ANALYSIS OF JCO CRITICALITY ACCIDENT FROM VIEWPOINT OF RISK MANAGEMENT

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ABSTRACT

The uranium criticality incident at a JCO plant in 1999 was Japan's worst-ever nuclear accident (INES Level 4). Sixty-nine persons were exposed to radiation, and of those two died. SMM, JCO's holding company, paid out about 11 million dollars in compensation to people and companies in the affected area. The direct cause of the accident was very clear: use of an illegal new process to improve productivity in the manufacture of nuclear fuel allowed the uranium concentration to reach criticality. JCO had a license that allowed it to handle uranium solutions up to 20% in concentration, and all processes and tools used to produce nuclear fuel were prescribed in detail so as to prevent criticality by STA, the competent authority. JCO successfully developed and introduced an easier production process without obtaining permission from the STA. After a yet more efficient process was introduced, following only a very cursory check by a qualified JCO engineer, the accident occurred.

The authors analyze this accident from a RM (Risk Management) viewpoint based on a MPM (Mathematical Planning Method) using released data pertaining to the accident. The authors first explain the MPM in brief, propose a matrix method of modeling, and then describe the results of simulating the JCO accident. It becomes clear that, even with imprecise and rather limited data, the proposed risk management method is applicable.

The authors conclude that, beyond serious human error, there were many causes of the JCO accident. These could be described as the 'overall circumstances', and the important ones were administrative inflexibility, the fear of nuclear reaction, and recession in the Japanese economy. The latter was the most powerful influence.

INTRODUCTION

Planning is a diverse function, and conventionally there has been no general methodology applicable to planning in all its manifestations. About 10 years ago, the authors and others formed a research group under the name RGMP (The Research Group of Mathematical Planning) with the aim of rationalization and generalization of planning.*1 The majority of the members were structural engineers, so they first took their analogy of planning from continuum mechanics, a technique that has established itself as very successful in modeling and mathematical applications for the expression of real mechanical phenomena. An added attraction for this group was that this type of mechanical analysis can generally be carried out by computers using approximate methods like FEM (Finite Element Method).

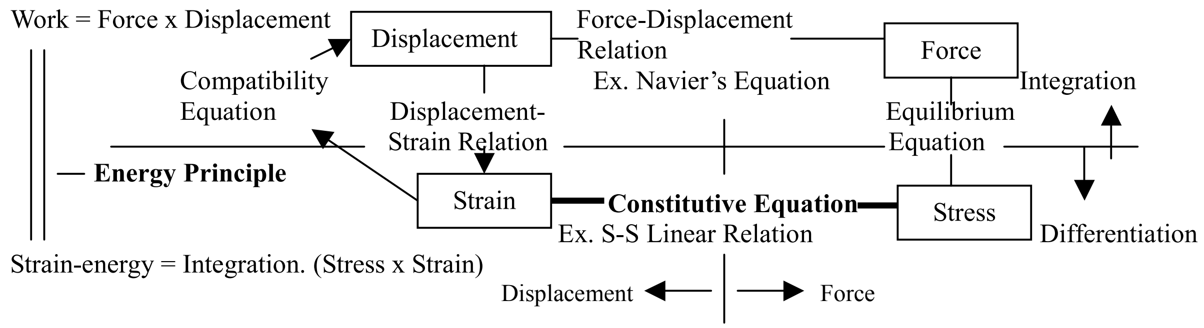


Fig.1 Basic Structure of Continuum Mechanics

In continuum mathematics, it is the constitutive equation that ties deformation and force that plays the most important role. Likewise, the relation linking planning with society might rule over the overall scheme (fig. 1). The fundamental principle of mechanics is that of energy; energy pierces the micro, mezzo, and macro models of mechanics. In planning, it is difficult to say what constitutes the equivalent of the energy principle, though the "selfish gene" might be cited: in every decision-making process, a person acts selfishly within the range that others allow him or her to take the action (usually limited by law). Considering this, it might be possible to develop mathematical planning methods (MPMs) based on analogies to fields other than mechanics.

Planning belongs to the group of time-series problems, and has spiral structure in which a cycle consists of four spaces: problem, structure of the problem, solutions, and choice of solution. Each space is connected to its neighbor-spaces by mapping relations (fig. 2). The cycle can also be written in the form of a flowchart, as in fig. 2. Both information and knowledge are essential to planning, and this is to be supplied through a net called a VRI (Virtual Research Institute).*2

MATHEMATICAL PLANNING

A problem arises in the form of a gulf between one's desires and the actual situation. It is usually impossible to realize one's desires completely, so compromises are made, taking into account the risks and returns. This is the selfish gene acting to set up a solution to the problem; in other words, planning. This step is called the problem space.

