Knowledge Management Aspect of JCO Nuclear Accident

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Abstract:

Except for what are sometimes called 'Act of God', any problems arising at a nuclear plant originate in some way in human error (INSAG, 1991). The IAEA Report also concluded that the nuclear criticality accident at the JCO nuclear fuel processing facility at Tokaimura seemed to have resulted primarily from human error and serious breaches of safety principles. However, unless there is a sufficient set of vulnerability causal factors and one or more triggering causal factors, neither an instance of human error nor a consequential event occurs. Based on their systemic analysis of the criticality accident the authors claim that its root cause was inappropriate knowledge management - combination of (1) inadequate risk awareness by the top management and (2) "kaizen" (production improvement) drives. Famous traditional Japanese culture "kaizen," an important determinant of the Japanese superior performance, had an adverse effect on the event. The authors argue policy exercise can be a new methodology to improve safety culture, meta-level knowledge to ensure safety.

Keywords:

criticality accident; human error; "kaizen"; knowledge management; risk awareness; safety culture.

On September 30, 1999, a nuclear criticality accident occurred at a uranium processing plant operated by JCO Co., Ltd. (hereinafter referred to as JCO) in Tokai village, Ibaraki Prefecture. A solution of enriched uranium in an amount several times more than the specified mass limit had been poured directly into a precipitation tank bypassing a dissolution tank and buffer column intended to avoid criticality. This action was in contravention of the legally approved criticality control measures. Three JCO plant workers were exposed to high levels of radiation in the accident. This has resulted in the death of two of the workers making this an unprecedented nuclear accident in Japan which has developed nuclear energy for peaceful purposes.

This paper provides a partial root cause analysis of the event using a systems approach. Most of the information came from the Interim and Final Reports of the Nuclear Safety Commission Investigation Committee (NSCIC, 1999; NSC, 1999). The rest came from the IAEA Report (IAEA, 1999) and other reports on the accident in newspapers and magazines.

1. An Overview of the Accident and its background

1.1 Criticality event

The criticality accident took place in the conversion building of the JCO uranium processing plant in Tokai village in Ibaraki Prefecture. JCO had obtained a license to use nuclear fuel material in this building in November 1980. Four years later, in 1984, the company was granted permission to alter this facility to the processing facility, which enabled it to produce uranyl liquid with an enrichment below 20%.

On the day of the accident, operations were being undertaken at the conversion building to produce uranyl nitrate solution with an enrichment of 18.8% (intermediate enrichment) and concentration below 380 gU/l, which was supposed to be used in “JOYO” a fast research reactor.

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 (work unit: about 16.6 kgU) into the precipitation tank which was designed to limit the mass to 1 batch (2.4kgU), 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. At around 2:30 a.m. on October 1, the operation of draining cooling water running through the jacket pipes installed around the precipitation tank was initiated. At 6:15 a.m. on the same day, the criticality terminated. Later, a boric acid solution was injected. At 8:30 a.m. the end of criticality was eventually confirmed.

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 (Fig. 1).

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.

Thus, for the preparation of fuel for the Joyo fast research reactor in late September 1999, workers dissolved uranium oxide powder in nitric acid in stainless steel buckets and poured the solution directly into the precipitation tank. About 26 L of the solution, with uranium enriched to 18.8% 235 U by mass, had been poured into the precipitation tank in four batches on 29 September. In the morning of 30 September, the workers continued to

