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SUBJECT: U.S. DOE TRIP REPORT OF VISIT TO TOKYO AND TOKI-MURA, JAPAN ON OCTOBER 18-19, 1999 RE CONCERNING TOKAI-MURA CRITICALITY ACCIDENT

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The Secretary of Energy
Washington, DC 20585

February 29, 2000

The Honorable Richard A. Meserve
Chairman
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Chairman:

On October 14, 1999, I chartered a delegation of nuclear experts to travel to Japan to exchange information with their Japanese counterparts on the September 30, 1999, criticality accident that occurred at the Tokai-mura uranium processing facility. This trip was chartered to better understand why the accident happened and what could be done to prevent a similar event from occurring in operations in the United States. An additional focus of the trip was to share information with the Japanese government and industry officials on United States regulatory regimes for criticality safety and on steps taken to confirm that nuclear operations in the United States involving fissile materials are well understood and safe.

The delegation was tasked with providing me a report on what they learned, including lessons learned relative to our operations and with providing an interagency briefing at the appropriate time. The interagency briefing was provided to representatives of the National Security Council, State Department, Nuclear Regulatory Commission, Energy Department, and Environmental Protection Agency on October 21, 1999, immediately following the delegation's return from Japan. The enclosed report is provided for interagency information and use.

The delegation found similarities between the event that occurred in Japan and the previous 21 world-wide criticality events that have occurred over the last fifty years. The Japanese accident occurred during processing of infrequently used material. The equipment in which the material was being accumulated was used in a manner that was contrary to its intended purpose and contrary to established procedures. Workers had not been trained on the fundamentals and consequences of criticality accidents and supervisory and management oversight appeared to be inadequate. Regulatory inspection of operations was infrequent. Lessons learned from the event for operations in the United States include the following:

- Ensuring fundamental understanding of criticality and consequences of criticality accidents by all levels of involved personnel;

- Ensuring controls are understood and rigorously followed for operations involving fissile materials -- including an understanding of why the controls are important;

- Ensuring sufficient oversight and monitoring of operations by supervisory, management, and regulatory personnel;

- Ensuring that analyses for fissile material operations which conclude that a criticality is incredible do not rely significantly on worker action; and

- Ensuring a basic public emergency response capability for nuclear operations.

Although I believe the Department of Energy's operations involving fissile materials are fundamentally safe, in light of the Japanese accident, and as requested by the President, the Department is re-examining the adequacy of criticality safety programs at our sites and will implement enhancements, where needed. Several of the assessments of key facilities are complete and others are proceeding. In general, the reviews conducted to date have found the criticality safety programs at the sites to be well designed and documented. In some cases, opportunities for improvement were identified and corrective actions are being taken. Based on the delegation's report, I am directing that DOE offices that conduct or oversee activities associated with fissile materials take any necessary steps to ensure that the lessons learned from the Japanese accident are appropriately factored into associated operational, safety, and assessment programs.

If you have any questions concerning the report or the Department's efforts to further strengthen criticality safety for our operations, please contact me or have your staff contact Ms. Melanie Kenderdine of my staff at (202) 586-8900.

Yours sincerely,

Bill Richardson

Bill Richardson

Enclosure

U.S. Department of Energy

Trip Report

Of

Visit to Tokyo and Tokai-Mura, Japan

On

October 18-19, 1999

For
Information Exchange with
Government of Japan Concerning
The September 30, 1999
Tokai-Mura
Criticality Accident

Frank R. McCoy, III
Thomas P. McLaughlin
Leroy C. Lewis

Executive Summary

On October 18-19, 1999, a three-member delegation of Department of Energy and National Laboratory nuclear experts visited Tokyo and Tokai-mura, Japan for the purpose of exchanging information regarding the September 30, 1999, Japanese criticality accident and similar accidents that have happened worldwide.

The team exchanged information with Japanese Government management officials from the Ministry of Foreign Affairs, the Science and Technology Agency, the Japan Atomic Energy Research Institute, the Japan Nuclear Cycle Development Institute and with officials from the JCO Company. The team also visited the facility in which the accident occurred. The information exchange included a candid and open discussion of the accident progression and recovery, and of the emergency response actions. Information concerning causal factors of the accident and subsequent personnel exposure are still under investigation by the Japanese Government.

