# Highly Reliable Governance of Complex Socio-Technical Systems

W. E. Carnes[i]

## Abstract

The Deepwater Horizon catastrophe is but the most recent and strident note in an oft repeated clarion call for new forms of governance. While a coherent story of what happened and why it happened is at least months, and perhaps years, from now, there are clear signals all too reminiscent of previous disasters warning us that mere band-aids and promises will not be sufficient to avoid future techno-centered horrors.

From what has been reported, there will be a wealth of technical lessons to be learned from this accident—what may be referred to as first order learning. As the Deepwater Horizon history unfolds, it seems that there are ample examples of second-order learning of human and organizational error and more trenchant examples of unprofessional conduct and malfeasance. But the larger story, the more insidious and intractable story, is that of a model of governance that is more suited to the industrial revolution than the long-forecasted and quickly emerging knowledge age.

The purpose of this paper is not to cast blame; rather to offer a perspective on the governance approach that allows Deepwater and kindred accidents such as Three Mile Island, Columbia, and Texas City to pose as singular examples of technical and corporate failure rather than as dying gasps of a governance model no longer suited for the techno-centric world we have created.

This paper is a pastiche informed by scientific research and centered in practice. Its purpose is not to define, but rather to provoke reflection and discussion. Its intended central argument is that theory-driven models, risk informed and performance based, are needed to explicate a new paradigm of highly reliable governance for complex, hazardous socio-technical systems.

The paper is presented around four thematic areas, the goals of which are to:

- Discuss the growing emphasis on the need for new models of governance for techno-centric societies where technical hazards have potential for major social harm;
- Place government regulation in the context of broader multi-agent governance models;
- Use U.S. commercial nuclear power as an example of such a multiagency socio-technical system model; and
- Identify steps forward for establishing such a model for the United States that can address the petrochemical industry and also serve as an impetus for cross-cutting efforts for emerging high-hazard technologies such as nano-technology and bio-engineering.

[i] Practitioner Associate, Center for Catastrophic Risk Management, Haas School of Business, University of California, Berkeley.

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# Acronyms

| Acronym | Definition |
|---|---|
| CSB | Chemical Safety Board |
| EPIX | Equipment Performance and Information Exchange |
| EPRI | Electrical Power Research Institute |
| HPI | Human Performance Improvement |
| HRO | High Reliability Organization |
| INPO | Institute of Nuclear Power Operations |
| INSAG | International Nuclear Safety Group |
| NEI | Nuclear Energy Institute |
| NEIL | Nuclear Electric Insurance Limited |
| NRC | Nuclear Regulatory Commission |
| OSHA | Occupational Safety and Health Act |
| PPA | Procedures Professional Association |
| PRA | Probabilistic Risk Assessment |

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# 1. Introduction

The history of safety science is a story of searching for risk mitigation and prevention of harm. Some trace the beginning of safety regulatory attempts to the Code of Hammurabi circa mid-1700s B.C. The start of safety regulation attempts in the United States is attributed by some to the Massachusetts Factory Act of 1877. However, the New York City Triangle Shirtwaist Factory Fire of March 21, 1911, in which nearly 150 women and young girls died because of locked fire exits and inadequate fire extinguishing systems, was a turning point. This fire prompted enactment of laws and regulations instituted by the government to protect workers. Even then, it was not until 1970 that then-President Richard Nixon signed into law the Occupational Safety and Health Act (OSHA), which gave the Federal Government the authority to set and enforce safety and health standards for most of the country's workers. It was also in 1970 that the Environmental Protection Agency was established as the first independent agency to protect human health and safeguard the natural environment. History will also record that as momentous as the year 1970 was in protecting the safety of workers, the public, and the environment, the prescriptive safety science theories of prevention—the intellectual underpinnings of the new safety regimes—were already being eroded by our successes in science and technology. For in the preceding year, 1969, construction began on the Three Mile Island Nuclear Generating Station, Unit 2.

Technology has been a primary driver for the improvement of social conditions since the beginning of the industrial revolution. Modern technologies represent the intersection of science, industry, finance, government, and global politics engaged in a delicate dance to serve social needs, corporate interests, and national interests. Technology is not static; its dynamic nature is the result of instantaneous communication, unceasing research and development, and the promise of technological solutions to address social inequities. Regrettably progress in safety practice has, in the main, lagged behind progress in technology and safety science.

Reiman and Oedewald summarize the history of safety science this way:

> …organizational theory and safety science have progressed in their over-one-hundred year's history. The knowledge of what is safety and how it is achieved has also developed. The safety measures taken in high-hazard organizations a couple of decades ago are not sufficient today. The focus of the safety work has changed from component-based risk control to organizational resilience and safety. Today's organizations need to systematically ensure the reliability of the components on the one hand, and, on the other hand, understand the emergent nature of safety. Designing both safety perspectives in organizational structures and processes is demanding. Usually, outside influences are needed in order to get the new views into organizations.[ii]

Complexity and dynamism of technology-involved issues have stimulated global research efforts on what is termed "risk governance." As discussed by the International Risk Governance Council, the notion of risk governance "builds on the observation that collective decisions about risks are the outcome of a 'mosaic' of interactions between governmental or administrative actors, science communities, corporate actors and actors from civil society at large, many of the interactions taking

[ii] Reiman, T. and Oedewald, P. Evaluating Safety-Critical Organizations – Emphasis on the Nuclear Industry. Finland: VTT, 2009.

place and relevant to only individual parts of the overall process. The interplay of these actors has various dimensions, including public participation, stakeholder involvement, and the formal (horizontal and vertical) structures within which it occurs." Risk governance "includes both intellectual and material 'assets', 'skills' and as well as the framework of relations, or 'capabilities', required to make use of the former two." [iii]

In many ways in the 1960s and 1970s, nuclear power represented the shining promise of all that was good about science and technology. In a 1954 speech to National Association of Science Writers, Lewis Strauss, then Chairman of the United States Atomic Energy Commission, uttered the phrase that now exemplifies failure of utopian promises of technology:

> Our children will enjoy in their homes electrical energy *too cheap to meter*. It is not too much to expect that our children will know of great periodic regional famines in the world only as matters of history, will travel effortlessly over the seas and under them and through the air with a minimum of danger and at great speeds, and will experience a lifespan far longer than ours, as disease yields and man comes to understand what causes him to age.

The 1979 accident at Three Mile Island, Unit 2, shattered our technological naiveté. In our enthrallment with future possibilities, the future in many ways seemed to rest in the hands of the scientists and engineers. Their ability to envision, develop, and design seemed limited only by time and resources. Yet that which can be designed must be capable of being operated. For that one needs organizations and people—the human element. And humans negotiate, compromise, balance competing priorities, and make mistakes. The investigations of the Three Mile Island accident reminded us of the human element, that we were no longer dealing with simple technologies for which protection could be prescribed, rather we were now dealing with complex socio-technical systems that functioned in new and ill-understood ways.

As with nuclear power, petrochemicals, aviation, electrical distribution, and medicine are examples of complex techno-social systems. Each accomplishes its socially productive missions through the application of technologies that if mishandled could result in catastrophe. Because of the complexity of the technologies, each requires the skills and knowledge of many scientific, technical, and management disciplines. Each exists within a web of regulators, customers, industrial suppliers and stakeholders. Regulation is necessary to protect society from the potential harm of improper operation and management, but alone it is not sufficient. Experience and research since the 1980s have demonstrated that complex socio-technical systems require complex adaptive governance models, engaging multiple agents to promote socially beneficial use of hazardous technologies. A framework for understanding these organizations has been developed: the framework of High Reliability Organizations.

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[iii] Ortwin, Renn. Risk Governance: Towards and Integrative Approach. Geneva: International Risk Governance Council, 2006.

