On the Edge: Heeding the Warnings of Unusual Events

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This paper's unique contribution lies in its integration of organizational learning concepts and the resource-based view of the firm. Through extensive analysis of two nuclear power facilities over several years, the authors discovered that the allocation and distribution of attention, knowledge, and resources influenced the recognition and interpretation of potential problems. They demonstrate that organizations are complex systems that can drift toward disaster unless they maintain a distribution of resources that enables them to learn from unusual events in their routine functioning.

Theresa Lant

Abstract

When organizations pay inadequate attention to unusual events, the possibility of breaching a safety barrier increases. With hindsight it often appears that full advantage is not taken of what is known. Part of the reason organizations neglect apparent warnings is because of limited resources and the way resources are allocated. Drawing on concepts from the resource-based view (RBV) of the firm, this paper examines situations where resource availability and use can compromise safety by initiating drift. Empirical evidence from the nuclear power industry is reviewed to demonstrate the relationship between resources, resource deployment, and drift. Drift is influenced by error signals, feedback loops, and imperfect watchfulness. Resource availability and use can initiate drift, but they do not necessarily yield catastrophe. Should organizations fall into a threatened position, they can enlist characteristics, behaviors, and capabilities to stabilize the situation, avoid breaching the safety border, and achieve greater security. Through an in-depth study of two plants with contrasting reputations for safety, this paper identifies the characteristics, behaviors, and capabilities that organizations on the edge exhibit. The characteristics, behaviors, and capabilities of the plant with the stronger safety reputation changed after a significant reduction of resources. Resource reduction led to movement toward the safety border, which in turn led to change. Evidence shows that organizations operating closer to the border of safety respond to warnings from unusual events in a resilient rather than anticipatory way. To overcome unexpected problems and limitations, they rely on after-the-fact intervention rather than preparation, foresight, and the provision of countermeasures. Once they recognize they have problems, they explore for novel approaches, typically seeking new knowledge and skills by dismissing old staff and hiring new people, buying advice from outside experts or consultants, and modeling, benchmarking, and copying other organizations' best practices. Organizations on the edge initiate change in response to external demands for change often only after painful public incidents. These organizations emphasize hierarchy and powerful headquarters staff, and their leaders tend to act as commanders and controllers rather than as catalysts and facilitators. The focus of this paper is not on the occurrence of accidents per se, nor on highly reliable operations, but on the precursors and consequences of drift within a safety border. Operating on the edge of the border extends beyond safety to other performance measures and beyond nuclear power to other industries. In settings as diverse as U.S. banks, hospitals, and universities, Israeli kibbutzim, Japanese kereitsu, and Korean chaebol, operating on the edge has become more common.

(*Safety*; *Resource-Based View*; *Regulation*; *Warnings*; *Organizational Learning and Drift*)

Evidence from a wide variety of studies (Subcommittee on Nuclear Regulation 1980, Shrivastava 1987, Starbuck and Milliken 1988, Rosenthal et al. 1989, Vaughan 1990, Westrum 1991, Buchholz 1992) supports the view that many accidents could have been avoided had warnings been heeded (See Table 1). Lawyers for the victims invariably find a "smoking gun" of warnings that were not fully acknowledged (Brodeur 1985). Retrospectively, it

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Table 5 Patterns in Past Accidents

Accident	Warnings	Knowledge Not Used	Declining Resources	Way That Resources Are Used
Three Mile Island (TMI)	Exact replica of events in plants in Ohio and Switzerland.	Lessons not learned by plant operators.	Poor utility earnings as a result of rising costs and inadequate rate relief.	Austerity program, layoffs, early retirements, and reduced construction expenditures.
Bhopal	Investigative journalist warning, prior leak, and evacuation.	Internal examination finds 50 defects, all labeled "minor."	Plant lost money 3 years in a row; stiff competition from less expensive products.	Workers laid off, maintenance deferred, and training reduced.
Challenger	Engineer responsible for O-Ring warned of seal problems that could cause "catastrophe."	On day of launch warned against proceeding, but management insisted.	Major cuts by NASA in safety spending.	Quality control personnel cut at Marshall Space Center from 615 to 88.
Exxon Valdez	Captain Hazlewood was a known alcoholic with continuous violations and a revoked driving license.	Hazlewood allowed to captain the boat.	Budgetary pressures.	Jobs of 9 top safety officials eliminated; radar coverage reduced.

is easy to say that inadequate attention was given to what was known; however, day-to-day, people have to contend with enormous amounts of information, and it is difficult for them to sort the true signals from the noise (Kiesler and Sproull 1982). Organizations have goals in addition to safety (Marcus 1995), and though the conditions that they may be trying to avoid are obvious ones (a nuclear power plant meltdown or a chemical plant explosion), the preconditions that lead to these states seldom are as clear. Their rules for safety cover known dangers that encapsulate theory and the lessons of the past. However, the theory in use is often incomplete, and the future does not perfectly replicate the past, thus making it difficult to accurately perceive problems and take appropriate action (see Carroll 1995).

Resources and the Border of Safety

Keeping an organization firmly in a zone of safety requires the recognition of problems, and heeding a warning requires having the resources to respond. Resource constraints and the way resources are allocated affect how organizations perceive, interpret, and deal with problems by using the knowledge they have. In comparison to operator error and mechanical difficulties, resource availability and use are further back in the chain of causation. They tend to be discounted or underemphasized in scholarly studies, popular accounts, and formal investigations of accidents (Reason 1990). The typical analysis focuses on human and other performance lapses, while resource availability and use, which are more deeply embedded in the system, receive less attention.

Even if ample resources exist, it does not necessarily mean that they will be applied appropriately. Both resource availability and resource use are important (Marcus et al. 1993). For example, Rose's analysis of airline safety (1989, 1990) found that lower profitability was related to higher accident and incident rates. This analysis was limited because she accounted only for resource availability, and not for resource use. She assumed that more profitable carriers chose to allocate resources for equipment, operations, and maintenance, while less profitable carriers cut corners and did not make these allocations. However, she did not have direct evidence to support this contention. For accidents to be avoided, resources not only have to exist. They have to be used appropriately.

A Resource-Based View of the Firm

The resource-based view (RBV) of the firm thus appears to have much relevance (c.f. Penrose 1968, Rubin 1973, Lenz 1980, Winter 1987, Itami and Roehl 1987, Ulrich and Lake 1990, Reed and DeFiliippi 1990, Hall 1992, Amit and Schoemaker 1993, and Hamel and Prahalad 1994). It can be helpful because its emphasis is not on the mere existence of resources, but on their combination and transformation in ways that allow organizations to accomplish worthy ends (Penrose 1968). According to RBV, organizations have *tangible resources* that are found in financial and accounting statements (Russo and Fouts 1997, Grant 1991) and are protected by legal rights

(Hall 1992, 1993). They also have other unique *intangible attributes,* the results of their specialized experience in combining and using resources whose value is not easily assessed (Rubin 1973, Barney 1991, Barney 1997). These skills, aptitudes, and capacities for deploying and combining resources to achieve desired ends are the hard-to-imitate characteristics and behaviors that make resources worthwhile. As Amit and Schoemaker (1993) argue, the ability to combine tangible resources in unique ways makes the factors organizations own and control valuable. Some organizations are able to take the exact same group of resources and combine them in a different way for better results (Mahoney and Pandian 1992). Applying these concepts to safety, Perin (1995) identifies policies, feedback, training, experience, rewards, trust, respect, and communication as safety-related attributes that make the use of resources worthwhile.