The accident involved three workers who were preparing an intermediate enrichment aqueous uranyl nitrate solution which would later be used for the preparation of fuel for the JOYO fast reactor. The accident occurred as two of the workers were transferring the uranium-bearing liquid into a process vessel which was being incorrectly used for accumulation of the liquid in preparation for transfer offsite. The operation was conducted contrary to company and government approved procedures and resulted in specified criticality safety mass limits being significantly exceeded.

A criticality accident ensued and the three workers involved received life-threatening radiation exposures. There were lesser exposures to emergency response workers and to members of the public immediately outside the company boundary. The accident continued for approximately 20 hours. Release of a small amount of gaseous fission products resulted in some detectable levels of radioactive contamination, which were significantly below levels of health concerns, on some soil and plant species in the near vicinity of the site.

The facility was evacuated when the radiation alarms sounded and an ambulance was dispatched to the site for the injured employees. The Japanese Science and Technology Agency was notified and the Japanese Atomic Energy Research Institute was contacted for technical guidance. Decisions were made to evacuate the immediate vicinity of the plant site and shelter members of the public within 10 kilometers of the site. There had been no planned emergency response for a criticality accident because such an accident was not considered possible. This is believed to have resulted in delays to immediate recovery and response actions.

During our discussions, we found that there were a number of similarities between the previous 21 world-wide process criticality accidents and the criticality accident at Tokai-mura. The criticality accident occurred during the processing of infrequently used material. The equipment, in which the uranyl nitrate was being accumulated, was used in a manner contrary to its intended purpose and contrary to procedures. Additionally, the uranyl nitrate was accumulated contrary to specified mass limits. Workers had not been trained on the fundamentals and consequences of criticality accidents, supervisory and management oversight appeared to be inadequate, and regulatory inspection of operations was infrequent. These are traits in common with previous world-wide criticality accidents.

Lessons learned from this accident for operations in the United States include the following:

1. Ensuring fundamental understanding of criticality and consequences of criticality accidents by all levels of involved personnel.
2. Ensuring controls are understood and rigorously followed for operations involving fissile materials. This includes understanding why the controls are important by the people performing the work.
3. Ensuring sufficient oversight and monitoring of operations involving fissile materials by supervisory, management, and regulatory personnel.
4. Ensuring that analyses for fissile material operations which conclude a criticality accident is incredible do not rely significantly on worker action .
5. Ensuring a basic public emergency response capability for any nuclear operation.

I. Introduction

On October 14, 1999, Secretary of Energy Bill Richardson directed a three member delegation of nuclear experts to travel to Japan to exchange information with their Japanese counterparts in order to better understand the September 30, 1999, Tokai-mura criticality accident. The obtained information would be used to help develop lessons learned that could be applied to nuclear operations in the United States. In addition, the team was to be prepared to share United States related information with the Japanese government. The Secretary's charter to the team is included as Attachment A.

The three member delegation consisted of: Mr. Frank R. McCoy, III of the Department of Energy's Savannah River Operations Office, an expert in nuclear operations and safety management; Dr. Thomas McLaughlin of the Los Alamos National Laboratory, an expert in nuclear criticality safety; and Dr. Leroy Lewis of the Idaho National Engineering and Environmental Laboratory, an expert in chemical processing.

The delegation arrived in Japan on October 16, 1999. On October 18, 1999, the delegation received orientation briefings from United States Embassy personnel, and met in Tokyo with Government of Japan officials from the Science and Technology Agency (the Japanese equivalent nuclear regulatory agency) and Ministry of Foreign Affairs in order to exchange information concerning the September 30, 1999, Tokai-mura criticality accident. On October 19, the delegation met with officials from the Japan Atomic Energy Research Institute and Japanese Nuclear Cycle Development Institute and officials from the JCO Company to continue discussions concerning the criticality accident. The delegation also visited the JCO Company site in Tokai-mura and, in particular, visited the Conversion building where the accident occurred. Attendees at each of the information exchange meetings are identified in Attachment B. Both meetings were conducted with a translator. During the first meeting, some written (untranslated) information, which was being collected for use by the Nuclear Safety Commission Investigation Committee, was provided to the delegation. During the second meeting, translated versions were provided for some of this written information. During each of the information exchange meetings, the delegation identified, for Japanese counterparts, salient management and regulatory practices associated with similar United States operations and provided them copies of United States national consensus standards regarding criticality safety. The delegation also provided Japanese officials with copies of the introduction of a soon to be published third edition of "A Review of Criticality Accidents" which contains summary information of all known criticality accidents in the United States, the United Kingdom, and the former Union of Soviet Socialists Republics as well as specific and generic lessons learned. The delegation requested that the Japanese government consider including details of the September 30, 1999, Tokai-mura criticality accident in this report and Japanese government officials acknowledged this request. The delegation also extended an invitation for appropriate Japanese officials to visit the United States for additional discussions related to this information exchange with U.S. counterparts. The delegation debriefed with the United States Embassy officials, including the Deputy Chief of Mission, on October 20, 1999, and departed Japan that day. On October 21, 1999, the delegation provided a United States interagency debriefing to officials from the Department of Energy,

