RISK ASSESSMENT

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WHAT IS RISK ASSESSMENT?

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Risk Assessment has become a popular, controversial, and sometimes misunderstood subject in the nuclear field. Part of the difficulty is the use of different meanings by different investigators, as well as variations in the depth of analysis considered to be appropriate. This paper discusses the various meanings, suggests a specific meaning for decisions involving radiological hazards, considers the phases of such an analysis, and proposes an approach to be used where the methodology is incomplete.

The concept of risk is used in many fields. For insurance purposes, risk is simply the expected value of a loss (probability times amount of loss), and is used to determine premiums and coverage. For business decisions, it is considered to be the possible loss from an action to be compared with the possible gain. In both cases the unit of measure for expected value is dollars. The decisions are often objective and based on expected gains and their uncertainties, since financial considerations outweigh non-quantifiable factors such as subjective values or human and environmental effects[a]. For radiological hazards, the decisions do involve potential human and environmental damage (real or hypothetical) which are difficult to quantify. The field of radiological risk has actually evolved from the need to determine a relative level of "safety" and has developed as a blending of applied decision theory and system safety analysis (to be discussed in more detail later), where the techniques include methods to quantify factors involved in determination of safety.

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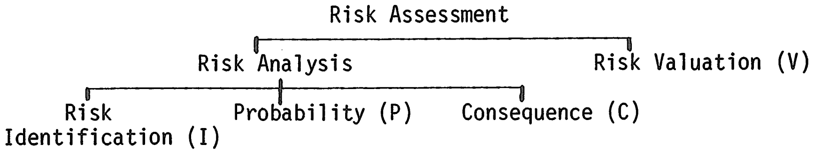
[a] Modern decision-making sometimes does involve the non-quantifiable factors, and in these cases the risk evaluation has similar problems to those discussed here for radiological hazards.

"Risk" is now defined as the chance of an undesired consequence (or loss), involving both probability and severity of loss. Risk assessment further involves identification of those events that contribute to the total risk as well as the importance or value of the components of risk:



From these considerations I define risk as

$$R = \sum_{\substack{\text{all} \\ \text{events, } I}} F_I \, (P_I, C_I, V_I)$$

Where F is the functional relationship between P, C, and V. A complete assessment includes identification of all "risk-significant" events (I) and determination of the distributions of P and C or at least a reasonable estimate of the uncertainties. Completeness implies that those events omitted would not make a "significant" change in the result within the uncertainty of the analysis. The functional form is not obvious in cases where the dependence on value is non-linear or unknown.

Risk assessment is one method for achieving the ultimate goal of safety determination which means that the predicted system risk (and its distribution) meets acceptable risk criteria or is judged acceptable by risk evaluators in cases where criteria or standards are lacking. It should be noted that safety can be (and has been) judged without risk assessment. Licensing criteria have long involved such things as multiple barriers, lines of assurance, single failure criteria, pre-selected maximum credible accidents, Quality Assurance standards, etc. However, this situation is changing. The Environmental Protection Agency has already proposed (40CFR191) probabilistic criteria, and the Nuclear Regulatory Commission is expected to propose risk-based standards for licensing within the next year.

For very simple cases involving projected outcomes of possible experiments with no human impact, and no value judgements (coin-flipping, dice-rolling, etc., without betting), risk is usually defined as

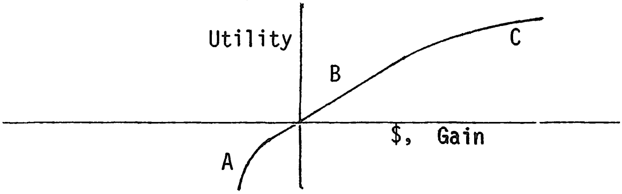
$$R = \sum_I P_I x C_I$$

or the "expected value" of the consequence.

