The Hybrid Vigor Institute
1300 20th Street
San Francisco, CA 94107 USA
+1 415 543-8113
http://hybridvigor.org
http://hybridvigor.net

RISK: THE ART AND THE SCIENCE OF CHOICE

Denise Caruso
caruso@hybridvigor.org

Co-produced for Earth Systems and Health Determinants

Prepared for
The Rockefeller Foundation
Global Inclusion Program

INTRODUCTION

The growth of scientific knowledge and the technological advancements of the past several hundred years have provided the catalyst for civilization and grist for ongoing, fundamental changes to social, political and economic systems around the globe. If one were inclined to reduce to first principles, a good case could be made that such advances have been possible only because humans have developed increasingly sophisticated ways of understanding and dealing successfully with risk.

Until roughly the 1970s, the field of risk was largely dominated by engineers, economists and epidemiologists, who calculated risk based on historical data and knowledge of existing systems and vectors. But over the past 30 years, exponential increases in both the volume of advancements in science and technology and the velocity at which they have been introduced into practical use have fueled an ongoing debate about the risks these advancements engender — how the risks are assessed, and how they are managed (and by whom) — in an increasingly interdependent world.

The central issue, as seen by a wide range of concerned scientists, public policy makers, citizens and other stakeholders, is the difficulty of accurately assessing risks, given the sparseness and uncertainty of scientific knowledge about most new discoveries and technologies. These uncertainties have highlighted the shortcomings of purely quantitative assessment measures and, over the past two decades, prompted a growing acknowledgment by risk experts (in theory, if not yet in widespread practice) of the co-equal importance of subjective factors, including values, for understanding risk.

Risk is a fundamental concern that is constantly under investigation in virtually all aspects of civilized life, from health and environmental safety to economics, politics, and the business world. For the past 20 years, an extraordinary number of disciplines have undertaken the study of risk — beyond engineers and economists, now psychologists, social scientists, lawyers, biologists, physicians, operations researchers and others[1] have entered the scene. This paper attempts to address and synthesize only a fraction of this vast literature.

First, we will sketch an historical landscape of risk in the broadest strokes. We will then briefly note the most pivotal of the various mathematical tools and approaches that have been developed and/or used in the quantitative assessment of risk.

Then we will segue into an exploration of the schools of thought which, over the past 20 years, have increasingly informed the study of risk. Rather than focusing on the latest permutations of mathematical theories of probability, or the relatively straightforward studies of economics and actuarials which have until now effectively employed these theories, this section will focus — more usefully, we expect — on the evolution of risk analysis beyond purely quantitative, probabilistic approaches into the realm of values and subjectivity, specifically where such analysis concerns the intersection of science, technology and public policy.

The paper will close with a brief note about risk studies outside of the United States, some relevant case studies of specific risk analyses and a bibliography to facilitate further, independent investigation.

The author would like to thank Baruch Fischhoff of Carnegie Mellon University for his generous contribution of time and thoughtfulness to this paper. His wealth of publications, expertise and extensive knowledge of a broad field was of incalculable value as a navigation aid through the “vasty deep” of the literature of risk and the many people who populate its waters. Any misinterpretations are solely the author’s.

A BRIEF HISTORY OF RISK

Simply defined, risk is the possibility of suffering harm or loss under conditions of uncertainty. A history of risk maps the history of humankind’s increasing ability over time to consciously avert that possibility, and to take advantage of that ability to the greatest possible degree. Toward that end, we have developed and learned to use sophisticated scientific and behavioral methods to evaluate a variety of potential outcomes, in service of making the “safest” or most successful decision.

The distinction between hazard and risk is an important one. A hazard has the potential to harm or produce a loss — or some other undesirable consequences — to some person or thing. But the concept of risk attaches the *probability* of the hazard being realized; the essence of the distinction is that risk takes probability into account. For example, someone who lives where a severe hurricane blows through once in 200 years faces the same hazard, but only 1/10th the risk, of someone whose region is hit with an equally severe hurricane once in 20 years.

Risk, then, has been traditionally thought of as a way to further quantify a hazard, given that hazards of the same magnitude do not always pose equal risks.[2]

But simple definitions belie the complexity of this evolving field, and increasingly included in the definition of “risk” are methods by which we are able to *qualify* hazards as well as quantify them, based on the inescapable value judgments and subjectivities of daily life. The integral role of values and subjectivity in risk analysis is central to the arguments presented in this paper and will be examined in much greater detail below. But it may be useful to attempt a baseline context, if not a precise definition, for the terms.

Decisions made by scientists, for example, about what types of hazards to study are based in part on technical information, but they are also based on *value judgments* about which hazards require the most immediate attention. These judgments are *subjective*; that is, individual scientists can (and do) make different determinations about what they will study.[3] In the same way, estimating a risk requires the value judgment of how a scientist decides to characterize the uncertainty of the information; therefore, risk estimations are also subjective, in the sense that different experts will (and often do) make different estimations based on the same quantitative data. And implications for action, once an assessment has been made, require tradeoffs among risks and benefits and will also inevitably be value-laden, thus subjective as well.

One method that scientists have used to avoid value judgments in risk assessment is to simply ignore potential risks that don’t have data or historical records attached to them, such as human factors or design flaws. However, a widely accepted school of thought (based on Bayesian logic, described below) says that even historical estimates require interpretation thus are also subjective, although not in the "values" sense. Thus it is possible for subjectivity to be value-free,[4] but difficult (more likely, impossible) for a comprehensive risk assessment to be truly objective.

IN THE BEGINNING. Risk has been a conscious undertaking for nearly as long as we have record of human activity. In fact, risky behavior in the form of gambling apparently trumps prostitution for the title of the Oldest Human Vice: cave paintings show our ancestors playing a game of chance — with dice made from the ankle bones of deer and sheep — long before the bestowing of sexual favors had developed into a fungible commodity.

However, our gambling ancestors had no mathematical conception of the (literally) calculated risks of today. It took thousands of years from the time the first ankle-bone was thrown for *homo sapiens* to develop the ability and the mathematical tools to calculate the probability of various outcomes, transforming our observations of events into mathematical formulae that might help us predict them.

These new formulae allowed scholars to begin to investigate and deconstruct the many patterns in nature that they had previously observed and pondered. But it wasn't until the Renaissance and the Protestant Reformation — when logic began to flower, and the belief was born that God gave humanity at least some control over its own destiny — that Europeans began exploring the radical concept of replacing the randomness of fate and subsequent terror of the unknown with the ability to systematically calculate the probability of future events. Very quickly, the notion that the future might be somewhat predictable, thus controllable, spurred much growth in foreign exploration, trade and commerce throughout the 1500s and 1600s.

