HUMAN FACTOR ANALYSIS ON CRITICALITY ACCIDENT

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Abstract

At 10:35 am local time (01:35 GMT), September 30th, 1999, a criticality accident occurred in a conversion building of a uranium processing plant of JCO Company Limited in Tokai-mura, Ibaraki prefecture in Japan during a job to make uranium solution. 150 people were exposed to the radiation. One of three workers who have engaged in the job and exposed to a massive dosage of radiation died of multi organ failure on 83 days after the accident, becoming the first such causality in Japan. A Japanese Governmental Investigation Committee under the Nuclear Safety Commission conducted investigation focusing on causes of this accident. Ibaraki Prefectural Police are also seeking criminal charges. These investigations have revealed that a deviation from a government-authorized processing method and a negligence of its illegal procedure manual, etc. had contributed to the accident. This accident broke the people's trust in the nuclear industry. The authors analyse causes of this accident from the viewpoint of human factors with focusing on two behavior. One is “pouring some 16kg-U with an enrichment of 18.8% to the precipitation”. The other is “using the modified procedure manual which describes the dissolution of uranium oxide powder with nitric acid in stainless steel buckets”. From the analysis, the authors find some latent factors behind this accident. This paper summarizes what had been happening in the uranium processing plant and the results of the author's analysis.

Introduction

On September 30th 1999, workers in a conversion building of a uranium processing plant owned by JCO Company Limited poured enriched uranium solution (U3O8 with an enrichment of 18.8% 235U) in nitric acid into a precipitation tank, becoming 16.6 kg uranium by mass in total. Then, a criticality accident, the first accident in Japan, occurred at 10:35 am local time in Tokai-mura, Ibaraki prefecture, some 120km northeast of Tokyo. 161 people in the area within 350m from the accident site were recommended to evacuate there for one and half days. An advice to stay indoors was given to some 300 thousand people in the area of 10km from the site. They spent 18 hours with a sense of uneasy. In this accident, 150 people were exposed to the radiation. One of three workers who have engaged in the job and exposed to a massive
dosage of radiation died of multi organ failure on 83 days after the accident, becoming the first such causality in Japan despite of massive efforts of medical doctors. The influence of this accident expanded to local farming industry, manufacturing industry, fishing industry, etc. Especially rumors on farm products suffered terrible damage to farmers.

The Investigation Committee was organized on October 4th under the Nuclear Safety Commission and investigated causes of this accident. The final report [1] was submitted to Japanese Prime Minister and the government on Dec.27th. Ibaraki Prefectural Police is also seeking criminal charges. It will substantiate that JCO committed professional negligence resulting in death and violated a law on nuclear facilities by the end of March 2000.

These investigations have revealed several unbelievable acts in the building and the facility. Those are making a procedure manual deviating from a government-authorized processing method, neglecting its procedure manual, using a stainless steel buckets in stead of the government-authorized dissolution tank, processing several times more than the specified mass limit of enriched uranium, etc. It was revealed that human factor issues and company policy giving emphasis on business aspect caused this accident. These finding farther more broke the trust in the nuclear industry.

This paper first summarizes what had been done in the facility, leading to the accident. Second, the result of analysis on human factor issues is described. Finally, it notes lessons learned from this accident.

**JCO Tokai Plant and the Conversion Building**

**JCO and its Tokai Plant**

JCO Company Limited is wholly owned by Sumitomo Metal Mining Company Limited. Its head quarters locate in Tokyo and it has one plant site in Tokai-mura, Ibaraki prefecture. 110 people are working for JCO as of September 1999. Its capital is 1 billion yen (about $10 million) and its sales in 1998 fiscal year which ended March 1999 was 1,723 million yen (about $17 million). JCO’s products are purified UO2 powder for light water and experimental fast breeder reactors, U3O8 solution for the experimental fast breeder reactor.

