recommended. Later NRC took the new step of providing numerical criteria for ALAP for LWRs, but they did this without changing their basic standards. So NRC has 10 CFR 20 radiation protection standards plus Appendix I to 10 CFR 50 numerical design guidelines for ALAP for LWRs below these.

Although agency officials have not said so, EPA apparently agreed that actual releases of radiation from nuclear power operations should be kept ALAP, and they also apparently chose to set their 40 CFR 190 environmental standards at this level. Thus the EPA standards are not directly comparable to either NRC's 10 CFR 20 standards or NRC's Appendix I to 10 CFR 50 numerical guidelines for ALAP for LWRs. They are set at what EPA apparently thought was consistent with ALAP. While the EPA language requires only "reasonable assurance" of compliance, it also specifies those circumstances under which the "standards ..may be exceeded," implying that the standards are to be interpreted as firm limits, not numerical guidelines with operating flexibility like the NRC regulations.

These differences are at the base of a criticism levied at EPA during the hearings on their standards (EPA, 1976, Vol. II, pp. A-255 and A-233). In estimating the health effects benefits of their standards, EPA assumed that without their proposed standards nuclear fuel cycle facilities would operate at the existing Federal Radiation Protection Guidelines and the standards contained in 10 CFR 20. This runs counter to the philosophy established along with these previously existing standards, namely, that these nuclear facilities should operate in ways that would limit actual radiation releases to ALAP levels below these standards. However, only for LWRs, where NRC's numerical design guidelines for ALAP existed, did EPA assume achievement of this ALAP level for actual operations prior to the adoption of the EPA standards. Therefore, EPA was criticized for overestimating the reductions in actual radiation doses and health effects that would be realized by the adoption of their proposed standards.

## DIFFERENCES IN SCOPE

The EPA and NRC regulations are difficult to compare because of differences in their scope. EPA's 40 CFR 190 environmental standards apply to the uranium fuel cycle as a whole, defined to exclude uranium mining, waste disposal, transportation aspects, and reuse of recovered non-uranium materials. NRC's standards in 10 CFR 20 apply to all of the nuclear devices that NRC licenses, and their design and their design objectives in Appendix I to 10 CFR 50 apply only to LWRs.

These differences in scope make it difficult to say whether EPA or NRC has more stringent "standards"; the standards are not directly comparable. Numerically EPA's 40 CFR 190 environmental standards for the uranium fuel cycle are much below NRC's 10 CFR 20 radiation protection standards, but are slightly above NRC's numerical design objectives for LWRs in Appendix I to 10 CFR 50.

In spite of the difficulties in comparing EPA's standards with NRC's combination of standards and guidelines, EPA asserted that satisfying NRC's Appendix I design guidelines would be sufficient implementation of the 40 CFR 190 radiation standards for LWRs. During the hearings on EPA's proposed standards several groups, including the NRC, questioned this, especially for multiple reactor sites (EPA, 1976, Vol. II). While NRC's Appendix I, like the EPA standards, had been originally proposed on a per site basis, the final version of Appendix I was promulgated on a per reactor basis. Thus it is possible that the EPA standards may, in fact, be more restrictive than the Appendix I guidelines when multiple reactor sites are considered. This is true per force if nuclear facilities in addition to reactors are clustered at a given site. The EPA standards call for a limit of 25 mrem/yr from the entire fuel cycle via all pathways and from all sites to the whole body or any organ except the thyroid of any individual in the population. The NRC Appendix I ALAP design guidelines, on the other hand, call for 5 mrem/yr from gaseous effluents and 3 mrem/yr from liquid effluents on a per reactor basis for the whole body of any individual. Thus if several reactors or other fuel cycle facilities are clustered at a given site, the EPA standards could be more restrictive than the NRC design guidelines.

Because allocation of EPA's 40 CFR 190 environmental standards to the various portions of the fuel cycle was left to the implementing agency, NRC, whether or not EPA's standards are more stringent for LWRs than NRC's combination of standards and design guidelines, depends largely on how EPA's standards are implemented by NRC. EPA did specify that the allocation of these limits to specific fuel cycle activities should be based on the contribution of each fuel cycle facility to the generation of electricity.

A problem with doing this arises if the capacity of the nuclear industry to produce electricity changes from year to year: When the nuclear industry is growing, each fuel cycle facility may not have a constant relationship to the amount of electricity generated in each year. This leads to implementation problems because all of the different fuel cycle activities related to the generation of a given quantity of electricity do not occur in constant proportions in each year. This results in uncertainty for the industry. The greatest uncertainty does not exist for nuclear power reactors, however, because EPA claimed that Appendix I is adequate implementation for the EPA standards with respect to LWRs. The greatest uncertainty seems to be with respect to reprocessing facilities, although such facilities are ruled out under current administation policy. EPA's standards for Kr-85 and I-129, for instance, were specified to be implemented by 1983, although the technology for controlling these radionuclides and others that would result primarily from reprocessing facilities had not been operationally demonstrated at the time the standards were proposed.

NRC actually implements radiation protection standards through their process of licensing nuclear facilities. Technical specifications for each facility are agreed upon by NRC and the licensee at the time that NRC grants a license. For LWRs these technical specifications are based upon the currently existing public and occupational radiation protection standards in 10 CFR 20 as well as the design objectives for LWRs in Appendix I to 10 CFR 50. For other nuclear facilities these technical specifications must be based directly on EPA's 40 CFR 190 environmental standards and the 10 CFR 20 radiation protection standards; only in the case of LWRs has NRC specified numerical design criteria for ALAP.

## DIFFERENCES IN TERMINOLOGY

Both NRC and EPA selected constant average benefit values. However, NRC expressed this in units of dollars per man-rem, while EPA expressed it in units of dollars per health effect. NRC chose a value of $1000 per man-rem in 1975, and EPA used a range of $100,000 to $500,000 per health effect in 1976.

The EPA claimed that their $100,000 per health effect was equivalent to $75 per man-rem. Neither specified in what year's dollars these values were expressed. The NRC value was originally intended to be a tentative value that was expected to be above the true value, but there are no current plans to revise it.

The fact that both agencies used constant average benefit values may mean that another apparent difference between their approaches could be only one of terminology. EPA reported using cost effectiveness analysis in establishing their 40 CFR 190 environmental standards, while NRC reported using cost benefit analysis in establishing their Appendix I to 10 CFR 50 numerical design guidelines for ALAP. However, looking at the more detailed discussions of what both agencies did, they may actually have followed the same general approach.

In both cases it is unclear whether the average benefit value was selected before or after the radiation standard or guideline; both agencies speak of the average control cost at the standard or guideline level of radiation control as being consistent with the available average benefit estimates. Whether the approach is more properly called "cost effectiveness" or "cost benefit" analysis, however, depends on whether the radiation standard or guideline is selected before or after the constant average benefit measure is chosen. Figure 1 shows the general shape of the radiation control costs curve observed by both NRC and EPA. A dollar benefit curve that has constznt average benefits at all radiation control levels is represented by a straight line through the origin; the slope of this line is the average benefit, i.e., the dollar per man-rem or dollar per health effect value. Now, if the slope of this line is selected first, then the radiation standard or guideline can be found by balancing the costs and benefits (cost benefit analysis). (Actually, it is where the marginal benefits are equal to the marginal costs and this may not be where total and average benefits and costs are equal, but the current discussion assumes this special case.) If (somehow) the same standard or guideline is selected first, the point on the control costs curve could be found by looking for the lowest control costs that provided the selected control level (cost effectiveness analysis). This point on the