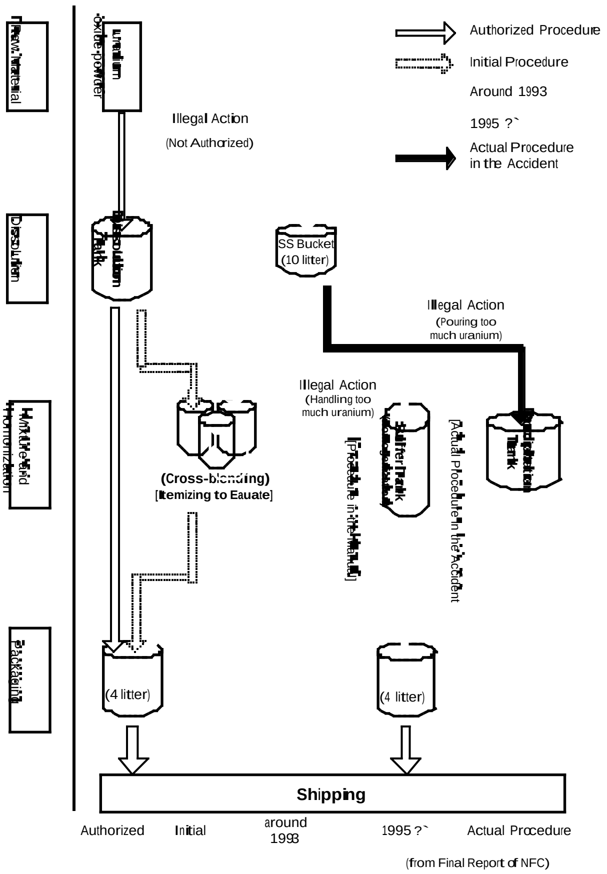


Figure 1 Changes of Procedure to Produce Uranyl Nitrate at the Conversion Testing Center

prepare uranyl nitrate solution and poured three additional batches into the precipitation tank.

At around 10:35 on 30 September, when the volume of solution in the precipitation tank reached about 40 L, equivalent to about 16 kg U, a critical mass was reached. At the point of criticality, the nuclear fission chain reaction became self-sustaining and began to emit intense gamma and neutron radiation. The area gamma monitoring device detected a high level of gamma radiation and the area alarms sounded. The three workers concerned evacuated the building. They were subsequently given assistance by emergency service workers. The other workers on site assembled in the muster zone.

2. Personnel Error

The IAEA Report (1999) concluded as follows:

> At this preliminary stage of assessment, the accident at the JCO nuclear fuel processing facility at Tokaimura seems to have resulted primarily from human error and serious breaches of safety principles, which together led to a criticality event.

Except for the results of sabotage, natural phenomena, and fully informed management tradeoff decisions, all adverse events in high-hazard industries are caused, at least in part, by personnel error. In fact, most events are the result of extended chains of human error that resulted in production of a situation that was susceptible to being converted into an accident by a relatively probable precipitating (triggering or consummating) causal factor (Corcoran, 2000). Human error is behavior (an act or omission) that by itself or in conjunction with other behavior could contribute to the causation of a consequential event.

However, Attributing the causation of an event to personnel error, without deeper explanation, is of little or no use for correcting the causal factors or addressing the generic implications. Personnel error cannot be corrected, but its underlying causes may be corrected, if and only if, they are known.

Unless there is a sufficient set of vulnerability causal factors and one or more triggering causal factors, neither an instance of human error nor a consequential event occurs. A sufficient set of vulnerability causal factors is the set of circumstances that makes “an accident waiting to happen.” Without the sufficient set of vulnerability causal factors, the triggering causal factor does nothing. Without the triggering causal factor, the vulnerability causal factors just wait for the next opportunity (Corcoran, 2000).

3. A Partial Root Cause Analysis

The author tried to identify the underlying causes of personnel error in the Tokaimura criticality accident. The first branch of inquiry is to identify those underlying causal factors that either set up the situation so that the personnel error was highly likely or triggered the personnel error. In most cases each of the vulnerability and triggering causal factors itself has causal factors. The other branch of the explanation of personnel error should deal with the inadequacy and /or non-existence of physical and administrative defenses (barriers) to personnel error.

3.1 Underlying causes of personnel error

3.1.1 Vulnerability causal factors

The development of a loop leading to accident in the figure 2 provided a sufficient set of vulnerability causal factors for the accident. There were two major causal factors behind it.

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 staffs was cut from 34 to 20.

Industrial organizations, including the nuclear industry, presently are facing a changing environment due to deregulation, an aggressive public opinion, and increasing commercial competition. 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 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 (Fig. 1 & 3). 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.

“Kaizen” means a process of continuous improvement involving everyone, taking small, incremental steps and pursuing the goal relentlessly over extended period of time (Tsuchiya, 1996). It depends on spontaneous creation, sharing, and implementation of knowledge at field levels. In Japan, the concept of “kaizen” is so deeply ingrained in the minds of both managers and workers in business that they often do not even realize that they are thinking “kaizen.”

