Table of Contents

Go Back

High-leverage changes to improve safety culture: A systemic analysis of major organizational accidents

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Abstract:
The purpose of this paper is to clarify high-leverage changes indispensable for improving safety culture through organizational learning. Although the concept of safety culture appears to have become increasingly important, there is no established way to improve it. Through systemic analysis and model building of the process of deterioration of safety culture in three recent major organizational accidents, we identified two main root causes: (1) tradeoff between economy and safety and (2) misperception of current reality. The reinforcing feedback loop between 'focus on efficiency' and 'misperception of current reality' created unhealthy safety culture, which undermined safety margin and prepared an environment where a triggering factor can cause an accident. The leverage points for improving safety culture are (1) accurate perception of current reality and (2) adequate open communication. In order to improve safety culture using these two leverage points, we are now designing two gaming/simulations for Tokyo Electric Power Company.
Keywords: high-leverage change; model building; organizational accident; organizational learning; safety culture; systemic analysis.

1. Introduction

The concept of safety culture appears to have become increasingly important for our understanding and management of safety at work. Cultural theory strongly influenced popular approaches to organizational performance and effectiveness in 1980s (e.g. [1]). In Japan, however, the idea that safety culture might be an important organizational attribute did not gain any significant level of acceptance until the JCO nuclear accident in 1999.

Less than one month before the JCO nuclear accident, at the 3rd International Conference on Human Factor Research in Nuclear Power Operation, Kazuo Sato, Chairman of Nuclear Safety Commission in Japan, proudly said, “Generally speaking, I believe that the level of Safety Culture in Japan is fairly high even as compared with those in other countries. Excellent performance so far demonstrated in Japanese nuclear power plants seems owing to adequate Safety Culture prevailing everywhere and everybody” [2]. At the same conference, Jiro Kondo, Chairman, Central Environmental Council and Vice Chairman, Atomic Industry Forum, proposed “Anzen-do,” a discipline for safety, as a contribution from the Japanese unique way of thinking. He said, “I would be happy if Japanese traditional culture would prove valuable for safe nuclear power. The Japanese nuclear industry has an operating performance of 40 years without any accident. The unique Japanese approach to safety may be useful as well for the Occidentals with cultures different from ours” [3].

Contrary to Sato's opinion, the JCO nuclear accident disclosed that adequate safety culture was not prevailing everywhere and everybody. Apparently, these important persons in charge of nuclear safety in Japan believed that well educated and trained Japanese workers with “kaizen” mind had prevented nuclear accidents in Japan. Actually, contrary to Kondo’s belief, Japanese traditional culture was a causal factor of the JCO accident in the authors’ opinion [4].

The safety culture of an organization is the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization’s health and safety [5]. The essence of safety culture is intangible, and primarily of the matter of thinking. Nevertheless, improvement of safety culture and actual safety cannot be realized by thinking.

2. Systemic analysis and modeling of organizational accidents

In order to find leverage points to improve safety culture through organizational learning, we analyzed three major organizational accidents using system dynamics modeling. Every company involved in the accident used to be a leader in the industry with of long no-accident record. For each case, we designed a model describing the process of deterioration of safety culture.

The two Japanese cases represent perhaps the most important events occurred in recent years, and the American case is quite unique because the nuclear power station had to demonstrate a safety conscious work environment to restart its units.

2.1. JCO nuclear criticality accident

This accident has resulted in the death of two of the workers making this an unprecedented nuclear accident in Japan.

2.1.1. Description of the accident

On September 30, 1999, a criticality accident occurred at a uranium processing plant operated by JCO Co., Ltd. (hereinafter referred to as JCO) in Tokai village, Ibaraki Prefecture.

The operation to produce uranyl nitrate solution, which was performed by three JCO workers, started on September 29, 1999. The government-approved procedure required the workers to dissolve uranium powder with added nitric acid in a dissolution tank. Instead of this procedure, they dissolved uranium powder in a 10-liter stainless steel bucket. In violation of the operation manual as well as of an approved procedure, they seem to have fed seven batches of uranyl nitrate solution into the precipitation tank which was designed to limit the mass to 1 batch, using a 5-liter stainless steel bucket and a funnel.

As a consequence of these actions, the uranyl nitrate solution in the precipitation tank reached a criticality and alarms sounded at around 10:35 a.m. on September 30. This criticality consists of a very short period in the initial stage in which a large number of nuclear fission reactions took place and the later stage in which the fission reaction continued slowly for approximately twenty hours.