Clearly, resources and how organizations deploy them are important, but they are not the sole determinants of safety. Most organizations in hazardous industries rely on a technical principle that in redundancy there is reliability (Sagan 1993). They have numerous backup systems. Their ability to recover if they fall into a threatened position is influenced heavily by the extent to which these backup systems are functioning. However, at any point in time it is known that some of these systems are not working (Marcus 1995). The recovery zone at Bhopal, for example, was excessively thin because at least seven backup systems were not in operation, including a safety valve, the refrigeration system, vent pipe, vent gas scrubber, flare tower, relief valve, and alarms and gauges in the control room (Marcus 1996). Resource availability and use do not inevitably yield loss of life or serious property damage, but they can narrow the margin of safety and breed situations such as those that prevailed prior to the Bhopal accident. However, these situations do not necessarily mean that there will be serious accidents. If warning systems are in place and people in organizations recognize that they are operating close to the edge, they can stabilize the situations, turn them around, and recover. Depending on the characteristics, behaviors, and capabilities these organizations exhibit, they can move from a precarious position to one of greater security. This paper is devoted to achieving a better understanding of the characteristics, behaviors, and capabilities that permit organizations to make this type of adjustment.

The Border of Safety

Organizations operate in a broad spectrum of acceptable performance that includes many factors. The problems they face typically arise from the fact that they must respond to contrasting requirements, for example the need to be safe as represented by regulators and the need to make money as represented by shareholders. A safety border may be seen as a set of boundary conditions around economics, work effort, and safety, which organizations are drawn to overstepping by a desire to optimize on the other dimensions (Rasmussen 1988). The feedback they receive as they approach the safety border may be weaker and more ambiguous than the feedback they receive when they approach the other boundaries, such as economics. The idea of a safety border is as evocative and metaphoric as it is literal. When such a border is approached, indicators give warning. These indicators cannot be treated mechanically, however. There is no single measure of proximity that increases in magnitude as the border is approached but rather multiple measures that have varying degrees of clarity, authority, and validity. Correction depends on the magnitude of signals organizations receive from diverse sources, the sensitivity they have in detecting contradictory and conflicting warnings, and the width of the recovery zone. This zone may be a function of the degree to which an organization's backup systems are, or are not, working. What happens depends on the characteristics and behaviors organizations display and the capabilities they enlist. Our interest is in the effects resources have on drift toward the border and on the characteristics, behaviors, and capabilities that organizations exhibit to preclude disaster.

In prior analyses (Sagan 1993), some argued that the interesting question was why accidents were normal, indeed inevitable, despite heroic human efforts to prevent them. Others maintained that the interesting question was why hazardous systems were so reliable, functioned so well, and made so few errors. The former group, not surprisingly, was pessimistic about learning from unusual events. For example, Perrow (1984, p. 12) writes: "In the past, designers could learn from the collapse of a medieval cathedral under construction, or the explosion of boilers or steamboats, or the collision of railroad trains on a single track. But we seem to be unable to learn from chemical plant explosions or nuclear power accidents." The latter group, in contrast, was sanguine, holding that people who managed hazardous systems could overcome interpretation problems by envisioning design flaws and operator errors and effectively adjusting procedures and routines over time in a trial-and-error fashion (Wildavsky 1988). Nearly all of the prior work consists of analyses of highly charged accidents (Three Mile Island, Bhopai, etc.), where loss of property and/or human life has been great (Perrow 1984, Shrivastava 1987), or examples of highly reliable organizations (e.g., aircraft carriers) with long histories of safe operations (Roberts 1990, 1993; LaPorte and Thomas 1990; LaPorte and Consolini 1991).

In contrast, our focus is on organizations that typically, but not always, operate within a safety border.

In the organizations focused on in this study, neither calamity nor successful recovery were guaranteed. Not all approaches to the border of safety have to have catastrophic consequences, as Perrow (1994) himself points out:

> Accidents are inevitable and happen all the time; serious ones are inevitable although infrequent; catastrophes are inevitable but extremely rare. Complex interactions and tight coupling make serious accidents inevitable, a property of the system, but a 'system accident,' the unexpected interaction of multiple failures that can defeat safety systems is still an unusual combination.

Though organizations approach the border of safety with some regularity, their likelihood of crossing it and having a serious accident is much lower. Heinrich (1959), for instance, estimated that in a sample of 5,000 incidents in a manufacturing plant, there was a 300-29-1 ratio: 300 incidents result in no injury, 29 produce minor injuries, and 1 had serious consequences.

Organizations approach the border, but do not always cross over. When they drift toward the border, a number of results are possible (See Figure 1). An initial equilibrium state (denoted by the starting point 1 in the figure) may exist which is far removed from the border. There may be a second point (denoted by 2 in the figure), where the organization begins to drift dangerously toward the border. It may cross over the perimeter and have a catastrophe (denoted by 3a in the figure), but there are ways to recover and rebound. These can lead to a new equilibrium closer to the border (denoted by 3b in the figure), to a point about equivalent to the starting position in its distance from the border (denoted by 3c in the figure), or to a point even further from the border and safer than when the organization started (denoted by 3d in the figure).

Based on organizations' ability to detect and act upon signals that have varying clarity, authority, and validity, they can come precariously close to the edge but regain their balance. As Sitkin and Pablo (1992) suggest, the outcome of this movement is neither inevitable disaster (based on a threat-rigidity cycle; see Staw et al. 1981), nor an ability to achieve an equal or better position. Organizations can heed warnings and prevent catastrophe but end up in a worse position than when they started. Sometimes the result is full recovery. Sometimes it is not. In the best of all possible worlds, organizations can return to a better end state. However, this best of all possible worlds is not guaranteed. Warnings can be heeded, disaster averted, and the organization can still find itself inside the border of safety but closer to the edge (point 3b).

Prior analyses have been confirmatory in nature (Sagan 1993). Scholars who believed in inevitable accidents concentrated on accidents, while scholars who believed in highly reliable organizations concentrated on that type of organization. Empirical evidence about a broad group of nuclear power facilities, however, has been accumulating (see Marcus et al., 1990, Hu 1990, Energy Information Administration 1991, Nichols et. al. 1992, Verma and Marcus 1995), and it has not been reviewed in this light. Moreover, an in-depth study of facilities with contrasting reputations for safety has not been done. In an attempt to overcome these shortcomings and break new ground in the study of safety, we review the empirical evidence and compare facilities with different reputations for safety.

The Effects of Resources: Empirical Studies

Empirical studies of the nuclear power industry (Marcus et. al. 1990, Hu 1990, Energy Information Administration 1991, Nichols et. al. 1992, Verma and Marcus 1995) provide support for the reasoning we have advanced so far. Though these studies are limited by the archival data upon which they rely and the methodologies they employ, they conform in broad terms. To summarize, these studies provide support for the argument that declining and misallocated resources lead to drift and warnings, and in response organizations change. The empirical studies mainly trace the effects of resources. To obtain a deeper understanding of the characteristics, behaviors, and capabilities that organizations close to the edge exhibit, we rely on the comparative case analysis presented later.