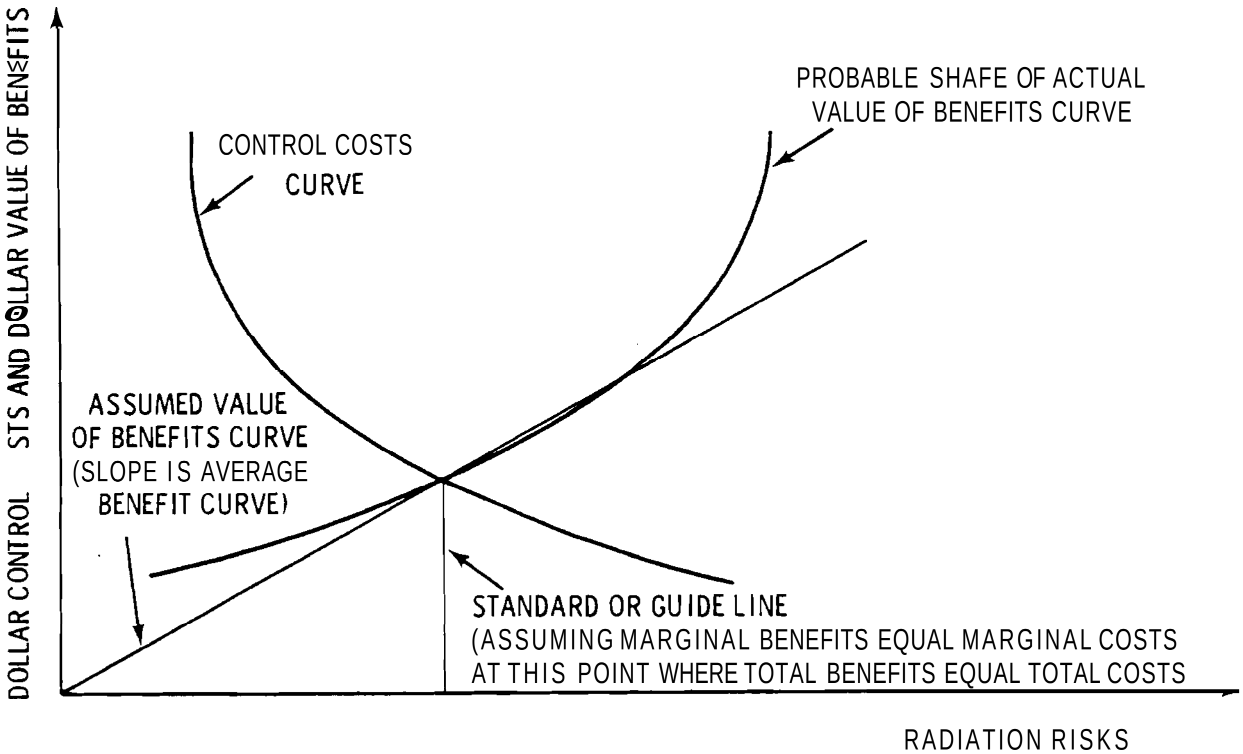


FIGURE 1. Cost-Benefit vs. Cost Effectiveness Analysis When a Constant Average Benefit Approximation is Assumed

control costs curve could then be used to infer an average benefit value by assuming that **it** *is* equal to average costs at this point.

**It** should be recognized that any constant average benefit value is likely to be at best an approximation within a limited range of radiation risks. A straight-line total-benefit curve is probably no more realistic than a straight-line control-costs curve. The nature and valuation of these benefits are discussed more in the next chapter.

## INTERTEMPORAL COMPARISONS

When all of the benefits and costs of a proposed action do not occur in the same time period, the issue of intertemporal comparisons arises. In benefit-cost analysis, the benefits and costs are expressed in dollar terms in each time period; then all benefits and costs are discounted to their present value before they are compared. If the values of all benefits and costs are correctly specified in each time period, then the same discount rate can be used to convert all these values to their present values.

Neither NRC nor EPA has applied this discounting procedure to the benefits of their standards, perhaps because of a lack of confidence in the benefit valuation measures used. The result of not discounting the value of prevented health effects is a larger dollar benefit figure; this weighs against any underestimate of the value of possible health and life benefits. Therefore, this approach leads to higher health and safety standards than if both benefits and costs were discounted to their present values.

These undiscounted benefits are compared to costs differently by NRC and EPA. NRC converts costs of radiation controls to an equivalent constant annuity using a discounting procedure. They then compare the undiscounted benefits in each year to these annualized costs (NRC Reg. Guide 1.110). If both the benefits and costs are in constant dollars, the NRC procedure amounts to using a lower (zero) discount rate to annualize benefits than that used to annualize costs. If the benefits are in nominal dollars, comparing them to the annualized constant dollars is still inappropriate.

EPA used a total present value rather than an annualized per health effect basis for comparing benefits and costs. They discounted radiation control costs to a present value using a discount rate of 7-1/2% (AIF, 1976, p. 175). This present value of costs was then compared to the undiscounted sum of benefits of prevented health and life effects over a 100-year period. While both the NRC and EPA intertemporal comparison procedures weigh the benefits more highly than if both benefits and costs were discounted, the EPA approach makes this clearer.

Many people would agree with the decision of both NRC and EPA to avoid discounting these future benefits. There seems to be a moral aversion felt by many to "discounting lives or health effects." It is morally repugnant to many people to think of the diseases or deaths suffered by people in one time period being worth more or less than those in any other time period. An important point to be made in this paper is that while such views may be strongly held by many, they may not be relevant to the problem at hand.

The real objection that many people may have when they object to "discounting health effects" is that they may not really believe that the benefits of reduced radiation risks to health and life have been adequately valued. Valuing such benefits is certainly no trivial task, and the next chapter is devoted to this issue. Unfortunately the literature reviewed there has focused on valuing "lives saved" by reducing risks rather than valuing reduced risks to health and life. It may be the use of this "value of life" concept rather than the discounting that is really offensive to people. (See pp. 55-58.) However, once these benefit values have been appropriately determined, then one is not faced with "discounting health or life effects," but rather with discounting the dollar value of benefits of reduced radiation risks to health and life. The arguments for discounting such dollar benefits are the same as those for discounting the radiation control costs or any other costs or benefits, primarily so that the intertemporal cost and benefit streams can be compared. If the benefits are not discounted in the same way as the costs once both have been appropriately valued, then the basis for discounting the costs could be seriously questioned. If a zero rate of discount is appropriate for the benefits stream, then it would be appropriate for the costs stream also.

## VALUING HEALTH AND SAFETY BENEFITS

Many common activities involve some risks to health and life. For example, driving to work or to stores for shopping involves such risks; yet many people chose to live so far from employment and/or shopping locations that such travel is a daily occurrence. These risks could be reduced by living closer to jobs and stores, but this would mean higher housing costs (for similar housing and neighborhood characteristics). So health and life risks are an integral part of living that can be reduced only at some cost.

Similarly, the setting of public health and safety standards calls for weighing the costs of higher standards against the value of the benefits of reduced risks to health and life. The principal obstacle to more effective use of benefit-cost analysis as an aid in doing this has been the difficulty of valuing these health and safety benefits. The attempts to empirically estimate the value of health and safety have focused on valuation of the change in expected loss of life. The first major section of this chapter is devoted to a review of the available methods for valuing the lives expected to be saved by health and safety regulations. Much of this literature uses data on stated or observed tradeoffs between changes in the probability of dying and dollars paid or accepted. This tradeoff is extrapolated linearly to the case of a certainty of dying to obtain a "value of life." This value is used to evaluate a different change in the probability of dying in a different case.

Following a discussion of the value of life estimates obtained and the factors that may influence the magnitude of health and safety benefits, it is noted that none of the methods used thus far really measure the right thing. The value of life times the expected number of lives saved is not the correct measure. The chapter concludes with a discussion of the change in the risks to health and life as the relevant concept of health and safety benefits. Because this value is probably a nonlinear function of the level of risks, among other things, it may cause significant error to use "the value of life" as an intermediate step. Research to correct these deficiencies in current approaches is recommended.

## VALUING "LIVES SAVED"

There are many instances where the probability that someone will die can be reduced at some costs. The benefits of such actions are almost always stated as the difference between the statistically expected number of deaths before and after some expenditure of funds. This reduction in the expected number of deaths is called the number of "lives saved." The problem of valuing health and safety benefits is thus (incorrectly, as noted at the end of this chapter) reduced to valuing this number of lives saved. The various methods of valuing lives saved can be grouped under three major approaches as follows:

- Implicit Value Approaches: based on individual or public actions.
- Explicit Value Approaches: based on statements by individuals or public representatives.
- Productivity Approaches: based on a person's gross or net earnings.

The implicit value approaches use information from individual and public decisions involving tradeoffs between risk levels and expenditures necessary to reduce these risks. These approaches assume that the rate at which people trade dollars for changes in risk levels is constant for all risk levels.

The explicit value approaches use direct statements by individuals and public representatives. These approaches have the potential for being theoretically superior measures of value compared to the implicit value and productivity approaches. However, when data is collected by direct inquiries, special care must be taken to avoid potential data collection biases, and this approach has been the least frequently used.

Productivity approaches measure the value of lives saved in terms of the present value of the people's foregone earnings. While these approaches are the least theoretically defensible measures of value, they are the most widely used. The reason for their popularity is apparently the comparative ease of obtaining a number.

Implicit Value Approaches

Both individuals and society frequently make decisions that involve changes in the risk that someone will die prematurely. These implicit value approaches assume that the levels of risk that people are observed to accept are chosen by balancing the costs of reducing (increasing) these risks against the benefits of reducing (increasing) them. These approaches further assume that the observed dollar cost/risk change tradeoffs are constant for all risk levels, including certain death. The linearly extrapolated dollar costlrisk change tradeoff for a probabililty of 1.0 of dying is called the "value of life."