The next space is the structural space, in which a rich and authentic store of information and knowledge is required. It begins with analysis, and various methods like check-sheets, flow-charts, event-trees, etc. are applied to the task. Following this is synthesis, when a model of the problem is set up. The plan-object and the surrounding circumstances, including societal factors, are related to functions and data. The model is verified using actual data. Naturally, simple models incorporating the important characteristics of the actual phenomena are preferable. In the case of simulation with computers, automatic modeling is preferable; object-oriented knowledge is piled up on an object-circumstance sheet. In risk analysis and management against natural disasters such as earthquakes, maps are often used as object-circumstance sheets. This reflects the importance of geographical relations and the GIS (Geographical Information System). For mapping of the model into mathematical formulas, a matrix formulation ($\mathbf{kx} = \mathbf{b}$) is adopted for a short time span Δt even in non-linear problems, as $\mathbf{k}$ usually depends on $\mathbf{x}$ and $\mathbf{b}$ directly or indirectly. Therefore, integration with respect to time t is required.

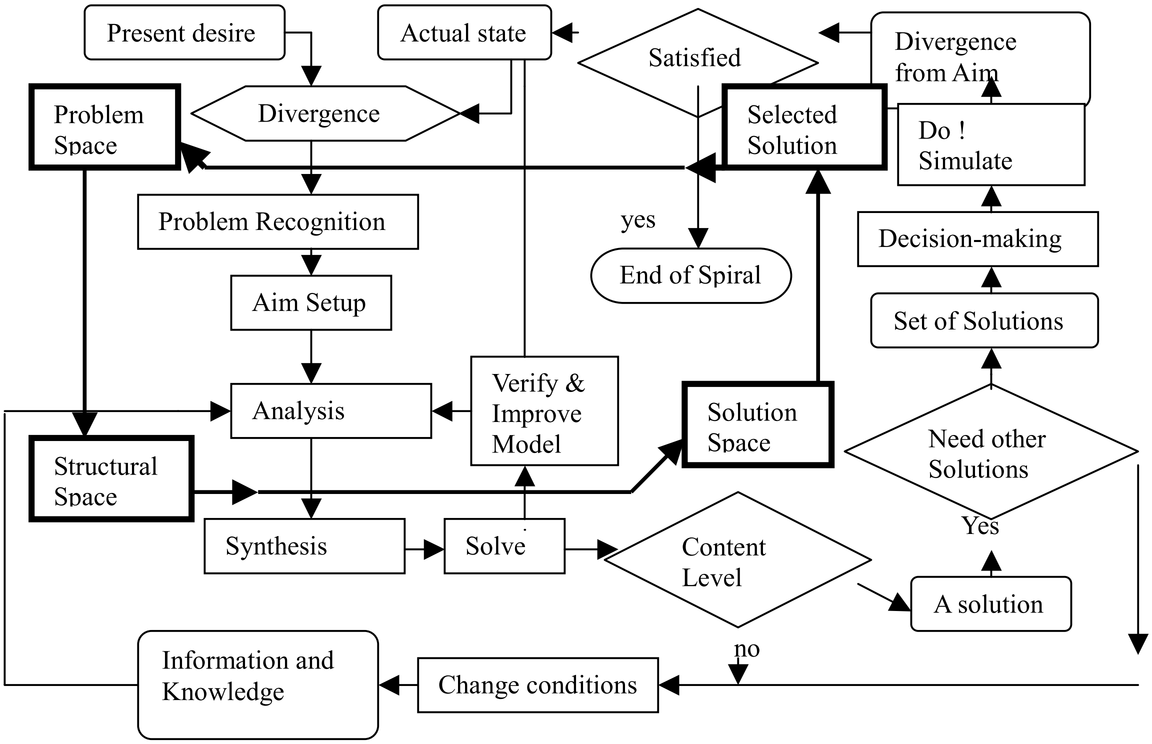


Fig. 2 The Four Spaces in the Planning Circle and Flow Chart of Mathematical Planning

Extracted information such as decreased risk and increased cost is obtained from **g**, the matrix product **f b = g**. Here, **g** is a vector with a minimum size of 2 x 1, and is usually bigger with additional components which give some of the information available at decision-making. Possible solutions that may lead to a certain contentment level for the persons concerned accumulate in solution space, and some decision-making method is used to make a choice of solution. The process of optimization is included in the process of accumulation and selection of solutions, so this is a form of Monte Carlo Method.