Production of nuclear fuel originally started by a division of Sumitomo Metal Mining Co. Ltd. in 1957 and nuclear fuel conversion began in 1973. The division became independent and Japan Nuclear Fuel Conversion Ltd. was established in 1979. In 1998 it changed the name to JCO Company Limited.

**Facilities in Tokai Plant**

JCO’s Tokai plant has 3 processing facilities. Two of them in the process buildings No.1 and 2 are for low enriched uranium (less than 5% of enrichment), with annual capacity of 220 and 495 tons respectively. The other one in the conversion building locating the western side of the site is for uranium with enrichment of not
more than 50%. Its annual capacity is 3 tons.

**Conversion Building**

The equipment in the conversion building was originally designed for making UO₂ powder of 12% enrichment from uranium hexafluoride (UF₆), uranium yellow cake or scrap when it had been owned by Sumitomo Metal Mining Co. All equipment without the precipitation tank in the conversion building was designed with criticality-safe geometry. The precipitation tank needs mass and volume control for criticality-safe operation. It was not designed with criticality-safe geometry because the shape of the precipitation tank should be designed with considering speeds of churning, crystal formation of (NH₄)₂U₂O₇, etc. [2] Therefore, it was the license condition given by the Prime Minister after reviewing by the Japanese Science and Technology Agency and in consultation with Nuclear Safety Commission and the Japan Atomic Energy Commission to stipulate a mass limitation for the precipitation tank. For example, uranium with an enrichment of 16-20% should be handled in not more than 2.4kg-U. In addition it also stipulated that the total amount of uranium between the dissolution tank and the precipitation tank should be 2.4kg-U. Therefore, the second 2.4kg-U of 16-20% enrichment could be handled when the handling of the first 2.4kg-U in the precipitation tank is completed.

This facility to handle highly enriched uranium was mainly used to make purified UO₂ powder or U₃O₈ solution in nitric acid for JOYO experimental fast reactor owned by Japan Nuclear Cycle Development Institute (JNC). Orders from JNC were few and irregular so that JCO conducted 9 campaigns (a campaign means a series of jobs for the production of JOYO’s fuel) in total. The accident occurred in the production for the 9th campaign which was first one in 3 years to make uranium solution.

Workers in charge of jobs in the conversion building belong to “Special crew” in the process group of the process division. The special crew which was organized in 1996 consists of 5 members and they are in charge of the job in the conversion building and support jobs for the low enriched uranium products in the process buildings No.1 and 2. Before organizing the special crew, the job in the conversion building was done by the technical division of JCO.

**JCO’s Business Situation and Personnel Reduction**

**Business Situation [3]**

Figure 1 shows that JCO’s output had increased smoothly since 1973 and hit the record high of some 500tons-U in 1993. The sales had also increased until 1985 but since then the sales were unable to move upward. However, it hit the sales record of 3,276 million yen (US$32 million) in 1993. Since 1993 or 1994 when import of UO₂ processed in lower price in Europe started increasing, JCO’s business situation has been deteriorating and the sales in fiscal 1998 was 1,723 million yen (US$ 17 million).

**Personnel Reduction [3]**
In 1973 some 50 people were working for JCO and the number increased along with the output and sales progress. Some 180 people were working for JCO around 1985. Since then the employees had been decreasing gradually. Due to the deteriorated business situation, JCO have executed the personnel reduction program since 1996. The number of employees was 110 as of September 1999.

Usually personnel reduction program is done to the employees in non-production division which does not make products. However, JCO’s personnel reduction is done to its production division. The employees in the non-production division decreased from 77 (in 1996) to 72 but the employees in the production division decreased from 68 (in 1996) to 38. There were 8 teams of 6 members for the process buildings No.1/2 and a team of 3 members for the conversion building in 1995. In 1998, there were 4 teams of 5 members for the process buildings No.1/2 and a team of 5 members for the conversion building. The drastic decrease of the employees for the process buildings No.1 & 2 was due to the reduction of output.