JCO had previously conducted at least four “kaizen” drives and this ‘improvement’ was the seventh. Since all “kaizen” activities are expected to lead to increased customer satisfaction eventually, it was natural that emphasis of the “kaizen” drives at JCO had been on efficiency, cost reduction and quality improvement, and not on safety.

The workers were supposed to take the initiative in “kaizen” drives and, in JCO, the manuals were often revised after the workers had changed the procedures. Management apparently condoned operating outside the company manuals and workers felt free to ‘improve’ production process without getting official approval by supervisors in advance. The famous Japanese tradition - “kaizen” drives by the workers with inadequate training let them finally cross the limits of safe practices.

3.1.2 Triggering causal factors

Three workers called “special crew” dissolved sequentially about 2.4 kg uranium powder with 18.8 percent enrichment in the 10 liter stainless steel bucket with nitric and pure water to produce uranyl nitrate. The procedure of homogenization to uniform uranyl nitrate specified that the narrow storage column-tank should be used to control the process on a one-batch basis. Actually, however, the precipitation tank was used instead. As a result, about 16.6 kg of uranium (equivalent of six to seven batches) was poured into the tank. This was the triggering causal factor of the accident.

The following are some of the replies by the workers to the question why they conducted such a risky work:

- In the last two campaigns (in 1995 and 1996), as much as 16 kg of uranium was poured into the buffer tank for mixing and homogenization. And so, they considered there would be no problems if they pour the same amount of uranium into the precipitation tank (Fig. 1).
- The buffer tank was inconvenient for mixing and homogenizing uranium.
- Bad working condition made them want to finish the work as quickly as possible.
- They wanted to finish the dissolution work as early as possible because they planed to train new comers who would join the “special crew” in October from the first phase of the dissolution process.

