Assessing and Managing Emerging Risks

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By Stephen Barrager and Warner North*

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*The views expressed in this document are those of the authors and do not necessarily reflect the views of IRGC.

“In the aftermath of catastrophes, it is common to find prior indicators, missed signals, and dismissed alerts that, had they been recognized and properly managed before the event, might have averted the undesired event.”

National Academy of Engineering [1], page 5.

Introduction

This background paper is intended to provide perspective for IRGC’s current work on building guidelines for assessment and management of emerging risks. It follows a previous effort on identification of factors that contribute to risk emergence (see the report ‘Emerging Risks: Contributing Factors, published in December 2010).

Our focus is on those risks that are emerging – in need of better risk management, rather than those that are well understood with good protocols already in place to accomplish oversight and management. Evolving science and technology may contribute to emerging risk, but other factors may be even more important, particularly the social and management structure in which the risks are embedded. Human history shows many examples of infrequent but catastrophic events, where anticipation and preparation were crucial to success or failure – floods, famines, attacks by enemies, and in modern times, epidemics of disease and natural disasters such as earthquakes, tsunamis, volcanic eruptions, and the failure of major engineered structures – space vehicles, bridges, dams, etc.

Our primary focus in this document is on the corporate and private sector, but it is our opinion that no sharp dividing line is possible, because government regulations and practices set through compliance with insurance requirements and industry standards have a nearly ubiquitous influence on private sector decision making. One must look both at the physical risks – the occurrence of natural disasters and failures of engineered systems – and risks that are more social, where human behavior plays a paramount role in understanding the sequence of events leading to the bad outcome. The authors view analysis and modeling as excellent tools for achieving better understanding of complex and uncertain situations where risks arise and must be managed. But responsible officials cannot commission detailed investigation and analysis on the very large number of situations in which there might be an emerging risk. So the focus of guidelines must, first and foremost, address the process of assembling and evaluating the potentially critical data from a large amount of background information. We believe that ultimately, success in meeting this challenge is a matter of pattern recognition. While mathematical and statistical analysis can help, human brains are still highly superior to the capabilities of computers and computer software for pattern recognition.

We view the successful paradigm of emerging risk assessment and management as a system whereby important data are recognized, evaluated, and then used in selecting the best management alternative to minimize risk. *The converse of this statement is that where data are not being* *collected, their importance evaluated, and the most important data transmitted and used for decision making, the system is deficient, and these deficiencies are in need of remediation.* In the remainder of this document we present ideas on how such deficiencies can recognized and remediated.

Background Reading and Key References:

An excellent report by the National Academy of Engineering [1] in 2004 sets forth the perspective that collection of data on accident precursors is an important aspect of good safety management. Many areas of industry, such as commercial aviation and management of nuclear power plants, have well-developed protocols and safety cultures to achieve such careful and comprehensive data collection and analysis. We recommend this report (available without charge on the web) as background for those unfamiliar with this viewpoint.

A recent article [6] by Frank W. Guldenmund of the Safety Sciences Group, Delft University of Technology, Delft, the Netherlands summarizes a great deal of social science literature on the relationship of safety to culture, in a variety of interpretations of the term “culture” within the social sciences. The article points out that research on culture in relation to safety is inherently difficult, because of the difficulty of obtaining information for analysis: culture is inherently “a multidimensional construct.” Data gathered by traditional academic means such as questionnaires may be of limited value for achieving insight into organizational safety culture. The author advocates an experience-based approach, with a strong emphasis on *processes.* We agree, and we refer our readers to this paper and its more than 100 references for detailed discussion.

We include a quote from [6] that we believe is especially important in setting out main themes for this background paper:

Importantly, significant information should be able to flow uninhibited throughout the organization so that anybody who has to be informed about something, actually also is. What is more, qualities like trust and responsibility are cherished within such organizations and can be discerned in their decision making processes. Similarly, trust and responsibility are also demonstrated within the workforce to solve safety issues online.
[6], page 1477.

Case Study for Illustration: Pacific Gas and Electric (PG&E), gas pipeline rupture and subsequent explosion and fire, San Bruno, California, on September 9, 2010

A 30-inch natural gas pipeline in San Bruno, California, a residential suburb south of San Francisco, ruptured. The resulting explosion and fire destroyed at least 35 homes, killed 8 people, and inflicted severe burns on about thirty more. The crater created by the explosion was 72 feet long and 26 feet wide [7]. It will take years to rebuild the neighborhood.

Despite reports from people in the neighborhood “smelling gas,” the rupture occurred without prior warning. A San Bruno fire captain described the intense fire as “like they took a Saturn V rocket and turned it upside down.” [8].

“At a hearing in Washington before a U.S. Senate committee, a top official with the agency investigating the blast said that alarms went off at a PG&E control center in San Francisco about the time of the blast indicating that pressure in the pipeline that led to San Bruno was spiking.” [7]. The maximum limit that PG&E told the public it maintained was 375 pounds per square inch (psi) , and the spike reached 386 psi. The pressure then dropped to 144 psi, triggering a low pressure alarm [7]. The line did not have automatic shut-off values. At the control center, replacement of an electrical back-up power system may have distracted workers such that the alarms were not noticed. PG&E workers “took nearly two hours to manually shut off valves to the ruptured segment of pipe.” [7]. The intense fire was then brought under control.

This pipeline, like many in the PG&E system, was installed before 1970. The spine of the pipe was welded using a method that is now considered outmoded. Federal regulators warned pipeline companies of danger from pipelines installed before 1970, because of concerns for pipe corrosion, the potential for dents and subsequent breaks from construction activity, and earthquake vulnerability [9].

There is a federal requirement for close inspection and replacement of pipeline where necessary. But federal authorities did not mandate widespread pipeline replacement or use of the most advanced inspection methods. While PG&E had an inspection program, it has used the preferred “smart pig” technology (a torpedo-shaped device that traverses the inside of the pipe and uses ultrasound as well as visual inspection) on only 21 percent of its system. The pre-1970 pipeline that ruptured was one that could not be inspected with this smart pig method because of valves and sharp turns [9]. While the other large California natural gas utility, Southern California Gas, has replaced many miles of old pipeline and now uses “smart pigs” on 80 percent of its system, PG&E still uses “direct assessment” (checking records and using probes to inspect the outside of the pipeline) for most of its “high risk” pipelines. The last such “direct assessment” inspection of the pipeline that ruptured was in November 2009 [9]. No leak or other deficiency was found.