However, when value judgements and/or subjective factors are involved, this relationship no longer holds. A few examples may help to illustrate the point. First, if coin-flipping is done for small stakes with a "fair" coin, the expected value is a reasonable estimate of risk (V is small and constant). However, if the stakes are so high that you don't have enough money to cover potential losses, the risk is essentially infinite. Perhaps more to the point is consideration of the various portions of a worker's salary. The first $5000 of the salary is usually more important than the last $5000, since the first $5000 provides basic subsistence (however poorly), while the last $5000 usually goes to non-essentials and taxes. Another way to look at this is a lottery (assumed "fair") in which $10 may be gambled to win $1,000,000. Many people would consider this a reasonable risk if the odds were right. However, would such people extrapolate and bet $100 to win $10,000,000? Some would, but many would not, because the extra $90 could be used for items of tangible and immediate value, whereas the additional $9,000,000 would have little more impact on their lives than the first $1,000,000. This concept is generalized in business risk-taking, in which a businessman gambles ("invests") part of his capital to seek increased earnings in following years. However, a prudent businessman holds part of his capital as insurance against a bad year instead of seeking further increased earnings.

If the possible outcome of the investment has a high uncertainty or wide distribution (as compared to another choice with lower expected value but smaller uncertainty), the additional factor of "risk aversion" to high negative outcomes may influence the decision. Thus a businessman may accept a choice whose expected gain would be $2,000,000 with no chance of more than a small loss instead of an alternative with expected gain of $10,000,000 and perhaps a 1% chance of bankruptcy (unless he already had a job lined up elsewhere).

In the language of decision theory, the above examples illustrate a "non-linear utility function", where utility is similar to importance or value. A typical function is illustrated below.



The central section, B, is the range in which the utility (value or importance) is directly proportional to the expected value of the monetary gain. Section A illustrates risk aversion to severe negative expected value (or consequence). Section C shows the decreasing importance of gains beyond the "normal" level of those expected or needed.

An additional difficulty with the expected value concept arises when comparing consequences whose measures are different (the "apples" versus "elephants" problem). If the parameters affected by a decision include human detriment, potential wilderness areas denied, field mice displaced, etc. as well as dollar-equivalent factors, there is no common measure available to use in a calculation of total impact of the decision.

In this case, one approach is to quantify each parameter in terms of its own measure (of which radiological risk is one), list the impacts expected (or judgements implied) by the choice of each alternative, and let the decision-makers apply their own subjective weights to the parameters to establish a preference. Considerable research has been done to determine subjective preferences of individuals and groups to pairs of parameters to establish relative weights or importances. However, the results are quite variable and controversial, so these results are not yet generally useful in risk assessment.

For radiological risk assessment, the difference in measures is sometimes expressed as the difference between economic risk and demographic risk. Economic risk is reasonably expressed in dollars and their distributions for different decisions. However, demographic risk is controversial when expressed in dollars per man-rem or value of life, so such measures as expected fatalities, increased chance of death (chances per million per year), or expected days of life-shortening may be appropriate.

The above discussion has considered some of the aspects of applied decision theory that apply to risk assessment. The other field that has strongly influenced the development of risk analysis is system safety analysis. Early accident analysis techniques included identification of initiating events, component failure modes and their system effects, and accident sequence analysis to determine system failure modes. These techniques were used deterministically to find out which events and components were critical to system performance. As interest developed in determining system failure probabilities as a function of component or event probabilities, failure equations and reliability block diagrams were introduced to use the techniques of Boolean Algebra for probabilistic calculation of system reliability. The combination of failure mode analysis, accident sequence analysis and probabilistic analysis of system characteristics is usually referred to as system safety analysis. Increasing system complexity led to development of probability tree techniques (fault trees, success trees, event trees, cause-consequence diagrams) and associated computer programs. The Reactor Safety Study used a combination of techniques with event trees for functions and systems involved in accident sequences leading to release of radiation, fault trees to determine system failure probabilities from component data, and event trees to evaluate human interaction effects. The most modern techniques include generalized probability trees with multiple states for event outcomes so that material transport probabilities can be computed instead of just success or failure. This is basically a two-dimensional capability which is used for predicting probability distributions of radioactive material release fractions.