During this time bookkeeping and forecasting were invented, which for the first time linked calculated risk with the payoff of increased wealth for risk-takers. Both were critical components toward a new, quantitative approach to assessing probability, which itself was the first step toward quantifying risk.[5]

A MERCIFULLY BRIEF PRIMER ON THE MATHEMATICS OF RISK

Calculating risk requires a knowledge of several mathematical principles, and any detailed examination of them is beyond the scope of this paper and the author's expertise. However, because these quantitative measures provide the scientific backbone for risk assessments of science and technology, it may be useful to touch briefly on a few of the key theories upon which the study of risk is based.

Somewhat paradoxically, *probability theory* calculates the likelihood of a random event's occurrence. Discovered in the 1600s by the mathematicians Pascal and Fermat, in its simplest mathematical form probability can be expressed as a number between one and zero, with one meaning "the event will always happen" and zero meaning "it will never happen." The equation that derives this result is at the heart of quantifying risk.

Weather predictions are an example of probability theory in practice. A weather forecast that predicts a 60 percent chance of rain is calculated by looking at all other days in an historical database that have the same weather characteristics (temperature, barometric pressure, humidity, etc.); in this case, it is determined that on 60% of similar days in the past, it rained.

While probability theory has proven to be a serious instrument for mathematical forecasting based on historical data, the quality of information that informs probability estimates is critical for accuracy. A sequence of mathematical discoveries that linked probability with quality of information followed Pascal and Fermat's work.

One such discovery was the *law of large numbers*, developed by Jacob Bernoulli. This was the first attempt to measure and define how to develop a numerical probability from a *sampling* of past events, rather than from the entire universe of such events. For example, he asked, could you calculate, within a predictable margin of error, the ratio of black to white stones in a jar by randomly selecting and measuring 100 of them at a time? Although the number of trials to answer this question was preternaturally large by today's sophisticated standards (more than 25,000), the short answer — "yes" — yielded the first set of tools for developing accurate probabilities of future outcomes based on limited data from the past.[6]

The law of large numbers was followed in relatively short order by several other discoveries, including equations to calculate *normal distributions* and *standard deviations*, which were noteworthy in that they mathematically defined how to derive an "average" value, and refined our ability to use even smaller samples of historical data upon which to base calculations of probability. These same formulae are still the mathematical basis for any population-based risk assessment, for example, within the insurance industry and to some degree, economics.

Then in 1763, Thomas Bayes made a striking advance in statistics and exponentially increased the sophistication of risk analysis with his demonstration of how to revise a probability and make better informed decisions by mathematically blending new information into old information.[7] According to Bayesian logic, the only way to quantify a situation with an uncertain outcome is by determining its probability. *Bayes' Theorem*, then, is a method based on probability theory for quantifying uncertainty.

The classic Bayesian example is of a covered basket that contains three balls, each of which may be green or red. In a blind test, you reach in and pull out a red ball. You return the ball to the basket and try again, again pulling out a red ball. Once more, you return the ball to the basket and pull out a ball — red again. You form a hypothesis that all the balls are all, in fact, red. Bayes' Theorem can be used to calculate the numerical probability that all the balls are indeed red, given that all the selections you've made to date have been red.[8]

Many familiar and important theories of probability that include multiple dimensions of uncertainty, such as *game theory, belief nets* and *decision analysis*, some of which are adapted for use in the calculation of risk, are based on Bayesian logic.

PROBABILISTIC RISK ANALYSIS. Any competent risk assessment calculates numerical probabilities using the mathematical tools and techniques described above, and their many subsequent and ongoing derivations. In practice, most probabilistic approaches to analyzing scientific and technological risks are still non-Bayesian; that is, they originated with approaches to modeling mechanical or engineered systems where the incorporation of new information into the model over time was not thought to be required. These computational approaches were largely based on engineering and epidemiology and were trying to integrate risk exposures with effects.

Probabilistic risk analyses for engineered systems was comprised of creating what is called a "fault" tree of possible negative outcomes and calculating statistical variables of how the system would perform under those circumstances.

For example, probabilistic risk analysis was deployed in approaching certain types of risks — like those, for example, posed by interacting parts of complex engineered systems, like nuclear power plants. If Widget A breaks and Sprocket B overheats as a result, what's the probability that the system will break — and when, and to what degree? Might it take the rest of the system with it? This type of risk analysis obviously works best when the decision maker has fairly deep knowledge of how the system works and interacts together.

Another school of probabilistic analysis looks at epidemiology and health effects. Let's say that the nuclear plant in the above example explodes. What happens then? Where does the pollution go; how does it interact with air and water; where is it deposited? What are the impacts on biological systems? This presents yet another complex set of interactions which also could be viewed as basically probabilistic: Imagine a release of a chemical, or radiation, from the aforementioned power plant. Based on our quantitative knowledge of the effects and the geophysics of an unanticipated release, can we predict what the health effects will be?

In a static world where objects are discrete and not connected to their surroundings, this narrowly proscribed type of probabilistic, non-Bayesian approach makes sense and in fact was long in use (and in many cases, still is), based on traditional views of risk assessment. But as in each progression of the example above, we now have learned through real-world experience that very few things or events in the world (if any) are truly discrete. Thus risk analysts are finding that in any accurate model or analysis of risk, broad, heretofore unconsidered categories of subjectivities and uncertainties must be accounted for in addition to probabilities — such as components in the model that are not well understood or that depend upon uncertainties outside the model, for example, or things that are not in the model that aren't known, or that should be included but are not.

THE SCHOOLS OF RISK: 'NUMBERS' V. 'VALUES'

One risk expert, Baruch Fischhoff of Carnegie Mellon University, has long observed the difficulty that "numbers people" have with the undeniable subjectivity and the dreaded "value judgment" determinations that accompany all risk analyses — undeniable because we cannot with certainty predict the future, dreaded because we love to believe that statistics and numerical values eliminate the subjectivity of values. As an example, Fischhoff cites typical engineers who will know how a system's components work and how those components depend on one another. They will initially recognize statistical uncertainty — not probability, but *uncertainty* — in how the system performs. But according to Fischhoff:

> [In order to address the uncertainty,] what they kind of begrudgingly recognize is that having a human being interpret the historical record requires an exercise of judgment. This isn't just statistical variability; this is judgment.[9]

In fact, Fischhoff asserts, it seems that in highly interdependent systems, the more you need the statistics, the less possible it is to rely on them. For example, referring to the recent Ford Explorer-Firestone Tires disaster:

> You may know a lot about cars and about tires, but the interaction between them turns out to be a mystery. Or you know a lot about the pieces, but they're all embedded in some kind of a management system which is unpredictable.[10]

Even in the world of economics, where the belief that markets behave predictably has long reigned supreme, these old notions are tumbling to new data about the influence of subjectivity. Witness the 2002 Nobel Prize in economics, which was co-awarded to a professor of psychology and public affairs for rather tidily explaining what had long been considered the "paradoxes" (according to traditional, probabilistic determinations) of stock market bubbles, utility regulation and many other economic activities undertaken by humans.[11]

Risk assessors can analyze discrete events, or even complex discrete events, from the past to calculate probability, but the larger question remains: How much can artificially constricted hindsight tell us about what's going to happen in the future — particularly in a situation teeming with uncertainties, complex unknown interactions and people making unprobabilistic decisions (a.k.a. "life")? How can quantifying uncertainty, even using the best probabilistic analyses, address and help avoid the risks that we know little or nothing about, or haven't thought to include in our models?