2.1.2. Background

The approved nuclear fuel conversion procedure specified in an internal document involved the dissolution of uranium oxide powder in a dissolution tank, then its transfer to a pure uranyl nitrate solution buffer column for homogenization by nitrogen gas purge and mass control, followed by transfer to a precipitation tank which is surrounded by a water cooling jacket to remove excess heat generated by the exothermic chemical reaction. The prevention of criticality was based upon the general licensing requirements for mass and volume limitation, as well as upon the design of the process, including use of a column with a criticality-safe geometry as a buffer to control the amount of material transferred to the precipitation tank.

The work procedure was modified in 1996, without permission for the modification having been given by the regulatory authorities, to allow the dissolution of uranium oxide to be performed in stainless steel buckets. This new procedure had been followed several times before this accident occurred.

In addition, when the criticality event occurred, they were performing homogenization of uranium oxide by mechanical stirring in the precipitation tank instead of in the mass control equipment. This was done by pouring uranyl nitrate solution directly from the steel bucket into the precipitation tank. The tank was not designed with a geometry conducive to preventing criticality. This means of homogenization in the precipitation tank is not even described in the revised procedure and was a further deviation from the approved procedure.

With regard to managerial provisions for the prevention of accidents, no clear and specific qualification and training requirements seem to have been established. Moreover, the STA representatives stated to the team that they had not found in the JCO qualification and training documents evidence of compliance with the legal and regulatory requirements.

2.1.3. Root cause model

We made a systemic analysis of the root causes of the JCO accident and built a model (Figure 1). There were two major causal factors behind the accident.

One was keen international price competition forcing JCO management to pursuit efficiency. The company had experienced financial problems due to international price competition. The sales decreased from 3.25 billion yen in 1991 to 1.72 billion yen in 1998. As a result JCO repeatedly took measures for management efficiency enhancement, including personnel reduction. Especially, the number of technical staff was cut from 34 to 20.

The other causal factor behind the loop was inadequate risk awareness by JCO top management, who are former executives or loaned officers of its parent company, Sumitomo Metal Mining Company Ltd that has had no other experience in nuclear business. Assuming that a nuclear criticality accident was impossible at the facility, top management had not learned any lesson from previous criticality accidents in other countries. There had been 21 accidents in nuclear fuel facilities in the past - seven in USA, one in UK, and 13 in Russia. Most of them occurred in 1950s and 60s, but one accident happened in Russia in 1997.

The reinforcing feedback loop of production improvement drives supplied a sufficient set of vulnerability causal factors, which are factors that either set up the situation so that the personnel error was highly likely or triggered the personnel error (Fig. 1). The "kaizen" drives resulted in bypassing certain design features that were supposed to prevent criticalities but at the same time made operations slower and more expensive. The revised company operating manual was in violation of the original operating manual, which had been approved by licensing authorities.

All of the four levels of defense either did not exist or were inadequate (Fig. 4):

- The first and most important level of defense was inadequate - the workers had no adequate safety knowledge because workers received no training on the criticality hazards of their work.
- Management and supervision, the second level of defense, was inadequate. There was apparently no involvement of management in the workplace. This facility had processed mostly low enrichment uranium and infrequently intermediate enrichment uranium. There was no change management safety analysis of the medium enrichment uranium change.

- The third level of defense, internal oversight, was ineffective. Management failed to establish proper technical management procedures for the preparation and revision of manuals and instruction. These include failure to require the approval of the safety management group chief and/or the chief technician of nuclear fuel. Furthermore, management was either ignorant or condoned operating outside licensed controls.
- External oversight, the fourth and last level of defense was either non-existent or inadequate. There was no oversight by the Japanese nuclear industry, which was mainly concerned with nuclear power generation and paid almost no attention to nuclear fuel conversion. The Japanese government had licensed this facility under the assumption that a nuclear criticality accident was impossible at the facility. There were no ongoing or periodic government inspections to ensure that there was no deviation from the approved procedure.