Pipeline inspection and replacement needed approval from the state regulatory authority, the California Public Utilities Commission (CPUC), before PG&E could recover the money from the rates paid by the customers for such diagnosis and repair activities. Only a small portion of PG&E’s requested amount was approved. PG&E had established a list of the 100 riskiest pipeline segments, in response to a request from the CPUC. The line that ruptured was not on this list. A Committee of the California State Senate is now investigating why the CPUC approved a rate increase to replace old pipelines, but did not follow up to see if the money was spent. PG&E apparently postponed the replacement. State investigation following the fire noted that that CPUC has less than ten inspectors to oversee the network of 110,000 miles of gas pipelines that the CPUC regulates. These inspectors spent only 400 days doing inspections. Federal officials had withheld a portion of federal funding for pipeline inspections for the past seven years because of the poor record of inspections in California [10].

There were many precursor events. The federal Office of Pipeline Safety reports 103 similar pipeline ruptures in natural gas pipelines, 95% in lines with pipe made before 1970. A 2008 pipeline rupture near Sacramento, California, resulting from an error by PG&E workers installing the wrong kind of pipe, caused a death and five injuries. Again, there were reports of a "gas smell" that went unheeded prior to this 2008 explosion [11]. An explosion and fire in 2004 in Belgium from a gas pipeline weakened by construction work killed 24 and injured 120 people, mainly among police and fire fighters [12].

After the San Bruno pipe rupture, PG&E used laser monitoring from airplanes to survey its natural gas pipeline network, and found 38 leaks, including four in "big lines"[13]. The leaks have since been fixed, according to PG&E [13]. But this reconnaissance was not carried out before the San Bruno pipeline explosion.

PG&E estimates direct total cost for damage from the San Bruno pipeline rupture at $238 million [14] and PG&E's needed system repairs bring the total cost to nearly $1 billion [15]. PG&E just reported earnings growth for the last quarter, if one does not include the charges for the San Bruno accident [14]. There has been a great deal of public criticism, and lawsuits and political fallout are proliferating. As of this writing 31 lawsuits have been filed by a total of 111 people. State and federal investigations are underway, which should provide more in-depth information than our summary above of this event from recent newspaper stories.

Other Disasters: Common Elements for these "Emerging Risks" from Established Infrastructure That Was Generally Considered Acceptably Safe by the Public.

We have described a disaster event involving a United States corporation, in this case a regulated public utility, which occurred in northern California. Millions of California residents and businesses, are supplied with natural gas by PG&E's pipeline system. Until the San Bruno accident, there has been little public discussion of natural gas pipeline safety, although much concern had been expressed by knowledgeable experts, including in a report on critical infrastructures from IRGC [12]. Efforts to get inspections and replacement of old pipelines may have been heeded in other gas pipeline companies, but they had little impact on PG&E, or on its state-level regulators. Federal regulators cut funds for inspections, but did not force actions. We are not aware of any actions taken by insurance providers, who might have been monitoring the complaints from federal authorities about California's poor pipeline inspection process. PG&E has told its investors that its $992 million fire-insurance policy should cover most third party claims and would cover the company even it is found to be in gross negligence [16].

There are a great many other well-known disaster case studies that could be investigated in addition to this recent event: We invite our readers to reflect on them. What are the similarities that can be observed and what lessons might we learn? The explosion and subsequent oil spill from BP's Deepwater Horizon rig has had a great deal of recent publicity. The Toyota gas pedal problem resulted in a massive recall and much adverse publicity for Toyota. AIG, the largest insurance company in the United States, incurred extreme liabilities by insuring credit default swaps on subprime mortgage-backed securities. This company was kept solvent only because the US Federal Reserve Bank stepped in with an emergency $85 billion loan [17]. (BP, AIG, and the Eyjafjallajökull volcano and its impact on transatlantic/European air travel are discussed in the INFORMS 2010 Omega Rho talk by John R. Birge [18]). Further back in time, the Space Shuttle Challenger disaster provides a classic example involving one of the most technically sophisticated of U.S. federal agencies, supported by its private contractors. (See the discussions in Argyris [19], and Tufte [20]). We will revisit the Challenger disaster below as an example of how a pattern in the available data was not observed in time to defer the launch and avoid the disaster that ensued.

There are many commonalities among these case studies: the focus on objectives other than safety; the lack of preparedness when the disaster occurred; the negative impact on corporate reputation and relations with the public and regulators, the aftermath of lengthy investigations indicating a systematic neglect of safety and a need to improve "safety culture."

The Ecosystem Analogy

One insight that comes from looking at the PG&E example and most other case studies is that risk management does not take place by decision makers in a private corporation making decisions in isolation from other organizations. Rather, the corporate decision process should be viewed as influenced by an "ecosystem" of organizations influencing that corporation. In particular, a corporation's activities in risk management may be strongly influenced by government regulatory agencies and the laws and regulations under which the corporation must operate, and also by insurance providers, who set rates and establish standards that affect corporate practices. Other parties in the ecosystem include the owners/investors in the corporation, and the perceptions of the financial securities industry that influence share price and availability of capital. Industry standards and standards and practices established through professional societies may also play an important role. For many decisions involving management of risk, decision makers may not be thinking about risk management as a decision process of choosing among alternative policies, but rather as a compliance process in which they do what they believe is expected of them, by government regulatory agencies, by insurance providers, and by investors. Often decision makers may be focusing on how other goals, such as increased profits or timely completion of projects, can be accomplished while also achieving apparent compliance with the established norms for safety in their part of the "ecosystem."

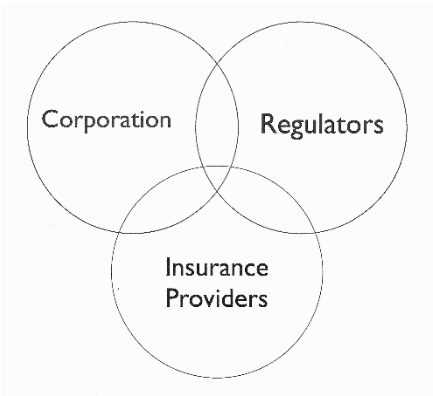

Figure 1: Corporate Risk Management as Part of an "Ecosystem"

PG&E is suffering much negative publicity, and this organization and its insurers will incur substantial losses. Other gas utilities may be motivated by the example of the San Bruno pipeline rupture to improve their processes for inspection and repair/replacement of gas pipelines. This PG&E example may help persuade public utility commissions in other states as well as California to allow the additional cost into the rates charged to natural gas customers. Similarly, insurance providers may use the PG&E example to change the eligibility rules for insurance against accidents. For example, increased inspections for corrosion inside the pipes, and automatic shut-off values, to stop the flow of gas quickly in the event of a rupture, may be required.

But conversely, firms that are spending much more than industry average on safety may find it difficult to sell their products against lower cost competition. (The history of underground mining provides many examples. Despite mine safety requirements, accidents in underground mines still happen frequently.)

Assessment and Management: Not by a Decision Maker, but by a Multi-level Organization within an "Ecosystem."