Declining Resources, Drift, and Warnings

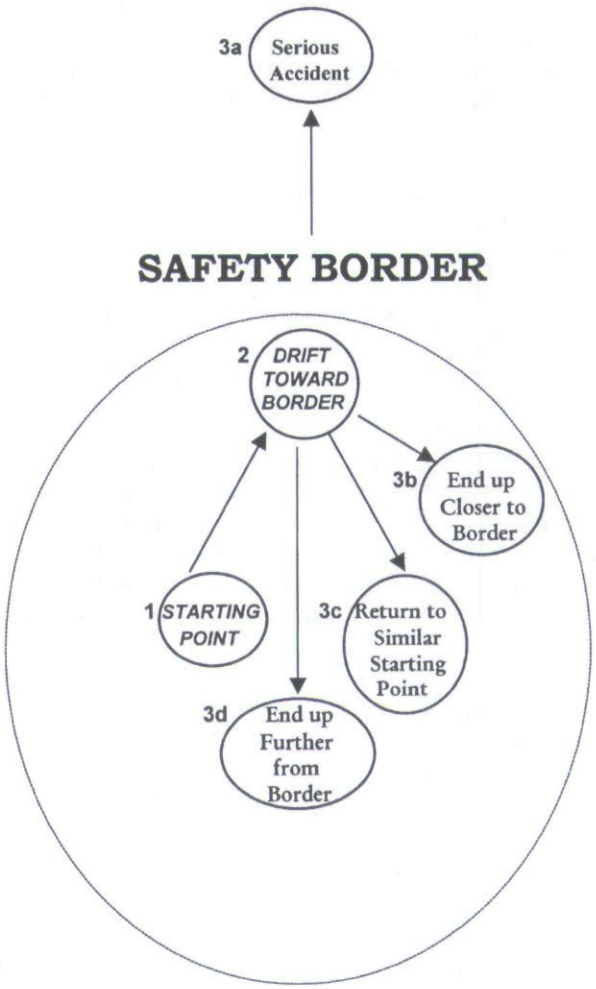
The empirical studies use publicly available data from the Nuclear Regulatory Commission (NRC) and the Department of Energy (DOE).[1] The indicator we chose to follow is significant events (SEs). Obviously there are other indicators of varying degrees of clarity, authority, and validity. The NRC, for example, also collects data on forced automatic shutdowns (so-called scrams), safety system failures, safety system actuations, and radioactive releases. Significant events, however, are the only one of these indicators that is significantly correlated with the others (see Marcus et al. 1990). Defined by the NRC as unexpected plant responses, the degradation of important safety equipment, complicated shutdowns, and unplanned radioactivity releases, SEs are a summary indicator that have both objective (e.g., radioactive releases) and subjective (unexpected plant responses) elements. Because they are an amalgam of other indicators and include both actual plant performance and the professional judgment

of NRC experts, we believe that they are a good way to represent the concept of drift. This choice is also consistent with the literature, where the most commonly used safety indicators are near misses (March et al. 1996). Under slightly different circumstances near misses could become accidents.

The standard economic reasoning advanced by Rose (1989, 1990), Feinstein (1989), and Moses and Savage (1989) is that declining resources lead to drift. According to this reasoning, there is a utilitarian calculus, where safety is desirable but costly, and organizations choose a level of safety by balancing the benefits of safety reduction against the costs of safety improvements. Thus, the level of safety sought is not the highest technically and humanly possible but depends on the resources available. Indeed, Marcus et al. (1990) find that low utility return on assets (ROA) in a prior time period is followed by a higher number of significant events in a subsequent period. The analysis is of 74 plants from 1980–1985. The analysis must be interpreted with some caution, however, because of the large number of variables, a relatively small N, and possible multicolinearity. Low profitability tends to lead to drift, as defined by more SEs. Drift then leads to warnings. The nuclear industry is heavily reined in by the NRC, which regularly inspects and evaluates plants, holds them to a philosophy of defense-in-depth, and forces them to maintain a host of primary, secondary, and tertiary systems to control the reactor and prevent radiation (Wood 1983, Osborn and Jackson 1988). Nichols et al. (1992) find that a higher number of SEs is significantly correlated with more violations.

Our view of the boundaries in which an organization operates includes economics as well as safety (Rasmussen 1988). Low capacity levels have plagued the U.S. nuclear industry, and Nichols et al. (1992) find that higher numbers of major violations are also significantly correlated with less production. Plant managers might dismiss warnings in the form of violations as misguided regulation, but they are less likely to dismiss declining production. Together, the violations and lower capacity levels function as warnings.

Figure 1 **The Drift Toward Accidents**



Organizations Change

In response to these warnings, nuclear power plants change their pattern of spending. They spend more money and spend it in a different way. An Energy Information Agency (1991) study, for instance, suggests that regulatory warnings result in more operations and maintenance (O&M) spending. This is over and above increases that were thrust on the entire industry during that time period. Due to higher levels of regulatory scrutiny, real nuclear power plant O&M spending rapidly escalated from 1974–89. Regulation contributed to more than half the total increase, $32.2 million out of $62 million (Energy Information Agency 1991). In comparison to plants that increased their average 1985–89 O&M spending by 36%, plants on NRC's *"watch list"* (those suspected of having the worst safety problems) increased their average 1985–89 O&M spending by 77%. Nichols et al. (1992) divide plants into three groups: the *worst* 10% (10 plants with a mean of 2.7 SEs per year), a *middle* group (67 plants with a mean of 1.23 SEs per year); and the *best* 10% (14 plants with a mean of 0.23 SEs per year). Average O&M spending for the worst performing group increased more than for the other groups over the time period (see Figure 2). Nichols et al. (1992) also find that with more significant events and violations, spending on maintenance supervision and engineering as opposed to operations supervision and engineering went up.

Operations and maintenance supervisors (nonunion

Figure 2 **Operations and Maintenance Expenditures by Significant Event Group**

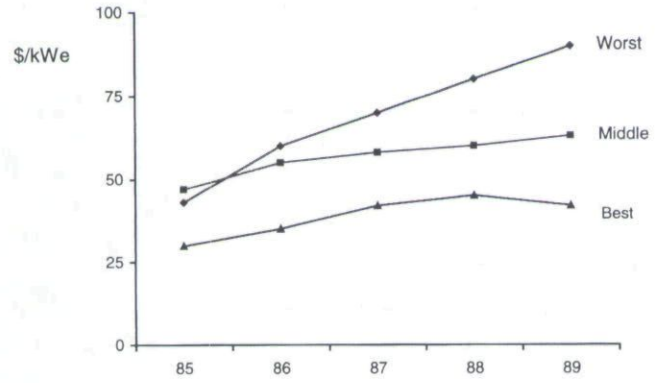
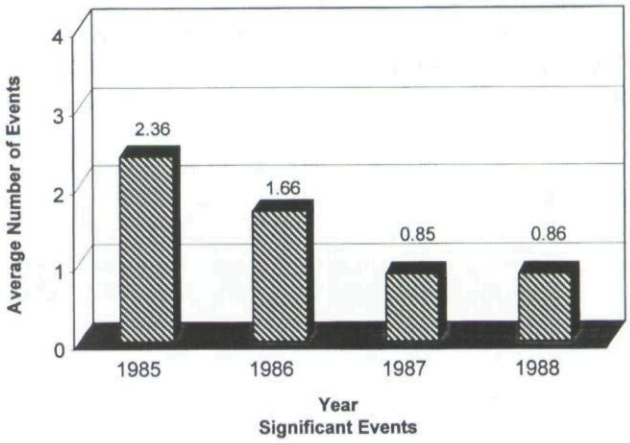


Figure 3 **Safety Improvements in Nuclear Power Plants**



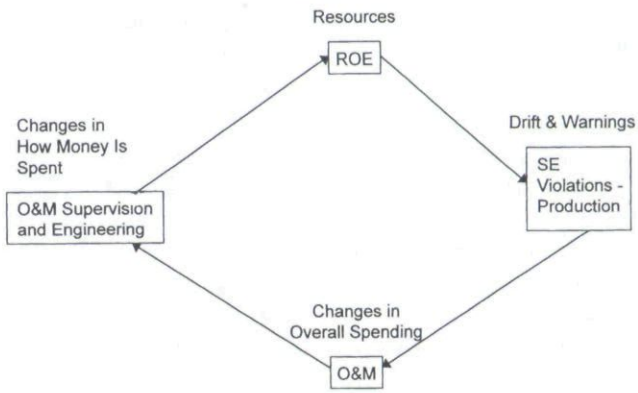
salary employees) and engineers are the main managerial groups in nuclear power plants. Carroll and Cebon (1990) propose that the maintenance group has a more focused, functional view of the plant, while the operations group has a broader view with more overall responsibility and more interfaces with other groups (also see Rochlin and Von Meier 1994). Nichols et al. (1992) create a variable called RSEOP, which is the ratio of operations supervision and engineering spending over total supervision and engineering spending including maintenance. This variable captures the pattern of operations supervision and engineering spending in comparison to maintenance supervision and engineering spending. Nichols et al. (1992) find that RSEOP is significantly and negatively associated with the number of significant events and the number of violations. The analysis utilizes a Poisson regression and controls for utility business strategies, past performance, regulatory and financial variables, type, and plant experience. The analysis must be interpreted with some caution, however, because of the large number of variables in the regression and the low n (58 plants).