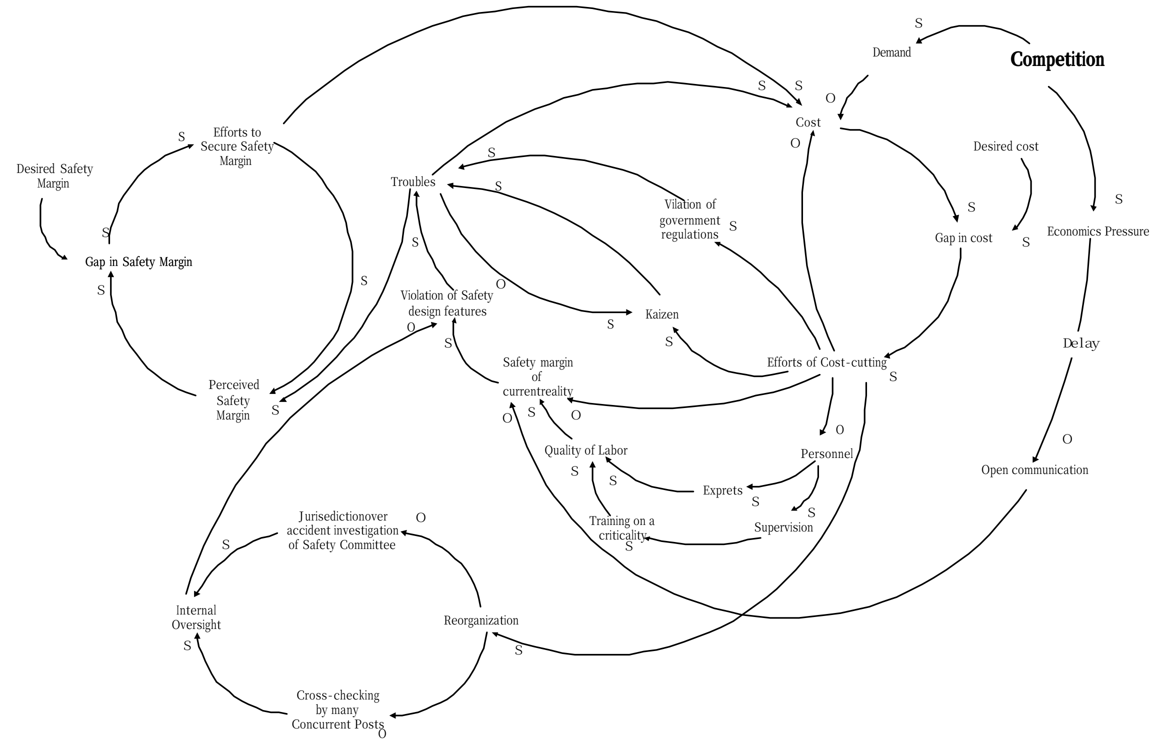

Fig. 1 Root cause of JCO accident

2.2. Snow Brand food poisoning

The total number of the victims of the widespread cases of food poisoning caused by the products of Snow Brand Milk Products Co., Ltd. (hereinafter referred to as Snow Brand) turned out to be over 14,000 making this an unprecedented food poisoning incident in Japan. Snow brand was and still is the industry leader in various milk products such as fluid milks, ice cream, cheese, etc.

2.2.1. Description of the incident

On June 27, 2000 the first several cases of food poisoning caused by milk were reported to the municipal authorities of the City of Osaka. It was the product of Snow Brand Osaka plant. Two days had past and 211 cases of food poisoning had been reported to municipal health authorities before the company made its first public announcement of a serious product defect. Since then, the company has repeatedly changed its explanations about the possible risks of other products and the results of its plant investigation. Public trust in the company has plunged

It was just the beginning. In August, 2000, the Hokkaido prefectural government ordered a Snow Brand skimmed milk plant to cease operations when it discovered the product was contaminated with enterotoxin made by a bacteria called staphylococcus aureus. The toxin is suspected to be a main cause of the food poisoning in the summer.

Within two months after the news of the Snow Brand food poisoning first broke, at least 50 cases of production withdrawals arose because of production errors and problems. Companies were aware that the Snow Brand case had made consumers increasingly sensitive and critical of slow, insincere responses by a company to product-related problems, not to mention the implied lax production controls.

The health and welfare minister, regional government officials, retailers and consumers blamed the company for bad crisis management. The number of Snow Brand victims reached 14,762 by the end of July, 2000.

2.2.2. Background

In the annual report 2000, the new president Nishi, who replaced Ishikawa, said, "In regard to this incident, we recognize that the problem was more than a failure in the quality control process. Rather, we believe that it reflected a false pride as the industry leader, neglect of our policy of placing the customer first, and lack of thoroughness in preparing internal controls. Furthermore, we regret that an insufficient response following the incident had the effect of losing people's trust" [6].

The triggering causal factor was shipping skim milk power contaminated with entrotoxin made by bacteria bred in the high temperature due to power failure accident at the Hokkaido plant. However, as the new president confessed in the annual report, there existed a sufficient set of vulnerability causal factors in the organization.

Snow brand recognizes that the fundamental cause of the food poisoning incident was loss of sense of responsibility and awareness of the importance of its mission that is to contribute to the healthy, nutritious and taste-conscious eating habit of its customers. The new president promises to return to the spirit of Snow Brand when it was newly founded, develop an open corporate culture with a keen awareness of our social role, and realize a reborn Snow Brand that delivers peace of mind for each and every customer.

2.2.3. Root cause model

We built a conceptual model of the root causes through a systemic analysis of the Snow Brand incident (Figure 2). There were two major causal factors behind the incident.