This can be illustrated using Figure 2. Suppose that two occupations differ only in the level of wages and the risk to life. Situation A on Figure 2 involves lower risk and lower pay, while situation B involves higher risk

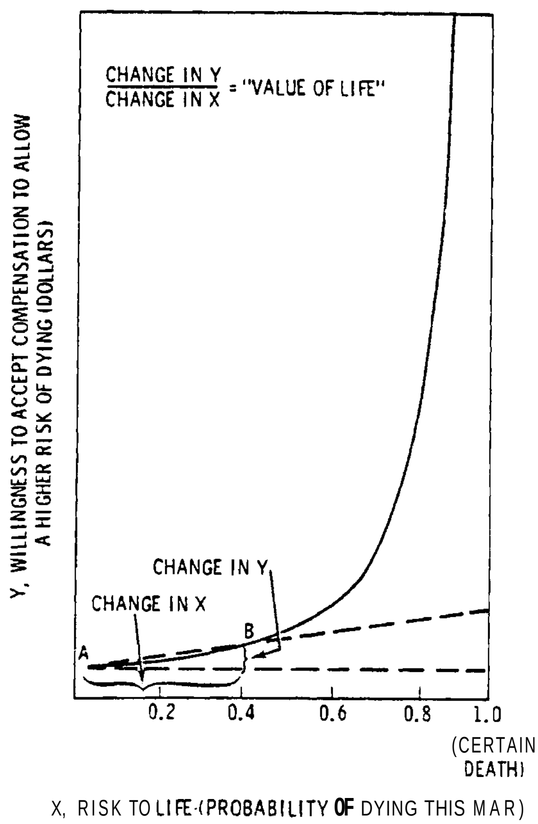


FIGURE 2. Common Approach to Estimating a "Value of Life"

and higher pay. A person who accepts situation B rather than situation A is said to implicitly value his life at the difference in pay (y) divided by the difference in risk (x). The shape for the curve in Figure 2 assumes that people are risk averse.

Various individual and societal decisions have been used to obtain values for the change in x and the change in y. These implicit value approaches are described next.

Individual Actions

Three classes of individual actions that reveal preferences toward risks to life have received considerable attention in the literature. These approaches use information concerning hazardous occupations, hazardous consumption and personal insurance choices to infer an implicit value people place on their lives. All of these approaches produce estimates that are more relevant to occupational than to public radiation standards.

Hazardous Occupations. Wages in hazardous occupations usually include a premium for accepting higher risks. Government service hazardous duty pay differentials, pay differentials in underground coal mining compared to strip mining, and high-rise compared to other construction are some examples of occupations where higher wages are paid to workers to compensate for the risk inherent in these occupations.

Suppose an individual were considering employment opportunities in highrise and other construction. In deciding between the jobs, the worker at least implicitly would consider the wage rate, the hours of work, the fringe benefit package, job security, mobility requirements, and a host of other considerations, including risk. When workers accept risky jobs it is assumed that they prefer them to the alternatives once all factors are considered. To the extent that the monetary premiums associated with a job and occupational risk to life differences could be identified, they have been used to infer implicit values of lives saved.

This has usually been done by obtaining measures of attributes for a variety of occupations and estimating a "hedonic price" equation (Griliches 1961) that expresses the wage rate as a function of the job characteristics.

Thaler and Rosen (1975) have developed the most comprehensive model of this type available to estimate the value of saving a life. In their model, for a given wage-risk structure, each worker is assumed to choose a combination of wage rate and risk that maximizes his expected utility. They use a hedonic pricing model, where the wage rate is defined as a function of occupational risk and other employee and employment characteristics, to empirically estimate the value of saving a life based on evidence from 37 different occupations. The expected positive coefficient on the risk measure reveals the fraction of the wage dollar that was necessary to compensate the employees for the risk they incurred.

For public radiation standards setting purposes, the values obtained from data on hazardous occupations are deficient in several ways. The job risks are voluntarily assumed and for most occupations the risk consequences are immediate, while radiation risks to the public have long latent periods and are externally imposed. These studies concentrate on the riskier occupations where actual risk measures are available, and because tastes for risk bearing are thought to vary among individuals, there is probably a self-selection bias in the samples used. Also, the actual job choices involve perceived risk, but Thaler and Rosen's analysis employed the proxy of actual risk from insurance estimates. For these reasons pay differentials between hazardous and safe jobs probably provide underestimates of the value of similar risk differentials to the public.

Hazardous Consumption. Certain consumption choices involve similar resource and risk to life tradeoffs. While expenditures on preventive health items, and purchase of smoke detectors for fire warning in homes reduce the probability of premature loss of life, they also entail costs. Implicit in individuals' actions is the rate at which they are willing to make tradeoffs between expenditure of their own resources and reduced risk to life. When a person accepts a risk that he could have avoided at some cost, it has been concluded that the value of reducing the risk is less than the cost to him. Melinek (1972) estimated the value of life from driving speed, use of pedestrian subways, and smoking. Joksch (1975) inferred values from seat belts, padded dash, and other safety features in autos.

A variant of this is the case of two similar goods which differ (ideally only) with respect to the risk associated with them and their cost. For example, the price and risk differentials between different modes of transportation can be used to infer a value individuals attach to their lives. The details of this method of valuation are analogous to the occupational choice model.

The validity of these occupational and consumption choice methods is claimed on the grounds that individuals' true preferences are captured, since preferences are backed by their actions. The quality of values obtained using this approach is dependent on the details of the empirical specification used to isolate the expenditures associated with the reduction of risk. Because they are inferred from past actions, the values assume that preferences are stable and that decisions were based on the same amount of information as is used in the application of the values obtained. While this is claimed to be a natural way of approaching the problem, the scattered evidence has not yielded convincing results. Furthermore, people who engage in relatively higher risk activities are probably not representative of society in general (Zeckhauser 1975). Lastly, these methods, like most others, imply a lower value of life for lower-income people.

Personal Insurance. The value of life saving may also be estimated by using values implicit in private insurance decisions. This method values life on the basis of the insurance premium an individual pays and the probability of his losing his life as a result of engaging in a particular activity. Fromm (1965) suggests this approach to obtain a value of loss of life based on the relationship between the probability of a person being killed and the sum that he would pay to obtain compensation for his heirs in such an event; this relationship is then linearly extrapolated to obtain a value of life.

The probable inaccuracy resulting from this common linear extrapolation was later addressed by Fromm (1968) himself. A problem which is more specific to this personal insurance method is that the relationship between probability of loss of life and insurance premium is more likely to reflect an individual's desire to provide compensation to his beneficiaries; thus it may not measure the value of life to the victim or his survivors. This relationship is further complicated by considerations of the investment features of many policies. Finally, insurance, like most other goods, is likely to be purchased in larger amounts as the individual's income increases; thus, the value of life obtained with this method also varies with income.

Public Actions

This method infers values of life saving implicit in previous public actions such as public health programs, construction of public highways, bridges, dams, and other public projects which had a goal of improving public safety. This method of valuing lives has been used extensively in conducting the benefit-cost analyses of new public programs. Its attractiveness stems from the assumption that resource-allocation and risk tradeoffs that have been accepted by the public in an existing program reflect society's preferences, and that the same tradeoffs are not only appropriate for a new project but will be acceptable to the public. It is also argued that public decision-makers are representatives of the society, and, therefore, the implicit value of life judgments exhibited in their past policy choices can be viewed as a reflection of the views of society on the value of life. For example, fatalities might be prevented at a four-way crossing by construction of traffic lights, but if the traffic department decides against such construction on budgetary grounds, this approach interprets their action as implying that the lives expected to be saved are not worth the costs. Such actions have been used to imply a community judgment on the worth of human life.

The use of previous public program decisions to infer an implicit value of life has two basic variations: 1) the item expenditure method, and 2) the residual method. The first uses expenditures for safety components or programs to reflect directly the present value of all the lives expected to be saved as a result of the expenditure. The residual method employs data on expenditures incurred in a project, measurable benefits obtained, and the number of lives that are believed to have been saved to infer the value of the lives saved as the excess of costs over benefits other than lives saved. An extensive discussion of this methodology can be found in Weisbrod (1968).

This residual method takes an implemented project for which the costs are greater than the measurable benefits but for which a known number of lives have been "saved." The excess of costs divided by the number of lives saved is the implicit measure of the value of life. Thus, if a renal dialysis program had net costs of \$10 million but one hundred deaths were delayed, the implicit value of life would be \$100,000. The method can be made more sophisticated by using the number of years by which life is extended and discounting the years of life saved later in time. Thus, the implied present value of a life (Z) would be the difference in the present value of the measurable costs ($C_0$) and benefits ($B_0$) divided by the sum of the lives extended each year ($L_t$), where each year of life extended is weighted by a discounting function of the number of years since the project was undertaken. That is:

$$Z = \left(C_0 - B_0\right) \Big/ \sum_{t=1}^{\infty} \frac{L_t}{(1+r)^t}$$

Such techniques could be employed using the work of Fromm (1968) on aviation safety, Lave and Weber (1970) and Joksch (1975) on auto safety, and a host of areas in the field of health: mental health (Fein 1958), cardiovascular diseases and cancer (U.S. Public Health Service 1962), syphilis (Klarman 1965), poliomyelitis (Weisbrod 1971), and heart and circulatory disease (Acton 1975).

