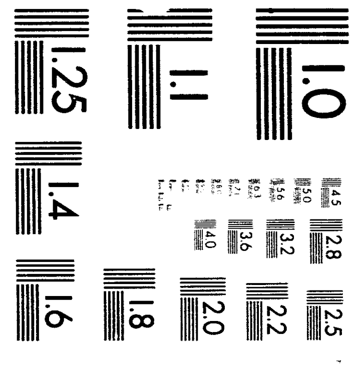

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RISK MANAGEMENT AT LOS ALAMOS NATIONAL LABORATORY

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INTRODUCTION

Los Alamos National Laboratory has risk management programs at a number of administrative levels. Each line organization has responsibility for risk management for routine operations. The Facility Risk Management group (HS-3) is the Los Alamos organization with the primary responsibility for risk management including providing input and expertise to facilities and line managers in the management and documentation of ES&H hazards and risks associated with existing and new activities. This includes program plans and schedules for implementing nuclear facility orders that involve risk management such as SAR (DOE 5480.23), TSR (DOE 5489.22), USQ (DOE 5480.21), and ORR(ALSD 54XA). One of the major contributions this group has made to the laboratory risk management program is to develop and implement a hazard identification and classification methodology that is readily adaptable to continuously changing classification guidelines such as DOE-STD-1027. This methodology is described in Ref. 1.

The increased emphasis on safety at Los Alamos has led to the formation of additional safety oversight organization such as the Integration and Coordination Office (ICO), which is responsible for prioritization of risk management activities. In the fall of 1991, nearly 170 DOE inspectors spent 6 weeks analyzing the environmental, safety, and health activities at Los Alamos. The result of this audit was a list of over 1000 findings, each indicating some deficiency in current Laboratory operations relative to DOE and other government regulation. The audit team's findings were consolidated and "action plans" were developed to address the findings. This resulted in over 200 action plans with a total estimated cost of almost $1 billion. The Laboratory adopted a risk-based prioritization process to attempt to achieve as much risk reduction as possible with the available resources. This paper describes the risk based prioritization model that was developed

METHODOLOGY

The methodology developed for the risk-based prioritization process is based on multiattribute preference theory. Multiattribute preference theory provides a logical and consistent basis for solving prioritization problems. The methodology quantifies uncertainty as probabilities, using the axiomatic logic of probability theory dating back to the 1700's. It quantifies objectives and values using axiomatic reasoning developed by John von Neumann in the 1940's during the time when he was also working at Los Alamos on the Manhattan Project. Together, these two methodologies allow the user to combine the technical assessments of scientists with the policy judgments of risk managers. The approach ensures that prioritization decisions have documented objectives and technical assessments, and an "auditable" logic to support the choices made by the decision makers.

Although several of the methodologies reviewed by the Laboratory claimed to be based on multiattribute preference theory, few actually were. Most of these methodologies confuse multiple-criteria models—models having more than one evaluation criteria scored and then combined to give an overall evaluation score—with multicriteria models that are in fact based on the axioms of multiattribute theory. Independent outside technical review committees studied the application of multiattribute theory to the prioritization problem at the Laboratory and the National Academy of Science reviewed the appropriateness of the application of the theory as it is to the prioritization problem within DOE.

Evaluation Categories

The development of a model to quantify the benefits of averting risk begins with the determination of the evaluation categories to be included in the definition of risk. Because the Laboratory was interested in the full spectrum of undesirable ES&H occurrences senior management eventually identified the categories shown in Fig. 1 as being complete in representing "risk."

These categories resulted from a series of interviews with Laboratory Associate Directors and ES&H Council members. After the first round of interviews, further interaction with special technical groups helped provide more detailed and quantitative descriptions of the categories. For instance, a Laboratory organization called "Our Common Ground," devoted to working with the Laboratory community to understand their concerns and the Laboratory's role in influencing their quality of life, was consulted as the basis for developing an operational way of measuring community concerns. Laboratory legal council was consulted in developing measures of compliance issues, and health and safety managers were involved in health and safety measures. The full development of evaluation criteria is shown in Fig. 2.