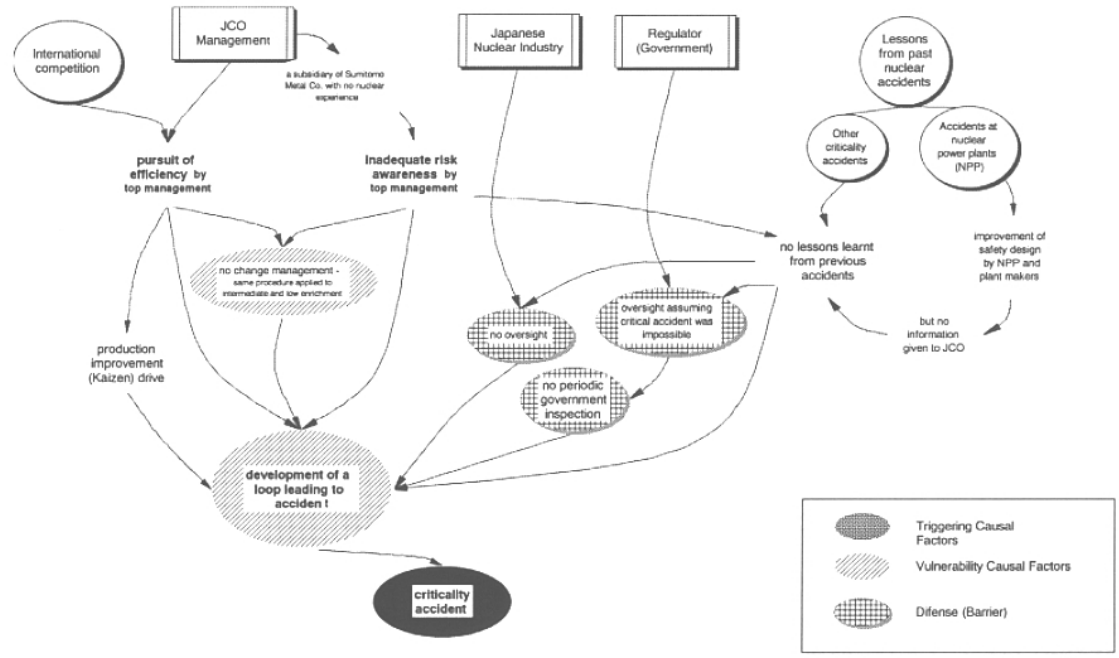


Fig. 2 An overview of JCO accident

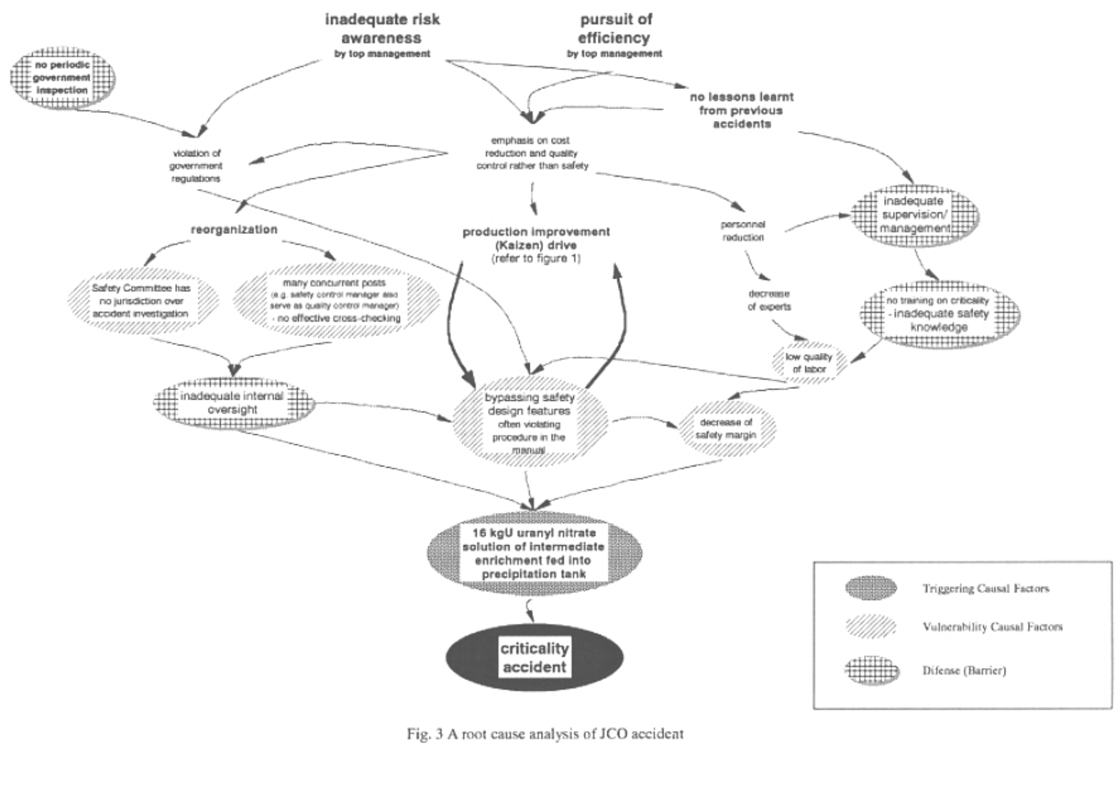


Fig. 3 A root cause analysis of JCO accident

3.2 Non-existing or inadequate defense (barriers)

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 (Corcoran, 2000).

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.

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.

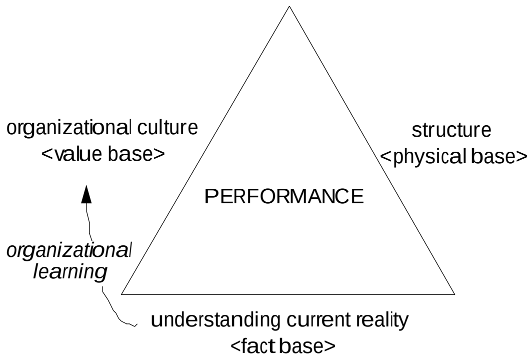
In the case of Tokaimura accident, all of these four levels of defense were either did not exist or inadequate (Fig. 2 & 3):

- 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. Self-assessment by plants is perceived to be a crucial capacity for safety assurance and continued improvement. Two important indicators of self-assessment capacity are the extent to which employees bring problems to management and management's openness to critical feedback (Carroll, 1998). However, We cannot expect workers to express safety concern unless they have adequate safety knowledge.
- 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. At the time of the accident, the production batch was intermediate enrichment uranium. Actually, before the three workers started the operation on September 29, 1999, they asked an expert in the management if it was safe to homogenize solution by mechanical

stirring in the precipitation tank (refer to Fig. 1). The expert replied it was safe apparently misunderstanding that they were going to process low enrichment uranium.