There are several criticisms which can be levied against the use of past public decisions to value lives saved by current decisions. First, the method assumes that the preference structure of the society is static; it is, therefore, not amenable to incorporating changes in social priorities. In a similar vein, there is the question of duplicating the conditions surrounding past actions sufficiently to guide current decision making. Such analysis also assumes that past public policies accurately reflected society's wishes; if not, then past mistakes will be repeated. In defense of this approach, it is argued that it does not matter what criteria were applied in the past; as long as these public programs are generally accepted by the society, it is argued that they reflect the value of life to society.

## Explicit Value Approaches

The explicit value approaches use direct statements by individuals or representatives of society to value health and safety benefits of risk reductions. Obtaining these statements as responses to carefully worded questionnaires can result in theoretically correct measures of value; this also has the most flexibility for modification to meet the specific requirements of each application of any of the available methods of valuing health and safety benefits. Use of surveys also has different potential sources of bias from those encountered when secondary data are used.

### Statements by Individuals

This method uses responses of individuals to direct inquiries to determine the value of health and safety benefits. Mishan (1971) has argued that none of the implicit value approaches to determining the value of lives saved are theoretically correct. According to economic theory the correct measure of the value of reducing the risks of premature loss of life should be an estimate (either implicit or explicit) of an individual's responses to one of the following four types of questions (after Erickson et al. 1978):

- "Assuming you are entitled to your current situation, how much would you be willing to pay to have a lower risk of dying?"
- Assuming you are entitled to your current situation, how much would you be willing to accept in compensation to allow a higher risk of dying?"
- "Assuming you are entitled to a higher risk of dying, how much would you be willing to pay to avoid this situation?"
- Assuming you are entitled to a lower risk of dying, how much would you be willing to accept in compensation to forego this situation?"

These four questions yield the following measures of value, respectively:

1. compensating measure of willingness to pay,
2. compensating measure of willingness to accept compensation,
3. equivalent measure of willingness to pay, and
4. equivalent measure of willingness to accept compensation.

Which of these four measures of value is relevant in a particular instance depends on 1) whether the individual is entitled to his initial welfare position, and 2) whether a lower or higher risk of dying is being considered (Randall 1977). If the individual has a right to his initial welfare position, the compensating measures are the correct measures of value. If he has no right to his initial welfare position but rather has a right to a higher or lower position, then the equivalent measures are the correct measures of value. The equivalent measure of willingness to pay and the compensating measure of willingness to accept compensation are the correct measures of the value of a higher risk of dying. Similarly, the compensating measure of willingness to pay and the equivalent measure of willingness to accept compensation are the correct measures of the value of a lower risk of dying.

When considering a radiation standard that would lower the risk of dying, the correct measures to consider would thus be the compensating measure of willingness to pay and the equivalent measure of willingness to accept compensation. (Questions 1 and 4 above.) Which of these is the theoretically correct measure depends on whether people are assumed to be entitled to the current level of risks from radiation or the proposed level of these risks. While most people may favor the former assumption, complete agreement is unlikely. Therefore, bcth measures should be estimated and a range of values given.

Applications of this method to valuing health and safety benefits have been all too rare. Acton (1973) used this approach in a study evaluating public programs designed to save lives in cases of heart attacks. He found that individuals' willingness to pay increased in a <u>nonlinear</u> fashion with increasing probabilities of death and increasing income and wealth. The importance of income had been indicated earlier (Patinkin 1963), but the significance of the nonlinear relationship between the value of a change in the risk to life and the probability of death is still not sufficiently appreciated.

This approach has the same potential sources of error inherent in any survey technique including:

- A survey has a certain degree of artificiality about it. Will the person take the endeavor seriously enough to actually sort out his true feelings and preferences?
- Even if individuals do take the procedure seriously, they have incentives to bias answers to questions which are intended to elicit individual bids. By intentionally over or understating their bids, individuals could affect the social valuation of the impact.
- A respondent's final bid may depend upon the starting point. For example, if the first question were "Would you be willing to accept $10?" a different final outcome could result than if the first question were "Would you be willing to accept $1,000?"
- The respondent may feel somewhat overwhelmed in the interview because of the context surrounding the process. This may lead the respondent to attempt to please the interviewer and ignore his true preferences during the interview process.

Most of these problems can be alleviated with careful experimental design and sampling procedures. The empirical significance of these potential sources of error has not been established in the literature.

In spite of these potential problems Mishan (1971) urged more use of this approach on the grounds that "there is more to be said for rough estimates of the precise concept than precise estimates of economically irrelevant concepts." This method has many advantages in addition to its theoretical allocative efficiency: It offers an opportunity to consider a wide range of probabilities of loss of life, thus providing a significant improvement over extrapolations from two-point tradeoffs. At low marginal cost, it can provide information on things like the value of an individual's life to others and issues of voluntary and involuntary risk. It is the most flexible and potentially comprehensive technique. It allows valuation of the specific combination of consequences in question rather than requiring one to search for as similar a case as possible in secondary data available. Finally, it allows valuation of situations which people have never experienced.

## Statements by Public Representatives

This approach uses mainly secondary data, such as court awards for damages in workmen's compensation (Hellmuth et al. 1966) and wrongful death suits (Kidner and Richards 1974) to obtain society's value of life. The court decisions regarding damage awards explicitly provide for both "economic loss" and "psychic loss." The "economic" component of the compensation is often based on the human capital approach net of consumption for the truncated years of life. The "psychic" component of the compensation is based on the subjective valuation of judges and juries regarding pain and suffering of victims and survivors. The valuation of pain and suffering of survivors has received little attention elsewhere in the literature.

Those studies that have derived values of life from court awards have found a wide range of values (Hellmuth et al. 1966). Medical malpractice damages are well-known for the extensive variation in the awards made. This large variance in the results does not lend confidence to the reliability of this method of valuation. In recent years economists have begun to play the role of expert witness in the courts. This may lead to more consistent awards for "economic loss" but is not likely to affect either the subjective variation in the perception of victim's and survivor's "psychic loss" by judges and juries or the valuation methods used in these cases.

Acton (1975) has proposed another possibility of obtaining a value of life, through an explicit statement from the political sphere. It is based on valuations of decision-makers themselves or of policy, advisory, or consultant panels. A semblance of systematic valuation and potential consensus could be introduced by methods such as the Delphi questionnaire, first developed by Dalkey (1969). This method has thus far received little attention and, like all statements by society's representatives, it neglects the preferences of the individuals at risk.

## Productivity Approaches

These approaches for assessing the value of life are based on the individual's potential for production. The notion of an individual's productive capacity, known as human capital, was first formalized by Becker (1962), but the use of this approach to valuing lives predates Becker's work. The productivity approaches, based on the discounted present value of a person's potential earning stream, are the most commonly employed approaches for deriving a value of life. Productivity approaches can be divided into two categories: gross output methods and net output methods.

Gross Output Methods

These methods are based on discounting gross values of a person's potential future earnings to their present values. These values are sometimes supplemented by including auxiliary values, obtained elsewhere, to account for features such as suffering of victims, individuals' loss of utility after death, and loss of utility of related persons (Mishan 1976). This method measures the productive capacity that the society as a whole would lose if the person were to die prematurely. This loss ($L_1$) could be calculated as follows:

$$L_1 = \sum_{t=\tau} Y_t p_\tau^t (1+r)_t^{-(t-\tau)}$$

where "$Y_t$ is the expected gross earnings of...the person during the $t^{th}$ year, exclusive of any yields from his ownership of nonhuman capital. The $p_\tau^t$ is the probability in the current, or $\tau^{th}$ year, of the person being alive during the $t^{th}$ year, and $r_t$ is the social rate of discount expected to rule in the $t^{th}$ year" (Mishan 1971). Use of this method is often individual-specific as in the case of court awards in wrongful death suits discussed above. However, the method is easily generalized over any group by using the mean expected income for that group.

The most notable empirical use of this method to estimate a value of life is by Rice and Cooper (1967). They employ 1964 data to calculate the present value of earnings for several sets of people defined by social and demographic characteristics. One problem in the practical application of this approach is the difficulty in estimating any growth in the individuals' productivity during their lives since the earnings profile commonly used as a proxy for the

$Y_t$ values is estimated from cross-sectional data (Mincer 1974). In view of the exclusion of productivity growth the values obtained should be treated as lower bounds of the actual value of gross productivity lost by premature death.

Net Output Methods

These methods differ from the gross output methods in recognizing that the net worth of an individual to the society is the discounted value of his earnings net of his personal consumption expenditures. Again following Mishan (1971), the loss ($L_2$) due to premature death could be calculated as follows:

$$L_2 = \sum_{t=\tau}^{\infty} p_{\tau}^{t}\left(Y_t - C_t\right)\left(1+r_t\right)^{-(t-\tau)}$$

where $C_t$ is the personal consumption expenditure of the individual during the $t^{th}$ period that is expected at time $\tau$.

Certain variants of these productivity approaches have been proposed. Zeckhauser (1975) suggests the present value of an individual's consumption stream over his remaining life as a possible measure of the value of life. This is based on the assumption that discounted consumption is the total gain that an individual receives for remaining alive. Another variant is to replace the earnings function by a "livelihood function," which would include unearned wealth in addition to labor earnings in deriving the value of life (Schelling 1968).