Measurement Scales and Value Functions

A series of meetings with Laboratory subject matter experts in each of the categories produced a quantitative measurement scale for each evaluation criterion. These scales

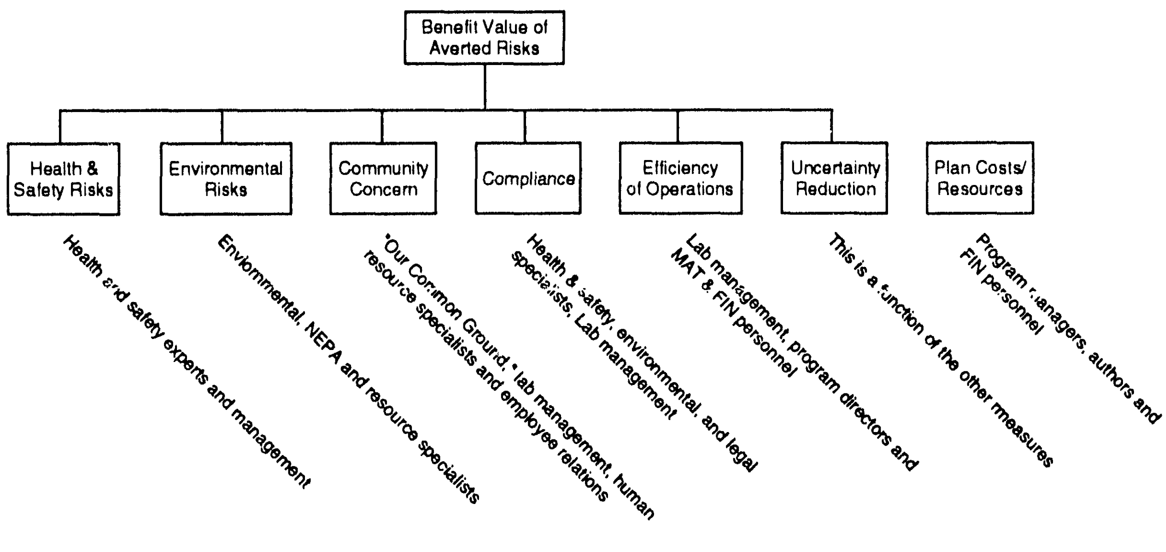

Figure 1. General risk categories.

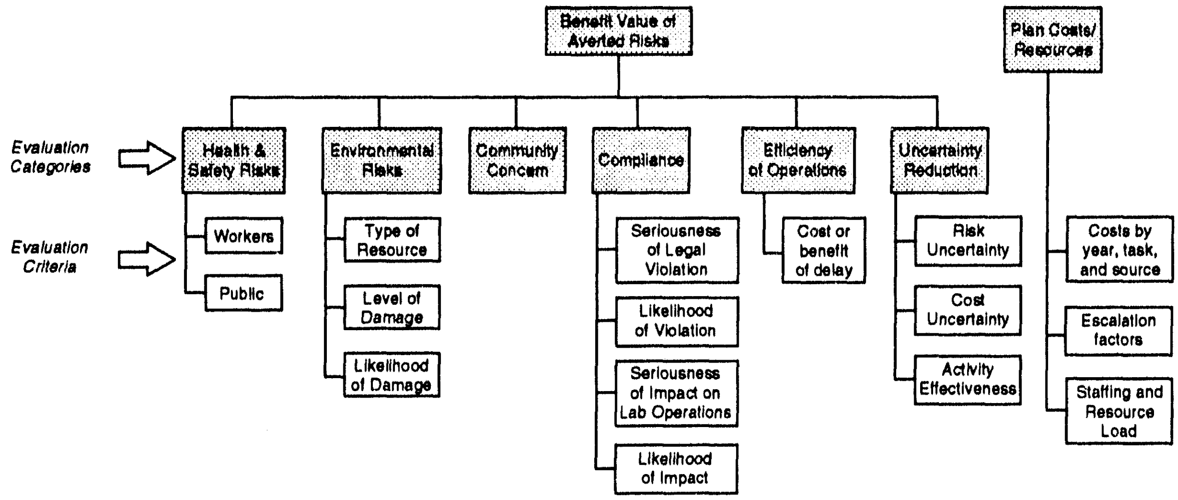

Figure 2. Risks are defined by the set of evaluation categories.

measure the degree to which an action plan addresses the evaluation criterion. The measurement scales and value functions for Worker Health and Safety, Public Health and Safety, and Environmental Insult are described below.