**What Had Been Happening in the Conversion Building?**

**Production of Uranium Solution**

The first 3 campaigns were to make UO₂ powder. In the 4th campaign which started in 1986, production of uranium solution in nitric acid was requested by JNC. Due to the license condition, one lot, a unit of the amount of uranium solution to be homogenized, was one batch (a unit of stipulated amount of uranium to be handled). However, it was requested by JNC to increase the amount of uranium solution per lot and JCO conceived “the cross blending method” to homogenize 40 litter-uranium solution (6-7 batches). First, they separately dissolve purified U₃O₈ of 6-7 batches in the dissolution tank and make 10 stainless steel bottles full of the solution. Second, they take tenths of uranium solution from each of 10 stainless steel bottles and put them into a different stainless steel bottle and make 10 bottles full of homogenized uranium solution [4].
Changes of Production Procedure [5]

Figure 2 shows the procedures to make uranium solution. The whole process to make uranium solution had two sub-process. The first one is the purification process and the last one is the homogenization process. This section describes how the procedure changed in 13 years.

(1) The procedure for the 4th campaign in 1986-88

Purification of $U_3O_8$ material to make purified $U_3O_8$ in the purification process was conducted via the dissolution tank, the solvent extraction column, the extraction stripping column, the buffer column, the precipitation tank on the ground of the government authorized method. However, they handled two batches of uranium or more in parallel, deviating from the license condition of one batch. In the homogenization process, the dissolution of one batch of purified $U_3O_8$ was conducted in the dissolution tank and the homogenization was done by the cross blending method described above.

According to the revision records of the procedure manual for the homogenization process [6], JCO made the first edition of the procedure manual describing this homogenization method in 1989 after the 4th campaign finished. It is not clear that the cross blending method was written in the first edition. At least, they did the homogenization without procedure manual.

(2) The procedure for the 6th campaign in 1990-93

JCO hit the sales record of 3,276 million yen ($32million) in 1993 when stainless steel buckets were used the first time. Both steps in the purification and homogenization process needs the dissolution tank to dissolve non-purified and purified $U_3O_8$ powder respectively. A worker or workers in charge of the work then hit upon using stainless steel buckets to dissolve it. This method was used in the homogenization process. Every one batch of purified $U_3O_8$ was dissolved in the stainless steel bucket and homogenized by the cross blending method.

(3) The procedure for the 7th and 8th campaigns in 1994-96 and 96-99

The method to use stainless steel buckets for the dissolution was also applied to the dissolution step in the purification process in 7th campaign starting in 1994. That is because they could shorten the time to dissolve U3O8 material to 15-20 minutes per batch from 30-90 minutes per batch.

JCO’s safety committee was held in September 1995 to discuss the deviations of actual processing method from the government-authorized method. They noticed the illegality but they recognized it criticality safe method because the method considered mass and volume control in each bucket and distances of those buckets. They made 2 kinds of the minute note of this meeting. One was public and the other was confidential. The confidential one describes what had been discussed in the committee. The public one, however, lacks this discussion [5]. This fact makes it clear that JCO recognized the illegality.
Fig. 2 Processing procedures in conversion building
The homogenization process in 7th campaign started in October 1995 when they changed the homogenization method. Dissolution of purified U₃O₈ was done in the stainless steel buckets and they used one of two buffer columns to homogenize the uranium solution. They separated the buffer column and one of pumps from the process line and put temporary pipes to circulate the uranium solution in the buffer column with the pump. The buffer column has a criticality safe geometry so that they could put 6-7 batches of uranium solution in it. Time required by this new method is 200 minutes per lot (one lot consists of 6-7 batches). It is not clear that this new method shorten the time for homogenization. However, it is clear that it made the job easier.

The process division of JCO in charge of the works in the conversion building modified their procedure manual for the homogenization process in October 1997 after the homogenization process for the 8th campaign, August 1996-November 1996, completed. The second edition of the procedure manual which was not reviewed by JCO’s Safety Committee describes the dissolution method of purified U₃O₈ with stainless steel buckets and the homogenization method of the solution with buffer column.