Risk management is accomplished not by a "decision maker," but by a multi-level organization that is part of an ecosystem comprised of other organizations. Information is gathered through assessment, then communicated, and when it indicates high risk, the information should motivate investigation, analysis, and decision making, including reevaluation of existing policies. But often that process does not work well. It requires skills in assessment and good communication with management, within the organization and to others who have important influence in the ecosystem. Both for new technology where experience is lacking, and for old technology where a good past safety record may be eroded through lack of diligence and aging equipment, it may be difficult to perceive that high risks are emerging. The need is to be observing of both the physical situation as well as the relevant human behavior. Then one must be able to evaluate these observations so as to deduce the increased risk. Then, in order to enable action to reduce the risk, the communication process to the decision making level must be effective.

It is unfortunately true that in much of human history, learning comes from experiencing disasters, then taking steps afterwards to reduce the risk of such the disasters recurring. It would be much better if organizations at all levels of society could learn to anticipate disasters in advance, especially the really big ones [21].

Early Warning System -The "Radar" Analogy: Detect, Filter, Prioritize

The authors, trained in engineering and physics, have selected radar, a key technological innovation in World War II, as an analogy to illustrate the steps involved for an early warning system. The three terms we are introducing here are also used in [1], a report from the National Academy of Engineering.

The radar process involves reflection of an electromagnetic signal from an object – for example an airplane. The signal is amplified and displayed on a screen – for example, as a white "blip" against a black background. In this way, radar operators in England were able to **detect** German bombers before they could be sighted visually, and warn the air defenses. In the opinion of many military historians, radar won the "Battle of Britain."

The key idea we develop here is that early warning is a complex task, carried out by human beings with mechanical aids for processing information. For engineers, the ideas may seem simple and obvious. For those without experience in such systems, we invite you to think about the difficulty involved in perceiving that an unexpected risk has emerged from the available information, such that prompt and effective action can be taken to deal with that risk. The simple illustration using this analogy is that radar can provide a warning that enemy planes are approaching. But how confident are we that the signal of the screen is really an enemy plane, especially if we think it is very unlikely there will be an attack?

When the Japanese airplanes attacked the U.S. Naval Base at Pearl Harbor, on December 7, 1941, the US had an operating radar system. Two privates watching the radar screen saw a large number of "blips" – the approaching Japanese planes. The supervisor, a lieutenant recently transferred to this assignment, dismissed the signal as that from six US B-17 bombers that were scheduled to arrive in Hawaii from the U.S. mainland. The lieutenant did not learn of the large number of blips, and for security reasons the lieutenant did not disclose to the privates the information he had about the scheduled arrival of the bombers. As a result of the miscommunication between the privates and the lieutenant, no warning was issued before the Japanese planes attacked [22].

Those with experience with radar learn that signal detection becomes much more difficult when objects besides the airplanes of interest also reflect radar waves back to the receiving antenna. These objects may include birds, clouds/water vapor, ocean waves, and countermeasures used by the enemy, such as strips of tin foil “chaff” dropped from airplanes to make a large curtain of reflecting material. How does one distinguish a signal (the blip from an airplane) from the “clutter” from other sources? We shall use her term “filter” to mean the evaluation of all the signals to find those that is important. For example, the radar reflection from a moving airplane causes a shift in frequency, from the Doppler effect. A system that detects radar waves shifted in frequency can discriminate a moving airplane from a large number of objects that are not moving. When a great deal of potentially important information is coming in and we must select out the very small amount of information that is important, we will use the term “**filter**” for this process.

The key idea of Bayesian probability is that new information is used to update a “prior” summary of important uncertainties (such as the probability that airplanes are friendly, rather enemy planes about to attack) to develop a “posterior” distribution that reflects both the new information and the prior probabilities. For those of you unfamiliar with the concept, think about how many observations of “heads” it would take before you conclude that the probability of a “head” on the next flip of a coin is not 50%, but a much larger value, because the person doing the flipping either has a two-headed coin or is a skilled magician. Early warning should be conceived as a process of going from assessment of a situation that was initially regarded as highly improbable, to recognition that the probability has increased to the point where warning others and further evaluation are needed. This recognition may require much more than conventional statistical analysis to determine that the probability of “signal,” versus “noise,” has exceeded a threshold for concern. It may involve a paradigm shift to a new hypothesis, that something is “wrong.” What could it be? The early warning system operators need to be able to respond quickly and flexibly to a wide assortment of possibilities.

As a non-technical example of recognizing a pattern in data, let us look at the information that engineers from Morton Thiokol, INC., the contractor, presented to the National Aeronautics and Space Administration (NASA) as part of 13 charts in the management meetings that preceded the launch of this mission. This discussion and the figures below are taken from [20].

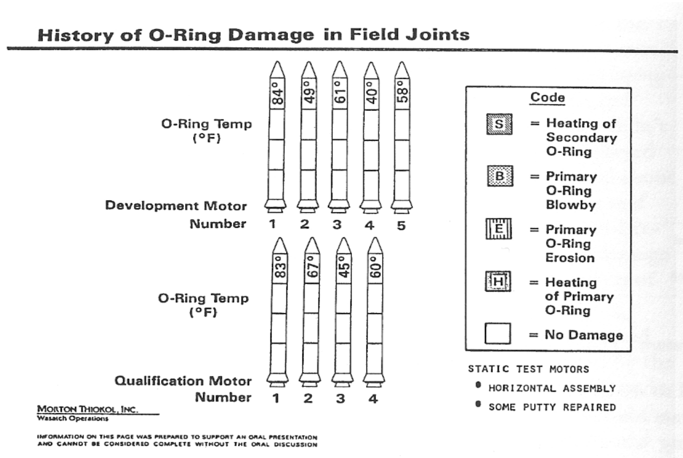

Fig 2a: Key to Rocket Diagram, from Tufte [20], p. 46.

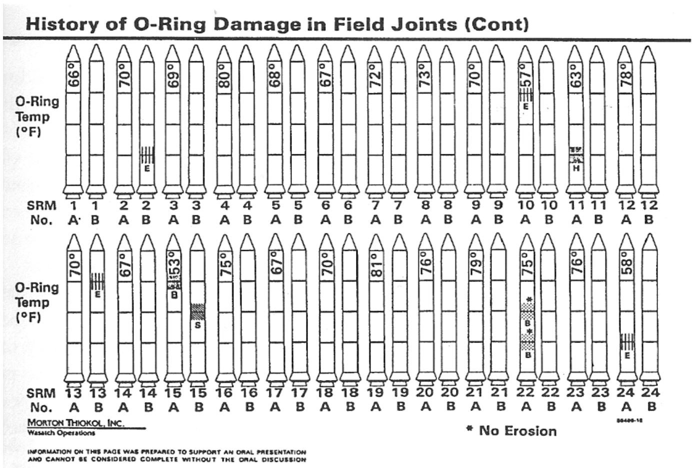

Figure 2b, History of O-Ring Damage in Field Joints, from Tufte [20], p. 47. Temperature data are included on this chart on the rockets representing the 24 prior shuttle launches.