There are thus indications that more spending on O&M and more spending on maintenance supervision and engineering, as opposed to operations supervision and engineering, appear to be reactions to drift and warnings. They may also help keep nuclear power plants within safe borders. After the Three Mile Island (TMI) incident there was no major accident in a U.S. nuclear power plant. U.S. plants, in contrast to the Soviet Chernobyl reactor, did not cross the border, go over the edge, or have a catastrophic event. From 1985–88, as O&M spending in the industry grew and resources were reallocated, SE occurrence declined (see Figure 3). Higher O&M expenses, according to Hu (1990), also contributed to an improvement in production, and Verma and Marcus (1995) show greater spending per unit of production contributed to this improvement.

A web of circumstantial evidence, including the finding of a lagged relationship between ROA and SEs, suggests that drift is initiated by fewer resources. Warnings take place in the form of more violations and less production, and in response, nuclear power plants change their level of spending, spending more on O&M than previously. They also change how they spend their resources, spending more on maintenance supervision and engineering, as opposed to operations supervision and engineering. These changes appear to help keep them from breaching the safety border and having a catastrophe.

The chain of causation is hard to unravel however. Self-perpetuating cycles (Marcus 1988b) may exist (see Figure 4). A vicious cycle would involve heavier spending on maintenance supervision and engineering as opposed to operations supervision and engineering, feeding back into the system and correlating with less ROA, more

Figure 4 **Self-Perpetuating Cycles**



SEs, more violations, less production, and more O&M spending. A beneficent cycle would consist of heavier spending on operations supervision and engineering (as opposed to maintenance supervision and engineering), feeding back into the system and correlating with more ROA, fewer SEs, fewer violations, more production, and less O&M spending. The former plants, where maintenance supervision and engineering dominate, may be closer to the edge. The latter ones, where operations supervision and engineering prevail, may be further away.

The characteristics, behaviors, and capabilities of the former plants thus appear to be different than the characteristics, behaviors, and capabilities of the latter plants. On the edge, i.e., plants experiencing more SEs, a more functional and focused view seems to dominate. These characteristics, behaviors, and capabilities may be better suited for skirting the edge without experiencing a breach. Away from the edge, a broader and more integrated approach may rule. These characteristics, behaviors, and capabilities may be helpful to preventing drift, barring a significant decline in resources. They require slack (Sagan 1993), which can be used for purposes other than technical redundancy, such as more staff to support tracking and analysis of problems. This enables organizations to respond to warnings before they occur. In essence, the slack allows the organizations to be more anticipatory. Without it, they have to react to events as they occur and are less able to show foresight and take precautionary measures against likely problems before they arise.

Characteristics, Behaviors, and Capabilities: A Comparison of Two Facilities

The data reviewed in the quantitative analyses, which focus almost exclusively on resources, fail to capture a deep understanding of organizational characteristics, behaviors, and capabilities. To probe more deeply into these phenomena we carried out a qualitative analysis, working inductively from cases (see Miller and Shamsie 1997). The research thus moved from the publicly available statistics to the sense making of the people involved. We scrutinized their socially-constructed shared meanings and their intersubjective world view.

The patterns of meaning found among management teams at two nuclear power facilities were compared. These two facilities were outliers in the industry. One was consistently recognized for its strong safety record. It was one of the only U.S. facilities that industry experts considered "world class" in the 1980s. The other had a record of past problems and was regarded as one of the U.S.'s most troubled facilities. We call the two facilities Medallion Juncture (MJ) and Peninsula Haven (PH), respectively. Fictitious names are used to protect their identities, and some details having no bearing on the phenomena under study are altered to protect the plant's identities. MJ and PH have the same reactor technology and were constructed, licensed, and started to produce power at about the same time. In-depth interviews were conducted at the facilities, cases written, and grounded theory building was used to gain a better understand of the characteristics, behaviors, and capabilities they displayed.

In-Depth Interviews and Cases

In-depth interviews were conducted with 24 people on the management teams at these facilities. The events in the history of the facilities on which we focused were startup, an industrywide accident (Three Mile Island), various mishaps that attracted the attention of the NRC, and central directives to cut costs. The interviews were carried out in 1992 and 1994, and the following people at both sites were interviewed:

- the site vice president or general manager and his staff:
  - safety review assessment engineers
  - quality assurance engineers
  - miscellaneous staff
- the plant manager and his staff:
  - outage and planning managers
  - radiation protection and chemistry managers
  - operations managers
  - maintenance managers
  - systems engineers and technical engineers

We examined how the people at these facilities adapted to the requirements of aging and the periodic discovery of design flaws, when their work deviated from a model of normal operations and was devoted to major installation repairs and upgrades. Business factors like deregulation and privatization and changes in the cost of competing energy production technologies played a role in the facilities' histories. They had to manage the end life of their plants in circumstances of resource scacity, while at the same time they confronted external forces calling for higher margins of safety.

To gain understanding of the facilities' characteristics, behaviors, and capabilities, we relied on the interpretations of the people we interviewed. We searched for consensus views among those interviewed, some of whom had been at the facilities since their inception and some who had not, but who nevertheless had understandings of the facilities' histories and the major events that shaped the direction that the facilities took. We looked for common understandings. A structured, open-ended interview

guide was used, copious notes were taken, and documents were collected and read. We triangulated information from diverse individuals and documents and tried to create a cohesive whole. On this basis, we wrote case studies that rested on broadly shared opinions and versions of events.

After completing the case studies, the main contact and two other knowledgeable persons at the facilities reviewed the cases, and their comments were incorporated into a revised version. A limitation of this approach is that the findings are based on the subjective understandings and perceptions of the participants. Another limitation is that the findings have been organized and assembled by outside researchers who may not have completely understood what they were told and how the various pieces of information that they were given fit together.

Identification of Characteristics, Behaviors, and Capabilities

In accord with grounded theory methodology (Glaser and Strauss 1967), we developed categories from the literature to describe the facilities' characteristics, behaviors, and capabilities. The analytical categories were plausible ones that emerged from the cases and our simultaneous reading of the literature. We tried to establish a baseline group of characteristics, behaviors, and capabilities that best described the two facilities, and then examined how this baseline was altered after a budgetary disturbance, when the resources upon which these two facilities had to rely were substantially reduced. In the period prior to the disturbance, MJ was more securely positioned at a distance from the border, while PH was closer to the edge. MJ's baseline characteristics, behaviors, and capabilities differed from PH's. After the budgetary disturbance, when MJ drifted toward the edge, its characteristics, behaviors, and capabilities started to resemble those of PH. A facility that was once far from the edge started to resemble one which was closer to it.

The categories used to describe the characteristics, behaviors, and capabilities distill the information collected, which is rich in detail, into a few key concepts which form a parsimonious framework to guide the analysis (see Table 2). At MJ, the facility with the better record that was farther from the edge (well inside the border), the primary characteristic, behavior, and capability we found was anticipation. Secondary characteristics, behaviors, and capabilities which supported the primary one were exploitation, retention, internal development, voluntary adoption, and leaders who functioned as catalysts and facilitators. However, these were starting to shift as resources tightened, restrictions were placed on the use of funds, and the facility came closer to the edge. The weaker performing facility, PH, started closer to the edge, and the primary characteristic, behavior, and capability we found was resilience. Secondary characteristics, behaviors, and capabilities which supported the primary one were exploration, turnover, external search, imposed solutions, and leaders who functioned as commanders and controllers. These were only reinforced and bolstered by new restrictions on resource use which made resources less available and kept this facility close to the edge.