(4) The procedure for the 9th campaign when the accident happened

9th campaign started in September 10th, 1999. The purpose of this campaign was to make purified 57kg-U dissolved in nitric acid. The appointed date of delivery was in November 1999. The amount of orders received would be some 20 million yen ($200 thousand).

In the original work schedule, the purification process would start on September 10th and would finish on October 8th. 54kg-U would be divided four lots of 6-7 batches of purified uranium solution. Homogenization of the first and second lots would be done on September 29th and October 7th. Even this original schedule neglected the license condition stipulating that not more than one batch of uranium should be between the dissolution tank and the precipitation tank. According to the original schedule, two or three batches could be between those tanks.

The actual work in the conversion building deviated from this illegal schedule. The purification process was finished for all 54kg-U on September 28th, 8 work days earlier than the original schedule7) and one day before the planned first homogenization. In addition, the job records show that there were 10 batches of uranium in maximum in the process between the two tanks. It means the workers deviated from the schedule and hurried the purification process. It is not clear that a series of this purification process was conducted by the three workers who were exposed to massive amount of radiation during the job when the accident happened. At least it is clear that those workers were in charge of this process in September 28th and later.

The preparation for the homogenization process started in September 28th. The three workers thought that they could use the precipitation tank with a stir propeller. They do not seem to have known the differences of the precipitation tank which requires mass control and the buffer column with criticality safe geometry. So that they seem to have thought that they could pour 6-7 batches of dissolved purified U₃O₈, the
same amount of solution to be poured into the buffer column. Then they started the preparation in September 28th. They washed the precipitation tank and disassembled the lower part of the tank to wash it in order to keep the quality of the uranium solution. During the preparation in the morning of September 29th, the leader of the three workers made a contact with a person in the planning group of the process division to ask whether there were any problems to use the precipitation tank for the homogenization. This person who is a licensed engineer of nuclear fuel, a government-authorized license and was one of members to make 9th campaign process program replied in the early afternoon of September 29th that there were no problems to use the precipitation tank. He was quoted as saying that he confused the process for highly enriched uranium and low enriched uranium.

The homogenization process for the first lot started in the afternoon of September 29th. They dissolve 4 batches of uranium with stainless steel buckets and poured them into the precipitation tank. The mass of uranium was 9.6kg at this time. In the next morning, September 30th, they continued the job. They dissolved 3 batches of uranium and poured them into the precipitation tank. At 10:35 local time the criticality accident occurred during two of the workers were pouring 7th bucket of the solution into the precipitation tank. Total mass of uranium poured into the precipitation tank was 16.6kg.

**Human Factors Analysis on Workers’ Behavior**

Japanese Governmental Investigation Committee revealed lots of unsafe acts and work habits. Among them, the direct cause of this accident is definitely the workers’ pouring some 16kg-U (18.8% of enrichment) into the precipitation tank which did not have a criticality safe geometry. Behind this unsafe act, there seems to be lots of latent factors which closely relates to the JCO’ work habits. Another unbelievable act is using the modified procedure manual describing the illegal method. The authors believed that analysis of these two unsafe acts would reveal the relations of the various unsafe acts and work habits. Therefore, it was conducted to analyze these two unsafe acts with J-HPES’s cause relation charts, CRIEPI-developed Fault Tree like method [8].

**Analysis I--- Why Did They Pour Some 16kg-U into the Precipitation Tank? [9]**

Figure 3 shows the summary of J-HPES’s cause relation charts on pouring some 16kg-U into the precipitation tank. There are 5 factors in the first layer. The first three factors relate to the workers’ situation awareness. The fourth one relates to JCO’s work habit and the last one relates to their superiors’ behavior.