The major problem with the productivity approaches is that they are not attempting to measure the theoretically correct concept. They ignore the preferences of those whose risk of dying prematurely is affected as well as any value which concerned friends and relations may add. These methods thus conclude that postponing deaths of unemployed or retired persons or persons who perform work for nonmonetary rewards, such as housewives, have either no value (according to the gross productivity approaches) or negative value (according to the net productivity approaches).

There have been a few recent attempts at the conceptual level to remedy this by developing models which combine the concepts of willingness to pay and human capital. Notably, Usher (1973) and Conley (1976) employ utility maximizing life-cycle models to derive optimal marginal tradeoffs between an increase in the probability of premature death and the amount an individual is willing to pay. The models are mathematically sophisticated but are less amenable to empirical estimation. While these models incorporate the affected individuals' tastes and preferences with the human capital approach, they retain many of the other deficiencies of the productivity approaches.

The popularity of the productivity approaches in the face of their many serious deficiencies stems from their relative ease of application. It is comparatively easy to get a deceptively precise numerical result, and many people must believe that it is better to be precisely wrong rather than vaguely right in spite of Mishan's (1971) recommendations to the contrary.

### "Value of Life" Estimates

The value of life estimates given in the literature and derived using the methods described above, range from a few thousand to several hundreds of thousands of dollars. Table 2 presents some of these value of life estimates; both the value reported in each original study and the value in 1976 dollars are shown. While one source of variation is that the same concept is not being measured by each method, note that even when similar concepts and decisions are used for valuation, the derived values are not found to be comparable. Even using the tightly defined gross output measure, the values range from about $30,000 to $783,000 in 1976 dollars. The other methods also yield a wide variation in values. In some cases the differentials may be due to identifiable inclusions, exclusions, or embellishments in the analysis, but the large variations in the derived values probably cannot all be explained by such differences.

## INFLUENCING FACTORS

Lawrance (1976) has noted some of the considerations that influence the level of risk which people find "acceptable" based upon their implicit or explicit balancing of benefits and costs. These factors, shown in Table 3 below, are really among the factors influencing the magnitude of the benefits

TABLE 2. Empirical "Values of Life"

| Method | Author | Notes | Value at Oata Oate | Value in 1976 |
|---|---|---|---|---|
| Implicit: Individual Consumption Choice | Ghosh et al. (1975) | Using 1972-74 data on auto accidents the authors derive the imputed values of life from average speeds. (£94,000). | $220.900 | $253,055 |
| | Melinek (1972) | Uses 1963 data on fatal accidents and driving speed. (£93,500) | 205,800 | 379,731 |
| | | Uses 1963 data on fatal accidents and pedestrian subways. (£86,500) | 246,240 | 455,544 |
| | | Uses 1960 data on smoking. (£31,000) | 86.000 | 165,576 |
| Implicit: Individual Occupational Choice | Melinek (1972) | Uses 1966 data on industrial accidents. (£65,000) | 181,440 | 315,840 |
| | Thaler & Rosen (1975) | 1967 data on labor market choices and actual risk levels are used. | 260,000 | 439,920 |
| Explicit: Individual Estimates | Acton (1973) | 1970 auestionnaire, 1/500 chance of dying yielded mean willingness of $56. 1/1000 chance yielded mean value of $43. Use of linear assumption yields the reported values respectivelv. | 28,000<br>43,000 | 40,736<br>62,350 |
| Explicit: Public (Court) Estimates | Abraham & Thedie (1960) | The authors use 1957 data on road accidents gross output plus "subjective values" determined from court decisions. (150,000 NF). | 35,719 | 71,692 |
| | Kidner & Richards (1974) | Authors cite Enqlish court settlement of 1970. (£16,848) They maoe adjustments and revised value. (£27,144) | 40,267<br>64,874 | 58,583<br>94.384 |
| Productivity: Gross Outout | Acton (1973) | 1970 data on deaths related to ambulance service. | 21,000 | 30,552 |
| | Ball (1977) | Author multiolies 1974 per capita income by 71.3, the average life expectancy. | 238,213 | 272,889 |
| | Cooper & Rice (1976) | The authors present a series of age, sex, and race specific values for 1972. The range is reported here. | 128<br>178,519 | 173<br>241,000 |
| | Fromm (1965) | Uses 1960 air traffic data but adds some subjective values of unspecified source. | 373,000 | 711,517 |
| | Fromm (1968) | Uses 1966 data on air carrier fatalities, along with "ralues" for family. community and others. | 450,000 | 783,333 |
| Productivity: Net Output | Oawson (1967) | Uses 1963 British road accident data plus other "subjective losses" (£8920) | 24,976 | 46,084 |
| | Dublin & Lotka (1930) | Early attempt to estimate value to dependents using age-specific mortality rates. | 9,802 | 26,958 |
| | Joksch (1975) | 1972 data presents economic loss due to an average traffic death. Adjustments for additional losses are made. | 115.000 | 155.286 |
| | Reynolds (1956) | 1949 data on road accidents are used. Medical, property and administrative costs are added in. (£2000) | 5.600 | 13,271 |
| | Weisbrod 11968) | Using 1954 data on earnings, the average value of premature death due to tuberculosis. | 10,111 | 21,252 |
| | | The average value of premature death due to poliomyelitis. | 13,210 | 27,741 |
| | | ihe average value of premature death due to cancer. | 4,950 | 10,395 |
| Other | Lave & Weber (1970) | Using 1964 data on reported auto accidents, the authors compute the minimum value of safety (injury and death) necessarv before buying safety devices is rational. | | |
| | | Padded instrument panel | 21,425 | 31,170 |
| | | Collaosible steering column | 16,183 | 23,465 |
| | | Seat belts | 7,237 | 10,494 |
| | | Dual braking system | 80,191 | 116,277 |

of reduced risks to health and life rather than the control costs. Some of these factors are discussed in this section of the paper.

Voluntary vs. Involuntary Risks

The first factor listed in Table 3 is whether the risks are assumed "voluntarily" or borne "involuntarily." Starr (1972) first recognized this factor. He defined voluntary activities as those in which the individual engages of his own free will and involuntary activities as those involving forced participation. Examples of voluntary activities would include skiing, flying, smoking, or driving. Involuntary activities might include exposure to polluted air or water, to lightning, or to risks of cancer from nonoccupationally encountered radiation. Starr (1972) observed that the level of "involuntary" risks which people find acceptable is about 1,000 times less than for "voluntary" ones.

TABLE 3. Considerations Influencing Level of Acceptable Risk

| Factors Increasing Level of Acceptable Risk | Continuum | Factors Decreasing Level of Acceptable Risk |
|---|---|---|
| Risk assumed voluntarily | ....... | Risk borne involuntarily |
| Effect immediate | ........... | Effect delayed |
| No alternatives available | ...... | Many alternatives available |
| Risk known with certainty | ...... | Risk not known |
| Exposure is an essential | ....... | Exposure is a luxury |
| Encountered occupationally | ...... | Encountered nonoccupationally |
| Common hazard | ............ | "Dread" hazard |
| Affects average people | ........ | Affects especially sensitive people |
| Will be used as intended | ....... | Likely to be misused |
| Consequences reversible | ....... | Consequences irreversible |

William W. Lawrance, Of Acceptable Risk, Science and the Determination of Safety, William Kaufmann, Inc., Los Altos, CA, 1976.

When risks are assumed voluntarily, these risks are always "acceptable." If the risks were higher, people might not voluntarily choose to bear these risks, but at the level that people do voluntarily choose to bear them they are acceptable. Thus occupationally related risks are always acceptable as long as people voluntarily take the job; considering their job alternatives, people accept a particular one including whatever risks may be involved in it. Because people do make these choices involving occupational and other voluntarily accepted risks on a daily basis, there is better data on such choices and the benefits of reducing such risks are easier to estimate than the benefit of reducing involuntarily borne risks.

Environmental pollution resulting from industrial production may cause some people to involuntarily bear risks to health and life. The possibility of public radiation exposures would be included here. The benefits of reducing these involuntarily borne risks are much harder to estimate than for voluntarily assumed risks. In the jargon of economics the involuntarily borne risks are a public good type of externality; there are no market prices that can be used to directly value such goods. From the economic theory about public goods one would expect the kind of result that Starr (1972) found: for involuntarily borne risks (like public radiation risks! a lower level of risks is "acceptable" to people than for voluntarily assumed risks (like occupationally related radiation risks).

Subjective vs. Objective Risk Estimates

A factor affecting the total benefits from reducing risks is how much people expect that these risks will decline as a result of some action. How much these risks will decline (or indeed how much they are) may not be the same as people's subjective estimates of them. Yet people always make decisions based on what they perceive to be the case, whether this is the truth or not.