One was prolonged depression in Japan forcing the Snow Brand management to pursue commercial success leaving safety to automated machinery with Hazard Analysis and Critical Control Point (HACCP) system. In fact, Ishikawa, who resigned because of the incident, was the first president elected from finance area. He was a financial expert but had no knowledge about technology and production.

The other factor was false pride and illusion of technological superiority as the industry leader that, together with inadequate open communication, resulted in misperception of current reality. The management and employees thought the HACCP system ensured safety, but in reality, the system had been reduced to an empty shell.

These two factors reinforced with each other and developed unhealthy safety culture.

All of the four levels of defense either did not exist or were inadequate (Fig. 2). Pursuit of commercial success cut down the number of experts in the company and lowered quality of labor, which resulted in inadequate first and second defense. Actually, the general manager of the Hokkaido plant did not know anything about the danger of entrotoxin. The plant inspection system was almost nonexistent. There were no stationing experts at the plants for inspection. The final defense of external oversight was also inadequate. The authorities used to make only superficial inspection because Snow Brand was the leader in the industry.

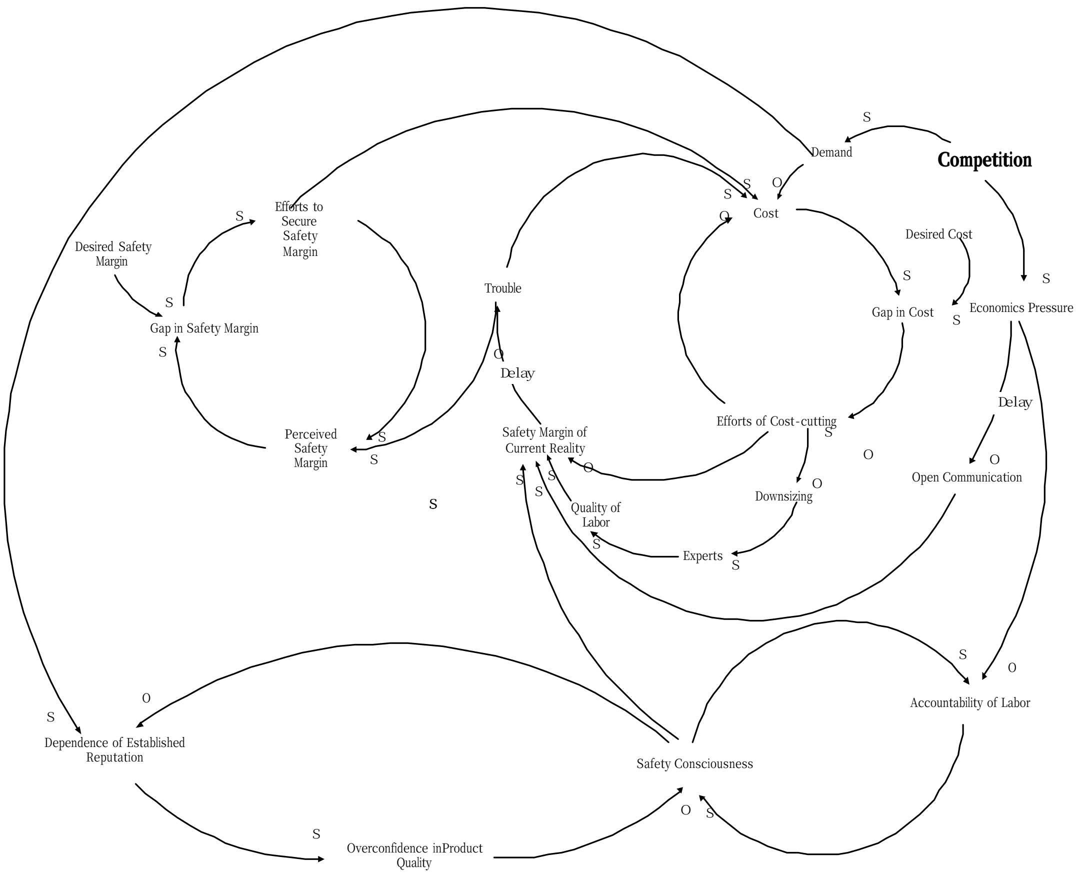

Fig. 2 Root cause of Snow Brand Milk food poisoning

2.3. Millstone nuclear power plant closure

The US Nuclear Regulatory Commission (NRC) issued an unprecedented Order that directed Northeast Utilities (NU), majority owner of Millstone, to devise and implement a plan for handling safety concerns raised by employees and ensuring a safety conscious working environment free from retaliation and discrimination.