**a) The workers were anxious to finish the job at the conversion building.**

The 3 workers wanted a/some new worker(s) who would be assigned to the special crew October 1st to try the waste processing from the beginning. In JCO, On the Job Training (OJT) was the main training program. It is guessed that the waste processing would start early October and the scheduled job for the purification and the ho-
mogenization would interrupt the OJT on the waste processing for the newcomer(s). Therefore, they hurried the purification process and finished 8 work days earlier than the schedule. However, as of September 28th, any homogenization process for 4 lots of uranium solution had not conducted. According to the original schedule of the processing, homogenization of one lot of uranium solution takes one day so it takes 4 days to handle all uranium solution. Therefore, they are guessed to have obtained the idea to use the precipitation tank which had a stir propeller in order to shorten the time of the homogenization. Dissolution in the stainless steel buckets takes 30 minute per batch. But they could use 3 buckets so that the dissolution for one lot of uranium would end in 2 hours. According to the media report, the estimated time to homogenize a lot of uranium solution in the precipitation tank would be 30 minutes. The authors guess that it would take 3 to 4 hours per lot, including bottling the homogenized solution and the whole homogenization process for the 54kg-U would finish in two days.

The operation space was small and located far away, giving a feeling of entering the premises of another company. The conversion building locates the western end of the JCO site and is adjacent to parent Sumitomo Metal Mining Co.’s site. The building, 260 square meters, has a corridor leading to the Sumitomo’s building. The work space was small. In addition, there are little jobs in the conversion building. It is guessed that these work environment and rare opportunity made workers in the conversion building uncomfortable so that they hurried the job.

(b) The workers decided to use the precipitation tank instead of the buffer column.

The system was designed for the purification process so that the usability was poor and it took much time to do the homogenization process. The system design does not consider to use the buffer column to homogenize the uranium solution. Workers had to cleanse the buffer column, put temporary lines to circulate the solution with a pump before homogenizing the solution and obtain the homogenized solution from the bottom of the buffer column, 10 cm above from the floor.

The precipitation tank has a capacity large enough to hold 6-7 batches of uranium solution because the whole system was designed to handle uranium solution with an enrichment of 12% in 45g-U/l. 6-7 batches of uranium solution comes to 40 litters. 100 litters is the capacity of the precipitation tank which was originally designed for making 45g-U/litter uranium solution for 4.7kg-U/batch with 12% of enrichment in the purification process.

It was easier to pour uranium solution into a different tank because the 3 workers were using the stainless steel buckets. Dissolving the purified U3O8 in the stainless steel buckets was JCO’s work habit since 1993. This work habit is guessed to have made the workers put the solution into another tank.

(c) The workers thought that there was no problems in pouring 6-7 buckets of uranium solution into the precipitation tank.

It was requested to homogenize uranium solution with an excessive amount of the license condition. So that the cross blending method was derived to meet this re-
quest. Dissolution was conducted in one batch but homogenization was conducted in 6-7 batches. However, this cross blending method takes much time to homogenize the solution. Then, the different method with the buffer column occurred to workers in 1995. The buffer column has a criticality safe geometry so that it is safe to put 6-7 batches into it. The modified procedure manual shows only the procedure steps but safety instructions. The procedure manual was modified to put 6-7 batches of uranium solution into the buffer column. It describes procedural steps but safety instructions.

The 3 workers did not have knowledge on criticality safety. 5 latent factors could be considered. First, the application for plant operation assumed that criticality accident could not happen because it was designed to operate safely in any circumstances. In the early days, JCO gave the criticality safety education to its employees. However, it was difficult for them to understand. Therefore, JCO stopped giving enough education on criticality safety to employees and gave emphasis on teaching them to follow procedure manuals. In addition, one of superiors in charge of giving instructions before the work in the conversion building did not give any job and safety instructions to the workers. Due to the personnel reduction program starting in 1996, experienced workers in the conversion building were retired or moved and the 3 workers without any experience had to be in charge of the job.

(d) It was not unusual for workers to deviate from procedure manuals.