So while there are various approaches to assessment that are deployed based on specific situations, if indeed there are "schools" of risk analysis they are probably most simply and accurately represented by this tension between the "science" and the "art" of making decisions. The objective/science side is represented by those who assert that the best risk determinations, thus the best decisions, are and should be based solely on quantification and numbers, determined by historical data in conjunction with calculating future probabilities. For these practitioners, the theory of probability is in the same category of "hard science" as the theory of relativity.[12]

The subjective/values side is represented by those who feel that scientific data are a critical factor and much welcomed into the decision-making process when they exist, but that even data contain subjectivities — and risk decisions *de facto* include more subjective degrees of unknowns and uncertainties about the future, with human behavior being a particularly unpredictable factor. They believe that incorporating subjectivities alongside their probability equations will yield a more sophisticated analysis, albeit with greater and unavoidable ambiguity than a purely quantitative approach. These risk analysts voluntarily include the role of judgment in their deliberations, and consider the psychology of the analytic process itself as well — for example, the subjectivity of definitions, what individuals choose to estimate, who they invite to the table.

THE UNWILLING SHIFT TOWARD VALUES. The schism between numbers and values is a longstanding controversy that is unlikely to be resolved any time soon. But it was the decade of the 1970s when the tenor of this debate began to shift from theory to practicality. As scientific evidence emerged that various widely accepted substances such formaldehyde and asbestos caused cancer or other chronic health problems, people and groups began to question the methods by which risk was being assessed by those entrusted with public safety.

When several man-made disasters struck one after the other in the 1980s – Three Mile Island (almost the '80s, in 1979), Chernobyl, the Dow Chemical plant in Bhopal, the *Challenger* explosion, the Alar-apple scare, the *Exxon Valdez* oil spill — many risk experts, spurred by circumstance and a frightened public's reaction, first began to seriously debate our broad reliance on purely probabilistic risk analyses as the determinants of how the products of science and technology were built and deployed. A new conversation began, asking value-laden questions such as, "What probability of harm *will we accept*?" and "What is the value of a human life?"[13]

And it was at this time that experts began to coalesce around the question of whether too tight a focus on probabilistic analysis and purely "scientific" or mathematical assessments of risk were leading us to ask only the questions for which answers were possible, or for which numbers could be derived.

For example, nuclear power was a relatively static technology and many aspects of nuclear power do lend themselves to probabilistic risk analysis. But according to Fischhoff, probability failed to accurately predict nuclear power risks in at least two key respects.

For one, nuclear risk analysts were found to have systematically avoided some of the most difficult risk factors — that is, both the most difficult to quantify and the most difficult to address — by simply ignoring them. The net effect was that they *de facto* exaggerated the importance of the factors they *had* been able to quantify, which subsequently produced a false confidence in the safety of the plant. In addition, much of the risk analysis that was done was not aimed at greater understanding of the system, but was designed to satisfy regulators. According to Fischhoff:

> [Risk analysts] just ignored human factors until after Three Mile Island – they just weren't part of the equation. Claiming to have really understood the system, yet not including the operators as part of the system, was misleading. The analyses were not done candidly, but probatively, to prove they were "safe enough." [14]

This and other similar post-disaster findings led the government to explore the importance of pushing risk analysis beyond the findings of statistics and probabilistic assessments, despite the protests of the scientific community and the nuclear industry.

EVOLVING RISK BEYOND SCIENCE AND STATISTICS

As noted above, the disasters of 1980s produced the first obvious moves toward including behavioral, as well as the more mechanistic, approaches when conducting risk analyses. We've chosen to trace this evolution using as our guide four studies on risk conducted by the prestigious U.S. National Academy of Sciences, published between 1983 and 1996.

Because these reports span a broad range of disciplines, were rigorously peer reviewed, and the field's most highly regarded practitioners were invited either to contribute research or review the work of their peers, they are considered by some to be the "accepted wisdom" in the field of risk — despite the fact that only small, slow changes in the process of risk assessment and management have taken place since their publication. (We will discuss the time scale of adoption of these ideas later in the paper.)

The influential 1983 report, *Risk Assessment In The Federal Government: Managing The Process,* widely referred to as the "Red Book," is best known for popularizing the concept that risk assessment (the science) and risk management (the making of policy) could and should be kept distinct without detracting from importance or credibility of either, or both. The result of a Congressional directive, the report sought to study the feasibility of limiting the decision-making power of scientists and engineers by declaring that the assessment of risk — its quantifiable scope and nature — is a separate function from managing the risk; i.e., deciding what to do about it.

Although the report was also clear that that the two functions were interdependent, thus on some levels would need to work together, it was clearly a signal moment in restricting the power of the industrial and scientific agenda, both condemning and attempting to mitigate the existing negative influence of what the report called "the collision of contending interests" over public risk decisions.[15]

It is why the report was commissioned, however, that makes it a turning point in the evolution of risk analysis. In the 1970s, citizens were demanding more government regulation as the technologies for the detection of toxic substances improved and evidence emerged about chemicals such as asbestos and formaldehyde that cause cancer or chronic health effects. Agencies had developed procedures for identifying these hazards and estimating the risks they posed. But as more information came to light about these substances, the procedures themselves became the target of criticism by virtually everyone involved — scientists, industry representatives and public interest groups.

Although the Red Book committee did not officially challenge the scientific issues involved in risk assessment, what they did look at was the then-current practice of assessing risk — its relation to the process of regulating hazards, past efforts to develop and use risk assessment guidelines, the experience of government regulatory agencies with different administrative arrangements for risk assessment, and various proposals to modify risk assessment procedures — and found that current practice was not yielding accurate or effective analyses of technological risks.