We consider these characteristics, behaviors, and capabilities to be the dominant ones at these facilities at the outset, but neither facility was a pure type. Neither could have functioned without some element of the opposing tendencies. In the period prior to the budgetary disturbance, MJ and PH started quite far apart on a continuum, and after the budgetary disturbance they began to converge. This convergence suggests that an organization's characteristics, behaviors, and capabilities adapt to different circumstances, and that the availability of resources affects how near organizations are to the edge and which set of characteristics, behaviors, and capabilities they are likely to exhibit.

The definitions for the categories used to describe characteristics, behaviors, and capabilities, their sources in the literature, and how they fit together are presented next. *Anticipation* refers to the ability of designers to anticipate stresses and foresee likely interactions and provide countermeasures, while *resillence* admits to the possibility of anticipatory failure and stresses on-the-spot, active intervention to overcome design limits (Wildavsky 1988). Anticipation is akin to the broad integrated approach, where foresight is present. Resilience is more like the functional, focused one, which is reactive in nature. To be anticipatory, slack is needed to establish complex, highly differentiated administrative structures for responding early to events. Without this slack, an organization cannot take sufficient countermeasures to deal with problems that are likely to develop.

A number of secondary categories, again with contrasting descriptions, relate to the primary categories. *Exploitation* goes along with anticipation in that it is the rapid refinement of ideas and their early implementation and execution. *Exploration* fits with resilience in that it is a constant search for new ideas through continuous variety, experimentation, and discovery (March 1996). Neither exploitation nor exploration is mutually exclusive. To a degree, in any real and functioning organization, they have to complement each other.

Anticipation fosters greater self-confidence and trust in the members of the organization, which promotes a more

Table 2 Characteristics, Behaviors, and Capabilities: Far from and Close to the Safety Border

Far from the Border	Close to the Border
Primary	*Primary*
Anticipation Preparation, foresight, and provision of countermeasures for likely problems	**Resilience** After-the-fact intervention to overcome unexpected problems and limitations
Secondary	*Secondary*
Exploitation Implementation of actions; execution; refinement of ideas	**Exploration** Problem recognition and search for novel approaches
Retention Stability and continuity of personnel to achieve tacit understanding of operations, preserve memory and instill instinctive reactions to situations	**Turnover** Acquisition of new knowledge and skills by dismissing the old staff, eliminating procedures, and hiring new managers
Internal Development Education of existing personnel; reflection on own experiences in comparison to others	**External Search** Purchasing advice from experts and consultants; modeling and benchmarking other organizations to copy their best practices
Voluntary Adoption The use of self-managed teams to introduce changes	**Imposed Solutions** Demands for change coming from regulators after public failures and known disgraces
Leaders as Catalysts and Facilitators Consensual decision making	**Leaders as Commanders and Controllers** Hierarchy and powerful headquarters staff trying to impose its will

inward-looking orientation. Resilience fosters less self-confidence and trust which promotes a more outward-looking orientation. *Retention* goes along with anticipation in that it assures more stability of personnel. *Turnover* goes along with resilience, as the organization tends to be recreated with new people from the outside (Simon 1996). *Internal development* coincides with anticipation in that knowledge and skills that unfold from training and development focus on the organization's own experience (Ulrich et al. 1994). *External search* fits with resilience in that knowledge and skills tend to be derived from research and investigation, modelling and benchmarking, and purchasing advice from outside consultants and experts.

The anticipatory route is for new ideas and competencies to be *voluntarily adopted* by self-managed teams, while the resilient way is for them to be *imposed* by outside pressures, regulatory demands, public failures, and well-known disgraces (Marcus 1988b). Under anticipation, leaders serve as *catalysts and facilitators*. Under resilience, they serve as *commanders and controllers* (Nonaka 1994), where adoption is driven by the top, as the consequence of efforts by a large and powerful headquarters staff and hierarchy.

Anticipation, in sum, is the classic idea of organization as *gemeinschaft* or well-functioning, stable community. Resilience is the classic idea of an organization as *gesellschaft* or society in flux. A well-functioning community nurtures and protects its knowledge and people (often one and the same) from outside influences. A society in flux cannot afford these loyalties. In the face of unexpected problems and limits, it recreates itself in a way that may be both contentious and stressful.

Results

In this section we assemble the pertinent parts of the case studies as they relate to the characteristics, behaviors, and capabilities that have been described. We focus first on the period prior to the budget perturbation when only PH was close to the edge, and then on the altered state after the disturbance has occurred when both PH and MJ were in that position. We move back and forth between MJ and PH and illustrate the characteristics, behaviors, and capabilities listed above with relevant passages from the cases.

Baseline Characteristics, Behaviors, and Capabilities: Prebudgetary Disturbance

Anticipation: MJ Shows Preparation, Foresight, and Provision of Countermeasures for Likely Problems. Recognizing it was not operating a coal plant, MJ had an operational group involved in testing the reactor

even before power production, it developed a reliability centered maintenance approach, started to keep a consolidated history on all the plant's equipment, and created a regular maintenance schedule to rebuild all the parts and fix all plant systems. All the major components were examined every five years. The startup of the reactors was not easy, and MJ understood their vulnerabilities and subjected them to increased maintenance and inspection even when assured by a vendor that it did not have to do so. Knowledge of a deficiency led to enhanced prudence and continued careful monitoring. Before outages, when the nuclear power plant would be shut down for refueling and repairs, staff worked on as many problems as possible—all the minor leaks, preventive maintenance, and component problems, so that it would have less to do during the outage. The outage manager constantly planned and replanned the important outage activities.

Resilience: PH Shows After-the-Fact Intervention to Overcome Unexpected Problems and Limitations. When PH's first reactor started to produce power, there was confusion and disorder at the facility. PH had a fossil-fuel mentality; its initial organization still resembled that of a coal plant, where the approach was to shovel coal into the boiler till it fell apart. If a boiler was not taken care of, it could be easily overhauled. The initial experience of the employees with nuclear technology was limited. Employees approached each task as it came. They operated on a very short time frame, a "month-by-month" basis. During an outage, when a reactor sustained severe damage, one of the main reasons the failure had not been detected was that the vendor did not require preventive maintenance and PH had not implemented a preventive maintenance program on its own.

Exploitation: MJ Shows Implementation of Actions, Execution, and Refinement of Ideas. MJ's maintenance group carried out a systems engineering program. It had the responsibility to keep all the components in top working order, to develop procedures for them, to test them, and to modify them when necessary. It also implemented work requests from operators who were alert to problems. MJ's approach was that if an employee recognized a problem, the employee should fix it immediately. Though MJ trended performance in many ways, the number of uncompleted work requests was the most important. It had a consolidated list of the commitments it made to the NRC and INPO (the Institute for Nuclear Power Operations, an industry self-regulatory body). A method for resolving persistent problems was to tie their resolution to the incentive pay of managers, who were reviewed quarterly as to whether they were meeting these objectives. MJ was oriented toward keeping on top of problems, and not letting them fester and get out of control.

Exploration: PH Shows Problem Recognition and Search for New Ideas. Upper level management at PH was viewed as having a "book-of-the-month-club" mentality. It hired consultants who suggested new approaches—new management oversight and monitoring techniques, training methods, physical design adjustments, procedure modifications, and administrative and other alterations. However, there was little follow-through. One vice president started a reliability-centered maintenance program, but after he left, the budget was cut, programs were reallocated, and preventive maintenance declined in importance. PH never seemed to solve its problems before new ones, even bigger and more demanding, came along and distracted it. The situation disintegrated, with name calling and the staff losing incentive, impetus, and enthusiasm.