# 2. The Need for a New Model: From Human Error to Complex Adaptive Systems

The Chemical Safety Board (CSB) report on the BP Texas City accident in 2005 commented on the BP safety model, stating that it was focused on a "worker safety model" versus a "process safety model." The distinction raised by the CSB is one raised by other accident investigations and safety researchers; the historical practices and programs designed to protect worker safety are necessary but not sufficient to prevent large-scale accidents. The language used may be that of "person models versus system models" or the "old view versus the new view."

To engage in a discussion of governance of complex adaptive systems a full understanding of the difference between a person model and a systems model is essential. The exclusive focus on the person model is rooted in ideas about human error as cause of accidents relieving the need for further examination and investigation. Thus, discussion of what safety science tells us about the fallacy of human error is a necessary first step.

Error, mistake, faux pas, gaffe, blunder, lapse, slip, goof, oops, blooper. How many phrases do we have to express the idea that things don't always happen as we expect or as we would prefer? At the 2009 CEO Conference of the Institute of Nuclear Power Operations (INPO), one CEO stated that the most important change in the commercial nuclear industry in the past decade was the recognition that people do not intentionally commit errors. INPO's training reference guide that introduced the commercial nuclear power industry's Human Performance Improvement (HPI) initiative stated that HPI represented "a new way of thinking." So the question is, how might we think differently about this concept of error that seems to be an inevitable aspect of the human condition?

The "fact" that some 80 percent of accidents are "caused" by human error appears in much of the safety literature. Formal accident investigation attributions of error as cause have been used for justification of blame and punishment, ostensibly to "prevent" recurrence of similar accidents. Yet after decades of labeling human error as cause, what do we really know scientifically about error as a fundamental human concept?

Much of the scientific work on accident causation can be traced to the aftermath of the Three Mile Island accident. Woods and Cook explain the situation as: "At that time, the folk model of accident causation was firmly in place among researchers and error seemed a plausible target for work on safety. It was only after a long period of empirical research on human performance and accidents that it became apparent that answering the question of what is error was neither the first step nor a useful step, but only a dead end." [iv]

As James Reason explains in his book *Human Error,*[v] error means different things to different people and depends on context. In Latin the meaning of error is "to wander." In baseball an error is the act, in the judgment of the official scorer, of a fielder misplaying a ball in a manner that allows a batter or base runner to reach one or more additional bases when such an advance should have been

[iv] Woods, D.D. and Cook, R.I. "Mistaking Error," in The Patient Safety Handbook, Youngberg, B. J. and Hatlie, M..J., Sudbury, Chapter 7. Jones and Bartlett Publishers, 2004.
[v] Reason, J.T. Human Error. Cambridge: Cambridge University Press, 1990.

prevented given ordinary effort by the fielder. In computer operation, an error is when an unexpected condition occurs.

The utility of error as causation is further complicated since error cannot be isolated as a particular psychological or behavioral phenomenon. Addressing efforts by cognitive psychologists to identify error types, Reason states that "Far from being rooted in irrational or maladaptive tendencies, these … error forms have their origin in fundamentally useful psychological processes." He continues, quoting Ernest Mach (1905), "knowledge and error flow from the same mental sources, only success can tell one from the other."

So it seems that what may be called error is distinguishable only retrospectively in the presence of an undesirable outcome. Absent such an outcome, error is not observable. So, if error is not observable sans outcome, is there any utility to this concept which is so rooted in the cultural views of causality yet so lacking in scientific validity?

Returning to Woods and Cook, "Error is not a fixed category of scientific analysis. It is not an objective, stable state of the world. Instead, it arises from the interaction between the world and the people who create, run, and benefit (or suffer) from human systems for human purposes—a relationship between hazards in the world and our knowledge, our perceptions, and even our dread of the potential paths toward and forms of failure.…To use 'error' as a synonym for harm gives the appearance of progress where there is none."

If the concept of error has no particular value in analysis of failure, and indeed, that such use may be counterproductive, perhaps its value lies elsewhere. Viewing error as a fuzzy concept, rather than an absolute concept, provides a basis for proceeding. William James' philosophy of pragmatism relates meaning to a concept's purpose. Operationalization is the process of defining a fuzzy concept so as to make the concept measurable in the form of variables consisting of specific observations. W. Edwards Deming explains that "An operational definition is a procedure agreed upon for translation of a concept into measurement of some kind."

How might we understand error in a purposeful sense that promotes the human condition; that is, how might the concept be operationalized? Consider, as an example, physical pain. Pain may be understood as a negative consequence; something to be avoided or even feared. Alternatively, pain may be understood as one of the body's key defense mechanisms, the purpose of which is to alert us of a threat to the body's safety or survival. Similarly we may shift the meaning of error as harm, to error as warning of harm. Thus error becomes a signal to prompt protective actions.

Reason offers three related "working" definitions of error, each predicated on a retrospective judgment of not achieving the desired outcome from pursuing a predetermined course of action. He then suggests that error be understood in terms of intentions, actions, and consequences. He also suggests that error be extended from purely an individual phenomenon to include organizational phenomena. So, if we understand error as a signal operating with intentions, actions, and consequences, we can view this formulation equivalent to Deming's description of the Shewhart Cycle of "Plan, Do, Study, Act." In this way, errors become signals that enable individuals and organizations to monitor the relationship of the doing of the plan in relationship to anticipated outcomes and then adjusting the plan and actions based on the feedback provided by error.

Error is life providing feedback on our interactions with the environment. By shifting the paradigm of error from one of "error as cause" to "error as system feedback", we find that error is nature's way of helping us proceed incrementally toward our goals while coping with an uncertain universe. Such a shift also serves to create a culture in which blame and recrimination are no longer the reflexive reaction, in which fear is replaced by the nurturing and development of human potential, in which human collaboration is the capital for innovation, and in which adaptation and continuous improvement become intrinsic value driven core competencies of individuals and organizations.

# 3. Governance and Complex Adaptive Systems

Those born to the World War II generation have seen a transition from a predominately rural, agrarian world, have lived through the industrial era, and are now part of the rapidly emerging knowledge era. The development of systems engineering and operations research that facilitated mobilization of the U.S. industrial machine to fuel the defense demands of the 1940s heralded the blending of technical and social science knowledge, which, in turn, gave rise to multidiscipline research and development. It was also the necessities of wartime and the post-war era that gave rise to the idea of socio-technical systems and the concepts of statistical process control and quality management.

The expansion of education, capital, and industrial capacity, along with government sponsorship of public and private research, produced technologies and organizations of a complexity never before witnessed. Beginning in the 1980s there were faint signals that the forms of government and management that had accompanied advancement since the early 1900s were becoming increasingly unsuited for the challenges of how to productively and safely control the technologies of which we were capable.

The publication by Thomas Kuhn of the *Structure of Scientific Revolutions* in 1962 introduced the concepts of paradigms and paradigmatic shifts in science. In summary Kuhn argues that over time prevailing scientific theories lose predictive value as anomalies are identified for which the theories have no explanation. Certain bold researchers begin a search for alternative explanations and, after continued research, better explanations for the hitherto unexplainable phenomena are developed, thus ushering in a new paradigm.

The 1980s marked such a period of beginning a paradigmatic shift. It was then that the previous view of a mechanistic, linear, so called deterministic universe came under challenge. The discovery of quantum mechanics in physics may be argued as the start of the unraveling of the mechanistic model. In 1984 the Santa Fe Institute was established by a group of physicists to study the concept of complexity. The goal of the Institute was to promote trans-disciplinary research on complex systems. The Institute gave focus to researchers from physics, biology, and chemistry, and their collaboration shifted the intellectual model from the idea of a universe governed by deterministic laws of linear cause and effect to a universe where multiple components (called agents) interact and connect in unplanned and unpredictable ways. From beginnings in the physical sciences, the discoveries in complexity were extended to the social sciences, and today permeate the research on human organizational systems.

As stated in the history of the Institute, "The discovery of common, fundamental principles in complex adaptive systems as varied as global climate, financial markets, ecosystems, the immune system, and human culture requires an inclusive, broad perspective, one that comprehends the components of a system but views those elements as actors in a large, interconnected, often unpredictable world."