The extension of system safety analysis to risk assessment involved the addition of a deterministic consequence model to predict transport of released material through available pathways (atmospheric, aquatic, and biotic) and biological dose resulting from the pathways to humans (inhalation, ingestion, and direct radiation). The final step involves a value model to express the importance of various events as a function of consequence level, along with presentation and communication of the results to those concerned ("risk evaluators").

Figure 1 summarizes the phases of Risk Assessment. Boxes 1, 2, and 3 (source characterization and system definition, initiating events and data, and release failure modes) are the steps usually included in accident analysis. The addition of box 4 (probability analysis) and reasonable completeness of the analysis constitute system safety analysis. Boxes 5 and 6 provide the consequence model and the Risk Assessment is completed with the

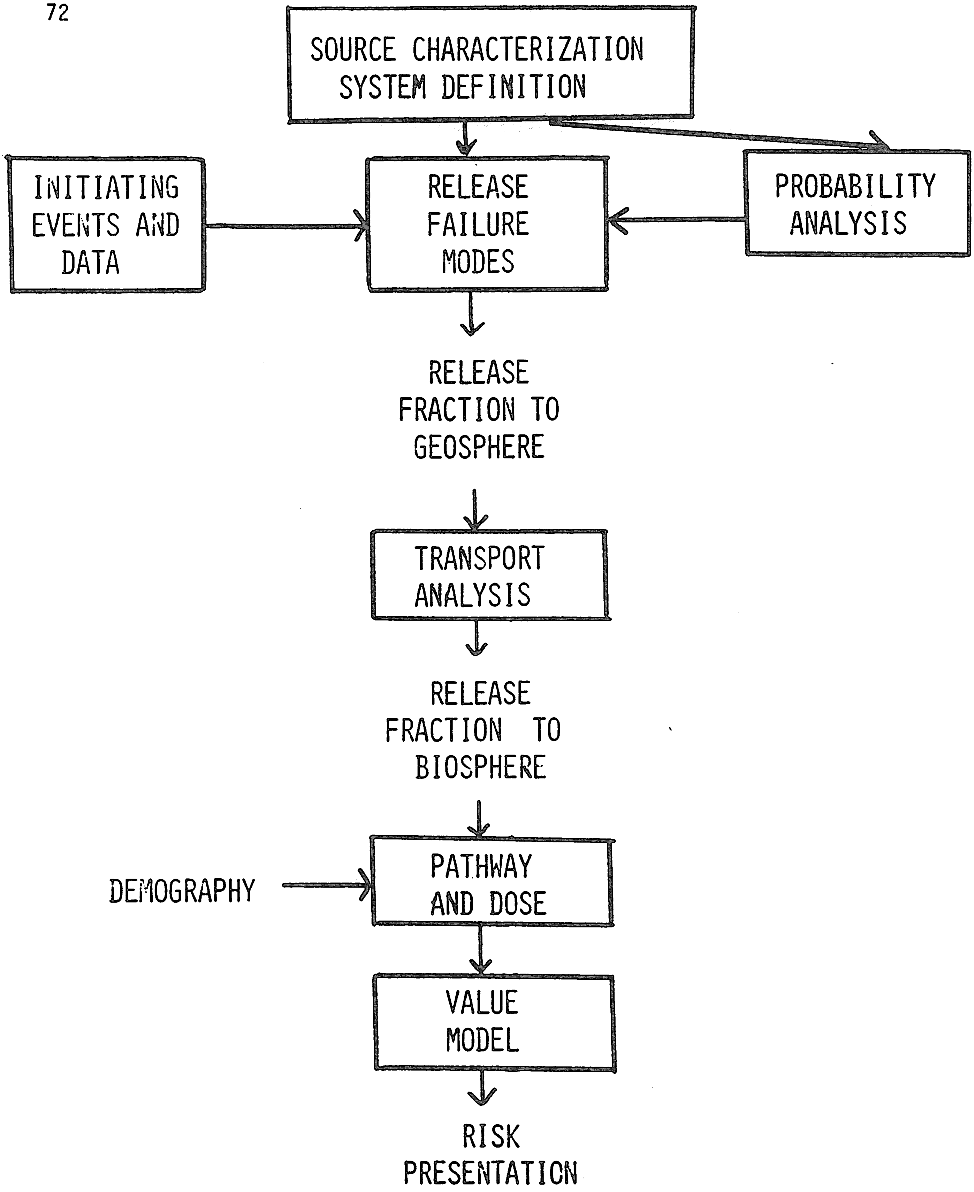


FIGURE 1. Risk Assessment

addition of the value model (box 7). Presentation and communication of results are not usually considered as part of the assessment, although they probably should be since understanding through communication is necessary before the results can be used in decision-making.

There are several approaches to Risk Assessment that will be examined here as background for the proposed approach. The ideal technique would be to determine probabilities, consequences, values, their functional relationship, and their uncertainty distributions, all as a function of time. The current level of technology is not adequate to this task, so various approximations have been devised.

The "expected value" of the consequence approach assumes that all events have equal weight so the value function is unity. Also the functional form is assumed to be multiplication, so

$$R = \sum_{I} P_I x C_I$$

which is consistent with the definition of expected value as the integral or sum of a variable (consequence) over its probability distribution. The sum must be reasonably complete or else the expected value is meaningless. In addition there are two problems with the assumption of constant value. First it is well known that the public is more concerned with high-consequence events (many fatalities) than with low-consequence events, regardless of probability. Furthermore there is little understanding of "risk" when expressed as a low probability times a high consequence (sometimes considered to be a "zero times infinity" problem). Thus high-consequence events are given high perceived negative value, and attempts to minimize their impact by quoting low probabilities are ignored. The situation is exacerbated by the current distrust of large institutions (political, economic, technical, and social). The quotation of a low probability is often disbelieved and considered to be an attempt to sweep the problem under the rug. The second problem is that "continued-threat" events which have low actual human consequence but high potential consequence (however unlikely), continuing over a period of time, have high perceived *impact*. The Three-Mile-Island accident is the classic example.