Retention: MJ Shows Stability and Continuity of Personnel. MJ's first employees, who came from an experimental reactor the utility established, started the nuclear division. They then recruited operations people and technicians from the Navy who had strong local ties and would stay with the plants for the long run. Of the first six people hired, five still remained. The plants were notable for their low turnover and the systems that were put in place to assure employee loyalty. For example, a senior reactor operator license commanded premium pay and was referred to as a "golden handcuff." Since other companies did not generally offer such lucrative pay for obtaining a license, talented people tended to remain with the company for long periods of time.

Turnover: PH Shows Acquisition of New Knowledge and Skills by Dismissing Old Staff. After a safety incident took place at PH, the immediate reaction was to introduce consultants, to reorganize, and to replace the top officers. After one such incident, consultants recommended that an outsider be inserted in the post of nuclear vice president. This person had worked at an adjacent utility. He then replaced top managers and instituted other changes that broke with PH's ingrained traditions. Concerning this reshuffling, it was felt that arbitrary decisions had been made which hurt morale. The next vice president, however, continued to reshuffle the top managers.

Internal Development: MJ Shows Education of Its Own Staff and Reflection on Its Own Experience. The changes MJ made after Three Mile Island (TMI) were to build internal capabilities in on-site engineering and construction and to upgrade training. It staffed the training function with more than 40 persons, encouraged personnel to acquire the senior reactor operating (SRO) license, introduced simulators to assist in training, and enhanced the training of maintenance personnel, making it more professional in character. MJ rarely relied on consultants.

An outside consultant came in and did a course on observation techniques to be used by supervisors, but the course did not work. The employees rejected what the consultant, as a third party unfamiliar with the plant, had to say.

External Search: PH Shows that It Purchases Advice from Outside Experts and Models Itself after Other Organizations. PH brought in many consultants: MAC (disguised name), a group like McKinsey, with limited nuclear experience; and DELTA, another group like McKinsey but with more nuclear experience. DELTA was made up of ex-nuclear Navy officers, tough operators who did a brutal job of tearing apart the organization. Its model was a traditional, military one that emphasized supervision, monitoring, assessment, and accountability. Consultants from DELTA interviewed plant personnel and determined within 15 minutes if they had officer capability. The consultants looked at all the management functions at PH. Other outside consultants served as trainers. They established a Management-by-Objectives MBO system. They set up Positive Discipline and Targeted Selection programs. They did a benchmark analysis to determine where the facility's values deviated from other *Fortune* 500 companies and an in-depth examination of its organization based on McKinsey's 7S model.

Voluntary Adoption: MJ Shows the Use of Self-Managed Teams to Introduce Changes. MJ's philosophy was self-assessment. It wanted to avoid outside scrutiny. It aimed to escape intervention as much as it could, from bodies like INPO or the NRC. On a daily basis employees talked and heard about problems in fairly closed groups. Every person in the group was responsible for solving its problems. Only if these mechanisms failed did management, INPO, or the NRC take notice. When a problem arose, MJ appointed an Internal assessment team consisting of plant employees from diverse functional areas. The reports that these teams wrote were distributed as required reading by up to 100 people, with nearly everyone at the plant having a chance to be briefed and to act.

Imposed Solutions: PH Shows Demands for Change Coming from Outside Bodies. After TMI, the NRC and INPO focused PH's attention on its nuclear operations. NRC inspectors criticized the program for not being "glued together correctly," and did "a nice job of rearranging the anatomy." Another safety incident meant tough times for PH as NRC brought in a team of investigators who unearthed problems in how the facility was organized. To recover from the incident, PH had to carry out the action plan NRC devised. In another instance, NRC shut down one of PH's reactors and demanded that PH discover the reasons for the "mess." The less success PH had, the more NRC and INPO "hit" PH "with a two-by-four."

Leaders: MJ Shows Consensual Decision Making. MJ's plants were considered "islands" away from headquarters, distant, independent, and self-sufficient. Headquarters gave the people closest to the information the right to make decisions. The line organization was supposed to be in control. Empowerment was granted to low levels in the organization. The assumption with which the supervisors worked was that capable, conscientious people had been hired, their training was good, and the procedures were more than adequate. Close work supervision was not needed.

Leaders: PH Shows Hierarchy and a Powerful Headquarters Staff Trying to Impose Its Will. PH upgraded programs by changing titles and giving managers more authority. The managers tried to instill high standards in employees by monitoring them to assure compliance. After one incident, the vice president for nuclear moved his offices next to the site, built an elaborate administrative building, and put new policy statements and stronger administrative procedures in place. He managed a massive reorganization. The next vice president created a new post—operations vice president, and had his position elevated to senior vice president. As an aspect of a revitalization program, he started to focus on procedures. PH developed procedures on how to write procedures. Nearly 1,000 procedure changes had to be made and the level of supervision grew.

Post-Budgetary Disturbance: Modified Characteristics, Behaviors, and Capabilities

It is evident the characteristics, behaviors, and capabilities of these facilities were very different. At this point MJ was further from the border of safety than PH. PH, being closer to the border, had to prevent further drift. It also had less room to maneuver. To use the terminology of Argyris and Schon (1978), it could not afford gradual, single loop learning. It was rushed into double loop learning or into the state that Tushman and Romanelli (1985) refer to as punctuated equilibrium. (Whether it succeeded or not is another matter.) The characteristics, behaviors, and capabilities organizations exhibit close to the edge are different than those that they exhibit farther away. This is evident when budgetary disturbances occurred for both plants, which made resources more constrained. We observe that the characteristics, behaviors, and capabilities MJ showed previously began to change. In some respects it became very much like PH. PH, on the other hand, responded to the budgetary problems it faced in its old ways, which only reinforced previous patterns. In this section, we first describe the tightening of resources at

MJ and PH and then present how their characteristics, behaviors, and capabilities evolved.

The story of the tightening of resources at the two facilities is very similar. MJ was told that it had to become more competitive, as its costs were being compared to those of independent power producers and it might someday be divested by the utility. Thus, it was supposed to become a low cost producer and do its work better and more cheaply. The utility's return on investment goals became a factor, and the budget took on greater importance. Management worked backward from a fixed budget, making decisions about personnel and deciding where expenses could be cut—overtime, travel, supplies, and equipment. Every month the managers reviewed spending. They had to cut the budget by as much as 4%, even while they maintained essential systems. For the first time, the facility had a formal business plan, and the utility introduced an integrated planning committee to review capital budgeting requests. Personnel were put in a position where they had to accomplish more with less. They had to be focused and devise creative solutions to get the work done. Not everything that had previously been done could still be carried out.

At PH, a new CEO with background on Wall Street declared that it had to become more competitive. It should become a low cost power provider, make cuts, eliminate workload duplication, and do more with less. It could not afford everything it had done in the past. A productivity study was carried out, and managers were asked to evaluate every job and its value to the company, the premise being that some functions simply were not worth doing and that others were more valuable. This process resulted in some departments and units losing resources. The number of senior reactor operators (SROs), for example, was cut, the amount of requalification training time available to SROs reduced, and the position of outage planner downgraded. How did MJ and PH respond to these budgetary pressures?

MJ Shows After-the-Fact Reaction to Overcome Unexpected Problems. At MJ, the sense of being proactive, of finding and correcting problems before they became serious, started to recede. Along with budget pressures, the plants were aging. Systems wore out and needed more maintenance. As stress levels grew, work loads increased. The system engineers had to do more, and they were uncertain if they could be as alert and watchful as they once were. The outages became more demanding. Each one revealed new problems. Before a routine refueling outage, scheduled as one of the shortest in MJ's history, the outage manager, with the assistance of system engineers, attempted to plot out all the activities that would have to take place in response to the different evolutions in plant conditions. However, as the outage proceeded, unexpected, on-the-spot decisions had to be made. New activities emerged and they had to be combined and carried out in unusual ways.