Do you see the pattern? The Thiokol company managers and NASA officials responsible for mission safety did not see the pattern.

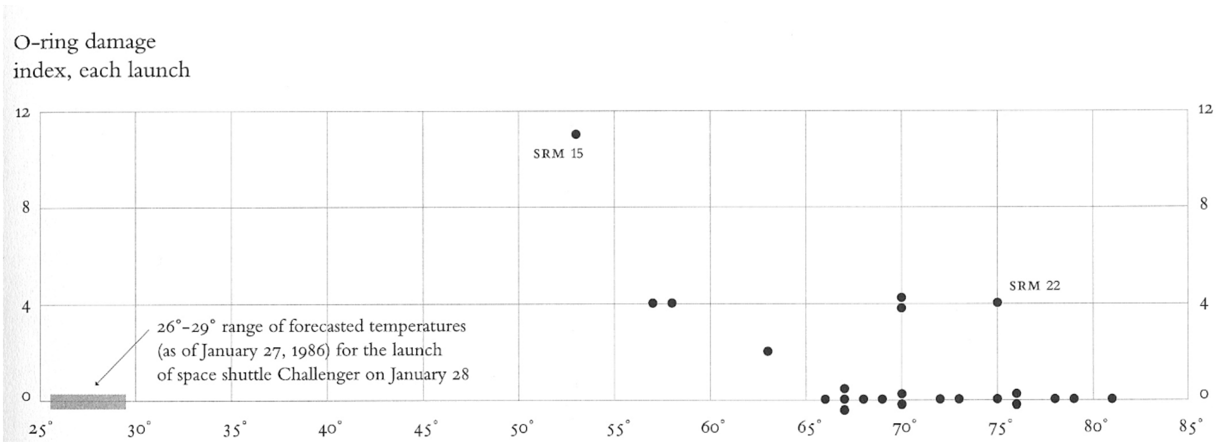

Figure 3. Graph of O-ring Damage against Temperature (℉) at Time of Launch.
Source: Tufte [20], page 45

Now look at essentially the same data plotted in graphical form to show o-ring damage as a function of ambient temperature at the time of launch. The planned launch of Challenger was to occur on a day with a forecast of unusually low ambient temperature. A plot such as Figure 3 might have allowed the concerned engineers to persuade NASA managers that there was a high risk of o-ring failure leading to loss of the spacecraft and crew during launch. But the data were not presented this way. The visual presentation of data can be a very important part of an early warning system.

The essence of filtering is to be able to extract the information indicating high risk from a great deal of other information. This other information is not "random noise" where well-known statistical procedures can be used to differentiate a signal from the noise. Rather it is a set of patterns that can be confusing and misleading, especially as viewed by the past experience of people who may have a mindset that disaster simply cannot happen, because it has not happened before, and the system they are monitoring has been built and operated by very smart people. Emerging risks are spotted by people who are skeptical, perhaps even judged slightly paranoid by their peers, and who are able to pose questions about whether a complex system is working properly, so as to recognize the value of a little bit of information indicating a departure from the usual – "something may be wrong." We will assert that the skill set needed for such recognition is not something that can be easily automated, although technical information processing may be very useful. It is a matter of **pattern recognition**, which is something that human brains can do amazingly well, especially after appropriate training.

After we have accomplished the filtering process to identify one or more specific threats – what may be "wrong" – the emerging risk(s) - we need to track and **prioritize** so that we can deal effectively with multiple threats, some of which may pose much greater risk than others.. Again, for those of you not familiar with radar, think about managing air defense in World War II, or using an air traffic control system to assure that civilian aircraft are adequately spaced so as to avoid mid-air collisions. A great many signals may need to be tracked, and we need to select the information that is critical for managing risks in a timely and effective manner.

A corporation that is assessing and managing risk needs to have an early warning system for emerging risks. This system is a means of acquiring and processing data so as to allow an emerging risk to be detected, and then evaluated through an efficient and low cost filtering process, so that information overload is avoided and only the potentially important risk issues appear as "blips." The system should allow these blips to be tracked over time, so as to guide the process of countermeasures to reduce or eliminate the risk.

To relate this section to the PG&E case study, suppose there were a data base on a computer with all the segments of natural gas pipelines linking the gas supply sources to the distribution points where gas goes out in smaller pipes to end-use residential, commercial, and industrial consumers. We can imagine a large network. Information on age, construction, and recent inspection results might be readily available by clicking on a link in the network. A telephone alert from a person who "smells gas" could be checked against the proximity of the caller to a gas line. A deviation in pressure above the allowable standard might be shown via a bright red light - plus identifying the link with the deviation for further information gathering. A sudden large decrease in gas pressure might indicate a pipe rupture – an extreme emergency situation that should immediately be communicated to fire and police authorities.

It would appear from the newspaper reports that PG&E had a system like this, but it did not work effectively. It took more than an hour after the explosion and start of the intense fire for the firefighters to learn that the source was a gas pipe rupture, and not the crash of a plane heavily loaded with fuel that had just taken off from the nearby San Francisco Airport. Gas continued to flow through the pipeline, feeding the fire with such intensity that firefighters could not get near enough to determine the cause.

Let's compare the PG&E example to a very well-known accident in U.S. history, the loss of cooling accident at the Three Mile Island nuclear power plant in March, 1979. This unexpected accident showed that a new technology claimed to be safe by the reactor manufacturers, the electric utility industry, and agencies of the U.S. Government presented a serious emerging risk. A Presidential Commission chaired by Dartmouth College President, mathematician John G. Kemeny investigated this accident and produced a thoughtful report [23] noting the importance of the ecosystem relationship between the regulator, the Nuclear Regulatory Commission (NRC), and the electric utilities. The NRC issued a large number of regulations, and the electric utilities with nuclear power plants viewed their responsibility as assuring compliance with NRC regulations, not taking responsibility to the overall assurance of safety. In the words of the Kemeny Commission,

… the fundamental problems are people-related problems and not equipment problems. … There are structural problems in the various organizations, there are deficiencies in various processes, and there is a lack of communication among key individuals and groups.
… wherever we looked, we found problems with the human beings who operate the plant, with the management who run the key organization, and with the agency that is charged with assuring the safety of nuclear power plants.
… what the NRC and the industry have failed to recognize sufficiently is that the human beings who manage and operate the plants are an important safety system.
[23], pages 8, 10
The Kemeny Commission concluded that,

<u>To prevent nuclear accidents as serious as Three Mile Island, fundamental changes will be necessary in the organization, procedures, and practices – and above all - in the attitudes of the Nuclear</u>

Regulatory Commission, and, to the extent that the institutions we investigated are typical, of the nuclear industry.
[23], page 7, first page of Overview, underlining in original.