RISK ANALYSIS

Risk is a function involving p_i and c_i as the arguments, where p_i is the probability of an undesirable event "i" occurring, and c_i is the cost of the event. To simplify the matter, the sum of these products, $R = \Sigma R_i = \Sigma p_i c_i$, is often used to express the total risk of unwanted events. When R_i is the product of p_i and c_i, and is a constant, it can be expressed by a hyperbolic curve on the c-p plane. This may be called the risk curve. People tend to be more fearful of "small p_i, big c_i" outcomes than "big p_i, small c_i" ones, even for the same value of R_i. The authors accept that risk is the product-sum of p_i and c_i, and that the value of R_i is dependent on c_i. Though the application of a logistic curve is suitable to express human psychology (fig. 4b)), a linear function of c_i is used for the modification of R_i in this paper for simplicity. A result of this is that the risk curve in the c-p plane becomes a hyperbola that crosses the line p = 0 at c = Ca, and Ca is the maximum allowable cost that a person or company, etc. will bear (fig. 4a). The risk curve changes with changes in event characteristics. In the realm of risk management, the curve corresponding to tolerable values of R_i is selected as the risk curve. It is fuzzy by nature, but the application of fuzzy theory to MPM will be our next step.

The aim of risk management is to decrease the values of R_i for all events and bring them below the risk curve. That means, on the c-p plane, moving points initially to the right and in the upper range of the risk curve down and to the left.

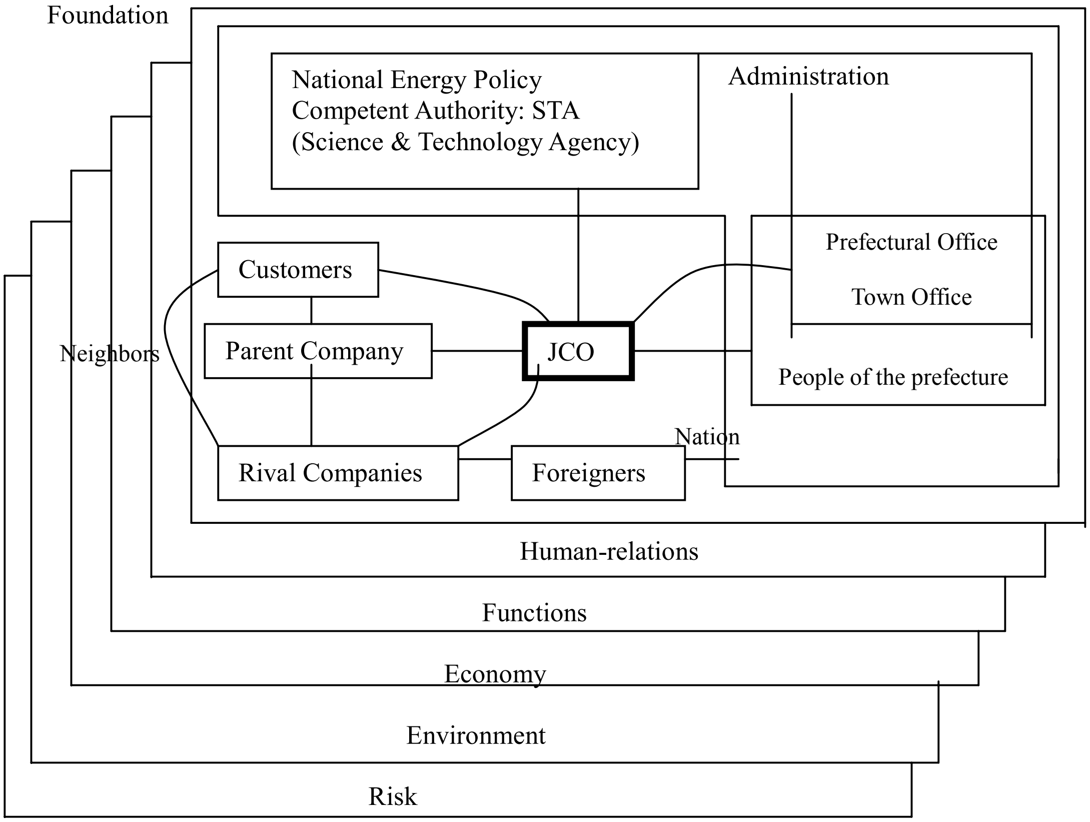


Fig. 3. Object-Circumstance Diagram

JCO ACCIDENT OF 1999

JCO and related sub-elements

JCO is a uranium-fuel manufacturer, and a subsidiary of Sumitomo Metal Mining (SMM). In 1998, it had 110 employees, and sales were 1.72 billion yen with a capital of 1.0 billion yen. The company's head office is in Tokyo, and the factory is in Tokai Village, Ibaragi Prefecture (which is administered from Mito City). The factory is located very close to Naka Town. The first Problem-Circumstance diagram drawn by the authors is shown in fig. 3. Generally, the problem is first specified, but in this JCO case the aim is to work out what problems led JCO to the big accident.