- 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. The reorganization in 1992 weakened internal oversight. As a result, for instance, the safety control manager concurrently served as the quality control manager. His emphasis was inevitably on quality control to satisfy customers. The safety committee lost jurisdiction over accident investigation.
- 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. They also did not try to learn

Based on this analysis, the authors argue that the root cause of this accident was inadequate organizational knowledge about nuclear safety. Appropriate knowledge was not diffused in the organization because of (1) improper understanding of the gap between the normative model and their current reality and (2) lack of ability to maintain open communication. These two factors prevented the organization from learning.



The authors have made further research on four additional incidents occurred recently and confirmed that their root cause was also inappropriate organizational knowledge due to misunderstanding of current reality and inadequate openness. The four incidents are Snow Brand Milk (food poisoning), Mitsubishi Motors (customer complaint cover-up scandal), American nuclear submarine (smashing into and sinking a Japanese training vessel), and Japan Airline (near midair collision).

4. Understanding Current Reality

Less than one month before Tokaimura accident at the 3rd International Conference on Human Factor Research in Nuclear Power Operation, Kazuo Sato, Chairman of Nuclear

Safety Commission in Japan, proudly spoke, “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” (Kondo, 1999).

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” (Sato, 1999).

4.1 JCO

Tokaimura 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 did not only prove valuable for safe nuclear power, but also was a causal factor of the accident in the authors’ opinion.

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 (ACSNI, 1993). We may understand safety culture as that aspect of an organization culture through which all relevant actors treat risk and safety in nuclear installations (Wilpert, 1999).

International comparisons of production efficiency have suggested that “kaizen” culture may be an important determinant of some of the Japanese superior performance. “Kaizen” is closely associated with quality control. With its different systems of motivation and reward, “kaizen” is vital to the success of quality control circles.

Like many other Japanese companies, JCO was devoted to “kaizen” activities. However, the main purpose of the activities was to improve quality of products and attention to safety was limited to prevention of workers’ accidents in general not including nuclear safety. Encouragement of “kaizen” often results in organizational culture where improvement takes precedence over written manuals. In JCO, managers and workers made light of manuals and considered operating outside written controls to be acceptable. For instance in 1995, the Safety Committee of JCO investigated the actual procedures in operation and approved them as safe procedures with no criticality danger. In 1996, JCO revised its manuals confirming the actual procedures in the facility.

4.2 A New Methodology

In search for a new methodology to improve safety culture, the first author has recently developed a policy exercise for crews of reactor control rooms of nuclear power plants.

4.2.1 A Policy Exercise

Based on the results of their recent research projects, the authors claim that policy exercise, a specific type of simulation, can improve implicit social norms that are predictors of safe performance in a reactor control room.

All control and steering activities in a reactor control room are highly structured. Practical observations show, however, that explicit rules are not always followed (Ignatov, 1999). Implicit social norms seem to define the 'proper' conduct of operators. Implicit social norms are what Aryris called 'theory-in-use' that actually guides behavior, that tells group members how to perceive, think about, and feel about things. Changing theory-in-use requires double-loop learning that is intrinsically difficult because (1) theory-in-use is often unconscious and taken-for-granted and (2) any attempt to reveal its incongruity with the organization's espoused theory would be perceived as threatening or embarrassing.

4.2.2 Description of the Actual Work

The first author induced hypotheses about the unique contribution of gaming/simulation through two detailed case studies, and verified their validity by additional case studies and theoretical reasoning (Tsuchiya, T. & Tsuchiya, S., 1999). Based on the hypotheses, the authors have recently designed a policy exercise called 'the Hidden Formula' for crews of reactor control rooms, run the exercise for the trainers of the BWR Operator Training Center (BTC) in Japan several times, and analyzed outcomes in details.