It should be of little surprise that the ideas of governance as a multi-agent mode of promoting the social good and the idea of high reliability organizations both emerged in the 1980s. Stimulated by findings of investigations of the Three Mile Island accident and confronted by the specter of future "normal accidents," researchers began to explore how some organizations, so called High Reliability Organizations, were able to create success while operating hazardous technologies within dynamic environments. What they found resonated with earlier work by Trist and Emery that led them to speak about socio-technical systems as the interface between society and complex technology.

In a similar sense the concept of governance as a complex adaptive systems approach arose from a growing recognition that the directive command and control concept of central government had become ill-suited and realistically impractical in democratic societies. The very nature of democratic systems combined with growing population size, the democratization of education, and the diversification of society cried out for better explanations of how people could work together to promote social good.

# 4. Government and Governance

The shift from the concept of Government to Governance has been discussed in a variety of scholarly papers and publications. Kemp, Parto and Gibson[vi] express the general thinking. Governance as a concept became:

> …attractive because it encompassed a broad set of factors that were increasingly important and insufficiently recognised in conventional thinking and because it encouraged a more integrated understanding of how these factors were, or should be, linked. Governance scholars viewed the political system as a complex of formal and informal arrangements that were ill-defined and unstable. This was in direct contrast to the conventional view of governments as formal, clearly identifiable, and static entities. Whereas government conjured up an image of formal structures ruling over people, the notion of governance highlighted the increasingly important role of formal and informal arrangements in the political economy.
>
> *Governance*, understood as a mode of social coordination, is different from *governing;* which is an act, a purposeful effort to steer, guide, control and manage (sectors or facets of) society….It involves the level and scope of political allocation, the dominant orientation of state, and other institutions and their interactions. Governance structures organise negotiation processes, determine objectives, influence motivations, set standards, perform allocation functions,

[vi] Kemp, R., Parto, S. and Gibson, R.B. "Governance for sustainable development: moving from theory to practice." Int. J. Sustainable Development, Vol. 8, Nos. 1/2, (2005): 12–30.

> monitor compliance, impose penalties, initiate and/or reduce conflict, and resolve disputes among actors....The effective exercise of power is through a network of interconnected actors, in which all actors hold power through knowledge, resources, money and rights granted to them.
>
> The notion of governance fits in with complex systems approaches to understanding the workings of the political economy through the inter-relationships among identifiable parts (e.g., social, economic, and ecological), rather than just the parts themselves. A complex systems approach to governance also implies explicit appreciation of complexity and uncertainty, likelihood of surprise, and need for flexibility and adaptive capacity.

Cherry suggests that "a complexity theory perspective is instrumental for understanding that government must increase regulatory resilience…government must create regulatory structures and policies of increased adaptability to the complexity and increasing pace of technological innovation and ensuing economic and social changes...problems revealed under deregulatory policies are symptomatic of a deeper, more fundamental set of sustainability problems arising from a historical process of accelerated technological and social change." [vii]

Priscilla Rabb Ayres argues that the industrial age approach to regulation is out of step in the information age and offers the following observations of the predominant historical regulatory approach:[viii]

- Traditional regulatory regimes are characterized by static focus
  - Highly prescriptive and rules-based
  - Compliance is siloed and risks stand alone
  - Compliance functions typically low level and dispersed throughout organizations
- Regulation viewed as exclusively the concern of the government
- Focus on discrete violations and correction of those violations
- Shortcomings for application in the 21st century
  - Inflexible and unable to keep up with rapid change
  - May not capture risk appropriately
  - Dependencies not adequately assessed
  - Can encourage "gaming the system" (e.g., Enron)
  - Highly labor intensive and slow

The Winter 2006 Issue of *Public Affairs Review* of the University of Central Florida contained an article synthesizing the literature on government and governance. The article concluded with the following observations:

> The government concept is historical and its work is recognized as the direction and distribution of public goods and services. Government is viewed as an institution. While a wealth of service delivery models may be utilized, direct service

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[vii] Cherry, B.A. "Institutional Governance for Essential Industries under Complexity: Providing Resilience within the Rule of Law." CommLaw Conspectus 17 (2008-2009).
[viii] Ayres, P. "Regulation in the 21st Century: From Prescription to Collaborative Supervision" (Paper presented at the 10th XBRL International Conference, Brussels, Belgium, November 16, 2004).

remains as a fundamental component of government activities. The government retains its status of principal actor, either through direct service or through the indirect management of contracts that are programmatically defined. Ultimately, government is a term that is not keeping pace with the changing work, structure, and culture of today's complex governance issues in a global arena.

On the other hand, governance is contemporary, it suggests an interactive approach to problem solving using a variety of tools and models within a network of partnerships and envisions the role of government as a facilitator-power broker within not only a regional, but global perspective. A new era of public problem solving has occurred in the United States as well as many other parts of the world. Rather than relying solely on the government to solve public problems, a multitude of third parties have been employed to not only participate, but to lead such activities. Governance represents a new public administration perspective, which harnesses the strengths and opportunities created by engaging stakeholders across boundaries into productive networks. Reorganizing concepts of government to governance is not enough to solve public issues, but multiple approaches involving a wide array of tools is necessary for addressing public problems.[ix]

# 5. A Framework for Governance of Hazardous Technologies

In many ways the investigations into the Three Mile Island accident and the response to that accident changed the way we think about potentially high-consequence accident causation. Likewise, the response by government and industry to this accident established a new model for governance of hazardous complex socio-technical systems. Over the past 30-some years research by scholars of governance and scholars of high reliability has begun to converge though the lens of complex adaptive systems to suggest a framework for governance of complex hazardous technologies; that of Highly Reliable Governance.

In the late 1980s, a group of researchers at the University of California Berkeley began research on organizations that were known to perform their missions with consistently high quality while operating complex technologies and operating within dynamic environments. They were soon joined by researchers from the University of Michigan and their research on U.S. Navy Aircraft carriers, the Federal Aviation Administration Air Traffic Control System, and U.S. commercial nuclear power plants gave rise to what is now known as High Reliability Organization (HRO) theory. While the organizations differed in their technologies, organizational forms, and regulatory regimes, they shared certain characteristics that differed from other organizations the researchers had studied. Much has been written about such highly reliable organizations since the early foray of inquiries, and today the application of HRO concepts spans an increasing body of organizational types, as well as a diversity of scientific and technical disciplines. As examples Roberts' research on incident command systems, Roe and Schulman's[x] 7-year longitudinal study of a large electrical distribution system, and

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[ix] Knepper, H., Sitren, A., and Smith, H. "An Examination and Synthesis of Two Public Administration Concepts and their Relevance for Public Administration Students." Public Affairs Review: e-Journal of the Doctoral Program in Public Affairs Winter (2006).

[x] Roe, E., and Schulman, P. High Reliability Management: Operating on the Edge. Stanford: Stanford Business Books, 2008.

the implementation initiatives of the wildland fire community have illuminated the relevance of high reliability concepts to dynamic domains.

In broad strokes, these HROs begin with deep knowledge of the technologies they employ. This is coupled with flexible organizational design where roles and responsibilities are clearly established and understood, yet they are bound together with extensive social communication networks; respect for diverse expertise; a healthy skepticism for what they do not know; unending inquisitiveness; a culture which values collaborative problem-solving; and an abiding respect for the hazards they manage, being ever mindful of the potential consequences of less than excellent performance. These organizations have internalized—through systems, processes, culture, and education—the essence of complex adaptive systems. Research into these organizations has produced a body of theory, which, when converted into models, has utility for guiding organizational change.

Human beings have a desire to impose order over chaos. It has been suggested that the designation Homo Sapiens would be better described as Homo Poetica—man the meaning maker. The Public Affairs Review authors observed that "Reorganizing concepts of government to governance is not enough to solve public issues, but multiple approaches involving a wide array of tools is necessary for addressing public problems." While high reliability organizations make use of tools such as quality improvement and human performance tools, the chief value of HRO theory is not in the tools themselves but rather in the intellectual framework the theory provides.