The nuclear industry, especially the electric utilities with nuclear plants, took these recommendations very seriously, and made safety of nuclear plants a top priority for senior management, and greatly upgraded the training processes for operators and supervisors [24]. U.S. and international experience with the light water variety of nuclear power plants has been without any further major accidents in the two decades since Three Mile Island. (The 1986 Chernobyl accident happened in a graphite reactor, a design discontinued except in the former Soviet Union.)

As another example, one of us has carried out a study on risk of health effects for dietary supplements derived from natural plant materials. These supplements are lightly regulated under U.S. law. The study followed a situation in which a widely-used product that helped achieve weight loss was found to cause fatalities under conditions of heavy exercise and dehydration – such as young athletes trying to achieve a weight limit by running in hot weather and not drinking water before the weigh-in. Given that a very large number of such dietary supplements are being sold in the U.S., how might problems of morbidity and mortality for small subgroups in the population be identified? Our group recommended careful tracking and recording of consumer calls with health complaints [25]. A pattern evident in even a small number of calls might indicate that an adverse reaction to *some* people under *some* conditions might be identified before a large number of incidents occurred. As a similar example, consider the impact of the drug thalidomide, which was not allowed in the United States but caused a large number of birth defects in its use in Europe before authorities recognized the pattern and stopped the use of this drug by pregnant women.

Two Problems: Reaching and Persuading the Leadership – and How the Leadership Can Improve the System for Identifying and Evaluating Emerging Risks

How can organizations be more effective in managing emerging risks? We must consider the problems seen from the bottom up, of communicating up a chain of management that a risk has been identified and needs management attention, and the problem as perceived by senior managers, that the system for identifying emerging risks needs to be more effective. From either side, the issue is one of achieving more effective communication, both in terms of operating processes and of the strategic decisions that are needed to make a significant change in how the organization is managing risk.

We might think about an organization that would like to get from where it is now to where it would like to be. This change may involve the people and their behavior, the processes carried out within various portions of the organization, the organizational structure – including reporting relationships, and finally a "culture" – the traditions, practices, and habits that determine how people react to situations and do their jobs.

What do you change? People? Talented people with the proper background are needed, but such people are usually hard to find, and their prior experience with the organization makes them more valuable than people who come in from outside and must learn about a new organization. Change the organizational structure? This is often tried, but rarely is successful. Reporting relationships change, but old patterns persist. Change the culture? That is hard to accomplish, and even strong financial incentives may not have much of an effect.

An important insight from a corporate leader (Vince Barabba) who became a scholar of the management process is that "If you want to change the culture, start with the processes." [26].
Processes can be identified and altered, and the progress in doing so can the monitored. Design, training, and coaching are needed to determine how a process should be altered. Formal tools and systems for identifying, collecting, and evaluating data can be specified. A variety of mathematical and statistical tools may be used in support of identifying, collecting, and evaluating data. Learning and adaptation are needed so that the process evolves to do its job well. Any organization needs good people – people with good training, who are thinkers, "doers," and willing and able to network with colleagues inside and outside the organization. An organization chart defines reporting relationships , and takes on greater importance in operational situations (including crisis management), whereas strategic decision making sometimes takes place via communication outside usual channels as executives reach out through an organization to collect the information and skills to deal with an unusual situation. All of this takes place within a culture.

Understanding the culture, and how to change it, is an area requiring special emphasis. We turn to this area in the next section.

Chris Argyris: Unilateral Control versus Mutual Learning
Harvard Business School Professor Chris Argyris has spent most of his professional life in the study of organizational culture and management [19], [27], [28]. A main insight from his research is the identification of several different kinds of cultures that develop within organizations, both public and private, although in most of his work the focus has been on private corporations.

Most organizations develop what Argyris calls a Unilateral Control culture. Managers who ascend to senior levels of responsibility remember the habits and practices that may have enabled their ascent up the management ladder. For example, they achieved a good understanding of the portion of the business for which they had responsibility, and they formed strong opinions and acted decisively in difficult situations when others did not. They may not be aware that habits and practices associated with past successes may result in a low tolerance for dissent and new ideas as the organization and its business evolve over time. And lower level personnel in the same organization may be reluctant to confront senior managers who appear unreceptive to their ideas, suggestions, and concerns. From either direction, the lack of effective communication in an ongoing shared process of learning and deciding is "error," in the Agyris terminology. Such error leads into a culture where organizations resist needed change in response to a changing business environment. Leaders become insensitive to their own limitations, and others are not capable of breaking through to overcome these limitations [29].

Argyris describes the desired culture as one of Mutual Learning. The insight developed in his writings is that most organizations gravitate into Unilateral Control culture, despite lots of claims that they are innovative, flexible, and managed by intelligent, well-trained leaders who would not fall into such bad habits and insensitivities. But from the vantage point of the authors, consultants who have experienced organizational defenses against change in a variety of corporate and government organizations, the Argyris insights ring true. A large number of others hold the same viewpoint, that the Argyris insights on organizational defenses are critical for understanding how modern organizations filled with smart and well-trained people can be slow and ineffective in dealing with problems. We are not aware that the Argyris insights are well known in the safety and risk management literature. We do not find the Argyris publications referenced in major surveys such as [1] and [6]. The Argyris insights seem consistent with the contents of such surveys, and with recommendations for improving risk assessment and management. One needs to focus on the processes for data collection, data evaluation (detection, filtration, and prioritization), and for communication and management decision making. When these processes are effective in providing the information needed for good decision making, a strong safety culture develops. And when the processes are inadequate to overcome organizational defenses, the Argyris insights may enable an understanding of why many organizations that have tried hard to do a good job in managing risks failed to make progress toward that goal.

The Mutual Learning Model: What Corporate Leaders Would Like to Think That They Do and That Their Organizations Do, Versus What Actually Happens.

When investigators such as business school professors (Professor Argyris and his many colleagues) have asked people in a corporate setting how people in that organization should think and behave, they usually are offered a Mutual Learning model:

Aims:

- Valid information,
- Informed choices, and
- A shared internal commitment to effective implementation.

Assumptions on the behavior of oneself and others are:

- People should humbly admit that "I might be part of the problem;"

- Others' logic may be better than their own, and
- Errors are puzzles to be understood and corrected.

The action repertoire is to:
- State the thinking behind your view
- Seek and offer illustrations
- Inquire into others' views
- Make dilemmas discussable
- Explore mutual responsibility, and
- Design ways to test differences.