(1) Primary Objective

The primary objective of this policy exercise is to train crew members in the cognitive area. This exercise can open their mind for reexamination of their implicit social norms and motivate them for making spontaneous efforts in their daily work to improve them. The first step is to let them realize what their implicit social norms actually are. Then, through experience in the exercise, let them learn what they need to do with their norms.

(2) Brief description

There are three perspectives and five roles in this policy exercise - one leader, one sub-leader, and three operators. The leader is to guess the hidden three numbers in the displays in front of the three operators and deduce the numerical formula applicable to these numbers.

On each display, a part of the three numbers is hidden behind the panels. One of the panels opens randomly for one second showing a part of the figure. The operators make verbal report to the leader and sub-leader what they see in the display. They are not allowed to record what they see.

The leader, assisted by the sub-leader, records the reports. It is difficult to record every utterance because two persons have to cover three reporters. In addition, since each operator has only a few seconds to make a report, a detailed report of an operator will force other operators either to make overlapping utterance or to skip a report.

Immediately after the exercise, the process of the exercise is reproduced on the screen so that the participants can make objective observance of their own activities. Three personal computers, three scan converters, a multi viewer, two video cameras, and a digital video recorder keep complete record.

(3) Special features

This exercise uses three PCs instead of game boards although it is designed for human interactions. It gives the following special features:

- The facilitator can reproduce the process of the exercise immediately after the exercise.
- The process as well as the results of the exercise can be fully analyzed later to assess performance of the crew and its members.
- The facilitator can also show the participants the activities of other crews for comparison.
- After several months, the participants can play this exercise again and compare their activities with these of the previous exercise to see if they have actually improved their implicit social norms.
- The facilitator can adjust the level of difficulty easily so as to keep all participants interested in the exercise.

4.2.3 Results

In 2000, after many test runs, the authors ran the 'Hidden Formula' for the trainers of BWR Operator Training Center - three times at Kariha and three times at Fukushima with intervals of about four weeks.

The authors analyzed the results and discussed with the president, participants and other trainers of the Center. They came to the following conclusions:

(1) This exercise enables participants to objectively observe their own activities that are often quite different from the image they have in mind. Acknowledgement of the gap between reality and normative model opens their mind for learning. The exercise can encourage the crew members to reexamine and improve their implicit social norms in their daily work.

(2) Observing other crews' activities, crew members can improve their normative model about activities in the reactor control room.

(3) By analyzing the process, trainers can assess implicit social norms of the crew and give necessary guidance.

5. Openness

Upward communications for difficult issues are often lacking (Argiris, 1990). Diffusion of employees' knowledge requires "openness" - both on the norm of speaking openly and honestly about important issues (participative openness) and the capacity continually to challenge one's own thinking. (reflective openness). Participative openness, the freedom to speak one's mind, is the most commonly recognized aspect of openness. While participative openness leads to people speaking out, "reflective openness" leads to people thinking inward. Reflective openness lives in the attitude, "I may be wrong and the other person may be right."

In all of the five cases mentioned-above, inadequate openness hindered knowledge from diffusing. For instance, in the case of the nuclear submarine accident, one of the crews in the control room said later he had thought the surfacing exercise being dangerous but not mentioned it because it would have embarrassed the Captain. The control room was too crowded with civilians for safe operation.

The first author is now designing a policy exercise to enhance openness in nuclear power plants for Tokyo Electric Power Company.

6. Conclusion

Based on their systemic analysis of the accident, the authors claim that its root cause was combination of (1) inadequate risk awareness by the top management and (2) "kaizen" (production improvement) drives. Famous traditional Japanese culture "kaizen" inadvertently brought about overconfidence in nuclear safety in Japan. Tokaimura accident made it clear that "kaizen" culture can be a fundamental causal factor of nuclear accident. The present circumstances now call for a shift in consciousness from the safety myth in nuclear power. The nuclear industry must attain efficiency and safety at the same time. The authors argue policy exercise can be a new methodology to improve safety culture that is meta-level knowledge to ensure safety.

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