Department of State, National Security Council, Environmental Protection Agency and Nuclear Regulatory Commission at Department of Energy Headquarters in Washington, DC.

The delegation's understanding of the September 30, 1999, Tokai-mura accident, its probable causes, and salient lessons learned, based on the information exchange meetings and site visit, is delineated in parts 2 through 7 of this report. It should be noted that at the time of the delegation's visit, the Government of Japan's accident investigation was still in its early stages. In fact, investigation officials were entering the room in which the accident occurred for the first time on the final day of the information exchange. Conclusions drawn from the information presented should be tempered accordingly.

2. JCO Site and Facility Description, Location, and Operating History

The JCO fuel fabrication plant is located in the village of Tokai-mura in the Ibaraki prefecture which is located approximately 70 miles northeast of Tokyo on the eastern coast of the Japanese Island of Honshu. The site covers an area of approximately 40 acres. Located in close proximity to the JCO site are the Tokai Power Plant of the Japan Atomic Power Company; the Tokai Establishment of the Japan Atomic Energy Research Institute, which has nuclear laboratories; and the Tokai Works of the Japan Nuclear Cycle Development Institute which has a nuclear fuel reprocessing facility. The Naka fusion research facility of the Japan Atomic Energy Research Institute is located approximately 2 kilometers from the JCO site. The fusion research site had two operating neutron detectors that identified the first pulse from the criticality accident.

The JCO facility is licensed for chemical treatment plants for fabrication of uranium fuel, auxillary storage facilities for nuclear fuel materials and a storage facility for radioactive wastes. The chemical treatment facilities include:

- Fabrication Facility building #1, which produces low enriched (less than 5% U-235) uranium oxide powder from uranium hexafluoride, scrap and yellow cake. It has a maximum capacity of 220 tonnes U/year.

- Fabrication Facility building #2, which has the same charter except its maximum capacity is 495 tonnes U/year.

- The Conversion building, which produces uranium dioxide powder, triuranium octoxide powder, or uranyl nitrate solution from uranium hexafluoride (enrichment less than 20% U-235), scrap (enrichment less than 50%), or yellow cake, primarily for the experimental fast reactor JOYO. Its maximum capacity is 3 tonnes U/year. This includes capacity for treating 20 kg U as scrap with an enrichment of not less than 20% but less than 50% U-235. This was the building in which the criticality accident occurred.

A diagram of the site boundary and the Fabrication and Conversion buildings is shown in Attachment C.

The site is owned and operated by the JCO Company Ltd which is a subsidiary of Sumitomo Metal and Mining Company. The site has 105 employees including 9 chiefs authorized to be in charge of nuclear fuel handling and 21 engineers. It was licensed for operation for low enriched fuel in the Conversion building, Fuel Fabrication Facility building #1, and Fuel Fabrication Facility building #2, respectively in 1980 and 1981. In 1984, a license amendment was approved to allow use of intermediate enriched uranium in the Conversion building.

Operations with 18.5 to 19% enriched uranium began in the Conversion building with a 3-month campaign to make 141 Kg U of aqueous uranyl nitrate solution between March 1993 and June 1993. Triuranium octoxide was produced in a 1994 campaign followed by two uranium dioxide campaigns in 1995 and 1996. UNH was made in two campaigns in 1995 and 1996. Uranium dioxide was then produced in two campaigns in 1996 and 1998. The total production between March 1993 and June of 1998 was 963 Kg of uranium. All of this material was produced for the JOYO program.