JCO is closely related to SMM (its parent company), the STA (Science and Technology Agency, the competent authority), customers, rival companies, local government (the prefectural, village, and town offices), and people living near the site.

In mapping the object-circumstance diagram into mathematical formulae, sub-elements such as JCO and SMM etc. are expressed in the form of block-matrices like $\mathbf{k}_{JCO}$ and $\mathbf{k}_{SMM,\ etc.}$, and these block matrices occupy a diagonal through whole **k**; that is, it forms a kind of state matrix. The non-diagonal portion of matrix **k** is filled with inter-relation-matrices, and many of them are zero elements. To make matters simple, only the diagonal blocks in matrix **k** are checked in the first place; that is, interrelations between sub-elements in the model are initially neglected. For example, in order to understand the financial condition of the company, a Z-score (an index expressing the possibility of bankruptcy) is calculated from data such as capital, annual gains, market prices, internal reserves, etc. When more data become available and the time history of the company's condition is clear, the survival and development tactics of the company are clarified through this kind of analyses.

Though there is a paucity of released data regarding the accident, it became clear through the analysis that the financial condition of JCO toward the end of the 20th century was not good. Productivity per person was very low, and survival of the company looked to be in doubt without some change, either external or internal. In the final model, the size of the matrix $\mathbf{k}_{JCO}$ is decreased to 5 x 5, and the diagonal elements of matrix **k** represent staff quality, characteristics of pollution, information-gathering capability, continuity of customer orders, and risk-character. The non-diagonal elements are fixed from the diagonal elements; for example, salaries appear in the fourth row and the first column. The **x** vector consists of a sufficiency of employees, ecology-invest ratio, information-invest ratio, profit-ratio, and risk-measure-investment ratio. Vector **b** has elements like human-relations, environmental improvement, future development, current conditions, and degree of risk. SMM, JCO's holding company, had moved a number of employees to JCO before the occurrence of the accident. But this caused an imbalance in the staff composition: there were too few factory workers compared with the number of executives and office workers. The relationship between JCO and STA was not very close; after JCO obtained its license as a nuclear fuel producer, STA held no reservations in trusting JCO to be law-abiding, believing that all JCO staff were familiar with criticality. Further, STA knew that the licensed production process was safe enough even allowing for human error. In the model, STA is tied to JCO through functions and risk.

Tokai Village is known as the nuclear center of Japan, and is home to factories, research laboratories, and a number of power plants. The people of the area have come to accept the situation. Besides, none of the inhabitants knew that they lived close to such a dangerous firm as JCO until he accident occurred. Thus, relations with local people and local government offices were normal. In the model, JCO is tied to its neighborhood by human relations, functions, economy, environment, and risk. Rival companies are indirectly connected to JCO via customers, while customers are chained to JCO through human relations and economy.

Financially, JCO seemed to have used up all its reserves in the era of opposition to nuclear power, and financial stability was poor. Since the Plaza Agreement of 1985, yen/$ rates soared and Japanese industry was faced with competition from cheap foreign products. JOC was not an exception, and it should have worked to increase productivity to face the competition. As a result, the principle of "safety first" was forgotten. This was the main cause of the accident.

The accident as time series

The authors drew up a time-series table of the accident from the scattered information available. This gives a general picture of the disaster (Table I). A fish-bone diagram then makes the cause of the problem clear. The diagram is redrawn to eliminate interrelations between the terms.