Another approach is to determine probabilities and consequences and present these data without multiplying, which leaves the reader to determine his own value judgements. This approach was taken by the Reactor Safety Study, which presented the results as a Complementary Cumulative Distribution Function (CCDF) of the consequences[b]. This approach is quite useful although it would be more satisfying to provide some separate consideration for events of high perceived impact. Actually one of the primary criticisms of WASH-1400 was related to a quite different matter - the calculation of "absolute" risk which required good estimates of confidence limits. These limits were criticized as being too small, but the basic presentation of the CCDF was not seriously questioned. The confidence limit problem can be minimized by using "relative" risk for decision-making.

The concept of "relative" risk implies the intention to make a decision among competing choices for solving a problem. The decision could be to build a reactor, select a site, transport radioactive material (to use for a beneficial purpose or move it to a safer location), choose an alternative for managing radioactive material, etc.

When viewed as a decision aid, risk assessment becomes simpler, since what is needed is "relative risk" rather than "absolute risk". The difference can be critical because absolute risk requires determination of absolute probabilities, good uncertainty ranges, and proper conversion to health effects. However, for relative risk, many uncertainties and errors cancel out in the comparison. For example the probability of intrusion into buried nuclear waste by drilling may be unknown, but shallow burial (0 to 100 ft.) can be compared to deep burial (1000-10,000 ft.) by estimating the ratio of probabilities for shallow wells versus deep wells for water, mineral exploration, etc. The uncertainty in conversion to health effects is also common to all choices (including "no action" or "continue present action") so this uncertainty has no effect as

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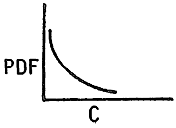
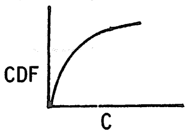
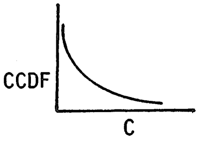
[b] A Cumulative Distribution Function (CDF) is the integral of a probability density function (PDF) of a variable from zero to some point, x, and expresses the probability that the variable (consequence in this case) is less than, or equal to, the specified value of x. A Complementary Cumulative Distribution Function (CCDF) is 1-CDF, and expresses the probability that the consequence exceeds the specified value.

e.g.:







long as radiological consequences of choices are compared[c].