There were three other campaigns which produced 104 kg U of uranium oxide between 1993 and 1995. In these three campaigns, all of the material was less than 10.6% enrichment.

3. Process and Operation Description

During the late summer of 1999, the JCO company was engaged in the preparation of a concentrated uranium solution (370 g U/liter) of 18.8% enriched U-235 as uranyl nitrate. This activity, which involved dissolving triuranium octoxide in nitric acid to form uranyl nitrate, was taking place in the conversion building, a small single story cinderblock building located in the northwest corner of the JCO compound.

The conversion building is designed for the preparation of uranium dioxide for the manufacture of fuel pellets for reactor fuels from either triuranium octoxide or uranium hexafluoride. For operations that begin with uranium hexafluoride, the Conversion building is equipped to hydrolyze the uranium hexafluoride using aluminum nitrate in nitric acid. This produces uranyl nitrate and aluminum fluoride in solution. The uranyl nitrate is separated from the aluminum fluoride by solvent extraction using tributyl phosphate as the solvent. The purified uranyl nitrate is then stored in geometrically favorable storage tanks for either bottling for transfer as a liquid to a fuel fabrication process or conversion to one of the uranium oxides.

For operations that begin with uranium oxides, the equipment train consists of a preparation station where the uranium oxide is weighed in a pan. The uranium oxide is then added to a dissolver where the oxide is converted to uranyl nitrate by dissolution with nitric acid. A small solvent extraction train follows the dissolver. It is primarily used to purify the product from the hydrolysis of uranium hexafluoride, but can also be used for dissolver product from impure triuranium octoxide from whatever source. If the triuranium octoxide is pure, it is not necessary to use the extraction train. The uranyl nitrate which is prepared in the dissolver can bypass the extraction train and be pumped directly into the geometrically favorable storage tanks. If the product is to be uranyl nitrate solution which is to be shipped to another plant for conversion into

uranium dioxide, it is loaded out into geometrically favorable shipping bottles directly from the geometrically favorable storage tanks. If the product is to proceed directly to uranium oxide, it is transferred to the precipitation vessel one batch at a time only and reacted with gaseous ammonia to make ammonium diuranate. The ammonium diuranate is then filtered and put into large flat trays for conversion into triuranium octoxide in a furnace followed by reduction to uranium dioxide in a furnace with an ammonia-containing cover gas.

The precipitation vessel in which the uranium diuranate is formed is 18 inches in diameter by 24 inches deep and is fitted with a cooling water jacket approximately 1 inch thick covering the bottom half of the vessel. Cooling water is supplied to the vessel jacket by a closed loop system in which the pump, a drain valve, and the heat exchanger are located outside the Conversion building.

The entire process described above and shown in Figures 1 and 2 of Attachment D was the process approved by the Science and Technology Agency.

Subsequent to initial operations in the Conversion building for intermediate enriched uranium, in 1986, an unreviewed and unapproved change was made to the flow sheet where the dissolution was carried out in a stainless steel bucket and then pumped into the geometrically favorable storage tanks. This reduced the amount of time needed to complete a processing cycle. A second unreviewed and unapproved change was later made to a company procedure in which the dissolver was formally removed from the process and a bucket for the dissolution put in its place. This procedure still required the dissolved product to be pumped into the geometrically favorable tanks for storage. The procedure and flowsheet, which were provided to the delegation by Japanese officials, indicated that multiple batches (six to seven) containing about 15,000 grams of intermediate enrichment uranium, could have been accumulated in the geometrically favorable storage tanks. This unreviewed provision would have allowed for violation of specified mass limits contrary to the license. These changes are shown Figure 3 of Attachment D.

A final unreviewed and unapproved modification to the process was informally made prior to the 1999 conversion of uranium oxide to uranyl nitrate. A decision, apparently made to save time and facilitate ease of handling of the uranyl nitrate solution, provided for continuing dissolution in the stainless steel buckets but, instead of pumping the uranyl nitrate product into the geometrically favorable storage tanks, provided for transferring the solution directly into the precipitation vessel by pouring it through a funnel in the large 10" diameter nozzle in the top of the vessel. This decision also provided for accumulating several batches of uranyl nitrate in the precipitation vessel thereby significantly exceeding specified mass limits established by the license. These activities were conducted contrary to procedures, the license, and established safety controls. This final process modification is shown in Figure 4 of Attachment D.