Table I. Time-Series of JCO Accident Process

1973, Feb.	SMM (Sumitomo Metal Mining) factory built in Tokai Village. By 1980 it was owned by Nippon Nuclear Fuel Conversion Company, a subsidiary of SMM.
1980, Nov.	Obtained license to handle nuclear materials. Processing license obtained in 1984 (with the concentration of uranium liquid limited to below 20%).
1986, Oct.	From this date (till 1988, Feb.) the licensed and legal process was used with a melt-tower.
1993, Jan.	Illegal process was came into use, where stainless containers (usually called buckets) were used instead of a melt-tower. This was entirely illegal and dangerous, but company staff provided manuals for the process.
1998	Change the firm name to JCO.
1999	
Sept. 10	Manufacture of highly condensed uranium 57 kgf started for FBR fuel.
Sept.29	Production of refined triuranium-octoxide batch was completed in the morning ahead of schedule. (Due on Oct. 8.)
	In the afternoon, the next process of dissolving the material into nitric acid began. A new method not described even in the illegal manuals was tried, following the suggestion of the vice-chief of a workers group. He had asked a licensed nuclear-fuel engineer about the idea, and had got an OK. The engineer's misjudgment was the direct cause of the accident. Instead of a store-tower, a settling tank was used, into which 9.6 kgf (4 buckets) of uranium liquid wereplaced before the day's work ended.
Sept.30	
8:00	Work restarted. 7.2kgf (3 buckets) uranium was to be put into the tank.
10:35	As the contents of the third bucket were added, criticality occurred. Two workers near the tank collapsed, and the alarm signifying abnormal levels of radiation rays went off. This was followed by announcements recommending evacuation of the factory.
10:43	JCO requested an ambulance from Tokai Village fire-station without mentioning the radioactive accident (meaning that the rescue crew were exposed to radiation). It took time to find a suitable hospital for the irradiated workers. At 11:49 three workers were dispatched to Mito National Hospital, then transferred to the STA Radiology Research Center by helicopter, arriving at 15:25, about 5 hours after the accident.
11:19	JCO informed STA of the accident, described the rescue process used for affected workers, and noted the possibility that criticality was reached.
11:22	JCO informed the nuclear power safety section of Ibaragi Prefectural Office about the accident.
11:30	The Tokai Village fire-station reported the accident to the Tokai Village Office.
11:34	The first report of the accident was made by JCO to the village office.
11:55	The first data on radioactivity levels in and around JCO reached STA.
About noon	Investigation by local STA officers at Tokai Village got under way.
12:15	A countermeasures center was set up in the village office.
12:29	The second set of data on radioactivity levels reached STA.
12:30	The accident was announced at a press briefing in Ibaragi Prefectural Office.
	First news of the accident reached the prime minister's official residence by way of the STA.
	The Tokai Village Office asked villagers to stay indoors via wireless. (Two hours had passed since the accident.)
12:46	NHK (Japan's national broadcaster) announced the accident over TV and radio. About 60% of villagers heard about the accident by way of the broadcasts.
About 13:00	STA dispatched the vice director of the Safety Bureau to JCO.
13:30	Naka Town (located near the JCO site) asked all townspeople (about 4,000) to stay indoors.
14:30	A disaster measures center was set up at STA.
15:00	The Tokai Village Office decided to evacuate people living within 350 meters of the JCO site.
	The government set up a disaster measures center to reinforce the STA center.
15:23	The new center decided to convene an Emergency Advisory Committee.
15:30	STA set up a local disaster measures center at STA, Tokai Village.
16:00	Ibaragi Prefecture Office opened the Nuclear Power Disaster Center.
	The Chief Cabinet Secretary met the press and denied the possibility that the accident was not contained. (Incorrect information)
18:00	The Emergency Advisory Committee went into session. It judged that criticality was still continuing, and decided to send experts to the site.

18:40	Naka Town decided on evacuation of people living within 350 meters of the JCO site (8 hours after the accident).
20:30	Ibaragi Prefecture Office talked with STA about a draft of the refuge-plan.
21:00	A countermeasures headquarters presided over by the prime minister was set up.
22:30	The Ibaragi Prefecture Governor requested people within 10 kilometers to stay indoors, partially closed a national road (Route 6) and an expressway (the Jouban Expressway), prohibited people drinking water from wells, and ordered a change in water intake locations. Schools were closed.
Oct. 1	
2:35	Water was drained from pipes around the settling tank through a drain pipe.
4:40	The water was completely expelled after argon gas was blown into the piping.
6:15	Criticality came to an end.
8:19	Boric acid was added to the tank to absorb neutrons.
8:50	The end of criticality was confirmed by experts.
9:20	The Nuclear Safety Committee announced to the press that the criticality incident was over.
16:30	Ibaragi Prefecture Governor's advice to stay indoors was revoked.
Oct. 2	
18:30	Evacuation order within 350 meters of JCO was revoked.
Oct. 4	The Countermeasures Headquarters and other centers were disbanded.
Dec. 21	One of the exposed workers died.
2000	
Apr. 21	A second exposed worker died.
July 15	Compensation negotiations between JCO and Kume-nattou, a food company, failed. Kume-nattou claimed 3.6 billion yen in compensation, but JCO offered only 0.037 billion yen.
Sept. 20	A victims group submitted to the prime minister the signatures of 25 thousand people who were claiming compensation for damaged health caused by the criticality accident. SMM, the JCO holding company, announced a payment of 14.5 billion yen, including 13 billion yen for compensation payments, as a special loss of the company.
Oct. 11	The Mito Local Public Prosecutors Office (MLPPO) arrested former JCO executives on charges of accidental homicide.
Oct. 30	The Nuclear Power Steering Committee of Ibaragi Prefecture gave approval for development efforts related to the nuclear fuel cycle to restart.
Dec. 19	A public hearing was held for the compensation claims of a marine product processing company; the claim was for 61 million yen. By the end of November, 135 out of 7,040 compensation cases were yet to be solved.
Dec. 20	The third injured worker left hospital. He still required home-based care.
2001	
July 15	The MLPPO prosecuted former executives of the company, including the director, on charges of accidental homicide.