Any latent factors behind this are not known. However, it is revealed that workers in JCO seem to have a habit that they do not always follow the procedure manuals and planned schedule. As described before, JCO’s procedure manual for the homogenization was compiled after they tried the procedures to be written. They did not follow the planned schedule for 9th campaign. They decided to use the precipitation tank without any permission from their managers. In addition, workers in the process group did small facility-improvement works without approvals from managers or JCO’s safety committee. It is guessed that making the procedure suitable for work and other circumstances is natural for them and JCO’s workers did not recognize procedure manuals to be followed.

(e) Their superiors could not stop the workers from using the precipitation tank.

There were two superiors who could stop the 3 workers to use the precipitation tank.

One was the superior A, a lower class manager in charge of work teams in the process group. This was the man who did not give any job and safety instructions to the workers. His another job was going a round of inspection during the work in the conversion building and checking the work progress, etc. According to the investigation, he did the inspection at least once a day until September 29th. However, he failed to detect their pouring some 16kg-U into the precipitation tank.

The other person who could stop them was the superior B. He was one of members who made the process program for the 9th campaign and a licensed engineer of nuclear fuel. As described before, he gave OK to the leader of the 3 workers after be-
The J workers were asking to tank the job in the conversion building.

The operation space was small and located far away giving a feeling of entrusting the processes of another company.

The system was designed for the purification process so that the usability was poor and it took much time to do the homogenization process.

The precipitation tank has a capacity large enough to hold 6-7 batches of uranium solution because the whole system was designed to handle uranium solution with an enrichment of 25% in 25g/L.

It was easier to pour uranium solution into a different tank because the J workers were using stainless steel barrels.

The modified procedure was to put 6 baskets of uranium solution into the buffer column.

The application for plant operation assumed that any criticality accident could not happen because it was designed to operate safely in any circumstance.

The J workers did not have knowledge on criticality safety.

It was not unusual for J workers to lecture from procedures manual.

The superiors failed to detect their pouring some 16kg U into the precipitation tank.

The superior A who was one of the superiors making job instructions and a licensed engineer of nuclear fuels did not stop them to use the precipitation tank.

The J workers wanted new workers who would be assigned Oct. 1st to try the safe processing procedure from the beginning.

The precipitation tank has a capacity large enough to hold 6-7 batches of uranium solution because the whole system was designed to handle uranium solution with an enrichment of 25% in 25g/L.

It was requested to homogenize uranium solution with an excessive amount of the license condition.

Homogenization with existing equipment and containers takes much time.

The application for plant operation assumed that any criticality accident could not happen because it was designed to operate safely in any circumstance.

UCC did not give enough education on criticality safety to employees because of difficulties.

UCC wanted to keep criticality safety by teaching the employees to follow the procedure manuals.

The superior A did not give job and safety instructions on the process.

Non-experienced workers had to be in charge of the job because of UCC's personal reduction.

Fig. 3 Summary of J-HPES's cause relation chart on pouring some 16 kg-U into the precipitation tank
Analysis II—Why Did They Use the Modified Procedure Manual Describing the Illegal Method? [9]

It is believed that one of reasons why they continued using unauthorized stainless steel buckets is regulatory authority’s failure to detect it during several inspections. This paper does not discuss the responsibility of the authority. It focuses on the responsibility of JCO why they had used the unauthorized stainless steel buckets and modified the procedure manual. Figure 4 shows the summary of the cause relation chart on using the modified procedure manual describing the illegal method.

(a) The procedure manual was revised only by the process division.

The reasons why the process division revised the procedure manual for the homogenization process are thought to be the following two. One is that the procedure was not uniform and thus dangerous, so they established a safe procedure. According to a JCO worker cited in a media report, the procedure steps depended on workers and the job was dangerous. Therefore, they wanted to uniform the procedure and improve the safety of the jobs.