2.3.1. Description of the event

In early March of 1996, Time magazine presented a cover story about harassment and intimidation of employees who brought safety concerns to management at Millstone Nuclear Power Station. The UN Nuclear Regulatory Commission (NRC) was receiving about 50 allegations per year from Millstone, the most of any nuclear power station. All three units at Millstone were at that time on the NRC "Watch List" due to a combination of operational deficiencies, weakness in documentation of the design basis/licensing basis, repeated inability to make promised improvements, and employee allegations. Each of the three units had been shut down by utility management to deal with particular problems. In June, the NRC placed all three units into Category 3 of the Watch List, which meant the units could not be restarted without an affirmative vote of the NRC Commissioners establishing that substantial progress had been made to correct the issues.

The order included an unprecedented requirement. Millstone Station had to demonstrate a safety conscious work environment (SCWE) in which employees would feel comfortable raising safety concerns to management without fear of retaliation and management would take appropriate action on these concerns [7]. There had been no physical event threatening the integrity of the nuclear core, no release of radioactivity, no sudden loss of safety functions. The Millstone event was a loss of public confidence and regulatory margin (ie., the NRC no longer accepted promises of improvement programs).

In July, 1997 Millstone established success criteria for SCWE: (1) employees are willing to raise concerns, (2) management is responsive, (3) Employee Concerns Program is a viable and trusted alternative, and (4) management has the ability to recognize and react appropriately to emerging situations. Millstone developed Key Performance Indicators for these four criteria. In October, Millstone presented their comprehensive plan to the NRC, which the NRC accepted in December as the first demonstration that Millstone could measure their own progress. Millstone was allowed to restart Unit 3 in 1998.

2.3.2. Background

During the 1970s and 1980s, Northwest Utilities was widely recognized as a leader in the nuclear power industry. It was especially respected for its engineering organization, and was a pioneer in the development and use of Probabilistic Risk Assessment, a technique for analyzing and managing the risks of damage to the uranium fuel in the reactor.

However, the utility expended tremendous resources building Unit 3 in the 1980s, at a time when many utilities are encountering increased public resistance to new plants and several either stopped projects short of completion or faced severe financial hardship. This also corresponded with a change of leadership as Leland Sillin, revered at Northeast Utilities as one of the pioneers of the industry, retired as CEO. Also, an external consultant's report in 1986 emphasized impending deregulation and the need to compete with other sources of energy. The result at Millstone was a focus on cost-cutting and efficiency, running the plants without spending unnecessary funds, promoting managers who could get the thing done within the budget,

By the early 1990s there were signs that Millstone was not keeping up with an industry where standards of performance were increasing each year. Engineers and other employees were complaining, sometimes publicly, that management would not listen to their concerns about design and operational issues. Millstone's response was, in general, to make legalistic denials, assert their competence, find ways to justify their positions, and promise that improvement programs would make things better. Funds for improvement programs were sometimes withdrawn or folded into new programs before the problems were solved. When management did not respond, unhappy employees looked for other issues, sometimes raising many issues, and dissatisfaction spread like cancer.

2.3.3. Root cause model

We made a systemic analysis of the root causes of the Millstone event and built a model (Figure 3).

The Millstone Independent Review Group identified seven principal root causes for continued employee concern problems at Millstone. Specific root causes included: (1) ineffective problem resolution and performance measures, (2) insensitivity to employee needs, (3) reluctance to admit mistakes, (4) inappropriate management style and support for concerned employees, (5) poor communications and teamwork, (6) lack of accountability, and (7) ineffective Nuclear Safety Concerns Program (NSCP) implementation [8].

There were two major causal factors behind the event. One was impending deregulation and the need to compete with other sources of energy. The funds for improvement programs management had promised to concerned employees were sometimes withdrawn before the problems were solved. The other factor was its false pride and illusion of technological superiority as a pioneer in the development and use of Probabilistic Risk Assessment. The illusion together with inadequate open communication resulted in misperception of current reality. The management apparently did not understand one of the most important attributes of safety culture—it deteriorates as time goes by. A bad organizational accident can achieve some dramatic conversions to the 'safety faith', but these are all too often short-lived [9].

The first level of defense was not functioning because the management did not listen to employees' concerns. Millstone focused on running the plants without spending unnecessary funds, promoting managers that could get things done within the budget and paying less attention to the engineering organization. Therefore, the second and the third level of defense were inadequate.

The fourth level of defense was also inadequate. Allegations did not always receive the level of NRC attention that was warranted. In some cases, NRC processes for following up on licensee correction of discrimination problems was not fully effective. In some cases of discrimination or alleger-identified violations, the NRC did not send a clear enforcement message to either the industry or the public. NRC inspectors, in general, were not qualified to effectively detect or assess potential discrimination at licensee facilities. Sometimes, the NRC abrogated its employee protection responsibilities to DOC.