The committee's final recommendations to separate science from policy whenever possible showed that risk experts had turned decisively away from the widely held notion that "value-free" probabilistic risk assessment is possible anywhere but in theory. It openly acknowledged that the basic problem in risk assessment is the sparseness and uncertainty of the scientific knowledge of the health hazards being addressed. In addition, and significantly, the report's acknowledgment of the types of uncertainties that are inherent in risk assessment opened the study of risk to a much wider range of disciplines, allowing it to move beyond probabilities, hazard identification, dose-response and exposure assessments. And noting that policy judgments are also embedded in risk assessment (separate from political, economic and technical considerations for regulatory strategies), the report stated that risk assessment methods themselves were subject to subjectivities that could change the risk profile — an idea that would be further developed five years hence.

RISK COMMUNICATION: ASSESSMENTS ARE SUBJECTIVE, TOO

Following the Red Book, the National Academy conducted another study, published in 1989, called *Improving Risk Communication*. The key finding, from an evolutionary perspective, was its explicit acknowledgment that risk does not exist in a vacuum of mathematical probability, and that while the assessments of scientists and engineers are critical, they are also subjective and need to be acknowledged as such in order to deliver responsible risk analyses.

With this finding as its anchor, the report explicates the many aspects of subjectivity and uncertainty in the assessment process itself where objectivity had previously been unquestioned. These myriad subjectivities, state the authors, require a new definition of risk communication.

Until the *Risk Communication* report, the desire for communicating about risk — whether by government to inform, industry to overcome opposition, or government to share power with public groups or develop alternatives to direct regulatory control – equated risk communication with the delivery of certain kinds of messages. These were generally one-way messages, from government or other risk communicators to the public, about the nature of risks; they took the form of experts "enlightening" or persuading an uninformed and passive public. The authors of *Improving Risk Communication* found this "get our message across," propagandist approach to be lacking in critical ways.

Their perspective was that conflicts about technological issues are primarily conflicts between different interest groups. One interest group describing the magnitude of a risk, or its costs and benefits, to other, possibly conflicting groups, will understandably and often lack credibility. Clearly technological knowledge is important, but the report strongly emphasizes that *technical choices are also value laden*. It clearly states that any formulation of the problem that substitutes technical analysis for debate, or that disenfranchises people without technical training, or that treats technical analysis as more important than values and interests, will likely elicit resentment (and probably a backlash), and increasingly polarize the conflict.

It further recommends that risk communicators abandon their one-way, propaganda-style "messaging" function and replace it with an interactive process of exchanging information and opinion among individuals, groups, and institutions. This redefinition is critical for many reasons, some of which have to do with a broader understanding of the nature of hazards and risks.

One critical reason is that the hazards which today are of greatest concern, and our knowledge about them, have changed in ways that make informed decisions harder to reach. Once the focus was simply on the presence or absence of danger. If food was "adulterated," if water was "impure," action was called for. People wanted simple, clear-cut measures. But with our increased understanding of the nature of these choices, we need to know more about the alternatives than simply that one of them is hazardous.

For example, eliminating one danger can create a new one. Chlorinating water rids the water supply of organisms that caused typhoid and other infectious diseases, but chemical reactions in the water as a result produce chloroform and other carcinogenic chlorinated hydrocarbons. Pesticides and herbicides improve the diets of the poor by making fresh food cheaper to produce, but at the very least expose agricultural workers to hazardous chemicals and pollute water supplies. Industries that pollute air and water also provide jobs and profits. Making the world safer for some people can make it more dangerous for others. Which dangers are more worth avoiding? How is society to weigh small benefits to many against larger dangers for a relative few?

Under these circumstances, judgments of both experts and non-experts can be affected by preexisting biases and the limitations of human cognition. The variability of human experience, values and concerns must be included in the analytic process, the report states, because humans are conducting the analysis. We know this because there are often disagreements between experts, and with non-experts, about the significance of risks even when facts aren't in dispute.

What's more, decisions about risk and hazardous substances are frequently made with incomplete information. Sometimes it is difficult to determine if a hazard exists. Sometimes hazards are delayed in onset, or exposures in small quantities make it hard to connect effects to causes. Not all hazards are studied, even in the laboratory. Data on estimations of exposure are frequently inadequate. Probability of harm estimates are often inadequate as well, because often there is no accumulated experience to track. Assessing risk of danger from breakdown of complex technological systems can be filled with errors of omission and commission, as was the case in the nuclear power industry. Additional uncertainty exists because exposure to one hazard can affect sensitivity to others. The problem of how best to interpret multiple uncertainties is yet another source of uncertainty and disagreement about risk estimates.

Thus simply understanding a risk is not enough, particularly since people do not choose between "risks." They choose between options, each of which presents some risks. The risks those actions entail are part of their decision-making process.[16] *Each option also presents benefits, which are as crucial to choice as risks.* Understanding both risk and benefit is required to make a balanced decision.

SCIENTIFIC JUDGMENT AND ERRORS IN JUDGMENT. The conflict for risk experts, who are under pressure to give succinct, unambiguous answers that can inform risk decisions, comes from being asked to create credible, trustworthy analyses from knowledge that's so full of uncertainties it hardly qualifies as knowledge, using scientific training in what they believe to be the accurate representation and calculation of uncertainties. Because they must rely, as we all do, on their ordinary human cognition to work with whatever data are at hand, their judgments can suffer from same frailties that affect humans in general, such as a tendency to rely to an inappropriate degree on limited information. Normal human tendencies can lead risk analysts to deliver overconfident analyses (either positive or negative) based on skewed ideas about the nature and reliability of whatever seems to be known. Although the net effects of these human tendencies cannot be known, the issues clearly do exist — and their existence obviously justifies a certain amount of skepticism about definitive claims made by risk experts.

Risk Communication's methodical outlining of such a damning array of obvious subjectivities hammers home its central point: that disclosure of biases and clear communication about the subjectivities inherent even in apparently objective data are critical, and not only for accurate risk assessment. Obfuscation and lack of disclosure will only increase the perception that people will believe they are being "sold" a too-risky proposition and reject a proposal that might also provide them and their communities with great potential benefits.

ORGANIZING KNOWLEDGE, INSTITUTIONALIZING UNCERTAINTY

An appendix in *Risk Communication* called "A User's Guide to Risk" details the many steps in a risk evaluation and all their attendant uncertainties.[17] Of extraordinarily practical utility, the guide also contains an intriguing sentence which, whether consciously or not, became a key theme in the National Academy's next (1994) report, *Science and Judgment in Risk Assessment*: The guide asserted that risk analysis, and particularly risk assessment — which just more than a decade prior had been the unchallenged domain of statistics and hard science — *was simply a way to organize knowledge*.