The other one is that the procedure steps written in the pre-revised procedure manual was quite different from the current procedure. The differences are the ways to dissolve the uranium and to homogenize the uranium solution in the homogenization process. The pre-revised manual developed in 1989 seems to have shown the method with the dissolution tank for dissolving the uranium and the cross blending method for homogenizing the uranium solution, the way of the process in 4th campaign in 1986-88. However, the actual method was dissolving with the stainless steel buckets and homogenizing with the buffer column. The current method was introduced to improve the product quality and operation efficiency. Then the 2nd edition of the procedure manual for the homogenization process was developed in October 1997.

(b) The modified manual was not reviewed by JCO’s safety committee.

One latent factor is that JCO’s safety committee approved using the stainless steel buckets in 1995. Therefore, the process division seems to have found the necessity of the review by the committee. Another latent factor is their habit to change process method. Although the modified manual also described using the buffer column for the homogenization, they did not feel any necessity of the review because it was not unusual to change process methods, etc. without approval.

(c) An advice to stop using the buckets was rejected by the manager in charge of the process division.

One of the employees noticed the illegality and danger of using the stainless steel buckets to dissolve the uranium and made an advice to his manager in charge of the process division. However, his advice was rejected because JCO’s safety committee approved using the stainless steel buckets.
Accident Scenario over 13 Years

The details and latent factors of this accident were discussed above. Here again, this section describes the scenario of this accident over 13 years.

Prologue:

The authors believe that the start point of this accident goes back to 1983 when the uranium dissolution started. JCO started to homogenize the 6-7 times of the licensed amount of uranium after the request to increase homogenized uranium solution. Some 16kg-U (6-7 batches) of uranium would not be poured into the precipitation tank if the request could not have been made.

Scene 2:

The second scene is that they started using the stainless steel buckets in the homogenization process in 1993. This was because the dissolution tank was shared in the purification process and the homogenization process. Poor process control or work plan was behind this. The stainless steel buckets later let workers move the uranium solution to any tank they want to use.

Scene 3:

The third scene is that JCO’s safety committee approved the method to dissolute the uranium in the buckets despite of recognizing the illegality. Furthermore, they
made 2 kinds of the minute note for the committee and covered up the illegal method.

**Scene 4:**

The fourth scene is that they started using the buffer column to homogenize the uranium solution. The buffer column has a criticality safe geometry so that they could put 6-7 batches of uranium into it. The merits of using the buffer column are easily homogenizing the solution in 200 minutes with a pump. It is guessed that a person or people who hit upon this idea probably had knowledge on criticality safety.

**Finale:**

The finale of this 13 year-long story is that the 3 workers poured some 16kg-U into the precipitation tank which requires mass control of 2.4kg-U with 18.8% of enrichment in order to hurry the job. They are quoted as saying that they did not have knowledge on criticality safety. As a result, they thought it had no problems to pour some 16kg-U into the precipitation tank, the same amount of the uranium to be poured into the buffer column with a criticality safe geometry. Lack of education on criticality safety given by JCO is one of latent factors of workers’ lack of knowledge.

**Organizational Accident and JCO Accident**

It is the fact that workers’ unsafe act of pouring some 16kg-U into the precipitation tank is the immediate cause of this accident. The analysis revealed lots of latent factors behind this unsafe act and the most of them were found to be related to the company activities and work habits. This accident could be said an organizational accident advocated by Reason [9]. The mechanism of organizational accident helps us to understand this accident.

Figure 5 shows the applied mechanism of the organizational accident to this JCO accident. The authors assume that there were 5 defenses preventing the hazardous uranium from criticality. The first one was education. This first defense was destroyed by abandonment of giving education on criticality safety to employees by JCO. The second defense was procedure manuals and other kinds of document. The procedure was recognized by worker to be deviated depending on work situation. The procedure manuals and other kinds of document describe no safety instructions. Therefore, the second defense was breached easily. The third defense was the batch control required by the license condition. However, homogenization of 6-7 batches of uranium broke this defense 13 years ago. The fourth defense was the mass control. The effort to improve the quality and productivity by homogenizing with the buffer column destroyed this defense. The last defense, criticality safe geometry was bypassed by using the precipitation tank. Finally, the criticality accident occurred in 1999.