PH Shows After-the-Fact Reaction to Overcome Unexpected Problems. At PH, the budget for reliability-centered maintenance was reduced, the program reorganized, and preventive maintenance given a low priority. Though the maintenance backlog at PH was above the norm for the industry, and some money beyond the base budget was allocated to bring in contractors to "clean up" the problem, it was hard to reduce because so many spare part suppliers had gone out of business. Management called for a systematic review of maintenance activities to determine which capital improvements should be made, but the capital improvement program was not in full swing. Given demanding outage schedules, it was hard to implement changes rapidly. During an outage, an incident took place in which equipment in one of PH's reactors suffered severe damage. Personnel at PH should have known that there was the potential for this failure because of past events. Warnings existed. Prior human factors studies had identified the possibility that an operator could make such a mistake. Key backup systems, moreover, did not function. Indeed, PH had been committed to addressing these problems, but had not followed through with the solutions.

MJ Shows Acquisition of New Knowledge and Staff. Along with the budgetary issues, the people at MJ were aging. Their health was declining. Training new employees to take their place was not proving to be an easy task. (Part of the reason may be that nuclear power is a declining industry.) Formality was replacing prior intimacy, communication was poorer, and there was less accountability. To integrate new employees and have them work effectively with existing groups was a challenge. For instance, a technical change had been introduced to reduce reliance on operator performance, and with the addition of new instrumentation, something that had been done manually before could be carried out automatically. With this change, operators did not have to be as attentive and could complete an activity more quickly. However, the new conditions permitted overconfidence, and when a problem developed, though some of the people present detected it, those in charge did not acknowledge what was taking place. The new personnel who were involved were less experienced and assertive than prior personnel had been.

PH Shows Problem Recognition and the Search for New Ideas. PH's management had a five-year commitment to make the facility a "recognized, consistent, excellent performer and a real success." Though this revitalization program called for integrated procedure

improvement and material upgrades, the changes made were purchases of general equipment and housekeeping (painting, replacing insulation, and cleaning up leaks), with more fundamental modifications relegated to the future. In the meantime, PH was continuing to buy management programs like *Root Cause Analysis* and *First Line Supervisor* from consultants, though it tried to rely more on in-house human resource people for training on interpersonal skills and employee behavior.

MJ Sees Demands for Changes Coming from Regulators. MJs relations with the NRC began to slip. NRC felt that MJ had human performance problems. It sent in a special investigation team, and MJ responded with investment in plant modifications, hardware changes, a reworked indicator system, enhanced procedures and training for infrequently performed operations, and more certain and clear lines of command. The NRC, however, did not consider these changes sufficient, inasmuch as its chief concern was an incident in which an individual carried out an action without independent review or a second check. Unlike the NRC, MJ believed it could not harshly discipline or blame employees upon whom it depended for so many things, including bringing problems to management's attention. Blaming them would just lead to the dissolution of trust and invite uneasiness, discord, tension, and enmity. Management thus tried "positive discipline," but NRC was not satisfied and wanted more control.

PH Sees Demands for Changes Coming from Regulators. Though performance at PH started to improve, the NRC still thought of it as a "loser." With regard to the reactor damage discussed previously, NRC refused to accept PH's claim that since a vendor had not recommended preventive maintenance, it was not required. NRC censured PH for not responding to precursor events in the same way as other plants. The NRC wanted to know why PH was not effectively assessing the information it had about incidents and providing for the necessary follow-up.

MJ Shows Hierarchy and Headquarters Staff Trying to Impose Its Will. In response to the apparent human performance problems, which started to eclipse mechanical malfunctions as matters of concern, MJ organized an assessment team to diagnose the problem. Its conclusion was that there was "empowerment without appropriate supervision." This issue was believed to be behind the decline in accountability, and it explained why problems had surfaced. MJ tried to address the matter with better supervision, more self-checking, and increased discipline. A task force did twice yearly reports that graphed the number of human errors and their causes. MJ tried to improve communications with employees. Not willing to introduce a military lingo of verbatim repeating when sending and receiving messages, it offered better prejob briefings from supervisors, more procedure training, and better coordination. It also, however, raised the level of scrutiny, sending out the message that the plants could do better, and adding controls that focused on work practices, procedural compliance, and paperwork.

PH Shows Hierarchy and Headquarters Staff Trying to Impose Its Will. PH disciplined managers who allowed incidents to take place. It communicated to personnel about the importance of procedural compliance. Its spending on procedures grew because it was concerned about dealing with young, less experienced workers. Its aim was "a culture of compliance." It was going to have to do careful monitoring to hold employees accountable.

Discussion

With resource constraints in place, MJ and PH resembled each other to a greater extent than previously. Being closer to the safety border stimulated similar characteristics, behaviors, and capabilities in these facilities, specifically, resilience, turnover, imposed solutions, and leaders as commanders and controllers. MJ's drift away from its earlier characteristics, behaviors, and capabilities merits consideration. In successful organizations like MJ, exaggerated confidence in historical understandings and routines may develop. The routines followed are those associated with success, and they are reinforced while other routines are inhibited. Alternatively, if failure is experienced, routines are changed in an endless search as at PH. In this respect, Barley's study of hospitals (1986) is very similar to our own. In one hospital he studied, an emphasis on collegiality led to decentralization, and a strong understanding of the technology by the technicians. This hospital was like MJ. In the other hospital, institutionalized "dominance scripts" lead to centralization, poor technician understanding of the technology, and poor performance, which increased the pressures for centralization.

> [T]he steady stream of directives, imperative speech, puzzling countermands, sarcasm, and usurped control . . . raised the level of threat and arousal experienced by the technicians, which in turn . . . narrowed their attention, (and) made complex learning more difficult. (as quoted by Weick 1990, p. 28)

This hospital was like PH. The patterns established in these nuclear organizations, however, changed after the budget perturbations. While MJ did not entirely abandon its earlier characteristics, behaviors, and capabilities, it did exhibit a change as financial pressures took on greater significance, its plants began to age, turnover increased, and there was more regulatory scrutiny. Heeding these

warnings led to more centralized supervision and reliance on controls and procedures. In contrast, financial constraints tended to reinforce and fortify PH's prior tendencies for resilience and exploration. In both instances, budgetary restrictions meant less anticipation, more imposed solutions, and leaders who now functioned as commanders and controllers.

Characteristics, Behaviors, and Capabilities

Baseline characteristics, behaviors, and capabilities were very different at the two facilities. At MJ there was anticipation and at PH resilience. The benefits of anticipation should not be surprising, for after all, designing something after the fact is much more difficult than designing it from the start (Wildavsky 1988). At MJ, we found exploitation and at PH exploration. The limitations of exploration require close scrutiny. As March (1996) suggests, exploration has to be combined with slack, relaxed control, and playfulness. At PH, it existed in a very different context of few resources, tight controls, and rigid management. Too much exploration, according to March (1996), leads to the costs of experimentation without the benefits. It may mean that there are too many undeveloped ideas in the organization and too little competence for completion (Eccles and Nohria 1992). PH was in this cycle of forever looking for new ideas (the "book-of-the-month-club" mentality), but not being able to successfully convert them to action, despite the tight controls and rigid management.

Too much exploitation, on the other hand, can lead to an organization being trapped in a suboptimal, stable equilibrium. March (1996) refers to this suboptimal equilibrium as a competency trap. He calls for organizations to maintain an appropriate balance between exploitation and exploration. Implementation of actions, refinement of ideas, and learning incrementally in a single loop and adaptive way from small incidents are far easier than learning from challenging and threatening issues (Sitkin 1992). This is because small incidents are more easily recognized and interpreted, and corrective action is aimed at clear, identifiable targets from specific stimuli that provide clear rationales for acting. Small-scale, continuous learning only goes so far, however. At some point in time, basic system parameters change, and incremental adaptation is no longer adequate. MJ apparently had reached such a point. It no longer could rely only on its past competencies to lead it effortlessly into the future.