Illegal process

JOC had made nuclear fuel for Jyoyo, a research fast breeder reactor (FBR), on an irregular basis at intervals of a few years. The manufacturing process for this fuel is as follows: 1) dissolve uranium-oxide in nitric acid in a dissolution tower; 2) extract nitric-acid-uranyl-salt through extractors; 3) blow ammonium gas into the uranyl-salt to cause uranyl ammonium to settle in a settling tower; 4) obtain refined triuranium-octoxide through thermal decomposition of the uranyl ammonium; 5) dissolve the refined material in nitric acid in a dissolution tower to obtain the final product, liquid nitric-acid-uranyl; 6) pour the product into 4-liter containers using a cross-blending method for homogenization. (This blending process was time-consuming and boring work, and the workers probably hoped for some improvement.)

Until February 1988, the licensed and legal process was used. The illegal process came in during Jan. 1993. Instead of the dissolution tower in step 5), stainless containers (bucket) were used. Then, step 1) was similarly changed. No trouble was had noted with this illegal process until JCO made a further change.

The accident happened during step 5), when the settling tower used in step 3) was reused to homogenize the product in the buckets.

To avoid criticality, the diameters of containers and towers should be less than a certain size determined from the concentration of the uranium solution. Since JCO had obtained a license to treat uranium solutions up to 20%

concentration, the maximum diameter was set to 17 cm. However, the settling tower (45 cm in diameter) was larger as it was supposed to be safe when connected to other diameter-limited instruments and pipes. The process was protected by both an equipment-size limitation and a material-quantity limitation in order to eliminate human error. It was use of the settling tower as a mixer that bypassed the safeguard against human error.

Human error

JCO carried out illegal activity: it developed and implemented an illegal manufacturing process, and even provided illegal manuals for this illegal process. In that sense, the accident cannot be attributed to human error, but to a crime. Yet the immediate accident was caused by human error. The organization of JCO was not specific; under the head of the firm, there were three directors. One director was in charge of the manufacturing section, where a manager looked after five groups of workers. Each group was a team of five: a sub-manager, a foreman, and three workers. A group usually engaged in waste liquid processing was in charge of the work to produce enriched nuclear fuel. Of the three workers, two were very new to the work. The sub-manager asked his manager, who was certified in the treatment of nuclear fuel, about the possibility of using the settling tower as a mixer and, after several hours, received a positive response. Faced with the accident, this manager excused himself by saying that he thought the question was about thin (5%) liquid not the enriched one (18.8%). This manager's misunderstanding triggered the accident.

SIMULATION FOR JCO RISK MANAGEMENT

Using MPM, the state of JCO and its environment before and during 1999 is expressed in matrix form. After the **k** matrix is condensed, it reduces to a small as 19 x 19. (The block matrices along the diagonal of **k** have sizes JCO 5 x 5, SMM 2 x 2, customers 2 x 2, STA 2 x 2, local governments 4 x 4, and the neighborhood 4 x 4.) The size of vectors **x** and **b** is 19 x 1 each, and **f** is 4 x 19. The vector **g** has four components: risk, return, sustainability of JCO, and contribution to the government's energy policy. Some elements of matrix **k** are functions of **x** and **b**, and the small increment in time Δt is set to a quarter of a year. Verification of the model (**k** matrix) is initially carried out with reported data covering the three years up to the accident, and data for 1999 is estimated for the assumption that the accident did not occur.