The psychological construction a framework has been described as the identification and categorization of processes or steps that constitute a complex task or mindset in order to render explicit the tacit and implicit. The original HRO researchers observed what their focus organizations did—how they acted. This activity-focused conceptualization was expanded in the Roberts and Weick article in *Administrative Science Quarterly*, September 1993, "Collective Mind in Organizations: Heedful Interrelating on Flight Decks." This article introduced the cognitive aspects of HROs.

A review of HRO theory by Andrew Hopkins suggests how the original definition by the Berkeley researchers "evolved" through the Weick and Sutcliffe work to shift from a functional conceptualization of an HRO to more of a cognitive conceptualization. James Reason speaks of HROs as resilient organizations that combine performance enhancing techniques to perform technical activities with a particular type of cognition. Resilient organizations are not bound by rigid adherence to preconceived ways of working, rather they are guided by a mental framework of "what good looks like" and are thus able to recognize indications that things are not going right and adapt to the unexpected. How HROs manage the unexpected was elaborated upon by Weick and Sutcliffe in their two books that advanced that theme. Weick's explanation of the value of frameworks is that "When people put stimuli into frameworks this enables them to comprehend, understand, explain, attribute, extrapolate, and predict."

The need for a framework by which people make sense of what they do and what is going on has been long discussed. Peter Drucker consistently challenged his clients and audience to define and refine their theory of business. His four key points were as follows:

- What assumptions are we making about: 1) the environment, 2) our mission, and 3) the core competencies that we need?
- Do the assumptions in all three areas fit each other?

- Is the theory of the business known and understood by everybody?
- Is the theory tested constantly—and altered if necessary?

Deming's famous 14 points constituted a framework for thinking about quality. He spoke of his points in terms of theory. According to Deming, having a theory is essential: "Experience by itself teaches nothing....Without theory, experience has no meaning. Without theory, one has no questions to ask. Hence without theory there is no learning." His teaching about theory echoes the oft repeated quote of Kurt Lewin: "There nothing as practical as a good theory."

John Carroll poses the question, "Why should effective behaviors and activities not be explicable and perhaps not discussible?" He concludes that the difficulty lies in the available "mental models" or understandings of organizations, people, and technologies. "When those mental models legitimate only certain types of behaviors, and exclude whole classes of effective behaviors, then there is need to broaden the models. When different knowledge bases and viewpoints cannot be negotiated across levels of hierarchy and occupational specialties, then organizations cannot make sense of events in ways that support effective learning." [xi]

Over the past several years High Reliability Organization theory has been examined in validity and utility in variety of hazardous domains. A prominent example is the adoption of the high reliability framework for improvement of health care quality and safety. This continuing research and application has been described by Karlene Roberts in her essay to celebrate the publication of the second version of Weick and Sutcliffe's book on Managing the Unexpected. Inherent in her essay is a subtle clue to the vitality of the theory as a framework. It is robust enough to transcend diverse technical domains, yet flexible enough to accommodate new discoveries of how organizations can adapt.

The HRO framework has been used for reflective learning in a wide range of technical domains, from the nuclear defense work of the Department of Energy's Pantex plant to wildland fire fighting, education, and medicine. These HRO learning applications were undertaken to enhance safety and performance in operating environments. Research on governance and the recent emphasis on risk governance are in resonance with high reliability theory. The interfaces of these research fields suggest an emerging new framework for governance of complex hazardous technological endeavors. Embarking upon a framework of Highly Reliable Governance, however, is perhaps best undertaken being mindful of the observation of Thomas Kuhn: "The success of a paradigm is at the start largely a promise of success discoverable in selected and still incomplete examples."

# 6. The U.S. Nuclear Power Industry: A Case Study in Highly Reliable Governance

As notable as HROs are as individual exemplars, they do not exist in isolation and have not been the products of forward engineered design. Rather they are the result of multiple agents interacting over time to evolve unique organizational forms. A particular type of governance has been shaped over time that allows HROs to exist and flourish through their carefully crafted capacity for resilience.

[xi] Carroll, J.S. "Organizational Learning Activities in High Hazard Industries: The Logics Underlying Self-Analysis." Journal of Management Studies 35(6), November 1998: 699-717.

When exposed to discussions of the U.S. commercial nuclear industry as an exemplar of high reliability, an often heard retort is "We're not a nuclear reactor." This superficial judgment based on technical systems belies a lack of awareness of the deep cognitive structures of organizations. Some, however, have recognized that at these deeper levels an analogy is present. Recently the President's Commission invited testimony from the current CEO of INPO and one of INPO's earlier CEOs. Others have also noted the value of considering the nuclear experience. One is former U.S. Secretary of the Interior, Bruce Babbitt, who served on the President's Commission on the Accident at Three Mile Island in 1979.

In July of this year, Babbitt offered his perspectives on what should be learned from the nuclear power analogy:

> The NRC [Nuclear Regulatory Commission], an independent body charged with oversight of all nuclear power plants, is perhaps the best starting point. In a nuclear plant, for example, all operating personnel hold licenses issued by the Commission, all contractors and suppliers must be certified, and the Commission conducts regular and rigorous inspections, aided by NRC personnel who are permanently stationed at each plant.
>
> Many of these regulatory procedures developed from reforms implemented after the near meltdown at Three Mile Island more than 30 years ago. Since then, the industry has compiled an admirable safety record.
>
> Regulation is, of course, not cost free. But as we are learning from the current Gulf disaster, good regulation is a lot less costly than the damage caused by shoddy practices enabled by inadequate regulatory oversight. And there is no reason why the costs of effective regulation should be borne by taxpayers.
>
> The oil and gas industry, which continues to report record earnings, can and should bear the costs of regulation. That is how it works in the nuclear industry; Congress requires the industry to reimburse the NRC for its continuing costs.[xii]

This section describes U.S. nuclear industry governance. It discusses the regulator and the regulatory approach and reviews how the nuclear industry organizes itself via three main industry groups, with particular attention on INPO. The description is necessarily broad as it is not possible to represent the depth or detail of some 30 years of learning and improving. It is, however, this learning and improving that is most notable about the nuclear industry and how it has evolved into its present form. Learning and improvement are inextricably embedded within the structures and activities of the regulator, the industry support groups, and each nuclear operating organization. So a brief overview of nuclear organizational learning approaches is offered for context.

## Nuclear Organizational Learning

One hallmark of High Reliability Organizations is that they have deep understanding of the knowledge and skills necessary to perform work safely. They seek to craft the appropriate blend of

[xii] Babbit, B., "Offshore Oil Needs Greater Regulation." Politico Blog, August 2, 2010. http://www.politico.com.

skill, knowledge, and procedures in consideration of work complexity and hazards. And they seek to capture the tacit knowledge of experts by converting this tacit knowledge to explicit forms, either in equipment, training, and procedures or in other performance support tools. Also they seek to keep the requisite knowledge current by robust change control and employee reporting systems to identify changes needed and to evaluate the implication of changes in technology, plant configuration, equipment aging, and employee capabilities as the workforce ages and new workers enter the organization.

Nuclear organizational learning is complex socio-technical systems thinking in action. Training and education are the foundation upon which organizational and industry learning are constructed. Education, knowledge, and skills requirements are established for all nuclear jobs; personnel are trained and qualified before being allowed to perform at the entry supervised level; and a nuclear career is one of ongoing training and development. In the United States this is true for regulators as well as the operating organizations. For example, it is not possible to achieve operational senior management levels in a nuclear organization without qualifying as a Senior Nuclear Plant Operator.

Technical competency is only the base requirement. Beginning with front-line supervisors and continuing to the levels of CEO and Boards of Director members, nuclear professionals are groomed in leadership and management skills, with heavy emphasis on safety culture and risk-conservative decision-making as well as performance analysis and improvement theory and techniques. Knowledge and skills in performance improvement and risk-informed decision-making are embedded in the job training of all personnel.