(Adapted from [28])

The same business school professors have then gathered the data on how people actually behave in their corporate activities. While these people talk a Mutual Learning game, but what is usually observed in their actions and interactions with others is a natural behavior developed through their past experience - what Argyris terms, "Unilateral Control.":

Aims:
- Unilateral control, not weakness
- Win, don't lose
- Be rational
- Avoid upset

Assumptions of the behavior of oneself and others are:
- I am acting sensibly.
- Those who differ are wrong
- Mistakes are crimes or sins.

The action repertoire is to:
- Assert own view
- Take own reasoning for granted as correct
- Minimize inquiry into others' views
- Ask leading questions
- Promote face-saving. (Adapted from [28])

Until an organization learns to recognize and overcome such "unilateral control" behavior, we should not expect good risk management. We can expect that those who try to bring in new data and new ideas are going to encounter strong opposition and not succeed in overcoming it. Many organizations, many leaders, and much popular culture note the problem of bosses and subordinates where effective communication does not occur, either because the boss is not receptive, or the subordinates dare not tell the boss. People engage in cover-ups, promote their own agendas, or those of their portion of the corporation (a division, or a functional area such as marketing, product development, or production), and they do not share what they know with others in other portions of the corporation. Those who bring unwelcome news can be sanctioned for it instead of thanked. Even a few messengers being shot, or shot at, will persuade nearly everyone not to become a messenger.

Finding a way to cure such embedded behaviors is not easy. Consultants who work for short periods of time in many organizations learn to assess the extent to which the problems are mild versus serious. Some honest reflection on our behaviors in personal, as well as business, relationships may persuade even wise and experienced consultants that we also often fall into the same patterns, of actually behaving in unilateral control mode while asserting that we are enlightened practitioners of mutual learning. An excellent test is whether needed data are being collected and used. A classic example for many men is whether they are willing to stop to look at a map, or to ask directions, when driving to an unfamiliar address. Are they open to collecting the needed data? Ask the wife or other family members.

A Third Culture or Model

We might add a third model or culture to these two from Argyris' writings. This third is the involvement of interested parties, or stakeholders, in the decision process. We are aware of a large literature in this area and have contributed to it ourselves [4], [30]. In a public policy context in democratic society, experience indicates it can be a bad idea not to involve stakeholders early in the decision process. To some extent the same idea holds in a corporate setting. It is usually good practice to involve customers and suppliers in a decision that will affect them, rather than deal with possibly adverse reactions from them after the decision is made. But decision-making by consensus in a group can be a slow and inefficient process, especially if some parties have an interest that is served by failure to reach agreement. Summaries, such as [4] and [30], stress that organizations are often charged by law, and individuals within an organizational hierarchy, with decision responsibility. While they may choose to consult with others, the responsibility remains with them and is not shared. A classic example is the captain of a ship, who gives the orders and is held responsible for what happens to the ship, the crew, and the cargo. Good decision making practice on risk management is to have clarity on who is responsible, and who has authority to allocate resources on behalf of the organization to assess and manage risks. (Such responsibility and authority should coincide.) Consultation with others to gather and evaluate data is generally good practice. But diffusion of responsibility through consultation may be detrimental. Responsibility for risk management should be clear and agreed upon, either through existing institutions or thorough compacts and agreements among the affected parties. Where such responsibility appears clear but is in actuality not clear, this situation should be recognized as a risk governance problem deserving attention. In our judgment, such problems occur more frequently in the public sector than in private corporations, where responsibilities should be clarified through laws, regulations, and contracts established among the parties, including the insurance providers. A main function of the legal system is to clarify responsibility for actions that lead to adverse consequences to others.

The Challenge: Improving Assessment and Management of Emerging Risks.

Guidance: Move toward Mutual Learning, Focus on Improving Processes.

Consider the opportunities for an organizational leader who has concluded that risk assessment and risk management need to be improved, especially in dealing with emerging risks. A leader has four areas in which to manage change – through people, through restructuring the organization, by changing processes, and by changing culture. As previously stated with the quotation from former corporate leader Vince Barabba [26], changing culture is very difficult. The best opportunity to improve the culture is by revising what is done at the process level. How does the early warning system work? Start the examination of this system with the processes for collecting and evaluating the data (detection and filtering) and using the resulting information to prioritize and manage risks. Is the important information reaching the points where it enables effective decision making? If not, how do we fix this deficiency?

It may also be useful to examine incentives and realign incentives if those for key individuals are not consistent with the goals of the organization [18]. It is our opinion that incentives may be more important in strategic decision making, but that assessment of emerging risks is more of an operations activity – with the added difficulty that large risks may emerge infrequently. We need people who will work hard at being prepared, so as to keep vigilant and effective in processing lots of information as an ongoing activity, in order to detect a risk when it occurs. Professional pride, and a sense of entitlement to ask hard questions that comes from being part of an elite team, may be more important than monetary reward. The high monetary rewards in the financial industry do not seem to have done much to encourage more careful risk assessment and management.

Ideally, processes should move people into the mutual learning model and keep them there. Experts can provide the people engaged in the processes with technical tools and train them in how to use such tools effectively. Accomplishing the revision in processes leading to an improved safety culture for assessing and managing risk is not a simple and straightforward task, but rather a situation requiring skills, experience, patience, and leadership. Essentially, one needs a good “coach.”

During the period leading up to the Peloponnesian War, Greek city states requested military assistance from Sparta, a leading city state that had provided the leadership that defeated the invading Persians. Sparta responded not by sending an army or weapons, but by sending one highly skilled and experienced person – a “coach.” [31].

A coach (perhaps a group, and not an individual) might set forth a prescription for how processes should be changed in order to become more effective. Technical tools for detection, filtering, and prioritization can be assembled, and the people engaged in risk assessment and risk management trained in the use of these tools. With time and experience, improvements are made in the processes, tools, and training. Many public safety and military organizations follow this format of developing, systematizing, and evolving processes and training, so that their people can carry out the tasks of diagnosing and responding to dangerous situations (fires, accidents at sea, criminal behavior, military preparedness and combat). The desired result is that the people involved know their procedures, have trained with and learned to depend on their colleagues, and are able to recognize specific situations and deal with them with appropriate actions. These same ideas hold for athletic teams and other endeavors where a high level of proficiency, training, and discipline are required – for example, a musical organization such as a symphony orchestra.

Often decision making is best accomplished at lower levels in the hierarchy that have immediate access to the best information, especially in a fast-moving situation. The medical staff in a mass casualty disaster, or on a battlefield, diagnose individual cases and practice triage – separating out those cases where immediate medical intervention can save lives, versus cases that are judged beyond help, and those that can wait until the more critical cases have been treated. Such situations need excellent teamwork in the mutual learning mode – accurate and timely transfer of needed information, clear understanding of goals, innovative improvising when needed to go beyond preset patterns in training (the "playbook"), and high commitment of the people to work toward overall team effectiveness rather than individual accomplishment. A successful athletic team is often the reflection of the work of the coach in assembling players with modest talent that work together effectively as a team. Conversely, a team with a few star athletes but without good teamwork may not be successful.