The small size of matrix **k** means that the analysis is not precise and so does not offer much detail. Some of the values used consist of a simple ranking, such as bad, average, or good, because of a shortage of relevant and accessible data. However, accuracy is adequate to get an overview of the company and its circumstances, and may be sufficient to carry out risk management for the company. For example, the probability of a criticality accident cannot really be expressed as a percentage, but the simulation indicates that it is high. Another example is when a verification system is modified from a direct one to a parallel one, risk becomes much lower if it is reasonable to treat the error in human action as small, such as 10%.

Solutions are obtained for variations in the **x** vector, and through this analysis the state of JCO around the first half of 1999 (before the accident) can be clarified as follows.

The employee count can be deduced to be about 70% of that in 1999, in the simulation. There are appropriate numbers of workers and engineers, but too many executives and office staff. The imbalance results from the relationship between JCO and SMM, the parent company. JCO is expected to provide jobs for excess staff of the parent company. Loose ties with SMM with respect to human relations would be preferable to JCO.

Introduction of parallel verification systems is effective.

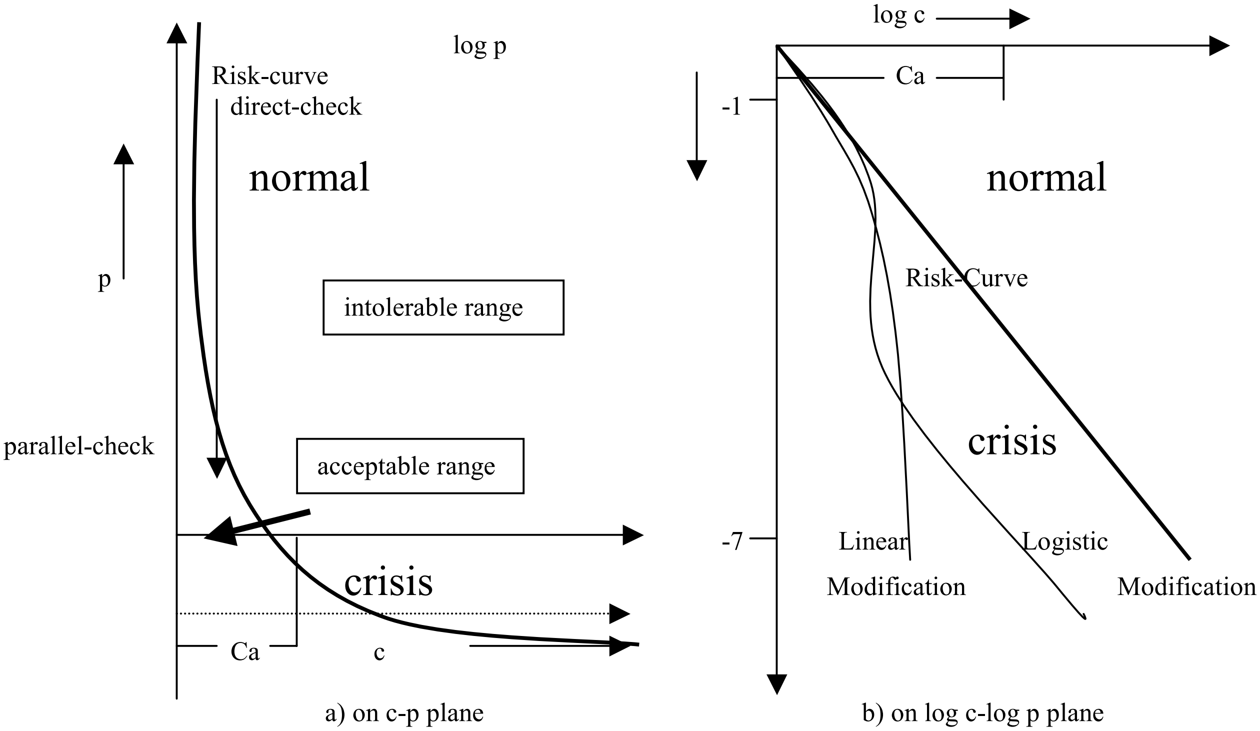
A parallel verification system might reduce efficiency, but costs would not be much higher. If an illegal process is in fact implemented, strict verification is essential.(Though the authors would never condone the introduction of illegal processes.)

The legal process prescribed by STA was safe but inefficient. And since this type of work comes in only once in a few years, the simulation shows that JCO was able to work within the legal process for this occasional task without a big overall loss. For the company such a small loss incurred through use of the legal process might be considered a kind of investment in the future. However, under very difficult financial conditions, JCO possibly decided to turn this into a profitable business, even though the work was occasional and small, even resorting to an illegal framework to achieve profitability.