Operating organization and industry learning are facilitated through sharing of operating experience, nested systems of performance indicators, and organizational evaluation. Operating experience is collected and analyzed by both the NRC and INPO. The NRC's Licensee Event Reporting system has threshold reporting requirements through which operating plants are required to report on certain events. The INPO operating experience program uses this input, along with a number of other types of information sources of operating experience that are obtained through agreements among INPO, U.S. nuclear plants, the international nuclear industry, and regulatory organizations. INPO typically receives 2,500 to 3,500 event documents each year that are screened for analysis. Analysis programs identify and communicate lessons learned from plant events, collect and trend various industry data, and communicate analytical results.

Both the NRC and INPO maintain nuclear plant data collection systems with the objective of providing reliability data for safety-related and selected other important nuclear plant systems and components. The NRC system is the Reliability and Availability Data System, and the related INPO system is called the Equipment Performance and Information Exchange System (EPIX).

These industry-wide reporting systems support examining for trends of potential industry significance. Each U.S. nuclear plant has extensive internal issue identification and reporting systems. These are designed to capture items that fall far below the regulatory required thresholds. For a well performing plant, from 9,000 to 11,000 items may be generated by plant personnel each year. These are striving to capture events or conditions that might portend a degrading state or practice.

Performance monitoring is also a combined plant-specific and industry-wide learning approach. For an individual plant, identification of indicators and trends begins with individual workers during their daily activities. These indicators roll up to work process levels, department levels (e.g., maintenance or engineering) and overall plant levels. INPO then processes the data further to produce industry-wide trends that serve to drive multi-year improvement initiatives.

Teemu Reiman and Elina Pietikäinen have conducted research on the evolving theory and application of safety indicators in nuclear power. "The role of the safety performance indicators is to provide information on safety, motivate people to work on safety, and contribute to change towards increased safety."

> Safety indicators are tools for effective safety management process. Safety management needs a continuous focus on lagging indicators of past deficiencies, leading indicators of current technical, organizational and human conditions and leading indicators of technical, organizational and human processes that drive safety forward. Drive indicators are chosen priority areas of organizational safety activity. hey are based on the underlying safety model and potential safety activities and safety policy derived from it. Drive indicators influence control measures that manage the socio-technical system; change, maintain, reinforce, or reduce something. Monitor indicators provide a view on the dynamics of the system in question; the activities taking place, abilities, skills and motivation of the personnel, routines and practices—the organizational potential for safety. They also monitor the efficacy of the control measures that are used to manage the socio-technical system. Typically the safety performance indicators that are used are lagging (feedback) indicators. Besides feedback indicators, organizations should also acknowledge the important role of monitor and drive indicators in managing safety.
>
> When selecting the indicators it is important first to consider what needs to be monitored, what are the critical goals of the organization (i.e., the core task that needs to be taken care of). PRA should also be utilised in identifying the most safety significant issues to monitor. The selection and use of safety performance indicators is always based on an understanding (a model) of the socio-technical system and safety. The safety model defines what risks are perceived. It is important that the safety performance indicators can help in reflecting on this model.[xiii]

Safety evaluation is the final nuclear learning approach for discussion. It is this element that is INPO's particular "stock-in-trade." Research on nuclear industry organizational evaluation by Reiman and Oedewald summarizes key aspects.

> A safety-critical organization can be defined as any organization that has to deal with or control such hazards that can cause significant harm to the environment, public or personnel...Control of risk and management of safety is one of their primary goals. They are expected to function reliably and to

[xiii] Reiman, T. and Pietikäinen, E. Indicators of Safety Culture – Selection and Utilization of Leading Safety Performance Indicators. Finland: VTT, 2010.

> anticipate the operating risks caused by either the technology itself or the organizational structures and practices. The ability of the organization to monitor its current state, anticipate possible deviations, react to expected or unexpected perturbations, and learn from weak signals and past incidents is critical for success. Organizational evaluation is one way of reflecting on this ability.
>
> …the aim of organizational evaluation should be to promote increased understanding of the socio-technical system. This means a better understanding of the vulnerabilities of the organization and the ways it can fail, as well as ways by which the organization is creating safety. Organizational evaluation contributes to organizational development and management.
>
> …the term organizational evaluation denote(s) the use of conceptual models and applied research methods to assess an organization's current state and discover ways to solve problems, meet challenges, or enhance performance.
>
> These approaches all share an idea of organization as a system, the functioning of which can be evaluated against some criteria. Organizational diagnosis emphasizes the idea of problem identification and solving, whereas organizational evaluation as we define it does not need to start with a problem, or end in concrete solutions. The production of information on the functioning and the current vulnerabilities of the organization is the primary goal of organizational evaluation.[xiv]

Note the recurring references to models. The regulator and the industry use a variety of models to understand, guide, and inform. INPO's guidance document "Leadership in Performance Improvement" defines the goal state of performance improvement as:

- The picture of excellence is well known.
- Problems are prevented and mistakes are avoided.
- Performance gaps are thoroughly analyzed and efficiently solved.
- Performance improvement is ingrained as a core business practice.

Models help define the picture of what "good looks like." For analysis as an example, INPO developed an Anatomy of Event model. The model, influenced by the Human Performance model of Gerry Rummler, is used throughout the industry to promote common terminology and a systems approach to help understand and diagnose events.

The Nuclear Energy Institute (NEI) coordinated the industry effort to develop a Standard Nuclear Process Model that defines processes, high level functions and common terminology for all aspects of operating a nuclear plant. This performance model has eight primary processes supported by 44 sub-processes. Communities of Practice were established for each process area and standards were identified or developed for each process area. This Standard Model was commissioned by the

[xiv] Reiman, T. and Oedewald, P. Evaluating Safety-Critical Organizations – Emphasis on the Nuclear Industry. Finland: VTT, 2009.

CEO's of the major nuclear utilities and is used to guide plant operations and for benchmarking of innovations in plant processes and performance.

The NRC's regulatory approach is also defined by a model, the Reactor Oversight Model. The regulatory framework for reactor oversight is a risk-informed, tiered approach to ensuring plant safety. There are three key strategic performance areas: reactor safety, radiation safety, and safeguards. Within each strategic performance area are cornerstones that reflect the essential safety aspects of facility operation. Satisfactory licensee performance in the cornerstones provides reasonable assurance of safe facility operation and that the NRC's safety mission is being accomplished.

Within this framework, the NRC's operating reactor oversight process provides a means to collect information about licensee performance, assess the information for its safety significance, and provide for appropriate licensee and NRC response. Because there are many aspects of facility operation and maintenance, the NRC inspects utility programs and processes on a risk-informed sampling basis to obtain representative information.

## The Regulator

Without an independent, technically competent, research-informed and systems-thinking regulator highly reliable governance is not possible. The NRC represents one of the most advanced risk-informed regulatory approaches. Ensuring plant safety begins by requiring a design philosophy that includes:

- Multiple, redundant, and independent safety systems;
- Multiple physical barriers, including robust reactor containment to prevent radioactive release; and
- Testing of emergency plans.

This design philosophy is supported by a strong analytical effort that goes beyond technical specifications to include operating experience along with organizational and human factors. The necessary start point for a shift from government to governance is a shift from deterministic to risk-informed regulation. This risk-informed approach combined with a performance-based regulatory regime, versus a prescriptive regulatory regime establishes a basis for a highly reliable governance approach. How these concepts are defined and combined has been described by the NRC as follows: [xv]

> The risk definition takes the view that when one asks, "What is the risk?" one is really asking three questions: "What can go wrong?" "How likely is it?" "What are the consequences?" These three questions can be referred to as the "risk triplet." The traditional definition of risk, that is, probability times consequences, is fully embraced by the "triplet" definition of risk.
>
> **Deterministic and Probabilistic Analyses:** The deterministic approach to regulation establishes requirements for engineering margin and for quality assurance in design, manufacture, and construction. In addition, it assumes that

[xv] Travers, William D. "White Paper on Risk-Informed and Performance-Based Regulation," NRC, March 1, 1999. http://www.nrc.gov/reading-rm/doc-collections/commission/srm/1998/1998-144srm.html.

adverse conditions can exist and establishes a specific set of design basis events (i.e., What can go wrong?). The deterministic approach involves implied, but unquantified, elements of probability in the selection of the specific accidents to be analyzed as design basis events. It then requires that the design include safety systems capable of preventing and/or mitigating the consequences (i.e., What are the consequences?) of those design basis events in order to protect public health and safety. Thus, a deterministic analysis explicitly addresses only two questions of the risk triplet. In addition, traditional regulatory analyses do not integrate results in a comprehensive manner to assess the overall safety impact of postulated initiating events.