This idea obviously piqued the interest of the next generation of researchers, who wrote the following recommendation in *Science and Judgment:*

> The conduct of risk assessment, it should be recognized, does not require any specific methodologic approach *and it is best seen not as a number or even a document* [our italics], but as a way to organize knowledge regarding potentially hazardous activities or substances, and to facilitate the systematic analysis of the risks that those activities or substances might pose under specified conditions. The limitations of risk assessment thus broadly conceived will be clearly seen as resulting from limitations in current state of scientific understanding.[18]

That is to say, a truly accurate risk assessment would by necessity include *all* the knowledge about the risk in question, including all the unknowns, the scientific and "cognitive" subjectivities, values and judgments, stakeholder perspectives, benefits, evaluative metrics and the like, with lots of communication flowing between all parties about this knowledge in order to best inform a management decision. This idea, that institutionalizing the uncertainty of judgment in risk analysis would actually improve the *scientific* process of assessing risk, signaled another evolutionary shift in the study of risk.

Science and Judgment was actually a study of problems at the Environmental Protection Agency, which based on the report's findings was clearly struggling with issues such as technical accuracy and the selection process of which carcinogens and other hazardous substances it should evaluate. But the report's findings can be generalized in almost all respects to scientific and technological risks.

For example, while risk analysis may well be a way to organize information, the report found that particular attention must be paid to keeping that organizational structure fluid, rather than static. It must be designed to respond holistically as new information is added to the database of knowledge, choices, and understanding about the substance or activity or technique that's being assessed.[19]

The description that the committee used for this approach is "iterative," suggesting that iterative approaches be used in risk assessment, priority setting and in the analysis of uncertainty. Iterative approaches allow improvements in the process until enough is known about the risk that it doesn't warrant further analysis. Iterative priority setting takes a flexible and responsive approach to gathering and evaluating existing evidence needed to prioritize which of the hundreds of chemicals the EPA (or whomever) would assess for risks — continuing to track new scientific results so it can identify when it ought to reexamine chemicals it has already assessed.[20] Similarly, iterative uncertainty analyses are important because it is easy to only realize over time how much you don't know; thus it is inordinately easy to make inappropriate decisions and err in either direction — either too conservative or not conservative enough — upon first analysis.[21]

One final recommendation was so profoundly logical, it was almost revolutionary — and could have enormous implications for the future study of risk. It was based on the committee's observation that, when its report was written, EPA did not "appear to use risk assessment adequately as a guide to research and might abandon some important risk-assessment and regulatory efforts prematurely because of data inadequacies."

The committee strongly exhorted EPA to change its behavior in this regard, suggesting that instead it should pay even *more* attention to substances and areas where data are particularly sparse or hard to come by, rather than setting them aside to study more accessible risks. "The conduct of risk assessment reveals major scientific uncertainties in a highly systematic way, so it is an excellent guide to the development of research programs (specifically) to improve knowledge of risk," the committee wrote. "Do not abandon assessments when data are inadequate. Instead, seek to explore the implications for research. *Uncertainties can help determine the urgency of developing such research* [our italics]."

A modern example might be: if EPA does not know the generational effects of gene flow on genetically modified crops (which at present is, in fact, unknown), the report suggests that knowledge of this uncertainty should drive research that relates directly to gathering data on the uncertainties of gene flow, rather than focusing on evaluating the more accessible GM effects that have been studied.

UNDERSTANDING RISK: TAKING IT TO THE STREETS

The National Academy report *Understanding Risk: Informing Decisions in a Democratic Society*, which was published in 1996, seems almost anarchic in comparison to the predictable days in the mid-20th century, when probabilistic risk analysis was on its own merits believable, acceptable, and in any case, simply the Way It Was Done. This report throws down the gauntlet and says that risk analysis is a political, ethical and values-laden activity, period, and that it should be conducted with full participation by the people whose fate is at stake.

Not much can go more against the grain of an "objective" scientist steeped in his own bounded methodology than to hear that ordinary, superstitious folk of questionable education should be ushered into, and have a right to be involved in, the design process of research that analyzes the risks that are relevant to them.

This negative attitude toward "mere mortals" is largely prevalent, despite the fact that most scientists and researchers from all walks have long understood that the ultimate subjectivity of their own research process is in how one chooses which question or problem to pursue. Even though many do not believe their choices affect the objectivity of the work itself, there is always a subjective narrative — a sociology, if you will — to a researcher's chosen focus, whether because of the strong influence of a graduate advisor or mentor, the premature or untimely death of a friend or a family member, or because a positive result would lead to great intellectual, social and/or financial benefit.

By the same token, there is clearly a growing acknowledgment that risk estimates are socially constructed and risk is socially produced as well. There are plenty of social and cultural factors that influence the selection of what some sociologists call "risk objects" — that is, event probabilities and characteristics, resulting impacts and losses, and the sources of those events and losses. But more relevant in this context are the social factors that influence the formal risk analysis process itself.

For example, according to Kathleen Tierney, a professor of sociology and criminal justice at the University of Delaware, because there is typically considerable pressure to produce tangible scientific projections and because of the politically charged nature of much of the research that is conducted in the field, risk analyses are invariably subject to distorting influences – perhaps more so than other types of scientific analysis. Social constructs become even more evident in the presence of the high degrees of uncertainty inherent to so many of the risk analyses in science and technology. "Clearly more research is needed that sheds light on how and why specific risk calculations are constructed, as well as on the processes through which they come to be accepted as valid," Tierney writes.[22]

But as the 1996 NAS report points out, even if *all* the uncertainties were satisfied — in other words, even in the (practically impossible) presence of complete data — the subjectivities would still exist. *And the ultimate subjectivity in risk analysis is choosing* *the risk to analyze.* For this reason, the most recent risk literature, including this report, supports the idea that risk analyses would improve if the public were involved in every phase of the process.

These are strong statements. If any shards of risk assessment's isolationism had been left after the three previous NAS reports, they should have been intellectually swept away after the publication of *Understanding Risk*. This report takes risk analysis to the streets.

The key evolutionary concept in this report starts with what the authors call "risk characterization," or, how best to make relevant knowledge intelligible to decision makers who may or may not be expert in the techniques of risk analysis.[23]

Risk characterization should be a decision-driven activity — that is, there should be a reason to undertake the analysis. The characterization should be directed toward informing people's choices and solving problems — not via a translation or summary, and not as an activity tacked onto the end of the process in order to persuade. What's required for a serious characterization of risk must be considered at the beginning of the analysis process. Its needs should *determine* the scope and nature of analysis. "The aim is to describe a potentially hazardous situation in as accurate, thorough and decision-relevant manner as possible," the authors write, "addressing significant concerns of interested and affected parties, understandably and accessibly."[24]

What the report calls the "analytic-deliberative" process is what yields this broadly inclusive risk characterization. Those who are attuned to the metaphors of interdisciplinary versus disciplinary research will immediately recognize this intellectual construct. In the report's view, analytic, disciplinary, vertical thought is of equal importance and rigor to deliberative, interdisciplinary, horizontal thought that synthesizes the scientific as well as various other perspectives.