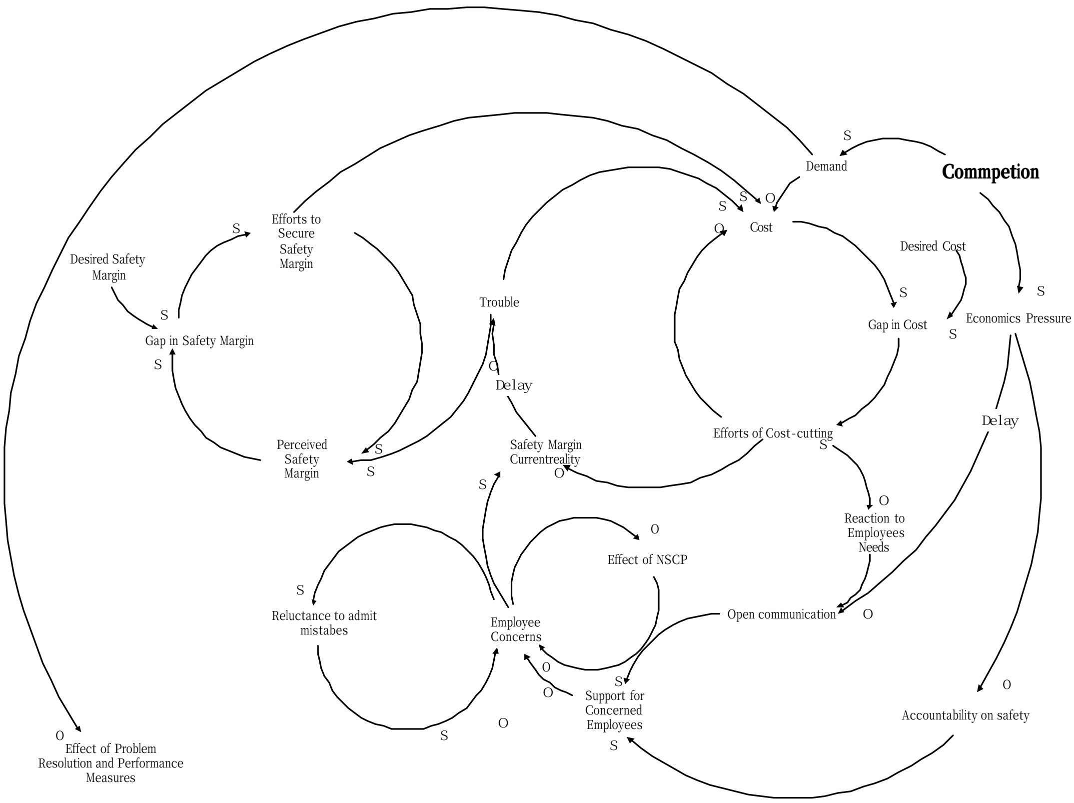

Fig. 3 Root cause of Milstone incident

3. Discussion

Through our systemic analyses, we identified two major root causes: (1) tradeoff between economy and safety and (2) misperception of current reality. In addition, the four levels of defense either did not exist or were inadequate. Those factors eroded safety culture of the organizations, decreased safety margin, and prepared an environment where a triggering factor could cause an accident.

3.1. Tradeoff between economy and safety

Industrial organizations, including the nuclear industry, presently are facing a changing environment due to deregulation, an aggressive public opinion, and increasing commercial competition.

Managers as well as workers are faced with conflicting demands and higher workload in the new industrial environment of downsizing and continual improvement. This is exemplified by the US nuclear power industry, which faces extreme cost pressures from competition with other energy sources and the challenge of reducing staff that multiplied in the decade following the Three Mile Island incident in the context of pressure from regulators and the public for increased safety.

Commercial success - sometimes even survival - in a competitive environment implies exploitation of the benefit from operating at the fringes of the usual, accepted practice. Closing in on and exploring these boundaries during critical situations necessarily imply the risk of crossing the limits of safe practices. The industry must attain efficiency and safety at the same time.

In their efforts to increase efficiency and enhance safety performance, the nuclear power industry along with many other industries has turned to the improvement of 'culture' [10]. A shift in regulatory emphasis has occurred in the US nuclear power industry. The older style of direct prescriptions of required behavior is being reconsidered. There are signs of a new style that attempts to force plant management to have appropriate priorities and procedures in order to meet safety objectives (as exemplified by the US Nuclear Regulatory Commission's Maintenance Rule, 10CFR50.65).