One explanation advanced for public opposition to nuclear plower plants, although they have low objective probabilities of causing health and life effects, is that the public perceives these risks to be greater than those reported. Such perception may result from a lack of information or from misinformation, but, for whatever reasons, the public's "subjective probabilities" may be much higher than these "objective probabilities." In contrast, many "experts" may have subjective probabilities approaching the objective values such as those in Table 4.

Kneese and Schulze (1977) suggest that increased perceived levels of risk may be the result of biased information in the form of publicity regarding the possible severity of particular forms of cancer, for example. Furthermore, it may be that individuals recognize objective probabilities as society's "best guesses" and consequently attach high degrees of uncertainty to these numbers. It may be that people are so averse to the large degree of uncertainty in the estimates that they oppose nuclear plants on safety grounds regardless

TABLE 4. Objective Risks of Fatality by Various Causes

| | Total Number | Individual Chance/Yr |
|---|---|---|
| Motor Vehicle | 55,791 | 1 in 4,000 |
| Falls | 17,827 | 1 in 10,000 |
| Fires and Hot Substances | 7,451 | 1 in 25,000 |
| Drowning | 6,181 | 1 in 30,000 |
| Firearms | 2,309 | 1 in 100,000 |
| Air Travel | 1,778 | 1 in 100,000 |
| Falling Objects | 1,271 | 1 in 160,000 |
| Electrocution | 1,148 | 1 in 160,000 |
| Lightning | 160 | 1 in 2,000,000 |
| Tornadoes | 91 | 1 in 2,500,000 |
| Hurricanes | 93 | 1 in 2,500,000 |
| All Accidents | 111,992 | 1 in 1,600 |
| Nuclear Reactor Accidents (100 plants) | --- | 1 in 5,000,000,000 |

Reactor Safety Study, An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, Executive Summary, WASH-1400 U.S. Nuclear Regulatory Commission, October 1975.

of the low degree of estimated risk. Reliable measurements of risks associated with hazards that evolve over a long period of time (or in subsequent generations) are always difficult to make. This is still the case for nuclear power plant effects even after great effort has been devoted to the risk estimation. Fellner (1961) argues that this uncertainty may itself lead to differences between subjective and objective probabilities. This is important because each individual uses his subjective probabilities and his subjective valuations of benefits and costs in making his daily decisions about acceptable risks. If public health and safety standards are to result in decisions comparable to these daily private risk choices, objective probabilities should be substituted for subjective probabilities only when no better proxies are available.

## Statistical vs. Identified Persons

It is the value of reduced risks to statistical rather than identified individuals that is relevant for public health and safety standards setting decisions. This is important because the value of the risk to health and life for an identified individual is higher than for a statistical individual. This is why charitable relief agencies personalize their appeals for donations to one identified, battered, starving child. It should therefore be recognized that the value of risk to health and life, appropriate for setting public safety standards, ought to be derived from sources reflecting values based on statistical rather than identified individuals.

## Anxiety About Risk

Finally, it should be recognized that what is being valued is the impact of a possible future event and not the event itself. This suggests that the relevant benefits of a more stringent health and safety standard are the reduced risks to everyone exposed to them and not the number of people no longer expected to die prematurely. This further implies that the relevant measure of these benefits is not the value of life or health but the value of changes in risks to health and life for everyone exposed to the risk. These impacts of a reduction in risks are of three basic types: 1) increase in everyone's expected length of life, 2) improvement in everyone's expected health, and 3) reduced anxiety about the possibility of injury and/or death in each time period for which these risks are reduced. The latter two components have been traditionally ignored partly because the right concept of health and safety benefits has not been used as the starting point of the analysis.

## VALUE OF RISKS TO HEALTH AND SAFETY

The key factor in explaining the variations in empirical value of life estimates in Table 2 above may be the inappropriateness of the value of life concept to the valuation of health and safety benefits from stricter standards. Adoption of a more relevant concept of health and safety benefits could greatly enhance the usefulness of benefit cost analysis as an aid to health and safety standards setting.

Recall that the value of life has been derived by observing some change in risk (x), generating a measure of willingness to pay (y), then postulating that the change in y divided by the change in x is value of life. (See Figure 2 and pp. 37-38 above.) This technique rests on the assumption that each unit of risk to life is equally valuable. There is little *a priori* reason to believe that this is how individuals respond to risk-resource trade-off decisions; it violates the standard theoretical assumption of a diminishing marginal rate of substitution between goods; and Acton (1973) suggests that it is empirically questionable as well.

Because the rate at which people are willing to exchange money for a change in the risk of dying is probably not a constant function of the level of this risk, the value of life derived as it has been in the literature should vary according to the level of this risk in the particular case. This variation is hypothesized to take the form shown in Figure 2 above. Using this figure, the traditional procedure for estimating the value of life should be expected to yield a higher estimate for data drawn from higher risk activities. Thus, the true value of a life which is certain to be lost is probably much greater than any of the values found in the literature, because they are linearly extrapolated from lower risk data. If the curve in Figure 2 is actually vertical near a 1.0 probability of death, then a single human life that is sure to be lost would have an infinite value. Whether or not this is true is an unanswered empirical question, but it may help explain why any health and safety benefit valuation process that includes "valuing lives" is offensive to many people.

However, the value of life estimates are never used to value the benefits of preventing certain loss of life. They are used to value the benefits of reduced risks to health and life resulting from proposed action. The value of these benefits depends on the risk levels relevant to the decision at hand. Only if these risk levels are the same ones used to derive the value of life estimate used will no error be introduced, and in this case deriving a value of life is an unnecessary as well as a potentially offensive step. It is not the value of life but the value of reduced risks to health and life which is the relevant benefit of a more stringent safety standard.

All of the approaches to valuing health and safety benefits attempt to measure the value of the lives and injuries expected to be saved rather than the value of the reduced risks of these events. Beyond this common error, the three major approaches reviewed in this chapter do not measure the same thing. Both the implicit and the explicit value approaches use data on the tradeoff between an individual's or society's willingness to pay or receive money and changes in risk to life to linearly extrapolate a value of life. The difference between these approaches is that the implicit value approach derives the value of life from the past actions of the individual or society while the explicit value approach derives the value from hypothetical questions regarding the proposed action.

The productivity approaches equate the value of life to the value of a person's expected future earnings. While this may measure the value of his productivity to society, it ignores the individual's, his family's, and friends' point of view. Hence, productivity estimates tend to undervalue the benefits of more stringent health and safety standards.

Of a11 the approaches which have been used to estimate the value of life only the explicit value approach, which relies on surveys of individuals, could be modified to measure the relevant concept of health and safety benefits of more stringent radiation standards. This is partly because appropriate data for application of other techniques is unavailable for such low probability, high consequence involuntarily borne risks as those allowable by present public radiation standards. Valuation of the benefits of lowering these standards should focus on the value of a reduction in risks to life and health to all those subject to these risks. <u>The value of changes in risks to health and life should be estimated as a function of several variables rather than continuing the search for a single value of life</u>.

The use of the value of reduced <u>risks</u> to health and life rather than the value of lives expected to be saved is not only more appropriate for setting safety standards, but standards thus set are likely to receive greater public acceptance. This approach should avoid even the appearance of the "discounting lives or health effects" that so many people find morally objectionable.

Finally, intertemporal effects are especially important in valuing the benefits of reduced risks of radiation-induced health effects. In dealing with these effects, one must be careful to separate the three following factors:

1. The intertemporal effects captured by the discount rate, including (a) the rate at which people are <u>willing</u> to trade current items for the same future ones, and (b) the rate at which people are <u>able</u> to make such trades.
2. The relative changes in value which may occur over time. For example, as incomes increase over time people may value environmental quality more highly in the future compared to an additional dollar of income than they do in the present. Such future changes in relative prices may have significant effects on present values, especially if current decisions regarding the future prove to be irreversible.
3. The effects of anxiety in the present about events which may occur in the future. Such anxiety effects may explain the significant present value which possible genetic and future health and life effects of radiation have for people in spite of the distant future time periods in which

these effects occur. (When the value of distant future effects is discounted by any positive rate, their present value is small.) Failure to include these anxiety effects in the value of the benefits of reduced risks may help explain people's objections to "discounting lives" or "discounting health effects" noted at the end of the previous chapter. Long delayed effects may reduce the level of risk people consider to be acceptable (as suggested by Lawrance (1976); see Table 3 above), because the length of time that the anxiety must be borne is increased.

## REFERENCES


Abraham, C., and J. Thedie. "Le Prix d'une Vie Humaine dans les Decisions Economiques," Revue Francaise de Recherche Operationelle (1960). As reported in M. W. Jones-Lee, The Value of Life, University of Chicago, 1976.

Acton, J. P. Evaluating Public Programs to Save Lives: The Case of Heart Attacks. R-950-RO, Rand Corporation, January 1973.

Acton, J. P. Measuring the Social Impact of Heart and Circulatory Disease Programs: Preliminary Framework and Estimates. R-1697-NHLI, Rand Corporation, April 1975.