The report defines the "analysis" half of the process as one that uses "rigorous, replicable methods, evaluated under agreed protocols of an expert community — such as those of disciplines in the natural, social, or decision sciences, as well as mathematics, logic and law — to arrive at answers to factual questions." Deliberation, it states, is "any formal or informal process for communication and collective consideration of issues."[25] As was stated in the original 1983 report, government agencies should start from the presumption that both will be needed at each step leading to a risk characterization, such as deciding which potential harms to analyze and how to describe scientific uncertainty and disagreement.

The chief challenges, which at this point should sound familiar, are to follow in practice analytic principles that are widely accepted but also to recognize the limitations of analysis. Equally important is to recognize that a broad-based deliberative process can improve an analysis, determining which particular techniques are used and how results are interpreted. Decision makers are likely to resist value judgments that are left implicit in analytic techniques and that are made without deliberation.

Reflected here, again, is the concept we heard voiced in the previous report: that iteration and the ability to respond to changes in the knowledge environment are critical to responsible risk analyses. “The analytic-deliberative process should be *mutual and recursive*,” write the report’s authors. “Analysis and deliberation are complementary and must be integrated throughout the process leading to risk characterization: deliberation frames analysis, analysis informs deliberation, and the process benefits from feedback between the two.”[26]

Recurring criticism of the risk decisions made (or solicited) by government is that these analyses did not adequately recognize the concerns of their constituencies — that is, those who were most interested and affected. The report makes the point that this is not a failure of analysis so much as *a failure to integrate analysis with deliberation* regarding what should be analyzed.

FROM THEORY TO PRACTICE, IN THE U.S. AND BEYOND

When so much research points so clearly to the scientific and social benefits of inclusive and communicative processes for risk analysis — when the literature of risk, produced by the best minds on the subject, reflects general consensus that this is the way risk is best and most responsibly evaluated — why haven’t these processes become standard operating procedure in industry and government? The reason will not surprise anyone who is familiar with the mechanics of paradigm shifts. To significantly change the course of a field of study, no matter how early or clear or powerful the evidence, requires a steady increase in volume until finally it can no longer be ignored. Although the ideas pop up in the literature for a decade or two in advance of the shift, without intervention the lag between theory and practice can span as long as 40 years, according to CMU’s Fischhoff. It can take between 10 and 20 years for these ideas to be broadly accepted by risk scholars, and another decade or two for the principles to be put into practice.[27]

The timing of the recent Nobel Prize in economics, which contradicts a long-held belief in the field about the rationality and predictability of market performance, seems to accurately reflect this lengthy timeline. Daniel Kahneman, the professor of psychology and public affairs at Princeton University who shared the Nobel with Vernon Smith from George Mason University, started his experiments on irrational behavior in the late 1970s and published his first results in 1981. An economics professor, Smith’s work on behavioral economics began even earlier, in the 1960s. Given the present state of the economy, now that their work has been accepted by the academy and is being studied by eager graduate students, it will be interesting to see if the financial industry will put their theories into practice more quickly than might otherwise have been the case.

The critical nature of some of the risk questions raised by the products of science and technology would also seem to warrant placing the theory-to-practice continuum on an accelerated timeline. One would think that the problems at EPA that had spurred the *Science and Judgment* report in 1994, for example, might provide slightly more incentive for EPA to improve its risk assessment and analysis processes. Although progress has definitely been made to standardize some risk assessment procedures across federal agencies, EPA and others who deal with public policy issues around risk have not formally adopted most of the recommended methods.

Still, it is noteworthy that other countries and governmental organizations are proposing similar guidelines. In the U.K., the Royal Commission on Environmental Pollution published a document in 1998 that espouses practices similar to those recommended in the NAS series, including public debates that are part of an ongoing dialog with the technical community about development and deployment of science and technology.

In addition, the Leverhulme Trust has funded a major new four-year "Programme on Understanding Risk," which is conducting research on the social dynamics of contemporary risk issues with relevance to NGOs, government and business. Its main themes are public risk perception; trust in institutions; risk communication; and stakeholder involvement. The case studies it has commenced to pursue are in the areas of genetic modification and food safety, hazardous waste, human gene technology and therapy, innovative information technologies and global climate change.

In the same spirit as the recommendations from NAS, the program's activities, and academics involved, bridge not only the various human science perspectives on risk perceptions (experimental psychology, sociology, economics, policy and health sciences) with basic risk assessment and theory, but will also draw upon natural science expertise.[28]

The Organization for Economic Co-operation and Development (OECD) has also produced extensive guidance documents on what it calls "socio-economic" risk analysis — including a detailed primer on setting up an effective process for stakeholder involvement — which investigates and provides information on the impacts of various actions on industry, regulators, consumers, the environment and society writ large, particularly in the field of chemical risk management.[29]

A report issued by OECD earlier in 2002, after the World Summit on Sustainable Development in Johannesberg, seemed to indicate that a broader "risk communication" conversation, of the type recommended by the NAS report, may be underway on the world stage, at least insofar as environmental concerns are being addressed.

"Ancillary benefits estimates are plagued by underlying uncertainties about the values of some key variables," wrote the report's authors, who then listed an entire roster of quantitatively derived cost-benefit issues and considerations of human behavior and the subjectivities and uncertainties that belie their accuracy.

The authors recommend abandoning this cost-benefit framework in favor of a standard checklist, customizable for country-specific case studies, that could estimate the source and likely magnitude of different kinds of benefits, as well as estimating their relative importance. They also acknowledge the silo-ized nature of most governmental institutions, and suggest ways to support decisions that are integrated across agencies.[30]

Whether or how widely these guidance documents are or will be used in the development of public policy worldwide is not immediately apparent. However, several government agencies in the U.K. have successfully convened public and stakeholder dialogues about technological risks such as "mad cow" disease, rail safety and the use of genetic information by the insurance industry, as has the Swedish government for disposal of nuclear waste, with an eye toward increasing transparency in the public policy process.[31]

One of the questions this paper hoped to answer was whether there were “alternative approaches” to risk analysis in the non-English literature, both historically and in the present. Although not exhaustive, some information was uncovered which may help inform this concept to some degree. However, more research will be required if this issue is deemed critical.

One interesting starting point is the international membership roster for the premier trade organization in the field, the Society for Risk Analysis. In 2002, the Society claimed 1645 members in the United States; 107 in Canada; and 404 members in other countries ranging from Belgium to Colombia. Notably, there are only two members in South Africa and one in Senegal. In Latin America, there are two members in Chile, one in Argentina, three in Brazil and one each in Colombia and El Salvador.