Prior to the budgetary disturbance, the characteristics, behaviors, and capabilities in place at MJ encouraged constancy. Simon (1996) suggests that organizations faced with new situations, and in need of developing new knowledge, skills, and approaches to deal with them, may have to rely on drastic measures like massive turnover. He writes that it is "often quicker to import new expertise and dismiss the old than to engage in massive reeducation" (p. 176). For nuclear utilities, it is difficult to bring in new talent because the industry is in decline and its people and technology are aging. It is also difficult because as Alvin Weinberg, a founder of the civilian nuclear power program in the U.S., pointed out, the nuclear industry is a type of "priesthood" (Marcus 1988a). Isolated, insular, and for all its pretensions of being rational, logical, linear, and scientific in nature, it is actually quite different. Success depends on complex, path-dependent, tacit relations.

A Rare and Hard-to-Imitate Competence

A competence for safety is rare and hard to imitate precisely because it is based on socially complex and hard-to-reproduce understandings and relationships (Reed and DeFillippi 1990, Hall, 1992). The techniques for effective safety management cannot be reduced to the numbers found in financial and accounting statements. They are the unique and hard-to-imitate attributes which RBV says are needed. MJ created and sustained these hard-to-reproduce understandings and relationships. PH failed to sufficiently develop them.

The characteristics, behaviors, and capabilities which make up a competence for safety persist for fairly long periods of time. By itself, an attribute like anticipation does not produce this long-lived phenomenon. Anticipation must be combined with exploitation, retention, internal development, voluntary adoption, and leaders as catalysts and facilitators. Once in place, these dense, highly connected elements are hard to change. Self-perpetuating cycles (refer back to Figure 4) support their existence. They are held in place by an organization's distance from the border of safety as well as by its pattern of resource availability and use. However, when an organization is close to the edge (see Gersick 1991), they begin to change. A competence for safety can be eroded by changes in resources.

Operating on the Edge

MJ cultivated a competence for safety through exploitation, retention, internal development, voluntary adoption, and leaders as catalysts and facilitators. PH was unable to develop this competence to the same degree because of exploration, turnover, external search, imposed solutions, and leaders as commanders and controllers. Though PH operated on the edge, its features did not let it cross over the border. As indicated, warnings can be heeded, disaster averted, and an organization can still find itself inside the border of safety but closer to the edge (see Figure 1, point 3b). As more organizations face resource constraints and budgetary pressures, the resilient style

that PH exhibited is likely to become more common. Operating on the edge is becoming a fact of life in settings as diverse as U.S. banks, hospitals, and universities, Israeli kibbutzim, Japanese kereitsu, and Korean chaebol.

Conclusion

Organizations can drift to the edge on several measures of effectiveness; safety may be just an example of a larger set of indicators. What we can learn from safety is that when people pay inadequate attention to unusual events and neglect warnings, the possibility of breaching a performance barrier increases. Drawing on concepts from the resource-based view (RBV) of the firm, this paper has examined situations where resource availability and use compromise safety by influencing attention to warnings. Our focus has been on drift within a safety border, which is influenced by error signals, feedback loops, and imperfect watchfulness. Resource availability and use can initiate drift, but they do not necessarily yield accidents. Should organizations fall into a threatened position, they can enlist characteristics, behaviors, and capabilities to stabilize the situation and achieve greater security.

This paper has identified some of the characteristics, behaviors, and capabilities that organizations on the edge exhibit. Focusing on nuclear power, it has analyzed the process of heeding warnings in response to unusual events. Like other industries, nuclear power uses technologies that are "parallel" ones involving both "a technology in the head and a technology on the floor." (Weick 1990, p. 17). In both the technology "in the head" and "on the floor," there may be an element of "mystery."

When organizations pursue activities, their understandings are not complete. To function, they must know how to combine people and equipment and transform inputs to valuable outputs. They must understand cause-and-effect relations and convert this knowledge into effective methods for governing behavior. Their understanding of the link between actions and outcomes is unlikely to be perfect, however. Unusual and puzzling events can take place. They can unfold in unexpected ways with some of the outcomes appearing random and unpredictable. These surprises are warnings that must be heeded.

Heeding these warnings can be occasions for learning. Organizations can interpret the events to foresee what is likely to happen next. They can make inferences from the interpretations and encode them in routines to guide future behavior. The events pose a challenge to the organization that it may be drifting too close to a performance border. In this paper, we have presented evidence which suggests that in response to the sense of being close to the edge, organizations both increase and change their pattern of spending. These alterations in the use of resources when accompanied by changes in other attributes may halt a drift toward unsafe conditions, but it is unclear if they restore the organization to an equal or more secure position.

An analysis of tangible resources takes us only so far in understanding this phenomenon. A deeper understanding comes from insights into the characteristics, behaviors, and capabilities that organizations exhibit. In this study, the following characteristics, behaviors, and capabilities have been identified as being important:

- anticipation and resilience,
- exploitation and exploration,
- retention and turnover,
- internal development and external search,
- voluntary adoption and imposed solutions, and
- leaders as catalysts and facilitators and as commanders and controllers.

Different combinations of these characteristics, behaviors, and capabilities are likely to be activated depending on how close organizations are to the border. Farther from the edge, the characteristics, behaviors, and capabilities organizations are likely to enlist are anticipation, exploitation, inbreeding, internal development, voluntary adoption, and leaders as catalysts and facilitators. Closer to the edge, the characteristics, behaviors, and capabilities they are likely to enlist are resilience, exploration, turnover, external search, imposed solutions, and leaders as commanders and controllers.

This study is an exploratory one from which we derive the propositions that:

- Resource availability and use affect an organization's drift within performance borders.
- Organizational characteristics, behaviors, and capabilities are compensating mechanisms designed to deal with the consequences of this drift.
- These characteristics, behaviors, and capabilities vary depending on how close an organization is to the border.
- They help firm up and position the organization within the border.
- They also can play an important role in initiating and reducing the likelihood of the organization's crossing over this border.

A limitation of this study is that the statistical evidence is partial and based on a review of prior studies. Another limitation is that the in-depth, qualitative analysis is based on the interpretations of the participants and that it is restricted to plants which are outliers in the population. Perhaps future studies can use objective measures for these characteristics, behaviors, and capabilities and can contend with the fact that the extremes shown by the outliers

are likely to appear in more mixed form in facilities whose histories are more alike.

This study also differs from earlier ones in that we started with the premise that hazardous facilities are neither inevitably accident prone nor necessarily safe and highly reliable. These organizations typically, but not always, drift within a space of tolerable performance. This perspective is an advance in that it highlights when crossovers to extraordinary states can happen. There are lessons from this perspective that can be learned by all managers, whether operating in hazardous industries or in organizations experiencing other types of stress and trying to recover. What keeps activities within the bounds of acceptable performance? What accounts for the possibility of their migrating into zones beyond the systems' capacities for recovery? This study has emphasized the role of resource availability and use, along with the role of a set of organizational characteristics, behaviors, and capabilities that are likely to be exhibited, depending on how close an organization is to the edge. These factors, we argue, affect an organization's movements to and from performance borders and influence its ability to heed warnings. Managers in all organizations need to focus on maintaining buffers to performance so that perimeters are not irreversibly breached. Resources, their deployment, and the characteristics, behaviors, and capabilities an organization displays can play an important role in this process.

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Endnote

[1]Sources of publicly available data for the studies reported in this paper are the NRC series of reports called *Performance Indicators for Operating Commercial Nuclear Power Reactors* and the DOE data on the utilities financial performance found in the annual Energy Information Administration (EIA) series called *Financial Statistics of Selected Electric Utilities* and in other EIA publications. Much of the data on the electric utility industry, from these sources and others, are compiled by the Utility Data Institute (UDI) in Washington, D.C. in *U.S. Nuclear Plant Statistics.* The data are also used by Public Citizen in its series of reports called *Nuclear Lemons: An Assessment of America's Worst Commercial Nuclear Power Plants.*

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