Quantifying Worker Health and Safety Risks

Worker health and safety risks are quantified using a simplified health-risk assessment model developed with the Health and Safety technical experts at the Laboratory. The model is

Severity of Effect x Probability of Exposure x Probability of Effect given exposure x Number of workers at risk x Time of exposure

The measurement scales and associated value functions for each of the evaluation criteria are shown in Fig. 3.

Multiplying these scales yields an estimate of the expected number of "effects," which is quantified next. The "severity of effect" scale was quantified by eliciting from Laboratory Senior Management, using standard decision analytic procedures, the value of preventing each of the effects relative to a standardize tradeoff activity (in this case, number of jobs lost due to higher costs of doing business in the marginally safer environment).

The Laboratory's value function for severity of health effects is given in Fig. 4.

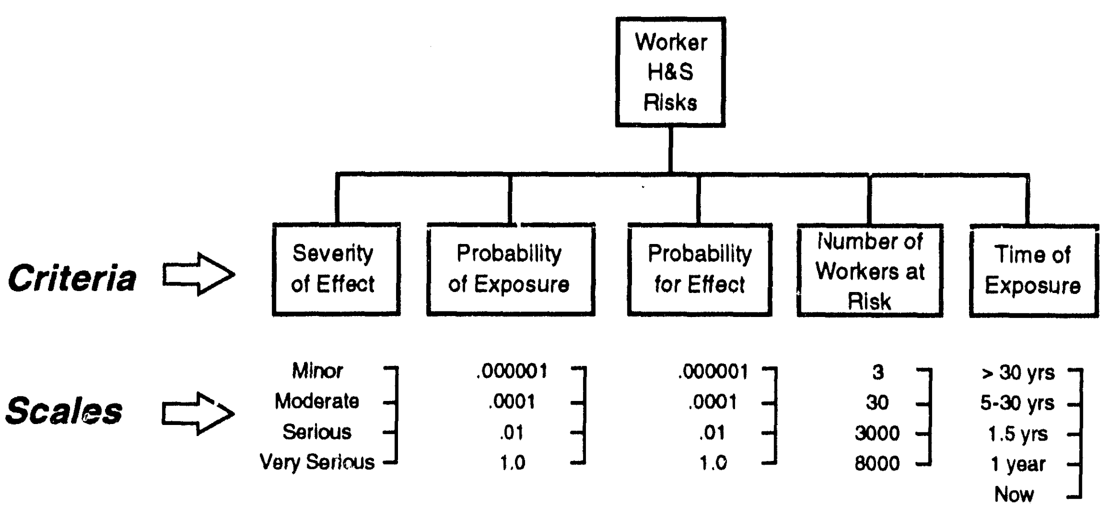

Figure 3. Measurement scales for worker health and safety risks.

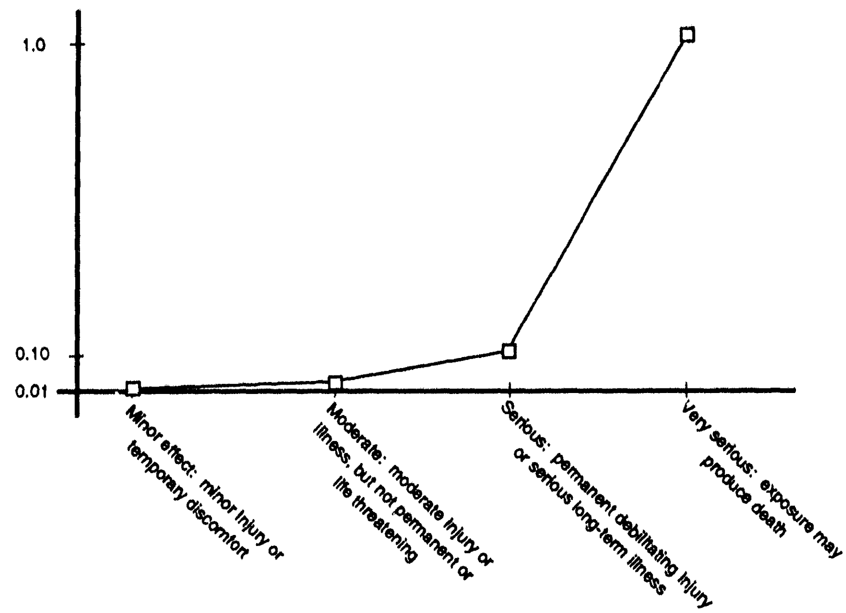

Figure 4. Value function showing the relative value of preventing health effects.