Ball, R. H. "An Economic Assessment of the Comparative Levels of Pollution Control for Fossil and Nuclear Power." Paper presented at the Western Economic Association Convention, June 1977.

Barclay, A.E., and S. Cox. "Radiation Risks of the Roentgenologist." Amer. J. Roentgen. 19:551, 1928.

Becker, G. S. "Investment in Human Beings." Journal of Political Economy, 70 (No. 5, Part 2):9-49, October 1962.

Becker, G. S. Human Capital. National Bureau of Economic Research, New York, 1964.

Carlson, J. W. Valuation of Life Saving. PhD. Thesis, Harvard University, Boston, MA, 1963.

Conley, B. C. "The Value of Human Life in the Demand for Safety." American Economic Review. 66:45-55, March 1976.

Cooper, B. S., and D. P. Rice. "The Economic Cost of Illness Revisited." Social Security Bulletin, February 1976.

Cornell, M., P. Daniels, J. Kirkland, and A. Wolff. A Survey of Methods for Estimating the Cost Value of a Human Life. G-DST-A/TRPT, Operations Research Inc. Prepared for U.S. Coast Guard, Washington, DC, May 1976.

Dalkey, N. C. The Delphi Method: An Experimental Study of Group Opinion. RM-5888-PR, Rand Corporation, 1969.

Dawson, R. F. "Cost of Road Accidents in Great Britain." Road Research Laboratory, Ministry of Transport, London, 1967. Health Economics, Cooper and Culyer, eds., 1973. pp. 336-356.

Dublin, L. I., and A. J. Lotka. The Money Value of a Man. Ronald Press, New York, 1930.

Englehart, R. W., D. E. Martin, R. A. Martineit, J. F. Pang, B. J. Reckman, and E. R. Smith. Technical Assessment of specific Aspects of EPA Proposed Environmental Radiation Standard for the Uranium Fuel Cycle (40 CFR 190) and its Associated Documentation. AIF/NESP-011, prepared for the Atomic Industrial Forum, Inc. by NUS Corporation, Rockville, MD, February 1976.

Erickson, L. E., J. W. Litchfield, J. W. Currie, C. L. McDonald, and R. C. Adams. Usefulness of Alternative Integrative Assessment Methodologies in Public Decision Making. PNL-RAP-24, Battelle, Pacific Northwest Laboratories, Richland, WA 99352, July 1978.

Federal Radiation Council, Background Material for the Development of Radiation Protection Standards. FRC Report No. 1, May 13, 1960.

Federal Radiation Council, Background Material for the Development of Radiation Protection Standards. FRC Report No. 5, 1964.

Fein, R. The Economics of Mental Illness. Basic Books, New York, 1958.

Fellner, W. "Distortion of Subjective Probabilities as a Reaction to Uncertainty." Quarterly Journal of Economics 75(4):670-689, 1961.

Fisher, A., and J. Krutilla. "Valuing Long Run Ecological Consequences and Irreversibilities." Journal of Environmental Economics and Management 1:96-108, August 1974.

Fromm, G. "Civil Aviation Expenditures," Measuring Benefits of Government Investment. R. Dorfman, ed., The Brookings Institution, Washington, DC, 1965.

Fromm, G. "Aviation Safety." Law and Contemporary Problems, pp. 590-618, Summer 1968.

Ghosh, D., D. Lees, and W. Seal. "Optimal Motorway Speed and Some Valuations of Time and Life." Manchester School, June 1975.

Griliches, Zvi. "Hedonic Price Indices for Automobiles: An Econometric Analysis for Quality Change" in The Price Statistics of the Federal Government, 1961; also found in Griliches, ed., Price Indices and Quality Change, H-arvard University Press, Cambridge, MA, 1971.

Hellmuth, G., G. Rodey, W. Johannsen, and E. Belknap. "Work and Heart Disease in Wisconsin, I. Medical Basis for Workman's Compensation Awards Over Ten Years." Journal of the American Medical Association 198(1):127-137, 1966.

Hirschleifer, J., T. Bergstrom, and E. Rappaport. Applying Cost-Benefit Concepts of Projects Which Alter Human Mortality. UCLA-ENG-7478, School of Engineering and Applied Science, University of California, Los Angeles, CA, November 1974.

International Commission on Radiological Protection, "International Recommendations for X-ray and Radium Protection, 1934." Radiology. 23:682, 1934.

International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection (Adopted September 9, 1958), ICRP Pub. 1, Pergamon Press, London, 1959.

International Committee on Radiation Protection, Report of Committee on Permissible Dose for Internal Radiation. ICRP Publication 2, Pergamon Press, London, 1959.

International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection. (Adopted September 17, 1965), ICRP Publication 9, Pergamon Press, London, 1966.

International Commission on Radiological Protection, Implications of Commission Recommendations that Doses Be Kept as Low as Readily Achievable. (Adopted April 1973), ICRP Publication 22, Pergamon Press, London, 1974.

Joksch, H. C. "A Critical Appraisal of the Applicability of Benefit-Cost Analysis to Highway Traffic Safety." Accident Analysis and Prevention 7:133-153, 1975.

Jones-Lee, M. W. The Value of Life: An Economic Analysis. University of Chicago Press, Chicago, IL, 1976.

Kidner, R., and D. Richards. "Compensation to Dependents of Accident Victims." Economic Journal 84:130-142, March 1974.

Klarman, H. "Syphilis Control Programs," Measuring the Benefits of Government Investments. R. Dorfman, ed., The Brookings Institution, Washington, DC, 1965.

Kneese, A. V., and W. D. Schulze. "Environment, Health and Economics--The Case of Cancer." American Economic Review 67:326-332, February 1977.

Kustner, H. "Wieviel R-Einheiten entspricht die HED," Strahlenther. 26:120, 1927.

Lave, L. B., and W. E. Weber. "A Benefit-Cost Analysis of Auto Safety Features." Applied Economics 2:265-276, 1970.

Lawrance, W.W. Of Acceptable Risks: Science and the Determination of Safety. Wm. Kaufman, Inc., Los Altos, CA, 1976.

Linnerooth, J. "The Value of Human Life: A Review of the Models," Economic Inquiry, Vol. 17, No. 1, January 1979, pp. 52-74.

March, H. C. "Leukemia in Radiologists." Radiol. 43:275-278, 1944.

McDonald, C. An Analysis of Cost Impacts of Radiation Standards and Other Factors on Nuclear Power Plants; 1965-1978. PNL-2/30, Battelle, Pacific Northwest Laboratories, Richland, WA 99352, expected September 1979.

Medical Research Council. The Hazards to Man of Nuclear and Allied Radiations. Cmd. 9780, H.M.S. Office, June 1956.

Melinek, S. J. "A Method of Evaluating Life for Economic Purposes." Fire Research Station, Note No. 950, November 1972.

Mincer, J. Schooling, Experience and Earnings. National Bureau of Economic Research, 1974.

Mishan, E.J., "Evaluation of Life and Limb: A Theoretical Approach." Journal of Political Economy 79, July 1971.

Mishan, E. J., Cost-Benefit Analysis. Praeger Publ., New York, 1976.

Mutscheller, A. "Physical Standards of Protection Against Roentgen Ray Dangers." Amer. J. Roentgen. 13:65, 1925.

National Academy of Sciences - National Research Council. The Biological Effects of Atomic Radiation - Summary Reports, 1956.

National Academy of Sciences, National Research Council. Report of the Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR), The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, Washington, DC, November 1972.

National Council on Radiation Protection and Measurements, Radium Protection. NCRP Report No. 2, NBS Handbook 18, March 17, 1934.

National Council on Radiation Protection and Measurements, Permissible Dose from External Sources of Ionizing Radiation. NCRP Report No. 17, published as National Bureau of Standards Handbook 59, USGPO, Washington, DC, 1954.

National Committee on Radiation Protection and Measurements. "Maximum Permissible Radiation Exposure to Man - A Preliminary Statement of the NCRP." Amer. J. Roentgen. 77:910, 1957 and Radiology 68:260, 1957.

National Council on Radiation Protection and Measurements, Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure. NCRP Report No. 22, National Bureau of Standards Handbook 69, USGPO, Washington, DC, 1959.

National Council on Radiation Protection and Measurements, Basic Radiation Protection Criteria. NCRP Report No. 39, January 15, 1971.

National Council on Radiation Protection and Measurements, Review of the Current State of Radiation Protection Philosophy. NCRP Report No. 42, January 15, 1975.

Parker, H. M. The Squares of the Natural Numbers in Radiation Protection. Laurston S. Taylor Lecture No. 1, National Council on Radiation Protection and Measurements, 7910 Woodmont Avenue, Washington, DC, presented March 17, 1977 and issued December 1, 1977.

Patinkin, D. "Demand Curves and Consumer's Surplus," Measurement in Economics. C. Christ et al., eds., pp. 83-112, 1963.

Ramsey, F. P. "Truth and Probability," Studies of Subjective Probability. H. E. Hyburg and H. E. Smokler, eds., Wiley, New York, pp. 61-92, 1964.