Accordingly, the workers set out to prepare the 18.8% enriched uranyl nitrate product. The target concentration was 370 g U/l in 0.5 molar nitric acid. A procedure that identified the amount of nitric acid to be added to the dissolution vessel was prepared. On the afternoon of September 29, 1999, the workers weighed out the appropriate amount of triuranium octoxide, added a liter of water which was blended into the solid, and then added a measured amount (6.49

liters) of nitric acid. When the triuranium octoxide was completely dissolved, the solution was poured into 5-liter beakers. Using a funnel, the workers poured the concentrated uranyl nitrate directly into the precipitation vessel thereby bypassing the geometrically favorable storage tanks. This process was repeated three more times for a total of four batches of 2.4 kg each of uranium, thereby exceeding specified criticality safety mass limits. The next morning, September 30, 1999, the workers prepared three more batches and transferred two of the three batches to the precipitation vessel further exceeding mass limits. During transfer of the third batch of solution to the tank, a critical mass was achieved resulting in a criticality accident. It is estimated that approximately 40 liters of uranyl nitrate containing 16 kg of 18.8% enriched uranium had accumulated in the precipitation vessel at the time of the criticality accident.

4. Accident Description

The nuclear fission reaction in the precipitation vessel produced an initial burst of radiation, both neutrons and gamma rays, and associated minor heating and bubble generation, but did not result in any mechanical damage to any equipment. On site there were only gamma radiation detectors, which alarmed, but which did not record the time profile of the radiation released during the accident.

After the first few minutes, a quasi-steady state fission reaction set in and the radiation emission rates of both neutrons and gamma rays became essentially constant. Two detectors located at the Naka Fusion Research Center of the Japan Atomic Energy Research Institute, one at two kilometers and the other at 1.7 kilometers away from the JCO site, continously recorded the neutron radiation at one second intervals. There were no details of individual pulses that might have occurred within less than one second; for example on the order of milliseconds. These detectors were also able to observe the quasi-steady state neutron emission that set in after the first minute or two and lasted for nearly 20 hours.

Preliminary estimates of the major nuclear characteristics of the accident are provided below:

Solution concentration, g/l, uranium/U-235: 370/70
Solution volume, l: 40
Mass, kg, uranium/U-235: 16/3
Solution addition rate, l/s: 0.1
Reactivity addition rate, $/s: 0.1
First spike fission yield, fissions: 4 x 10+16*
Total fission yield, fissions: 5 x10+17 to 5x10+18*

***Subsequent Japan Atomic Energy Research Institute calculations determined the fission yield over the first 25 minutes of the accident to be 1.2×10^{18} fissions and the total fission yield to be 2.5×10^{18} fissions.**

These values were provided by officials from the Japan Atomic Engergy Research Institute with the exception of the first spike fission yield which was estimated by one of the authors of this report.

The reaction continued for about 20 hours, until water was drained from the cooling jacket that surrounded the precipitation vessel. This reduced neutron reflection back into the vessel and thus increased neutron leakage from the vessel, bringing the fissioning solution subcritical and stopping the reaction. To provide added assurance of continued subcriticality, about 17 liters of boric acid solution were added to the vessel shortly after the radiation field had dropped due to the draining of the cooling water. The workers who fed the boric acid solution into the precipitation vessel could not visually detect any anomaly. They indicated the ventilation system was still functioning and that the tank stirrer was deenergized.

On the morning of October 2, sand bags and concrete blocks were put in place to bring the gamma radiation field (due to fission products in the solution vessel) at the site boundary down to near background levels. The authorities then permitted those who had been evacuated from within the 350 meter radius zone to return to home and work.

5. Dose Assessments and Emergency Response Actions

The worker who was holding the funnel and the other worker who was pouring the solution into the funnel are reported to have received about 18 Gy Eq and 10 Gy Eq exposures. These are life-threatening values. The third worker in the building was a few meters away and received an estimated 2.5 Gy Eq exposure. As a result of the initial fission burst, alarm systems sensitive to gamma radiation sounded in the accident building as well as in the two main fuel fabrication buildings.

