BRIDGING THE GAP: A METHODOLOGY TO PROVIDE BALANCE BETWEEN THE QUALITATIVE AND QUANTITATIVE ASPECTS OF TECHNOLOGY DEVELOPMENT

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ABSTRACT

Many in the technical community have been disappointed when large-scale technological projects become severely curtailed, or even terminated, because those projects are controversial and publicly unacceptable. This experience has led some, and particularly those in the nuclear disciplines, to reexamine the ways in which technology is assessed. The current status of a research project to develop a systematic method for bringing social values into the technical assessment framework is discussed. This method, social value assessment, uses a dialog-based platform for identifying explicit and implicit beliefs about an emerging technology and influence diagrams for representing those beliefs. Those diagrams can then be used by each decision maker for comparing similarities and differences of their choices and decisions. A hypothetical decision problem, transmutation of fission products in high-level waste, is used to demonstrate the social value assessment method.

INTRODUCTION

Many people have observed the unhappy course of a number of large-scale technological projects to see them curtailed or terminated because the project became very controversial. These observations have been of particular note in the case of regulated technologies. One might witness time consuming technical development of a project, its subsequent clearing of regulatory hurtles, and elimination or extensive delay because it was not publicly acceptable. This experience has led some, and particularly those in the nuclear disciplines, to reexamine the ways in which technology is assessed.

Realizing that a new approach for assessing large-scale technical projects is desirable has not been easy. The technical community often laments that the public has a distorted view of the true risks or that the media portrays science inaccurately. There is also the concern that irrational fear of the public is based on mistaken perceptions of the risks. They also believe that the public needs to be educated to the real hazards. These views, though widely held, will not lead to resolution of the problems encountered when trying to evaluate and successfully deploy technologies. There is a need for technologists to understand and value the public's perception of risk. This need is elegantly stated by Slovic (1) where he uses psychometric techniques for identification of similarities and differences among groups regarding perceptions and attitudes. Slovic's observations lead one to an understanding that each side, both expert and public, has something valid to contribute and that insights and intelligence of the other should be respected.

Indeed, according to Slovic(2) the Yucca Mountain project "has been brought nearly to a halt by overwhelming political opposition, fueled by perceptions of the public that the risks are immense. These perceptions stand in stark contrast to the prevailing view of the technical community, which argues that nuclear wastes can be disposed of safely, in deep underground isolation." What is being evidenced at Yucca Mountain is a large-scale project in which the public perception of the problems is totally different from the problems perceived by the developers. Reflecting upon Slovic's statement in his 1987 paper, he concluded that "... there is wisdom as well as error in public attitudes and perceptions. Lay people sometimes lack certain information about hazards. However, their basic conceptualization of risk is much richer than that of the experts and reflects legitimate concerns that are typically omitted from expert risk assessment.

New Methods are Needed

Traditional technology assessment methods have, in general, ignored issues related to public values and concerns. For an acceptable and justifiable assessment of a project, all factors must be incorporated in the decision-making process. If social factors are ignored, there is a high probability that large-scale projects can become controversial. Vlek and Cvetkovich(3) identify some of the reasons for this conflict:

- The project might be aimed at delivering massive benefits for a large number of people, but might also have serious negative consequences for others. Therefore, it is perhaps in the interest of special groups of people and may ultimately affect many others which gives rise to the issue of fairness;
- The project might be well understood and evaluated by a relatively few people but its actual consequences will or may affect a multitude of people requiring a great deal of their trust;
- There can also be short-term and long-term consequences; it can be a novel approach, loaded with uncertainties. This potentially leads to deferment of unintended costs and possible harm; and
- Because of its complexity there is also a catastrophe potential where the classical statistical view of risk appears too restrictive to deal with concerns in a socially and politically feasible manner.

The technical community has attempted to address these important issues by performing more complex feasibility studies and risk assessments. But these multifaceted analyses have their share of problems. Many of those conventional methods can lead to the point where the complexities or the effects of choices cannot be comprehended. A simple method is needed where the values of many people are equitably represented. In addition, the method must be robust enough to accommodate the evolution of beliefs that will inevitably change with time.