**Lessons Learned from This Accident**

**Safety culture**

People believed that safety culture had been established in Japanese nuclear in-
industry. However, this accident revealed that safety culture had not shared among the whole nuclear industry in Japan. The governmental investigation committee insists in the final report the necessity of sharing safety culture among the whole nuclear industry. Then the nuclear industry established an organization named “Nuclear Safety Network (NS Network)” in December 1999. This organization aims to share information on safety, to inspect nuclear related facilities each other to confirm the safety. The member of NS Network includes 10 electric power companies, vendors, nuclear fuel processing companies, research institutes, etc. in Japan. CRIEPI is a member of this organization and will offer research products of Human Factors Research Center and Nuclear Information Center. The nuclear fuel processing companies also established their own world-wide organization named “International Network for Safety Assurance of Fuel Manufactures (INSAF).” Through activities of these organizations, various efforts will be done to establish safety culture and to regain the people’s trust on the nuclear industry.

Fig. 5 JCO accident and organizational accident.

Usability and Work Design

This accident indicates the importance of usability and work design. The problem was conducting a job which were not considered in the system design. However,
this accident reminds us that poor usability and work design let people deviate from an assumed way of work. Especially in a circumstance requiring high productivity, high performance, low cost, etc. people will find a better way to work. Rich usability and work design can be said one of measures to prevent people deviating from designed work procedure.

**Corporate Ethics**

As profit-making companies, cost-reduction is an essential program to survive competition in their market. This accident indicates that excessive cost-reduction could deteriorate safety. Reason [10] indicates some issues involved in the complex relations between production and protection. He said the level of protection should match the hazards of the productive operations. However, production is the main activity of companies and visible. Protection is important but money-consuming and invisible. Therefore, protection is gradually neglected and an accident happens. The Investigation Committee said in the report that companies as well as public people should accept cost for safety. It is important to understand it by public people. However, it is more important to recognize this matter by employees and executives of companies, especially ones in hazardous industries. That is because companies are responsible for safety of hazardous technology.

**Conclusion**

The criticality accident on September 30th 1999, which killed one worker of the plant broke the safety myth of Japanese Nuclear Industry. In addition, deviating from the government-authorised processing method and neglecting the procedure manual shocked nuclear people and destroyed the people’s trust in the nuclear industry. The immediate cause of this accident was the workers’ unsafe act of pouring some 16kg-U to a precipitation tank. The analysis shows, however, that behind it were many latent factors closely related to the company’s policy on business and safety. It can be said that the 3 workers and other people directly or indirectly having caused this accident are the victims of the company’s poor policy.

Since the accident, lots of reactions have been taken by the nuclear industry and Japanese government. The reactions by the nuclear industry were two organisations to share safety related information, to do peer review of nuclear related facilities, etc. On the other hand, the government is making several actions against this accident. Diet on December 13 enacted two bills in response to the accident. One is the new antinuclear disaster law. Under the new law, the Prime Minister is authorised to declare a state of emergency, set up a crisis management headquarters and request the dispatch of Self Defence Forces troops in the event of accident. The central government is responsible for ordering evacuations or advising residents to stay in doors. The other is the revised Nuclear Reactors Control Law which newly requires periodic inspections at nuclear fuel facilities like JCO. Ministry of International Trade and Industry in charge of regulating commercial nuclear power reactors and Science and Technology Agency in
charge of regulating the other kinds of nuclear related facilities are establishing Off Site Centers which be combined headquarters of the central government’s local office, prefectural government and municipal governments in case of nuclear disaster. The Nuclear Safety Commission will be given greater power and autonomy in its operation and the number of its secretariat will be increased to some 100.

Although the government is improving the related law and disaster prevention programs, etc., it is the responsibility of each company and the nuclear industry to keep safety in nuclear related facilities. This accident reminded people in the nuclear industry of it.

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