The value function is scaled to the range of 0 to 1 because the tradeoff coefficients will reflect the relative importance of the each of the categories. From this value function, it is clear that the value tradeoff between statistical fatalities and permanent debilitating injuries is 10 injuries to one statistical fatality. The implication is that a health and safety risk to workers with an expected outcome of 20 debilitating injuries is worse, in the value structure of Laboratory management, than a health and safety risk with an expected outcome of one statistical fatality, for example. The important point about the model made here is that while fatalities are worse than permanent debilitating injuries, a fatality by itself is not worse than *any number* of permanent debilitating injuries.

The computation of the expected number of statistical fatality equivalents for each activity allows non-integer scores on each of the scales. The computer calculation uses either linear or geometric interpolation, as appropriate, for assigning values for intermediate scores on each of the scales.

Quantifying Pubic Health and Safety Risks

Health and safety risks to the public are quantified in the same way, except that the population at risk can be much larger, up to the population of Los Alamos County. Figure 5 shows the quantification logic for the public health and safety risk category.

Quantifying Environmental Risks

A measurement scale based on sensitive environmental resources was developed by adapting appropriate structure from "Final Hazard Ranking System for Uncontrolled, Hazardous Substance Releases, Final Rule," from U.S. EPA, 1990, in the *Federal Register.* The scale is applied to each instance of a sensitive resource impacted by an activity. If a single resource qualifies for two different scores (e.g., a resource on both the state and Federal registers), then the scores are added. The use of this scale is illustrated in Fig. 6 and the logic for the full quantification is shown in Fig. 7.

Once the resource is valued, then the risk can be estimated using the equation shown below.

Measuring Risk (The "Risk Scoring" Process)

The person most familiar with each action plan uses the measurement scales to "score" the impact on total risk if the action plan is implemented. The scorers provide two sets of

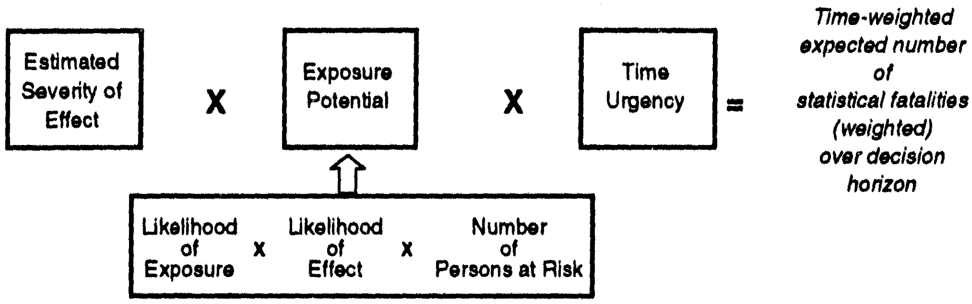

Figure 5. Logic for quantifying health and safety effects.