In an attempt to address the current limitations in technology assessment, this research has developed a systematic method for bringing social values into advanced technology development. The method has its foundation in the creation of a common platform for discussion, reasoning, and negotiation among many people. This method identifies quantitative (fact-based) and qualitative (value-based) beliefs associated with the technology, assesses the impact of those beliefs, and tracks the multiple values and differences in beliefs so that trade-offs might be explored. The central theme of this method is that the decision-makers' beliefs must be represented equitably and systematically. Decision-makers are defined as the public, technologists, and those whom they both represent.

Foundation of the Method

Since a decision-maker's beliefs are by their very nature uncertain and dynamic, accommodation of these characteristics is essential. To this end, a new method, called social value assessment (SVA) brings together the dominant features of three techniques: value oriented social decision analysis (VOSDA), developed by Chen and Mathes(4), principled negotiation techniques, developed by Suskind and Cruikshand(5) and Raiffa(6), and an artificial intelligence tool for reasoning and quantification of uncertainty known as influence diagrams. The combination of these features implemented within the framework of influence diagram methodology resembles computer-assisted group decision-making. It is also similar to concurrent engineering in manufacturing and decision support in health care. Some researchers have used decision trees or multi-attribute utility measurements for clarifying public values in risk debates and for effective communication between stakeholders (for example, Edwards and von Winterfeldt(7)). The success of these methods have been limited due to the complexity of the analysis. The uniqueness of SVA is the use of influence diagrams for representation of values and concerns of the decision-makers.

Influence diagrams effectively represent the state of knowledge that corresponds to the problem at hand. They are a powerful tool for quantification of uncertainties, identification of influential components of the knowledge structure, and simulation of different scenarios. These diagrams visually depict sources of uncertainty, dependence, and flow of information in the decision process. Therefore, they are effective for communicating, modularizing, and identifying holes in the knowledge relevant to the technology. Influence diagrams incorporate Bayesian analysis with mathematical random graph theory. When the diagram is constructed, one can hypothesize a series of "what if" scenarios and see the impact of different values on the complex decision problem. This method is also normative. Normative theory provides a set of criteria for assuring consistency among beliefs, preferences, and choices that must be observed and used by a rational decision maker(8). Given a set of beliefs and preferences, the normative theory prescribes which decision should be chosen to maximize the outcome of an analysis.

Social Value Assessment

The SVA method uses common sense judgment for making decisions where there are multiple opinions and values to be considered. The benefit garnered by this approach is that it can provide a basis for understanding if modifications to the technology are feasible and if those modifications are socially valued. As shown in Figure 1, after an innovative concept for a technological project comes into focus and before it is developed, the following processes must take place:

Dialogue Based Platform – This framework for communication between the decision-makers instills a common language for clarifying the needs for and benefits of pursuing the innovative technology. Areas are identified where uncertainty pervades and the need to reduce these uncertainties are elucidated. During this phase, explicit and implicit values can be clarified. This is a very important step. It is dynamic and subject to modification throughout the process of SVA.

Influence Diagrams – In this phase of SVA, the values and concerns identified in the previous phase can be captured and represented in a knowledge base. Each individual can develop his/her own model of the problem. These models can then be used to compare each individual's concerns. Decision-makers can view how their concerns and choices influence the complex decision process. Their concerns can be modified as they change. This step facilitates efforts to reduce uncertainties and determines the range of flexibility for the final step of this process.

Search for mutual gain – The captured information from the previous two phases is used for principled negotiation. Similarities and differences are compared among participants and, from this, they make an informed judgment of their range

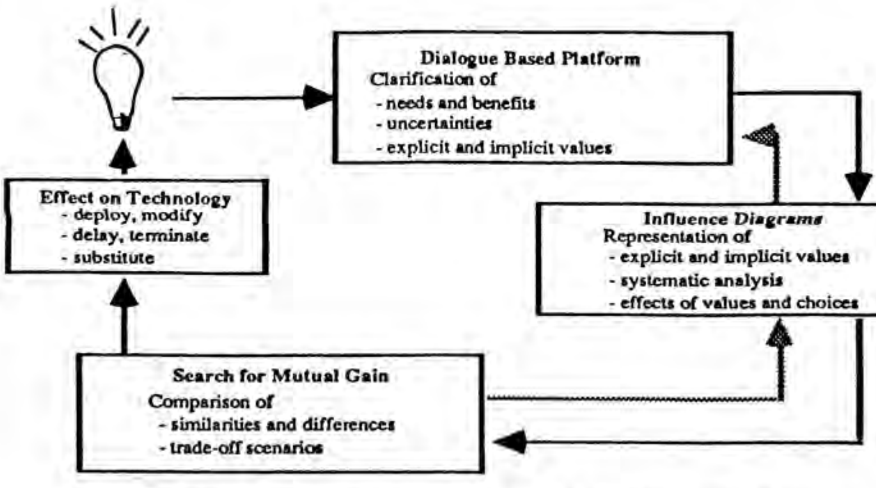

Fig. 1. A conceptual representation of the SVA method.