**Risk-Informed Approach:** A "risk-informed" approach to regulatory decision-making represents a philosophy whereby risk insights are considered together with other factors to establish requirements that better focus licensee and regulatory attention on design and operational issues commensurate with their importance to public health and safety. A "risk-informed" approach enhances the deterministic approach by: (a) allowing explicit consideration of a broader set of potential challenges to safety; (b) providing a logical means for prioritizing these challenges based on risk significance; operating experience, and/or engineering judgment; (c) facilitating consideration of a broader set of resources to defend against these challenges; (d) explicitly identifying and quantifying sources of uncertainty in the analysis (although such analyses do not necessarily reflect all important sources of uncertainty); and (e) leading to better decision-making by providing a means to test the sensitivity of the results to key assumptions. Where appropriate, a risk-informed regulatory approach can also be used to reduce unnecessary conservatism in purely deterministic approaches, or can be used to identify areas with insufficient conservatism in deterministic analyses and provide the bases for additional requirements or regulatory actions. "Risk-informed" approaches lie between the "risk-based" and purely deterministic approaches. The details of the regulatory issue under consideration will determine where the risk-informed decision falls within the spectrum.

**Performance-Based Approach:** A regulation can be either prescriptive or performance-based. A prescriptive requirement specifies particular features, actions, or programmatic elements to be included in the design or process, as the means for achieving a desired objective. A performance-based requirement relies upon measurable (or calculable) outcomes (i.e., performance results) to be met, but provides more flexibility to the licensee as to the means of meeting those outcomes. A performance-based regulatory approach is one that establishes performance and results as the primary basis for regulatory decision-making, and incorporates the following attributes: (1) measurable (or calculable) parameters (i.e., direct measurement of the physical parameter of interest or of related parameters that can be used to calculate the parameter of interest) exist to monitor system, including facility and licensee performance; (2) objective criteria to assess performance are established based on risk insights, deterministic analyses and/or performance history; (3) licensees have flexibility to determine how to meet the established performance criteria in ways that will encourage and reward improved outcomes; and (4) a framework exists in which the failure to meet a performance criterion, while undesirable, will not in and of itself constitute or result in an immediate safety concern. The measurable (or calculable) parameters may be included in the regulation itself or in formal license conditions, including reference to regulatory guidance adopted by the licensee."

**Risk-Informed, Performance-Based Approach:** A risk-informed, performance-based approach to regulatory decision-making combines the "risk-informed" and "performance-based" elements discussed above, and applies these concepts to NRC rulemaking, licensing, inspection, assessment, enforcement, and other decision-making. Stated succinctly, a risk-informed, performance-based regulation is an approach in which risk insights, engineering analysis and judgment, including the principle of defense-in-depth and the incorporation of safety margins and performance history are used, to (1) focus attention on the most important activities, (2) establish objective criteria for evaluating performance, (3) develop measurable or calculable parameters for monitoring system and licensee performance, (4) provide flexibility to determine how to meet the established performance criteria in a way that will encourage and reward improved outcomes, and (5) focus on the results as the primary basis for regulatory decision-making.

As former Secretary Babbitt said, this regulation does not come without a cost. Currently the NRC employs about 4,000 employees to regulate U.S. nuclear reactors, materials (e.g., medical x-ray equipment), and nuclear waste management. The NRC budget is about $1.04 billion. About 75 percent of the NRC staff and budget are applied to regulating the 104 licensed nuclear power reactors in the United States. In 2009, each U.S. nuclear plant received 6,000 hours of regulatory inspection. The licensed nuclear operating organizations pay the costs of regulation by congressionally approved approaches.

## The Industry

Babbitt's comments on regulation have been augmented by calling for an oil and gas industry organization to promote safe practices; he has said a model is INPO. Similarly William Reilly, Co-Chair of the President's Commission has said that the oil industry needs to create a safety organization modeled on one that has improved operations at nuclear-power plants. An organization modeled on INPO would not be a substitute for stronger Federal oversight but could "create the safety culture that's needed" in offshore drilling, according to Reilly.

Building upon a sound, forward-looking regulatory approach, progress toward high reliability governance requires industry-wide, collaborative self-governance. The U.S. commercial nuclear industry funds three main organizations that perform an array of technical and management functions: the NEI, the Electric Power Research Institute (EPRI), and INPO.

The NEI role is to support the industry in developing policy on key legislative and regulatory issues affecting the industry. It serves as a unified industry voice before the U.S. Congress, executive branch agencies, and Federal regulators, as well as international organizations and venues. NEI also provides a forum to resolve technical and business issues for the industry. Finally, NEI provides information on the nuclear industry to members, policymakers, the news media, and the public.

EPRI conducts research and development relating to the generation, delivery, and use of electricity for the benefit of the public. An independent, non-profit organization, EPRI brings together its scientists and engineers, as well as experts from academia and industry, to help address challenges in electricity, including reliability, efficiency, health, safety, and the environment. EPRI also provides technology, policy, and economic analyses to drive long-range research and development planning and supports research in emerging technologies. EPRI's members represent more than 90 percent of the electricity generated and delivered in the United States, and international participation extends to 40 countries.

INPO represents a "defining" new approach to independent evaluation of industry performance. INPO does not develop industry standards adopted by the regulator, nor does it conduct advocacy on behalf of the industry. Its charter and operations have been carefully crafted to draw a clear distinction between the NRC as the regulator and INPO as an independent organization that promotes excellence though four keystone programs of evaluation, training, analysis, and assistance.

INPO collects and analyzes equipment performance data, but does not engage in technical standards development. INPO also manages the National Academy for Nuclear Training. The Academy accredits the training programs run by nuclear power utilities similar to how academic programs of universities are accredited. INPO also conducts professional development seminars for nuclear power management ranging from supervisors to corporate Boards of Directors. Once every 2 years INPO evaluates each U.S. nuclear plant using the Objectives and Criteria. Plants are ranked annually based on INPO evaluation results, and the lower performing plants are held to account by the rest of the industry for upgrading their performance. The insurance providers use INPO plant ratings as a component of setting fees paid by utilities for nuclear plant insurance.

INPO standards of excellence, referred to as Performance Objectives and Criteria, are derived from best performers in the nuclear industry, other high hazards industries such as aviation, and insights from the academic community. The standards are not static; they are continually scrutinized, informed by research, benchmarking, and operating experience; and upgraded as issues emerge and better practices are validated. The basic premise is if you keep doing what you have been doing, in a dynamic environment you are falling behind, not improving. Constant improvement is more than a mantra, it's a fact of survival. INPO standards are performance-focused, not prescriptive and address the following management and operational topics.

| FUNCTIONAL AREAS | CORPORATE AREAS |
|---|---|
| Operations | Corporate Leadership & Management |
| Maintenance | Corporate Oversight & Monitoring |
| Engineering | Corporate Support |
| Chemistry | Human Resources |
| Radiological Protection | Communications |
| Training | |

**CROSS-FUNCTIONAL AREAS**

Organizational Effectiveness
Foundation for Nuclear Safety
Leadership and Management
Human Performance
Management & Leadership Development
Independent Monitoring & Assessment
Industrial Safety
Operational Focus
- Operational Safety
- Operational Decision-Making
- Operational Alignment

Equipment Reliability
- Equipment Performance
- Prevention of Equipment Failures
- Long-Term Equipment Reliability

Work Management
Configuration Management
Maintaining Margins Consistent with Design Requirements
Operational Configuration Control
Design Change Processes
Reactor Engineering and Fuel Management
Performance Improvement
Self-Assessment and Benchmarking
Corrective Action
Operating Experience
Emergency Preparedness
Fire Protection

The guiding principle behind INPO is that all U.S. nuclear plants are "Hostages of Each Other"—that an accident at one plant can cause serious damage to the entire industry.[xvi] While the NRC is responsible for regulating the safety of U.S. nuclear plants, the industry uses INPO to promote excellence, thus improving performance industry-wide, and to protect the industry as a whole from bad management and declining performance of the few poor performers. It should be noted that the INPO influence is now world-wide; after the Chernobyl accident in the Ukraine in 1986, the international commercial nuclear industry formed the World Association of Nuclear Operators to transfer the INPO excellence approach to all commercial nuclear plants in the world, and the INPO Performance Objectives and Criteria are now becoming the world "standards" for nuclear plant management and operations.