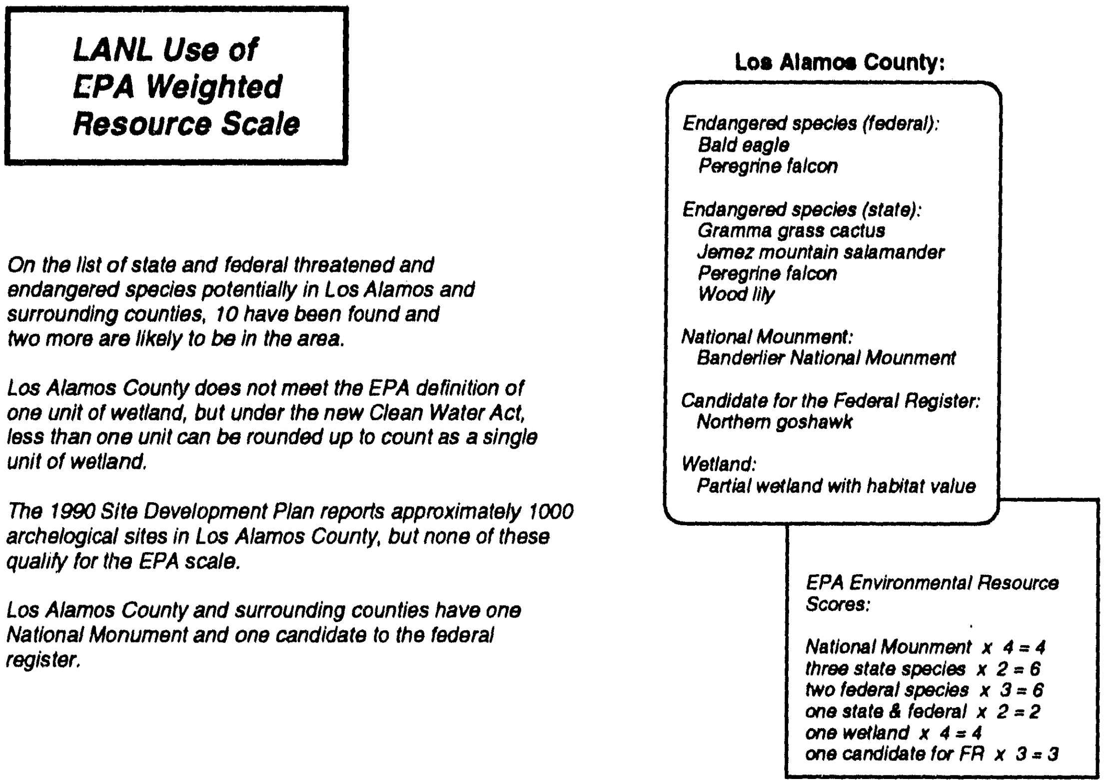

Figure 6. Use of adapted EPA scale for quantifying the value of sensitive environmental resources.

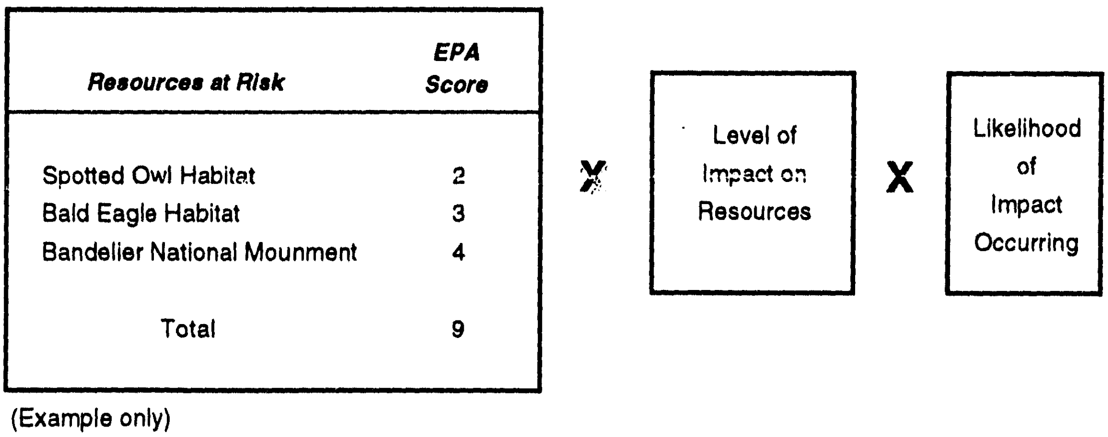

Figure 7. Logic for quantifying environmental risk.

scores for each plan: the first set give an estimate of the "baseline risk," the risk level if the deficiencies addressed by the action plan were left alone; the second set estimate the "modified risk," the risk level after the action plan is fully implemented. The difference between these two sets of scores is the averted risk attributable to the action plan.

The scoring process was not designed to be conducted as a "mail-out questionnaire." A team overseeing the scoring process provided group training sessions for all action plan scorers, and then individual training were needed. Help was provided throughout the scoring process and many scorers can in for guided scoring sessions.

There is always the concern that the person scoring an action plan, while being well informed about the plan, may not score it objectively. To guard against this kind of "advocacy" scoring, both the scoring process and the resulting scores were thoroughly reviewed. The underlying value model is not known to the scorers, so gaming the system to get a higher score is not a straightforward process because the best way to game the system is not known. Moreover, since the scores are subject to repeated reviews, it is very difficult for scores not supported by data and logic to remain unchanged.