Self-assessment by plants (in the line and in quality control) is perceived to be a crucial capacity for safety assurance and continued improvement. Regulators are insisting that plants find and solve their own problems. Dr. Shirley Jackson, the Chairman of the US Nuclear Regulatory Commission says that self-assessment 'should be an integrated part of every licensees' way of doing business' and that it will become increasingly important 'as we move to more performance-oriented regulatory approaches' [10].

Two important indicators of self-assessment capability are (1) the extent to which employees bring problems to management and (2) management's openness to critical feedback. If employees focus on production and ignore minor problems, or try to avoid blame by not bringing up problems, then a profusion of small problems may create the condition for serious trouble later. A lack of feedback or unwillingness to hear critical feedback may short-circuit proactive efforts at prevention or rapid response.

It is important to note that, in self-assessment, the most important defense against accidents is considered to be individuals and work groups. Employees are being asked to do more than what they are told: they are increasingly expected to be proactively aware of potential problems and areas for improvement and to be personally committed to corporate goals such as safety, quality, and profitability. Managers who used to pass messages down to the troops and to monitor compliance are now expected to solicit suggestions and criticisms from below and to be communicators, facilitators and motivators rather than controllers.

There are four levels of defense against the effects of faults and errors.

3.2. Defense

Analysis of industrial accidents invariably conclude that some 80% of the cases are caused by human error and great effort is spent to improve safety by better training schemes, by safety campaigns motivating the work force to be safety conscious, and by improved work system design. However, low risk operation of modern, high hazard system normally depends on several lines of defenses against the effects of faults and errors. The analysis of recent major accidents has also shown that they are not caused by a stochastic coincidence of faults and human errors, but by a systemic erosion of the defense.

Defense, or barrier, in this article is any measure or device that does or is intended to reduce the probability or consequences of an event. There are four levels of defense of quality and safety [11].

(1) The first level of defense is individual or work group,
(2) The second level of defense is supervision or management,
(3) The third level of defense is internal oversight, and
(4) The fourth (last) level of defense is external oversight.

The first level of defense is the most important. As the level goes higher, depth of review decreases although objectivity, independence, breadth of perspective, and integration capacity increase. In addition, the first level is full-scope, on-line, and real-time defense whereas the fourth level is sample, off-line, and after-the-fact defense (Figure 4). This is another reason why the notion of safety culture is now gaining importance in all sectors of industry and has been highlighted as a contributory factor in a number of major disasters.

In the usual defense-in depth situation the individual or work group itself is expected to find and correct the vast majority of work errors. Of the remaining undetected errors, management or supervision is expected to detect a majority. The few errors remaining are the ones internal oversight is to identify. If the effect of the error is there for the internal oversight to either find or overlook, then the defect has already passed through two layers of defense.

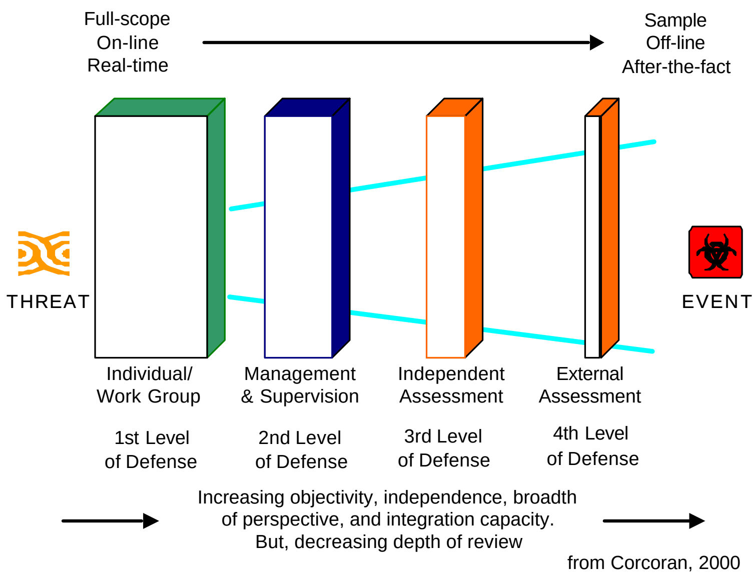

Fig. 4 Four levels of defense

3.3. Leverage point

In order to find the leverage points to improve safety culture, we built a model showing root causes commo n to those three cases (Figure 5).

The bottom line of systems thinking is leverage—seeing where actions and changes in structures can lead to significant, enduring improvements. Often, leverage, follows the principles of economy of means: where the best results come not from large-scale efforts but from small well-focused actions. Our nonsystemic ways of thinking are so damaging especially because they consistently lead us to focus on low-leverage changes: we focus on symptoms where the stress is greatest. We repair or ameliorate the symptoms. But such efforts only make matters better in the short run, at best, and worse in the long run [12].