of flexibility for possible trade-offs. They might even decide to revisit some of their choices.

Effects on the technology – At this stage, a mutually agreed upon decision may be arrived at to go forward with the development, modify the concept, delay, terminate, or perhaps substitute it with another concept.

The modeling of the participants' concerns is a complex task. To underscore this complexity, consider a study by Ramspott(9) which investigates the impact of new developments in partitioning and transmutation on the disposal of high-level nuclear waste in a mined geological repository. The investigators identified some of the factors that could influence the selection of a given technology. Some of these factors are illustrated in Fig. 2. Although this is a partial representation of the potential factors, it displays the complexity of the assessment task and delineates the need for a systematic approach.

Since influence diagrams are known for their illustrative power and computation and storage efficiency, they are extremely useful for this application. Building the influence diagram is a beginning toward representing the state of knowledge about the decision problem. Through SVA, the structure of the influence diagram evolves to the point that the demands and expectations of all the participants are met.

Application of SVA To A Hypothetical Decision Problem

To illustrate the SVA method, the public acceptably of transmutation of fission products in high-level waste is addressed. Transmutation is defined as the conversion of one element or nuclide into another either naturally or artificially(9, p. 3-1). Coupled with chemical separation (partitioning), partitioning and transmutation (P-T) of high-level nuclear waste is a waste management strategy that could complement geological disposal. This strategy is under review by a National Academy of Sciences panel for its feasibility. As part of the review, questions of potential public acceptance are included.

Consider the following decision problem. According to Pigford(10) safety analyses of geologic repositories include the prediction of radiation doses to future individuals caused by radionuclides reaching the environment for time periods of 100,000 years or longer. The analyses, particularly of the U.S. proposed repositories in unsaturated rock, show that the long-term risks are dominated by long-lived, soluble, weakly sorbing fission products. In addition, the radiation dose risk from spent-fuel radionuclides that reach the biosphere is expected to be due predominantly to the long-lived fission products technetium-99 and iodine-129 (see Fig. 3), because of the solubility and greater release rate from the waste solid, long half lives and the weak sorption on rock. If this prediction is true, then transmutation of the fission products of concern prior to geological storage of the waste may be one viable technical option.* This is a good example of a case where a technically based decision-maker might wonder if transmutation is publicly acceptable because it could potentially remove the long-lived fission products of concern and help mitigate fears of high-level waste disposal. For this hypothetical decision problem, the decision-makers are to choose between two alternatives for disposing of nuclear waste.

The conversion of some of the fission products or actinides through the transmutation process is the first alternative. This option may or may not lead to the elimination of the need for a geologic waste disposal facility. The second alternative disposes the waste without any treatment. The objective of this decision-making process is to select a technology that is acceptable by the public. In the first phase of SVA, the values and concerns relative to the acceptance of transmutation technology are identified through an iterative dialog among all the decision makers. For this hypothetical example, the following values and concerns are identified:

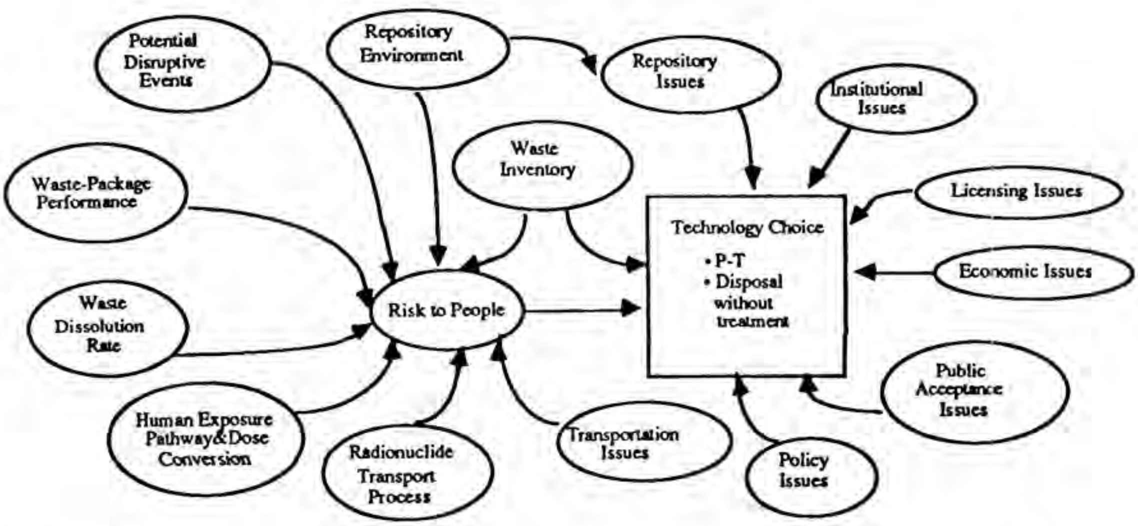

Fig. 2. Partial representation of factors affecting high-level waste disposal options as identified by Ramspott(9).

* In this example, only the transmutation process is analyzed.

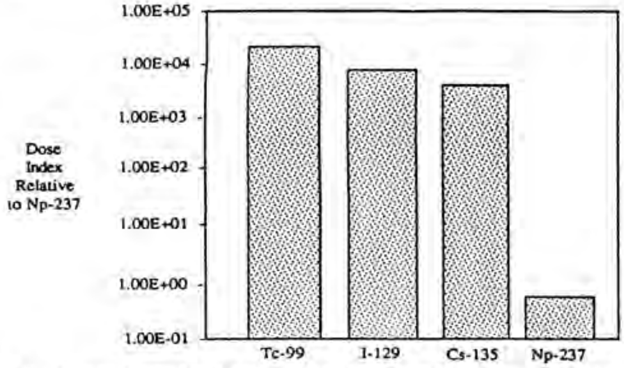

Fig. 3. Doses from the fission products technetium-99, iodine-129, and cesium-135 are among the most long-term concerns. The doses from neptunium-237, the greatest actinide contributor, would be about five orders of magnitude below that of technetium-99(10, p. 13).

- cost of the technology;
- effects on the environment; and
- individual health effects.

An influence diagram that represents these concerns is shown in Fig. 4. In this network, the circles represent events that are beyond the control of the decision-maker, such as the values and concerns identified by the decision-makers. These are probabilistic nodes. The rectangle contains choices available to the decision-makers. The diamond is the outcome of the analysis, in this case, the acceptance of the transmutation technology by the public. An arrow incident on a probabilistic node provides conditional statements. The node at the end of an arrow is conditioned on the node at its beginning. An arrow incident on the value node represents a variable whose value affect the calculation of the outcome. The labels on the arrows represent the information that is transmitted from a parent node to its children.

The decision node D denotes the choice of technology by the decision-makers and has two possible values, $D \varepsilon \{d_1, d_2\}$, where d_1 stands for the decision to transmute the waste before its disposal. Value d_2 represents the decision to dispose of the waste without any treatment. Node C represents the cost of the technology, $C \varepsilon \{c_1, c_2\}$, with c_1 and c_2 corresponding to costs associated with d_1 and d_2, respectively. These costs include those of design and construction of the alternative technologies and their respective projected operating expenses. Alternative d_1 may be more expensive than d_2 due to its required initial investment and projected annual budget. At the same time, it could lead eventually to a substantial savings by lowering the probability of ground water contamination. Cost of each alternative is expected to have a direct impact on the acceptability of the technology which is represented by the utility node Public Acceptance. Node E, $E \varepsilon \{e_1, e_2\}$, represents the effects on the environment that is influenced by the choice of technology, D, and the prediction of a transport model, node P. One possible value of E, e_1, is ground water contamination near the repository due to the release and migration of fission products. Complement of this event, e_2, represents the base-case scenario in which the ground water quality remains uncontaminated and is thus acceptable according to future standards. Since node E is conditioned on nodes P and D, a conditional probability matrix $P(E \mid P, D)$ for all values of E, P, and D must be elicited from the decision-makers and stored with node E. Node E has also a direct impact on public acceptance of the technology. Node P, $P \varepsilon \{p_1, p_2\}$, represents the prediction of the transport code analyzing the migration of radionuclides through unsaturated and saturated zones. Value p_1 corresponds to the prediction of the transport model about the nature and quantity of the radionuclides that reach the accessible environment at a given time. The prediction of the model that no detectable amount of radionuclides reach the accessible environment within a given time frame is represented by p_2. The quality of the environment is known to impact the individual health, which is represented by node H, $H \varepsilon \{h_1, h_2\}$. A possible value for H is h_1 which represents the threat to health due to contamination of the ground water and subsequent migration to biosphere. Value h_2 represents the base-case scenario of known health hazards in the absence of the potential contamination. Event H is conditioned on event E and, therefore, a conditional probability matrix $P(\mid E)$ for all values of H and E must be constructed and stored with the node. Node H also influences public acceptance of the technology.