The scoring was reviewed to control internal consistency across evaluation criteria (this is within-action-plan variance) and to control consistency across action plans (this is between-action-plan variation).

Combining Evaluation Measurements

The next step in estimating the overall value of an action plan is combining the scores associated with each action plan into a single measure of overall benefit. This single number represents the benefit of the risk averted by implementing the action plan.

The difference between the "before" (baseline) and the "after" (modified) risk scores for an action plan is the benefit of the averted risk due to implementing that action plan. The value functions for each evaluation category converts the scores for each category into a value measure. The tradeoff coefficients, elicited from Laboratory management, represent the relative value in dollars for each of the evaluation categories and are used to combine the category scores into an overall benefit estimate.

These tradeoff coefficients, sometimes called "weights," reflect the fact that the evaluation categories are not of equal importance. For example, worker health and safety is much more important than Laboratory efficiency. A formal elicitation determined the set of weights for the risk categories, using various combinations of evaluation criteria and full tradeoff questions as discussed in Keeney and Raiffa [1976].[2] The resulting set of tradeoff coefficients reflect the values of risk managers at the Laboratory when they allocate resources to competing risk reduction opportunities. All Laboratory management was involved in some part of this elicitation process so that all perspectives on relative importance of risk categories were taken into account.

In addition to determining the relative weights for the evaluation categories, the assessments also produced a rule for combining these weighted risk category measures. By testing for preference independence and additive independence in a series of tradeoff exercises. it was determined that it was valid to use a linear combination of category scores.

Combining Benefit and Resource Estimates for an Action Plan

The relative priority of an action plan depends on both the benefits that it produces and the resources that it requires to be implemented. A traditional way to represent the attractiveness of an action plan is to estimate the net return of the action plan as a proportion of its total cost. This is one form of a "return on investment calculation." The calculation associates a single number with each action plan. The number is the benefit produced by the action plan divided by the cost to implement the plan. If an action plan's benefit is less than its total cost, this number is less than 1, indicating a return on investment that is less than the investment itself.

The straight prioritization of action plans can be based on ranking the action plans according to benefit to cost ratio. The implicit optimization rule for this approach is that we wish to optimize the risk reduced by each dollar spent. An alternative to this optimization rule is to optimize the total amount of benefit that can be obtained over a set of years and a set of budget constraints. While each dollar spent in each year may not be optimal, the total benefit obtained over all the years is optimized.

Obtaining the Maximum Benefit for Given Resources

Selecting a set of action plans that yields the greatest total benefit for given resources (by year and by source) is an optimization problem sometimes referred to as a portfolio problem. Because resources come from different sources with different limitations in different years, it is not possible to just "follow a list" of action plan priorities based on benefit to cost ratio and stop when the money runs out. Instead, a collection of plans consistent with the funding sources and timing constraints must be determined to maximize the total benefit achievable. Linear (and integer) optimization computer codes can solve this problem and find the portfolio of action plans to implement for any set of resource constraints over the planning horizon.

To solve this portfolio optimization problem, it was formulated as a mixed-integer problem where small action plans can either be done or not in any given year (the integer portion of the problem) and large action plans can have yearly portions done without committing to the entire action plan for contiguous years (that means that later years can be delayed in implementation, although they must be done in the proper order; years can be skipped in the implementation of a plan, if necessary). Future costs were discounted at the Laboratory discount rate and future benefits were discounted at the same rate. The solution of this optimization problem relied on a powerful library of optimization software capable of solving problems with thousands of action plans, funding sources (by time period), and constraints. The problem was solved using IBM's optimization software OSL (Optimization Software Library) on a large IBM personal computer.

CONCLUSIONS

The risk-pased prioritization procedure allowed the Laboratory to responsibly address all the ES&H risks identified by the DOE audit, systematically plan for the future implementation of action plans and document the basis upon which it allocates resources to reduce risk. The model provides an auditable system for defining risk, measuring its reduction, and effectively allocating resources over time. The model used to combine all this information into a decision-aiding tool is based on a sound methodological foundation of multiattribute preference theory. The procedure serves as a powerful communication tool for making the Laboratory's risk reduction objectives, priorities and risk measurements explicit.

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