Tackling a difficult problem is often a matter of seeing where the high leverage lies, a change which—with a minimum of effort—will lead to lasting, significant improvement. The only problem is that the high-leverage changes are usually highly *nonobvious* to most participants in the system. They are not "close in time and space" to obvious problem symptoms.

The model shows the process of deterioration of safety culture. The reinforcing feedback loop between focus on efficiency and misperception of current reality creates unhealthy safety culture, which undermines safety margin. Because safety is not quantifiable and competition is fierce, this loop continues to operate until an accident breaks out.

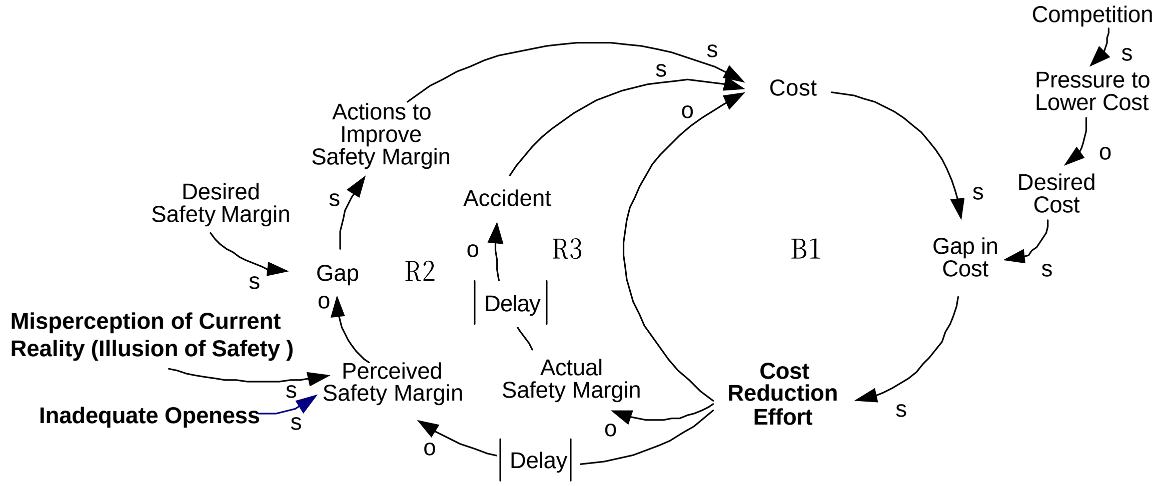

Fig. 5 Conceptual map of root cause

Then, what should be done to cut this feedback loop? Improving safety culture requires double-loop organizational learning in Argyris's theory [13]. As the Figure 6 shows, there exist two main obstacles that prevent the organization from making such learning. They are

(1) inaccurate understanding of current reality and
(2) inadequate open communication.

These are the high-leverage changes indispensable for improving safety culture.

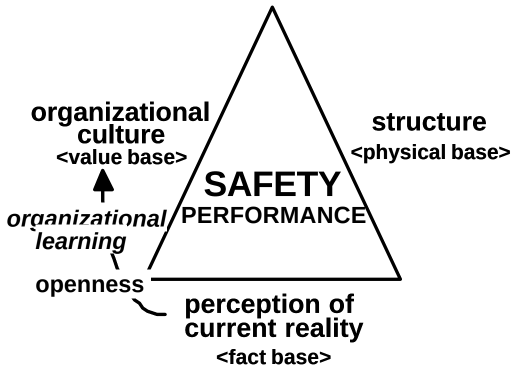

Fig. 6 Safety performance

Accurate understanding of current reality is a vital ability for safety assurance and continued improvement. Current reality is often quite different from what the management and the employees perceive as 'reality.' Most importantly, the explicit rules in the manuals are not always followed. Implicit social norms in the organization seem to define the 'proper' conduct of its employees.

Two important indicators of adequate open communication are (1) the extent to which employees bring problems to management and (2) management's openness to critical feedback.

4. Conclusion

Through systemic analysis and model building of the process of deterioration of safety culture in three major organizational accidents, we have clarified that the reinforcing feedback loop between 'focus on efficiency' and 'misperception of current reality' creates unhealthy safety culture, which undermines safety margin. We claim that the high-leverage changes indispensable for improving safety culture are (1) accurate understanding of current reality and (2) adequate open communication. In order to improve safety culture using these two leverage points, we are now designing two gaming/simulations for Tokyo Electric Power Company.

Acknowledgements

This research project was financed by the Grant-in-Aid for Scientific Research of the Japan Society for the Promotion of Science, and the grant from the Foundation for Fusion of Science & Technology.

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Back to the Top