It is beyond the scope of this paper to derive a theory on these data, but one could speculate that developing countries are in such dire straits dealing with life threatening problems such as drought, hunger and failed (or failing) economies that they do not believe they have the luxury to worry about what may seem to them like theoretical or far-distant risks, or that they may not have the infrastructure, staff or organizational capacity to respond.

This perspective dovetails with a finding by the U.K. Government's Better Regulation Task Force, governments in developed countries now find themselves having to deal seriously with risk because of the increased expectations of regulatory protection which tend to accompany increased affluence.[32]

Whatever the reason, the lack of risk expertise in developing countries is a worrisome situation today, since these countries are often cited as most at risk for various modes of exploitation by biotechnology companies.[33] In addition, developed countries have a long-chronicled penchant for dumping their questionable or unsafe products in the developing world. Thus the question of whether non-English speaking countries have developed alternative approaches to risk seems less the issue than how one might best increase basic knowledge and understanding about risk in developing nations.

Africa is of particular concern. One recent article in the *Economist* claims that 14.5 million Southern Africans are “dangerously hungry,” and labels Zambia’s refusal of American genetically modified corn to be “silly” from a health perspective. It also slams “pampered northerners” for their refusal to eat GM foods, a refusal which the article claims keeps Africa from planting GM crops that Europeans will later refuse to import.[34] From a risk communication standpoint, both sides of this debate are engaging in the kinds of propagandist messages that the NAS *Risk Communications* report warned could (and in this case, did) create a backlash against the messenger(s). What’s worse, polarizing these debates into soundbytes is a great misrepresentation of the reality of the GM debate, leaving unacknowledged and unaddressed the paucity of our knowledge of how these organisms behave in the ecosystem, in either the short or long term.

An organization called BIO-EARN in East Africa has taken a somewhat more responsible approach, and from its informational materials, at least, seems desirous of expanding the debate beyond sloganeering. The mission of BIO-EARN, which stands (somewhat imprecisely) for "East African Regional Programme and Research Network for Biotechnology, Biosafety and Biotechnology Policy Development," is to build capacity for biotechnology in Ethiopia, Kenya, Tanzania and Uganda and "promote appropriate research and related policies."[35]

But despite its obvious pro-biotechnology stance, much of the organization's website is devoted to warnings. It states that "the main problem facing East African countries is the insufficient capacity for enforcement of biosafety regulations and lack of biosafety information," and claims to be working to develop that capacity. However, while the network claims it want to use biotechnology "in a sustainable manner in order to help improve livelihoods, ensure food security, and safeguard the environment," it is notable that only scientists serve as members or management and there appears to be no stakeholder involvement.

PROCESSES IN COMMUNITIES USING THESE APPROACHES

In addition to the Swedish and British risk analysis projects mentioned earlier that were built around public-involvement components, the NAS *Understanding Risk* report also provided several case studies which employed analysis-deliberation techniques that were built around strong community and stakeholder involvement.[36] A sampling of them are briefly summarized below.

• **Application of ecosystem management principles for the sustainability of South Florida.**[37] This project focused on issues related to sustainability for the Greater Everglades and South Florida. It involved more than 100 scientists representing academic and government sectors in both the natural and social sciences. The four-year project was conducted by the US Man and the Biosphere Program (US MAB) Human-Dominated Systems Directorate, and studied ecosystem management for the sustainability of South Florida's ecological and associated societal systems. Although the project was never envisioned as an experiment in risk characterization, it had a strong emphasis on problem formulation: the project appears to have changed the dialogue on the future of the South Florida environment by redefining the issues into an ecosystem management framework. It also used the analytic-deliberative process to define policy goals that would, in turn, generate questions for analysis. And finally, the project used a diverse group of natural and social scientists to represent the concerns of the spectrum of interested and affected stakeholders.

• **Approval of the Waste Technologies Industries (WTI) incinerator at East Liverpool, Ohio.**[38] Planning for this incinerator began in1980, and the project reflected all the usual controversies around hazardous waste facility siting, particularly incinerators. A series of test burns fueled the controversy, drawing the attention of national media and producing much scientific, technical and political debate on the safety and appropriateness of incineration and having an impact both on national EPA policy and even presidential politics. The initial risk assessment regarding cancer risks, including dioxin, was thus expanded to include accidents and ecological impacts. Opponents of the WTI plant, which is already built and operational, include the local Board of Health, which pushed EPA to use more than theoretical trial emission data to assess risk by regularly monitoring the community's air, soil and crops at numerous sites within the community, including sensitive subpopulations (in this case, African American) who live near WTI. What the authors found noteworthy about the WTI example is that it illustrates the difference between risk assessments based on a public health paradigm and the standard approach to scientific risk assessment, for which simulations and mathematical approximations of harm were deemed sufficient to make a risk evaluation. Because the incinerator was built and put into service despite protests, while the scientific studies have been "detailed and extensive," local residents continue to mistrust the data and the objectivity of the scientists conducting them.

• **Regulatory Negotiation for Disinfectant Byproducts Rule**[39]
This example was presented in detail in the NAS report because it is a successful example of how regulatory negotiations, when done well, can show how "respect for a few very simple principles" can help characterize risks in a way that meets the needs of public officials and the interested and affected parties. The technical problem in this specific situation is that water chlorination, which kills many pathogens, also creates a reaction with other compounds called "disinfectant by-products" or DBPs, some of which are carcinogens. The analytic-deliberative process EPA used to decide what to do about DBPs included the development and selection of a negotiating committee to review evidence, order analyses, negotiate, and develop proposed rules that all participants might accept. It hired an outside firm to interview potential stakeholders and determine who in fact did have interest in or was affected by the proposed rule. After much debate, the chlorine industry was not granted a seat on this committee, but served on a technology advisory group and was "invited to state the group's position" at the first negotiating session.

The negotiating committee was not able to define the problem because it was constrained by law, so instead it "sought to define the characteristics of a good solution." It specified the information it needed to do so, which changed over the eight months it worked on the project as part of the analysis-deliberation process. Most interesting was how it handled the fact that by the end of the process, there was still insufficient information available to make many important decisions. So it proposed an "Information Collection Rule" which required large public water supplies to monitor source water and test it for DBPs and required certain, detailed actions based on results of these tests. This breakthrough compromise — a rule that allows the DBP rule to be modified over time based on ongoing data collection and evaluation, therefore building in a *legislated* means by which to reduce scientific uncertainty over time —made the rule politically feasible. And importantly, it provides precedent for building flexible legislation to deal with the uncertainties inherent in making public policy and protecting public interest in the area of science and technology policy.