The inflexibility exhibited by the competent authority fostered secrecy and underhand activity at JCO. If there were a means by which new, safe, and efficient processes could be proposed to the authority by private companies, careful verification would be possible by both the company and the authority. However, such a counter-proposal system may not be welcomed on either side; the authority may be reluctant to take responsibility for accidents if safety were compromised, and the company may be reluctant to release details of an efficient method that it has invented. Such an invention can be considered part of the company’s expertise and its profit-earning potential. This contradiction helps to illuminate the fact that only tacit consent of illegal processes allows the nuclear-energy-industry develop while satisfying the government.

Illegal manuals are hardly an admissible way to operate. However, a long interval between work orders, such as the few years of this case, requires that manuals be written. Even if covering an illegal process, they work in that the process can be followed accurately. A new process that is not even described in an illegal manual must never be introduced. If any new process is worthy of consideration, then it is important to carry out a careful study followed by changes to the manual.

Occasional tasks carried out at long intervals may lead to trouble, since workers will not be accustomed to the work. Also, instruments and equipment may not be efficiently used or even left in a corner of the factory. This leads to a poor work situation form the workers’ point of view. In cases where a large market is not foreseen in the near future, such occasional work should be turned down. JCO should still be in business, if the accident had not have taken place. Staff at small factories should be specialists not generalists.



a) on c-p plane

b) on log c-log p plane

Fig. 4. Risk-curves

The Japanese people are concerned about nuclear energy. Even with 80% of our energy coming from outside the country and nuclear power offering a clean alternative, attitudes in Japan are still anti-nuclear. Bringing the population around requires the government to act with excessive safety with regard to nuclear-related matters. But the result of this is that the competent authorities become inflexible, and as already noted encourages nuclear-related-companies to be secretive. The result is that nuclear accidents both in Japan and elsewhere cause a hatred of nuclear power.

Risk-education is effective. It need not cost more, but it can decrease risks remarkably. It is essential that everyone at a factory like that operated by JCO knows about criticality and why only a small quantity of uranium may be treated in a process at one time.

Product pricing has a considerable effect on the solution in the model matrix. In a period of recession, manufacturers have to achieve low prices. In general, they will sacrifice safety for price. Prices that are too high lead to bankruptcy, with few exceptions. That is, during a recession, it is not possible to prevent an increase in risk unless there are no rival companies.

CONCLUSION

The application of a mathematical planning method (MPM) to risk management (RM) was explained and the JCO criticality accident was analyzed using this method. It was clarified that the method offers certain advantages: it incorporates important factors without fail and is very suitable for computer analysis. To consider similar problems in future, it may be possible to provide a general form of $\mathbf{k}$, a state matrix, that was is generated by hand this time.

One outstanding problem is the lack of data to properly fill out the whole matrix. In the JCO case, this shortage of the data was overcome by adopting a rough ranking method, and as a result the system was able to operate with quite rough data. Also, the matrix was condensed by hand in this case, but it would be easy to apply a computer to the task by erasing elements that are zero and that have small absolute values.

The recommendations extracted from the simulation results for JCO are a decrease in the number of high-ranking staff members and office workers, elimination of occasional work (thus maintaining specialization in the work group), establishment of a parallel verification system, and accident prevention education for staff and workers.

At the same time, this work made it clear that the whole nuclear industry, not just JCO, is being pulled in two directions. The Japanese people fear nuclear power through its connection with the atomic bomb. Yet Japan has insufficient energy and currently relies on nuclear power. The Japanese government needs to persuade people of the merits and safety of nuclear power, and also requires that the nuclear industry is safe against natural and artificial disasters. To avoid public anxiety, the industry and the government pursue secrecy, and this in turn sows doubt in people's minds. Accidents at home and abroad make the nuclear industry look deceptive, and as a result the regulations become more severe.

Now, yet another force is acting on the industry. With the end of the cold war and growing industrialization in developing countries, global prices are being forced downward. It is almost impossible to manufacture very safe products under severe cost pressure, so efforts to cut costs are the norm. The authors fear that safety margins may be gradually peeled off if there are no regulations specifically requiring them. There is less and less room for an engineer's judgement to be exercised.

REFERENCES

:*1 M. Izumi, S. Kurita, and others, Mathematical Planning, Proceedings 5th EAPCSEC, July 1995
*2 M. Izumi, Analogy of Mathematical Planning to Continuum Mechanics, Proceedings of Tohoku Univ. of Art and Design, Vol. 2, June 1996
*3 O. Hiroi, Lecture at the Insurance Rating Organization of Japan, July 2001