Randall, A. "Evaluating Non-Market Goods and Services: Some Conceptual Consideration." Staff Paper 51, Dept. of Ag. Economics, University of Kentucky, Lexington, KY, 1977.

"Rasmussen Report," Reactor Safety Study, An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, Executive Summary. WASH-1400, United States Nuclear Regulatory Commission, October 1975.

Reynolds, D. J. "The Cost of Road Accidents." Journal of the Royal Statistical Society, 1956.

Rice, D., and B. Cooper. "The Economic Value of Human Life." American Journal of Public Health 57(11):1954-1966, November 1967.

Schelling, T. D. The Life You Save May Be Your Own," Problems in Public Expenditure Analysis. S. B. Chase, ed., The Brookings Institution, Washington, DC, 1968.

Schulte, S., C. McDonald and M. Wood. Costs of Regulatory Compliance: Cost Categories and Estimating Techniques. PNL-2428, Battelle, Pacific Northwest Laboratory, Richland, WA 99352, October 1978.

Shepard, D., and R. Zeckhauser. "The Assessment of Programs to Prolong Life, Recognizing Their Interaction with Risk Factors." Discussion Paper Series, No. 32D, Cambridge, MA, June 1975.

Sievert, R. "Einige Untersuchen uber Vorrichtungen zum Schutz gegen Roentgenstrahlen." Acta Radiol. 4:61, 1925.

Starr, Chauncey. "Benefit-Cost Studies in Sociotechnical Systems," Perspectives on Benefit-Risk Decision Making. National Academy of Engineering, Washington, DC, 1972.

Taylor, L. S., Radiation Protection Standards. CRC Press, Cleveland, OH, 1971.

Taylor, L. S., The Origin and Significance of Radiation Dose Limits for the Population. WASH-1336, USAEC, 1973.

Taylor, V. D. How Much is Good Health Worth? P-3945, The Rand Corporation, 1969.

Terrill, James G. "Cost-Benefit Estimates for the Major Sources of Radiation Exposure." American Journal of Public Health 62:7, July 1972.

Thaler, R., and S. Rosen. "The Value of Saving a Life: Evidence from the Labor Market," Household Production and Consumption. Terleckyj, ed., National Bureau of Economic Research, pp. 256-297, 1975.

Thompkins, P. C. Thompkins to the Greater St. Louis Citizens Committee for Nuclear Information, 11 January 1965, Hearings Before Sub-Committee on Research Development and Radiation of Joint Committee on Atomic Energy, 89th Congress, First Session, June 29-30, 1965, pp. 184-186.

U.S. Atomic Energy Commission, Final Environmental Statement Concerning Proposed Rule Making Action: Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion "As Low as Practicable" for Radioactive Material in Light Water-Cooled Nuclear Power Effluents. WASH-1258, Volumes 1-3, USAEC, Washington, DC, July 1973.

U.S. Atomic Energy Commission Concluding Statement of Position of the Regulatory Staff, Numerical Guides for Design Objectives and Limiting Conditions for Operation To Meet the Criterion "As Low as Practicable" for Radioactive Material in Light-Water-Cooled Nuclear Power Reactors, Docket No. RM-50-2, USAEC, Washington, DC, February 20, 1914.

U.S. Environmental Protection Agency, Office of Radiation Programs, Final Environmental Statement, 40 CFR 190 Environmental Radiation Protection Requirements for Normal Operations of Activities in the Uranium Fuel Cycle. EPA 520/4-76/016, Volumes I and II, November 1916.

U.S. Nuclear Regulatory Commission, Office of Standards Development, Cost-Benefit Analysis for Radwaste Systems for Light-Water-cooled Nuclear Power Reactors, Regulatory Guide 1.110, USNRC, Washington, DC, March 1976.

U.S. Nuclear Regulatory Commission, Opinion of the Commission, Rulemaking Hearing: Numerical Guidelines for Design Objectives and Limiting Conditions for Operation To Meet the Criterion "As Low as Practicable" for Radioactive Material in Light-Water-cooled Nuclear Reactor Effluents. Docket No. RM-50-2, USNRC, Washington, DC, May 5, 1975.

U.S. Public Health Service, Economic Costs of Cardiovascular Diseases and Cancer. Health Economics Series No. 5, 1962.

Usher, D., "An Imputation to the Measure of Economic Growth for Changes in Life Expectancy," Measurement of Economic and Social Performance. M. Moss, ed., National Bureau of Economic Research, 1973.

Weisbrod, B. Economics of Public Health. University of Pennsylvania Press, 1968.

Weisbrod, B. "Costs and Benefits of Medical Research: A Case Study of Poliomyelitis." Journal of Political Economy 79:527-544, 1971.

Wintz, H., and W. Rump. Protective Measures Against Dangers Resulting from the Use of Radium, Roentgen and Ultraviolet Rays. League of Nations, C. H. 1054, Geneva, 1931.

Zeckhauser, R. "Procedures for Valuing Lives." Public Policy 23:419-464, Fall 1975.

# DISTRIBUTION

No. of Copies

## OFFSITE

R. P. Blaunstein
DOE Office of Technology Impacts
Washington, DC 20545

P. Cho
DOE Office of Technology Impacts
Washington, DC 20545

A. A. Churm
DOE Chicago Patent Group
9800 South Cass Avenue
Argonne, IL 60439

R. Clusen
DOE Assistant Secretary for Environment
Washington, DC 20545

J. A. Coleman
DOE Office of Technology Impacts
Washington, DC 20545

C. W. Edington
DOE Office of Environment Research
Washington, DC 20545

P. H. Gerhardt
DOE Office of Technology Impacts
Washington, DC 20545

A. J. Goldberg
DOE Office of Technology Impacts
Washington, DC 20545

J. C. Hock
DOE Office of Technology Impacts
Washington, DC 20545

H. L. Hollister
DOE Office of Environmental Compliance and Overview
Washington, DC 20545

No. of Copies

P. W. House
DOE Office of Technology Impacts
Washington, DC 20545

A. B. Joseph
DOE Office of Nuclear Regulatory Research
Washington, DC 20555

F. G. Lowman
DOE Office of Nuclear Regulatory Research
Washington, DC 20555

J. R. Maher
DOE Office of Technology Impacts
Washington, DC 20545

D. M. Monti
DOE Office of Technology Impacts
Washington, DC 20545

W. E. Mott
DOE Office of Environmental Compliance and Overview
Washington, DC 20545

M. Reilly
DOE Division of Fossil Energy
Washington, DC 20545

G. J. Rotariu
DOE Office of Technology Impacts
Washington, DC 20545

R. D. Shull
DOE Office of Technology Impacts
Washington, DC 20545

J. Swinebroad
DOE Office of Environmental Research
Washington, DC 20545

No. of
Copies

W. N. Thomasson
DOE Office of Technology Impacts
Washington, DC 20545

B. W. Wachholz
DOE Office of Technology Impacts
Washington, DC 20545

E. R. Williams
DOE Office of Technology Impacts
Washington, DC 20545

R. W. Wood
DOE Office of Environmental
Research
Washington, DC 20545

27 DOE Technical Information Center

E. Croke
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

L. J. Hoover
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

T. Surles
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

P. M. Meier
Building 475
Brookhaven National Laboratory
Upton, NY 11973

P. Palmedo
Building 475
Brookhaven National Laboratory
Upton, NY 11973

W. E. Siri
University of California
Lawrence Berkeley Laboratory
Berkeley, CA 94720

No. of
Copies

D. Layton
University of California
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94550

E. Hammel
Los Alamos Scientific Laboratory
P.O. Box 1663
Los Alamos, NM 87545

R. K. Lohrding
Los Alamos Scientific Laboratory
University of California
P.O. Box 1663
Los Alamos, NM 87545

R. M. Davis
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830

W. Fulkerson
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830

A. Rudolph
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

10 L. E. Erickson
1201-W. 15th Place
Kennewick, WA 99377

C. L. McDonald
Math Sciences, Inc.
P.O. Box 1887
Bellevue, WA 98009

3 DOE Richland Operations Office

P. W. Gottschalk
W. Lei
H. E. Ransom

No. of
Copies

ONSITE

41 Pacific Northwest Laboratory

W. J. Bair
C. H. Bloomster
D. L. Brenchley
J. B. Brown
D. E. Deonigi
T. J. Foley
R. F. Foster
D. W. Fraley
P. L. Hendrickson
D. L. Hessel (10)
J. W. Litchfield
S. Marks
E. L. Owzarski
C. R. Rolland
L. C. Schmid
S. C. Schulte
R. W. Widrig
G. L. Wilfert
L. D. Williams
T. L. Willke
Economic Library (5)
Publishing Coordination (2)
Technical Information Files (5)

7 Human Affairs Research Center (HARC)

C. Cluett
F. Morris
J. A. Hebert
S. M. Nealey
M. E. Olsen
C. Sawyer
R. E. Schuller .