• **The California Comparative Risk Project (CCRP)**[40]
Comparative risk projects start from the assumption that policy priorities for environmental problems should be determined by the magnitude of the risk each problem represents. When it began the process of determining these policy priorities in 1992, CCRP acknowledged good science was important to ranking risks, but also realized that scientists deliberating amongst themselves wouldn't provide sufficient basis

for setting policy priorities. Direct citizen participation did not play a large role, but instead the project called for involvement of academics, industry, business, activists, residents and political interests to help design the process. Soon this group included critics of conventional risk analysis approaches. The resulting process design included three technical committees for the areas of human health, the environment and social welfare, and another three committees that supplemented technical risk assessment with social and economic concerns — including environmental justice, which addressed concerns about the inequitable distribution of risk to subpopulations.

Although the California state government eventually distanced itself from the CCRP report — trade groups went directly to the press and the governor's office, complaining that a new environmental risk assessment basically ignored science and ranked risk according to "people's values, opinion, fears and anxieties" — the process was instructive for many reasons. It was particularly notable in using iteration and deliberation to help refine the problem, and brought together conventional forms of risk analysis with analysis and deliberation about social, economic, equity and other concerns. It is also worth following what happens the next time a broad-based risk project is attempted in California, as the report's authors state that many hard-working participants were alienated by the fact that their concerns were painted as "unscientific," or because their hard work was shunted aside when it became a political football.

CONCLUSION

Despite the ongoing distrust that many scientists have for qualitative risk analysis, it is clear that the study and practice of risk has evolved in this direction over the course of the past 30 years, acknowledging (even if somewhat begrudgingly) that both the "art" and the "science" is required to form balanced, useful and accurate risk analyses in a technological society. While it is also obvious to non-scientists — and some of the processes discussed in this paper prove the point — that the subjectivities and uncertainties presented by social, cultural, economic and political considerations are also crucial factors in risk management and communication, the most important thing that's happened in the study of risk is that many, many more scientists have now been convinced that value judgments, contingencies and uncertainties, their own inherent biases and omissions, affect the outcomes of scientific assessment models.[41]

But as the research and the case studies above show, public involvement — whether in the form of direct citizen participation, or by selecting representative stakeholders — is critical if science and industry are to move forward smoothly and with the blessing of the societies and governments which support them. Not communicating with the public about these critical risk decisions often creates a conundrum that industries bring upon themselves: If the public is not informed of a potential risk, whether out of ignorance or malice, and a company's product or action becomes an "issue," then, as CMU's Fischhoff says, "people on either side don't behave very well." Conversely, some companies would like to talk about the potential risks of what they're doing, but if that issue is not yet on the public agenda, it's difficult for a company to get the required attention. And then, of course, it is held accountable if something goes awry.

A way past such conundra is to start refining these methods so that more broadly effective risk analysis can move quickly from today's largely theoretical "accepted wisdom" into common practice. Given the incredible velocity at which the products of science and technology are flooding our ecosystems and our bodies, it seems we can ill afford to wait another decade or two to begin evaluating risks in a way that can both protect the public and allow progress to continue, equitably and with eyes wide open, for the betterment of humankind and the planet.

END NOTES

[1] Fiksel, Joseph, "Risk Analysis in the 1990s", *Risk Analysis*, Vol. 10, No. 2, 1990, p. 195

[2] *Improving Risk Communication*, p 32

[3] Ibid. p 47

[4] Fischhoff, Baruch. October 12, 2002. Personal e-mail to author.

[5] Bernstein, Peter L., *Against the Gods: The Remarkable Story of Risk*, p21

[6] *Ibid*, p121-128

[7] "Bayesian logic," *Whatis.com*, http://whatis.techtarget.com/definition/0,,sid9_gci548993,00.html

[8] Ibid.

[9] Fischhoff, B. September 27, 2002, Conversation with author.

[10] Ibid.

[11] Altman, Daniel, "A Nobel Prize Bridges Economics and Psychology," *The New York Times*, October 10, 2002, p C1

[12] Kaplan, Stanley and John Garrick, "Some Misconceptions About Misconceptions: A Response to Abramson," *Risk Analysis*, Vol 1, No 4, 1981, p 231

[13] Fiksel, Joseph, "Risk Analysis in the 1990s", *Risk Analysis*, Vol. 10, No. 2, 1990, p. 196

[14] Fischhoff, B. September 27, 2002, Conversation with author.

[15] *Science and Judgment in Risk Assessment*, p. 4

[16] *Improving Risk Communication*, p32

[17] *Improving Risk Communication*, pg 211

[18] *Science and Judgment in Risk Assessment*, p 266

[19] *Science and Judgment in Risk Assessment*, p 264

[20] *Science and Judgment in Risk Assessment*, p 266

[21] *Science and Judgment in Risk Assessment*, p 267

[22] Tierney, Kathleen, "Sociology's Unique Contribution to the Study of Risk," paper presented at the 13th World Congress of Sociology, Bielefeld, Germany, July 18-23, 1994, p7

[23] *Understanding Risk*, p 155

[24] *Understanding Risk*, p 156

[25] *Understanding Risk*, pp 158-160.

[26] Ibid.

[27] Fischhoff. B. October 9, 2002. Personal email to author.

[28] http://www.uea.ac.uk/env/pur/programme_rationale.html. Accessed 10-13-02

[29] "Technical Guidance Document On The Use Of Socio-Economic Analysis In Chemical Risk Management Decision Making," Organisation for Economic Co-operation and Development (OECD), March 2002, Pg 30.

[30] "Beyond Johannesburg: Policies And Finance For Climate-Friendly Development," Policy Brief No. 21 OECD Development Centre, Georg Caspary and David O'Connor

[31] "Risk as Continuum: A Redefinition of Risk for Governing the Post-Genome World," *The Hybrid Vigor Journal*, February 2002, The Hybrid Vigor Institute, pg. 53-57

[32] Programme on Risk, http://www.uea.ac.uk/env/pur/

[33] Caruso, D. "Risk as Continuum: A Redefinition of Risk for Governing the Post Genome World," *The Hybrid Vigor Journal*, The Hybrid Vigor Institute. February 2002, p. 11, 36.

[34] *The Economist*, "Better dead than GM-fed? Europe's greens are helping to keep Africans hungry," September 21, 2002.

[35] http://www.bio-earn.org/FAQ.html

[36] Appendix A, "Six Case Studies in Risk Analysis and Characterization," *Understanding Risk*, pp167-198.

[37] *Understanding Risk*, p 167

[38] *Understanding Risk*, p 176

[39] *Understanding Risk*, p 179

[40] *Understanding Risk*, p 193

[41] Jasanoff, Shiela, "Bridging the Two Cultures of Risk Analysis", *Risk Analysis* 1993, 13, 2, Apr, 123-129.