Collectively these three organizations provide the essential industry component of the nuclear governance model. However the industry augments with working groups and communities of practice as deemed necessary. One example of a formalized community of practice is the Procedures Professional Association (PPA).

PPA is the nuclear industry's collective voice and leader in procedure writing and processing. The association provides consistent and benchmarked guidance to commercial nuclear facilities. The mission of PPA is to function as a non-profit organization, developing and exchanging technical information on the design, development, implementation, and use of procedures to increase reliability improve performance, and ensure safe and efficient facility operation. PPA promotes excellence in procedure writing and processing through education and information sharing.

PPA was founded in August of 2005 after functioning in a working group fashion for the prior 17 years. It was determined that an industry association would give stakeholders a strong platform from which to provide input to industry oversight groups such as INPO and NEI. In 2006,

[xvi] A book by this name by Victor Rees chronicled the development and significance of INPO in the nuclear industry.

members of PPA were integrally involved in the development of the AP-907-001, "Procedure Process," and AP-907-005, "Procedure Writer's Guide," both elements of the Standard Nuclear Performance Model. The Standard Nuclear Performance Model is a comprehensive model that includes INPO, NEI and EPRI process descriptions and provides a consistent basis for describing how work is done at nuclear power plants for process areas.

## Insurance

Insurance is both a forcing and reward feature of the nuclear governance approach. The Price-Anderson Act, which became law on September 2, 1957, was designed to ensure that adequate funds would be available to satisfy liability claims of members of the public for personal injury and property damage in the event of a nuclear accident involving a commercial nuclear power plant. The legislation helped encourage private investment in commercial nuclear power by placing a cap, or ceiling on the total amount of liability each holder of a nuclear power plant licensee faced in the event of an accident. Over the years, the "limit of liability" for a nuclear accident has increased the insurance pool to more than $12 billion. Under existing policy, owners of nuclear power plants pay a premium each year of $375 million in private insurance for offsite liability coverage for each reactor unit. The average annual premium for a single-unit reactor site is $400,000. Insurance under Price-Anderson covers bodily injury, sickness, disease or resulting death, property damage, and loss, as well as reasonable living expenses for individuals evacuated.

Separately from the Price-Anderson required insurance, utilities acquire property casualty accident coverage through Nuclear Electric Insurance Limited (NEIL). NEIL insures nuclear plants and their generating units, owned by electric utilities (the "Members"), primarily in the United States. It provides property insurance coverage to all of the commercial nuclear power generating facilities in the United States for: (1) the costs associated with certain long-term interruptions of electric generation, under the primary and accidental outage programs due to accidental physical damage to insured sites; (2) decontamination expenses incurred at such sites arising from accidental nuclear contamination; and (3) other risks of direct physical loss at such sites, including certain premature decommissioning costs under the primary and excess programs.

## Research

Research on new technologies is supported by many industries. For High Reliability Organizations, a corresponding emphasis is placed on the socio aspects of socio-technical systems. The need for such research was elaborated by the National Science Foundation.

> Over the last decade, the thesis that scientific and technological research can contribute to overcoming sustainability challenges has become conventional wisdom among policy, business, and research leaders. By contrast, relatively little attention has been given to the question of how a better understanding of the human and social dimensions of science and technology could also contribute to improving both the understanding of sustainability challenges and efforts to solve them. Yet, such analyses would seem central to sustainability research. After all, human applications of science and technology pose arguably the single greatest source of threats to global sustainability, whether we are talking about the energy and transportation systems that underpin global industrial activities or the worldwide expansion of agriculture into forest and savannah ecosystems. These applications arise out of complex social, political, and economic contexts—and

> they intertwine science, technology, and society in their implementation—making knowledge of both the human and social contexts and elements of science and technology essential to understanding and responding to sustainability challenges. Thus, while science and technology are central to efforts to improve human health and well being, the application of science and technology has not always contributed as anticipated in past efforts to improve the human condition. It is essential, therefore, that research on the relationships between science, technology, and society be integrated into the broader sustainability research agenda. [xvii]

The NRC has for years invested in risk and social systems research. The NRC's Human Performance Research program focuses on the interaction of people with the systems and the environments in which they work. It establishes the technical basis for NRC initiatives in areas such as inspection guidance for evaluating emergency operating procedures, a systems approach to training, human system interface design for current and advanced control station design, human performance contributors in events, communications-related corrective action plans, shift working hours, and fatigue management programs.

As an example, NUREG/CR-6753 "Review of Findings for Human Performance Contribution to Risk in Operating Events," [xviii] was performed for the NRC by researchers at the Department of Energy's Idaho National Laboratory. The results showed that human performance contributed significantly to analyzed events. In the events reviewed, 270 human errors were identified and multiple human errors were involved in every event. Latent errors (i.e., errors committed prior to the event whose effects are not discovered until an event occurs) were present four times more often than were active errors (i.e., those occurring during event response). The latent errors included failures to correct known problems and errors committed during design, maintenance, and operations activities. This study was instrumental in helping to shift the emphasis from discipline, training, and procedure fixes to a systems view of the technical, management, workplace, and cultural factors that influence individual and collective human behaviors.

INPO also invests significant attention to research. From an operational perspective, analysis of operating experience to identify industry-wide issues is an INPO cornerstone. This analysis is often an impetus for industry-wide performance improvement initiatives. For instance, even before the NRC's NUREG/CR-6753, INPO began research on human performance contribution to events though the Human Performance Evaluation System. That effort reached similar conclusions—that latent errors were primary drivers of performance. To change the "blame, shame, retrain, and fix procedure" paradigm, INPO developed the Human Performance Improvement (HPI) initiative. INPO did an extensive review of human performance literature and engaged the nuclear industry in developing practices and techniques to reduce and mitigate adverse consequences of human error while concentrating organizational attention on remedying the underlying factors that influenced risk-provoking behavior.

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[xvii] Miller, Clark, et al. "Science, Technology, and Sustainability: Building a Research Agenda," National Science Foundation Supported Workshop, September 8-9, 2008.
[xviii] http://adamswebsearch2.nrc.gov/idmws/DocContent.dll?library=PU_ADAMS^pbntad01&LogonID=2e49dde151434488745b3edc36b15e6f&id=004065859.

For nuclear plants in Sweden and Finland, the VTT Technical Research Centre of Finland has conducted a series of studies that examine human, organizational, and cultural factors that affect nuclear operations. Currently VTT is engaged in research on the implications of these factors for construction of new plants.

## Multi-agent Collaboration

Collaboration on issues of industry-wide concern is another distinguishing characteristic of commercial nuclear power. The currently ongoing collaboration on safety culture serves as an illustration.

Safety culture was established as an important to safety concept by the International Atomic Energy Agency's International Nuclear Safety Group (INSAG) in the 1988 "Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident." [xix] INSAG described safety culture as: "That assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance." In 1989 the NRC expressed its expectations for a positive safety culture.