The above considerations lead to an approach to Risk Assessment which acknowledges the difficulty of doing the ideal job, but nevertheless uses the best information available to provide an understanding of the issues and highlights the difference between factors that have a real impact on the decision. The proposed approach acknowledges the difficulty of providing a value model for events of high perceived impact while retaining the expected value interpretation of risk for low impact events. The approach is:

1. Define all accident sequences that might make a significant contribution to the risk, and calculate their probability and consequence (in health effects).

2. Take the ΣPxC for all sequences with a value function of unity.

3. Define a "special" class of events that have:

    A. High consequence (perhaps more than 1 health effect) or

    B. High perceived impact (concern level), or

    C. Probability poorly known (like human intrusion).

4. Present each individual "special" event separately, with its probability and consequence quoted individually.

5. Provide perspectives and benchmarks for each special event, as well as for the total system ΣPxC.

6. Present the results for all alternatives in a concise form (tabular and text) to provide contrast among the alternatives and highlight the differences that allow risk evaluators to make a reasonable value judgement about the importance of the differences.

A perspective is a way to view a result that has some relation to human experience, usually a comparison with more familiar occurrences. This might include comparison to a fraction of background,

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[c] This situation is no longer valid if non-radiological parameters (resource use, cost, aesthetic values, etc.) are to be compared to radiological consequences.

uranium deposits, radium in soil, non-nuclear hazards, physical effect of major accidents, toxicity indices, etc. A benchmark is something to compare against, such as 1% of background, chest x-rays, one in a million increase in risk, etc. The benchmark is <u>not necessarily</u> an acceptable risk - such a judgement is left to the risk evaluator.

The unweighted system risk (ΣPxC) is computed and compared to a benchmark such as 1% of background or the increase in cancer incidence over the normal rate. A perspective is provided by plotting the CCDF for the sequences and comparing to other risks (as in WASH-1400). Then each choice of possible action is compared to each other choice (one by one). It is essential that the number of choices be small (3 or 4 at most) or that a larger number be grouped into a small number with similar unweighted risk and CCDF.

The "special" sequences are compared, one by one, for the alternatives. It is essential that the number of sequences be small (perhaps less than a dozen), although grouping might help where similarities can be found. Actually the number <u>should</u> be small in a well-designed system since release barriers will be in place to eliminate all but a few events. Probability and consequence are quoted separately, and each sequence is given a separate perspective and/or benchmark.

Examples are:

1) Compare effect of massive glacial flooding on a near-surface waste disposal site with the amount of radium in soil released by the same event, the effect on a uranium mine if present in a similar location, and physical damage to occupants and land.

2) Compare groundwater transport of material from a repository to similar transport of natural radioactive material deposits.

3) Compare meteorite effect to the effect of random impact on population.

Finally, the alternatives are compared to state what gains (or losses) are achieved by one choice versus another and what value judgements are implied by the choice of an alternative. For example if the choice is to dig up waste from a near-surface disposal site, process it and ship it to a repository instead of stabilizing the site with appropriate erosion and intrusion barriers, a few implications of the choice are:

1) increased routine exposure from operations and transport as well as population risk from operational accidents.

2) probability of intrusion is reduced (farming, archaeologists, shallow drilling eliminated, but deep drilling still possible).

3) meteorite probability is reduced.

4) land contamination is reduced but not eliminated since groundwater transport is still possible.

The method discussed above is proposed to achieve the maximum usefulness of Risk Assessment to a decision process, recognizing that complete methodology is not available for all phases of the analysis. Relative risk is used instead of absolute risk, and the uncertain judgement factors involved in demographic risk are acknowledged. The concept of "expected value of the consequence" is applied to only the consequence range where the concept is reasonably valid, and an alternate presentation is suggested beyond such a range. The method is intended to assist in improved judgement of safety and selection of alternatives until complete methodology and standards become available for risk judgement.