At this stage, the decision-makers can hypothesize different scenarios and see the impact of their choices on public acceptance of the technology. Knowledge about the feasibility of technology choice is stored as a set of functional relationships with the utility node, Public Acceptance and its parents, nodes H, E, and C. Given the cost of the technology, say c_1, the effect on the environment, e_1 for example, and threat to health, h_1, public acceptance of the technology can be specified. This is the stage that the decision-makers can conjecture many scenarios to dissect the decision problem from any possible angle. If costs could be associated with all the values of and , the expected value of the Public Acceptance node can also be calculated. It allows the decision-makers to identify the factors, such as health effect, that could have a tremendous effect on the acceptance of the technology. At the same time they may conclude that the cost of the technology may not be the primary factor in the acceptance of the technology. They may even discover that polemical factors that could potentially block the deployment of the technology may not have any influence on the final decision anyway.

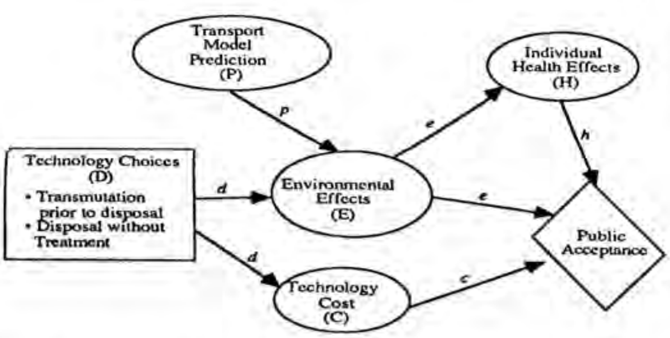

Fig. 4. Influence diagram for the hypothetical decision problem.

CONCLUSION

Incorporating social values into technical assessment brings to focus the need for a balanced representation of both qualitative and quantitative aspects of technology development. This a difficult task at best because of the complexity of the problem and the large number of diverse values that must be considered. If technologists understand and respect the public's perceptions of risk, then different decision choices might be made so that the ultimate outcome is acceptable. Within the framework of a systematic approach, such as the social value assessment method, this outcome may be possible.

SVA combines the effective features of value oriented social decision analysis and principled negotiation techniques with the representation power of influence diagrams. This methodology provides a coherent structure for determining an optimum decision with respect to existing values and concerns. Advantages of using this methodology include the ability to represent all factors that influence the decision, clearly enunciate interdependencies among the components of the decision problem, and directly incorporate decision-makers' knowledge(11). These features of the SVA method can be, for some, emotionally less demanding than face-to-face decision conferencing or other more conflict oriented modes of interaction(4).

By effectively representing the quantitative and qualitative beliefs of the participants, SVA establishes an environment in which the decision-makers can experience and learn from their choices and decisions. SVA has also been developed within a context of discovery rather than justification. Discovery is often non-methodological and is driven by factors that are highly non-rational, i.e., hunches, predilections, biases and imagination. Justifying an idea is a scientific approach which must be subjected to the twin principles of reproducibility and empirical control(12). In this method the participants reflect their biases and values that cannot be reproduced by others. What is known about a large-scale technological project, especially its risks, is conditioned by beliefs which are not always rational. By treating those values and concerns seriously and equitably, and combining those implicit values with explicit technical knowledge, trust among decision-makers can flourish.

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