Problems at the Millstone plant in 1996 led the NRC to raise concerns about the plant's safety culture, primarily related to the handling of employee safety concerns. In 2002, a major corrosion of the nuclear reactor head was discovered at the Davis Besse nuclear plant. Investigations led to a concern about safety culture that expanded beyond earlier attention to employee safety concerns to generalized concern about the utility's risk management philosophy and behaviors. In 2004, the NRC communicated new directions for evaluating safety culture and made subsequent revisions to the Reactor Oversight Process to specifically address safety culture.

The U.S. nuclear industry took note of the importance of safety culture soon after the Davis Besse event. INPO issued number of prompt recommendations to which utilities were committed to respond. Then INPO assembled a group of industry representatives to develop guidance. This guidance, published in final form in 2004, took the form of a statement of safety culture principles and supporting attributes. This document became the basis for INPO review of safety culture during the formal INPO evaluations. The nuclear industry also engaged the assistance of Dr. Edgar Schein of MIT as an advisory member of one of INPO's senior advisory groups; Dr. Schein is well respected as a leading authority on organizational culture. Building upon the INPO efforts the industry turned to NEI to lead an effort for safety culture management and self assessment.

NRC continued work on a new policy on safety culture intended to address not only reactors, but also other licensees that use regulated nuclear material, including medical isotopes. A series of public meetings were initiated to inform stakeholders and the public of the NRC's continuing emphasis on safety culture and seek input. In February of 2010, a 3-day workshop was held at which NRC and major stakeholders presented views on safety culture improvement activities and working groups of the stakeholders' communities suggested revisions to the draft NRC policy language. Most recently NRC and INPO collaborated on an industry-wide survey of safety culture in an effort to ascertain which characteristics of the principal safety culture models might be most influential on risk. The study was conducted by INPO, with input from the NRC in study development; 100

[xix] "Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident: A Report by the International Nuclear Safety Advisory Group Safety." INSAG, 1986.

percent of the U.S. plants participated in the study, and the results were jointly analyzed by a team of scientists from NRC and INPO.

As this example illustrates, issues of industry-wide significance warrant and require involvement of major stakeholders, the public, and the regulator. Only through such collaborative effort can the requisite knowledge, skill, experience, perspectives, and scientific rigor be assembled to produce robust improvement initiatives with the flexibility to be applied in a manner appropriate to a variety of operational contexts.

# 7. Application of Concept

There are three prevailing perspectives on the BP Deepwater Horizon accident:

1) It's just BP—everyone else is fine; just follow procedures, trust the industry.
2) Restrict deep-water drilling, develop more prescriptive regulations, and conduct more frequent inspections.
3) Fundamental change is needed—a Highly Reliability Governance approach.

The "It's just BP" perspective is the prevailing view being heard thus far from other petroleum operators in the Gulf. The second perspective is heard from a number of environmental groups. The third, "Highly Reliable Governance," is being talked about in various terms by a number of prominent individuals, including leadership of the President's Deepwater Commission. The Highly Reliable Governance approach would involve the U.S. government, the petroleum industry, and the academic community informed by stakeholders and the public. This approach recognizes that the regulator cannot develop prescriptive regulations to foresee all possible conditions that could result in accidents. It recognizes that technology, operational, and management techniques are constantly evolving. And it recognizes that the organizational and cultural aspects of complex socio-technical systems are determining factors in safe operations. The main components of this approach that are actively being discussed include:

1) New government regulation model with
    a. Independent government regulatory agency funded by industry fees
    b. A systems safety regulatory model clearly establishing that system safety is necessary to prevent major events; that worker protection models, while essential and mandatory, alone are not sufficient
    c. Safety cases (including detailed drilling and spill response plans)
    d. Risk-informed regulation (a combination of traditional engineering requirements for technical systems and components informed by probabilistic risk assessment to focus on safety critical systems and components, combined with performance regulations for management and organizational systems and processes)
    e. Intense training and qualification programs for inspectors
    f. Onsite inspectors
    g. Industry-wide reporting system with "whistle blower" protection
2) An independent organization, established by industry, to perform evaluation of drilling and production operations
3) Independent standards and training to promote excellence
4) Industry-funded accident insurance pool

5) Research on petroleum industry management excellence
6) Research and investment in developing new safer and cheaper technologies
7) Safety equipment standardization and qualification
8) Industry-wide emergency response capability

# 8. Concluding Thoughts

Many of the items mentioned for inclusion in a Highly Reliable Governance model have already been discussed in public statements or reports on Deepwater. Applications of advanced risk analysis and risk management in the petroleum industry are not new. [xx, xxi, xxii] Of course it is difficult to project what will happen until after the formal inquires have been completed and the Congress and Administration take action. Many stakeholders will have input to the deliberations, and the petroleum industry inputs will be important. The industry response will directly shape public opinion—an attitude of business as usual will only heighten the public distrust of the industry.

Except for discussions about a joint spill response program, the statements from the petroleum industry in the United States have generally been that this is just a BP problem; the other companies would not have behaved as BP did. Perhaps there is yet another lesson to learn from the nuclear industry.

Immediately after the Three Mile Island accident many utilities responded similarly—the plant operator Met Ed was just a poor performer; all the others were better. Then, a few far-seeing leaders emerged. The stature of these individuals among their colleagues, and statesman-like efforts, helped catalyze other to commit to themselves and the public that another Three Mile Island would never occur in this country. Thus INPO was born with all industry CEO's agreeing to form the Institute, fund it, and adhere to an unending search for excellence. The journey continues after 30 years. Today the nuclear industry is emblematic of an industry-wide HRO effort.

There are a number of permutations of approaches that could emulate the nuclear success factors. Some combination of an NRC model and Federal Aviation Agency model is a possible regulatory approach. However independence will be essential. Regulator acceptance of API standards and multiple nation flag certification for drilling rig vessels is counterproductive to independent regulation. Industry standards may be used to share best practices in search of excellence, but they cannot be used as surrogate for government-mandated requirements based on science, engineering, and operating experience. Upon this basis, and this basis alone, can regulation then be risk informed and performance based.

Independent industry self-governance could be enabled through a single entity such as INPO, or enhanced portfolios of highly respected certifiers like Det Norske Veritas could be a possibility. However a single overseer would have to validate performance of reviews by multiple certifying

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[xx] Bea, R. G. "Performance shaping factors in reliability analysis of design of offshore structures." Journal of Offshore Mechanics and Arctic Engineering. Transactions of the ASME. Vol. 122, no. 3, (August 2000): 163-172.
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agents and the inspection and certification functions would need to be separated from other consulting functions. The U.S. regulatory agency would have to figure what status might be accorded to such certifications. Whatever governance regime is established, excellence in risk management will be essential.

In a his 1991 paper, "Human Factors in Large-Scale Technological Systems' Accidents," Najmedin Meshkati[xxiii] examined commonalities among the Three Mile Island, Bhopal, and Chernobyl accidents and offered human factors recommendations to prevent reoccurrence. The urgency of these human factors recommendations was emphasized with the admonition that these actions were "long overdue and constitute only a necessary step toward ensuring the safety of complex, large-scale technological systems." His recommendations and the urgency of improvements needed remain true today to prevent future Deepwater Horizon accidents.

Dr. Meshkati's paper concludes with observations foretelling the need for Highly Reliable Governance. While technical and human factors improvement are necessary:

> "To make it sufficient, in the long-run, we need much more commitment, communication and cooperation among those who could make these systems safer—the government and regulatory agencies, plant manufactures and managers, unions, and the human factors and other concerned research communities. We need an overall paradigm shift in dealing with complex technologies' safety and operation. We need more institutionalized interaction among all stakeholders in the public and private sectors. Above all, we need genuine and real dedication of all parties, not rhetoric or public relations ploys for this collective effort. As professed by the late Nobel physicist, Richard Feynman, in the context of another complex technological system's accident, the Space Shuttle Challenger explosion: "For a successful technology, reality must take precedence over public relations, for nature cannot be fooled."

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