Box: **Organizational Structure and Technical Support Tools for Risk Assessment and Risk Management: Aids to Analyze and Communicate about Risk**

A. Leadership and responsibility for risk assessment and risk management on emerging risks needs to be established as a goal and an activity for the organization. There needs to be a leader/ manager, and in the event of a fast-evolving disaster, we might use the term, "commander." Military and public safety organizations use such a structure. Corporations sometimes have committees or task forces. Our perception is that this leadership position should be clearly established with appropriate authority and responsibility by the top management of the organization. Conversely -- if many people in corporate management are responsible for emerging risks, the press of other responsibilities for these managers may result in a situation where in practice, no one is responsible, and the activity is not well organized and managed. Senior management may then get involved only when a crisis has already occurred.

B. The leadership should have a location and times for meeting regularly to review information and activities. In an important and fast moving disaster situation, management may need a command center or "War Room" - with appropriate technical aids for summarizing information. Initially an emerging risk leadership center should focus on problem framing and threat assessment: What should we be worrying about, and what should we be doing about these sources of worry? The initial

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output should be a hierarchy of potential concerns, resource allocation decisions, and response plans for dealing with concerns, and evolution from concerns into risks that are described in terms of likelihood of occurrence and magnitude of consequences. An overall evolving status summary is needed. That summary might be in a form ranging from a simple spreadsheet to the output of an elaborate computer-based information and control system. Such elaborate systems are appropriate for assessing and managing risks for complex physical systems where events leading to disaster can happen quickly, as in a gas pipeline network, an oil refinery, or an offshore deep drilling rig.

In the context of an athletic competition, one might think of the summary as the scoreboard, the clock, a list of who the players are on both teams, extent of penalties for rule infractions based on previous game history, etc. The organization's leadership needs this display of the "big picture" – the important information on status that can be modified as an emerging risk situation is identified, as more information is collected and evaluated, and as decision alternatives are selected and implemented for risk management.

For the PG&E example:

a. PG&E: Map of the pipeline system, flow of gas and status of valves, indicators of upset conditions such as overpressure and under-pressure in pipes, list of maintenance activities, construction activities that might impact pipelines, etc. Management should have the capability to move into disaster management should a pipeline rupture or other serious network failure occur.

b. For fire and other public safety authorities: location of fire, location of fire fighting resources and people and structures threatened by the fire, and a management plan for evacuation and exclusion of people from the threatened area. The fire agencies have lots of experience fighting fires, but the San Bruno fire was more intense and persistent than any in recent history for the fire fighting organizations involved.

The PG&E San Bruno fire and many other disaster situations (the BP oil spill, Hurricane Katrina, etc.) suffered from delay because information needed for decisions was not in a central place, and who was in charge was not clearly established until the emergency happened and its impacts were unfolding. Military, public safety, and other organization facing ongoing risk situations usually have a command center established, or have provisions in place to set one up quickly.

For situations where there is no immediate emergency being managed, but ongoing surveillance, the command center might be a monthly or weekly meeting to review information and status of risk assessment and management activities, to assure that team resources are properly deployed, and that any important emerging information is being acted upon in timely fashion.

C. The leadership authority needs the ability to assess what is happening and forecast what may happen as the risk situation evolves: a projection of the state of the system involved with the risk. Data bases, maps, diagrams, and models showing the state of system and its future trajectory are needed. Model outputs will be based on inputs – information on the system environment and the state of system components. Simulation of the system, especially inference about the impact of past events and projections of how the system will evolve are important capabilities to be developed through investments in models, tools and staff training. The risk team needs to capture and use the available knowledge about the complexities and the dynamics of the system.

In an athletic competition, such assessment might occur through data collection and meetings of team members, coaches, and scouts, to share and summarize what is known about the strengths and weaknesses of the opposing team, as the basis for developing a game plan. In a corporate situation, a top manager has meetings with subordinates and sources of information to discuss what is going on and what the corporation should do. Models at some level from very simple to highly complex are almost always useful as a way of summarizing information, from simple summaries of cost accounting to complex models of wide ranging corporate operations and physical and biological systems – for example, how an epidemic might spread through a population or how an ecosystem might be adversely affected by human activities.

In the case of a physical system such as PG&E's natural gas pipeline system, important information might come from maps and models of gas flows and quantities, points of control such as valves, plus records of inspection and maintenance by location, and location of any sensor information – aerial laser surveys, dead vegetation, or calls from citizens complaining that they "smell gas."

The analysis and communication process should enable information from diverse and widely distributed sources to be assembled, evaluated, and made available to the responsible authority in the command center. While modern information processing and analysis tools do not change the essence of the process, they do provide means for transmitting and processing large amounts of information very quickly. Consider the analogy of radar again, with many radar installations and many airplanes whose positions should be tracked. Going from a single radar installation to a continental air defense system is not a matter of adding new concepts, but rather implementing the same concepts on a greatly expanded scale. Assessing and managing emerging risks needs to be able to go from initial signal detection through evaluation into risk management. Doing these tasks quickly and effectively usually requires setting up the processes and training the team in advance. Ongoing training and practice dealing with simulated emergency situations ("emerging risks") may be appropriate to keep the team at high efficiency.

D: The display of information, especially visual display, may be extremely important in enabling effective understanding and communication. The case study on the display of information for the

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decision making preceding the space shuttle Challenger disaster [19,20] is an excellent example illustrating how the display of the available data affected the decision process, where some of the brightest engineering talent in NASA failed to understand the significance of the available data on o-ring performance at low temperatures, and , as a result, a spacecraft exploded with the loss of its astronaut crew. PG&E staff at the control room apparently did not notice and then act on the gas overpressure in the line that preceded the rupture, or the drop in pressure after the rupture. When something important goes wrong, management would like the equivalent of a bright red warning light and an alarm bell. But too many red lights and alarms going off may simply confuse the operators, as happened in the Three Mile Island nuclear reactor accident [23]. Finding adequate ways to convey an effective warning is a very important part of the risk assessment and management process.

E. Methods for statistical analysis of data, inference, and probabilistic reasoning can support forecasts on outcomes with alternative management actions. Engineering, management science, and systems analysis have developed technical tools that can detect signals in the presence of background noise, evaluate complex patterns of signal in a complex dynamic environment, and carry out analysis in support of decisions among risk management alternatives. Versions of these tools can be developed to aid in fast-moving emergencies. The authors have lots of experience with such tools, and they, and many others like them, in professions such as risk analysis and safety engineering, can help organizations find appropriate analytical tools for detection, filtering, prioritization, and decision analytic support. Professional societies can be focal points for identifying and disseminating best practices, but organizations with a focus on risk governance, such as IRGC, might be a vehicle for more rapid and effective collection and dissemination of best practices for improving risk governance in specific emerging risk situations.

Discussion of specific technical tools is outside the scope of this background paper. We are rather focusing on describing the concepts and the setting in which such tools are needed. The scale and sophistication of the tools should fit the magnitude of the emerging risks. But the following broad categories are clearly important.

F. Sensitivity analysis: “What if” questions should be asked, and answers received to probe and gain insight from activities C and E. Careful questioning and examination of uncertainties, and taking advantage of opportunities for gathering additional information, can greatly improve the basis for decisions once an emerging risk is identified as deserving serious concern and analysis.

G. Expert judgment may be needed, from specialized experts on components or inputs affecting the system, and perhaps on the overall system, since available data may be insufficient as the basis for decision.

Sometimes decisions must be made quickly with the available information. Firefighters fought the San Bruno fire for more than an hour thinking they were dealing with a downed airplane and burning aviation fuel. Perhaps someone from the fire agencies should have immediately called PG&E to ask about a possible gas pipeline rupture. That information came only later. Meanwhile, the fire fighters on the scene were fully occupied working to find and rescue people and to slow the spread of the fire.

When the time is available to do so, information from those most familiar with the system or the component can be collected by querying these knowledgeable people. Scientists and data bases are not the only sources of good information. Military organizations and corporations often learn that the best information is from the people "in the trenches" and not the executive offices or the research community. (See [4] for examples and further discussion.)

G. Pattern recognition and updating of models, parameters, and even the problem framing are potentially very important. Bayesian analysis concepts and procedures may be especially valuable here. People are still far superior in performance to computer programs for pattern recognition tasks such as recognizing faces, recognizing a dangerous health condition (e.g., that the mole on the patient's skin could be a melanoma skin cancer), or recognizing that the $100 bill may be cleverly produced counterfeit money. Statistical analysis can be very powerful, but of little help, or even badly misleading, if the wrong assumptions are used [32].

The "Coach" Proposal

The authors have considered a number of ideas for guidance on improving the way an organization assesses and manages emerging risks. We think the best alternative we can suggest to a corporation that wishes guidance on how to do this is to obtain a good "coach," and have this coach provide the detailed guidance. We see the coach as needing both experience in how to overcome organizational defenses (especially when such defenses are substantial) and needing to know the skills for detection, filtering, prioritization, and analysis in support of risk management decision making. The coach needs to understand the communication process on risk as it will occur within the corporation.

The coach need not be a line manager. The coach could be an advisor. Leadership is needed, but the coach may act in support of the leadership, and not be the leader himself or herself. The coach does need to be respected and trusted by the team, the staff of people who will do the assessment and management of emerging risks. Time will be needed to develop this relationship. We can envision that the coach might be a group of people, perhaps an advisory board.

The coach needs to have skills in recognizing new patterns, and the ability to impart and nourish such skills in the team. Technical skills in statistical analysis, Bayesian probabilistic inference, and decision analysis are potentially useful, but not essential. Some great coaches in the corporate world, and more visibly in the world of athletic competition, have succeeded brilliantly in team-building and in the ability to read the situation without such technical skills. Good common sense often does quite well without the formal mathematical analysis. But common sense is often uncommon. The virtue of the formal mathematical and statistical techniques is that they can be brought to bear individually and collectively by people of modest intellectual capacity (i.e., not “geniuses”) , so as to illuminate a highly complex task by breaking it into pieces and then assembling the pieces. The coach needs to know and be able to explain the basic concepts. Detailed knowledge of the mathematical techniques can be an important asset, but such knowledge can be obtained from specialists. We expect that that mathematical and statistical tools will be increasingly used. They are incorporated into software that is or will become established practice in many corporations with the passage of time, with the enormous processing power now available from computers. Organizations that learn such methods will have a powerful advantage over their competitors.

Perhaps the most important role of the coach is one of training and discipline in carrying out the processes, and in setting an example of *forthright skeptical inquiry* on risk issues. A good coach will not be deterred by assurances that a risk is vanishingly small. The coach will want examination of the underlying evidence supporting the assertion, and the coach needs to train others to look beyond the assertion (or assumption) of safety -- to the underlying evidence. The coach’s task is to train the team to look for signals (blips on the radar screen) that could indicate an emerging risk, evaluate these signals though a careful evaluation process, and, if the evaluation so indicates, communicate with and educate the management on the risk that has emerged.

Revolutions have occurred in management when it has been demonstrated that new methods will give improved performance compared to traditional practices. The work of W. Edwards Deming on quality improvement, in Japan, and then in the United States, is an example of such transformation [33]. We see it as an example with much to offer for what we are discussing for emerging risk. Quality improvement following the Deming ideas and methods occurred through process changes, which took place first in Japan, over a time of about four years, and then were widely adopted in the United States in areas such as the auto industry, when it became apparent that Japanese performance on quality had become much better than what was being achieved by U.S. firms. A key quote from Deming is the following: “If things are not working, don’t blame the people, blame the process.”

As a topic for discussion at the Rüschlikon Workshop, we might consider how introducing a coach for emerging risk at PG&E might, and might not, have helped avoid or mitigate the disaster that occurred in San Bruno. Part of the consideration is how PG&E might have reached out to other organizations within the “ecosystem,” based on what was known before the disaster, to improve the ability to detect potential pipe ruptures and to respond quickly and effectively in the event that a rupture occurred.

We might also discuss how one can locate a good coach, and how the skills needed to be a good coach can be acquired and refined. Should IRGC, or some other organization, try to take a leadership role in finding and developing people who can play this role?

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[31]. *Tides of War: A Novel of Alcibiades and the Peloponnesian War*, Bantam, 2001,by Stephen Pressfield, New York, Doubleday, 2000. Spartan warriors were the top level of their society, landholders trained for combat from childhood, whose lands were worked by slaves. These warriors were not educated in the same way as Athenians, who considered them simple and stupid. But they were the best warriors in ancient Greece. Their skills and bravery at Thermopylae enabled the Greeks to defeat the invading Persians (*Gates of Fire*, 1998, another Pressfield book), and they ultimately defeated Athens in the Peloponnesian War.

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[33]. A good summary of Deming's ideas and publications is at: http://en.wikipedia.org/wiki/W_Edwards_Deming. Deming's success as a coach is a model of how management processes can be transformed. His work in Japan came from an invitation from the Japanese Union of Scientists and Engineers (JUSE), while he was in Japan with the US Army during the US occupation after World War II, to assist on a census. The invitation from JUSE was to teach statistics for quality control. Deming's contribution went far beyond teaching statistics; his ideas had enormous impact with top management of leading Japanese companies as Japan restored itself as a major industrial power. Deming's ideas have subsequently spread around the world.