Following planned evacuation procedures, all personnel immediately evacuated to the muster location, a field at an extremity of, but within, the plant site. Health physics personnel with portable instrumentation quickly pinpointed the accident location as the Conversion building. Shortly thereafter, it was realized that the fission reaction was still proceeding and that dose rates at the muster location were significantly higher than background, although not immediately of health concern. At this time, about 30 minutes after the accident, the decision was made to relocate personnel to a wing of an administration building where gamma radiation dose rates were close to the natural background.

During this first half-hour the local fire department emergency response personnel were also called to assist with the evacuation of the three workers and their transportation to specialized medical facilities in Mito. These firefighters were estimated to have received doses between 0.5 mGy Eq and 4 mGy Eq.

The only other doses identified, subsequent to the activities described above, were those to seven offsite individuals in a building materials yard adjacent to the plant boundary closest to the building in which the accident occurred, and those to the JCO employees involved in the termination of the quasi-steady state fission reaction. The off-site individuals (non-JCO

employees) were not evacuated until the villages of Tokai-mura ordered a general evacuation out to 350 meters from the Conversion building at approximately 3:00 p.m., more than 4 hours after the accident. It is estimated that these individuals received doses between 0.4 mGy Eq and 9 mGy Eq. The 24 JCO workers who were involved in the termination of the accident received doses estimated at between 0.1 msv and 120 msv. The total number of JCO employees receiving significant whole body exposure was 59.

Details of the dose estimates for all individuals in each of the three categories described above are provided in Attachment E. All of the dose estimates were based on the analysis of blood sodium activation, a common technique to estimate doses subsequent to neutron exposures. Once appropriate quality factors have been established, the effective biological dose equivalent can be determined for these individuals as well as other members of the public.

A small amount of gaseous fission products was continuously being released during the 20 hours of the accident through the building ventilation system. This led to detectable levels of radioactive contamination on some soil and plant species in certain regions in the near vicinity of the plant. Based on data provided by Japanese government officials, these levels were far below levels of health concern. As a precautionary measure, residents within a 10 kilometer radius surrounding the plant site were advised to stay indoors. This advisory was not issued until 12 hours into the accident and then rescinded 10 hours after the accident was terminated. Details of the preliminary environmental monitoring are also provided in Attachment F.

6. Safety Assurance and Regulatory Oversight Considerations

The JCO Company Conversion building was commissioned for intermediate enriched uranium (<20%) nuclear fuel fabrication in 1984 after license application review and approval by the Government of Japan Science and Technology Agency. It had previously been commissioned (in 1980) for low enrichment uranium operation. The license application submitted by JCO contained stipulations on safety philosophy, specific measures or controls to ensure safety, and company verification of satisfactory implementation for design, construction, startup, and operation.

The review and approval by the Science and Technology Agency involved review of information to ensure acceptability of the actual work or business to be performed and to ensure acceptable measures for how the facility should be built and operated, including specific safety limits. The approval process also involved verification through onsite pre-use inspections which were conducted prior to 1985. The specific criticality safety limits for the JCO Company, Ltd. fabrication, storage, and conversion facilities are shown in Attachment G.

In response to questions by the delegation, Science and Technology Agency officials stated that an analysis submitted by the JCO Company in support of the license application had concluded that a criticality accident was not credible for the operations under consideration. The Science and Technology Agency independently reviewed the analysis and approved this conclusion. The team believes, based on review of system parameters, this conclusion had to rely significantly on assumptions that workers would adhere to procedural requirements and limits. Science and

Technology Agency officials stated that, as a result of this conclusion, some mitigative features, such as providing for a planned emergency response in the event of a criticality accident, were not required to be in place. The delegation believes this may have contributed to the length of time required to establish protective measures for members of the public and to terminate the criticality accident.

Officials from the Science and Technology Agency stated that seven discretionary post-operation inspections had been conducted at the JCO Company facilities since licensing; the latest of which was conducted in 1992. Officials also indicated a discretionary safety and security monthly patrol program conducted by Science and Technology Agency inspectors had been instituted in 1998. The Conversion building in which the accident occurred had been patrolled twice in the 1998/1999 timeframe; however, operations were not being conducted in the building during those patrols. Areas examined during post-operational inspections and monthly patrols included: Human Resources and Staffing, Training and Education, Operations, Radiological Controls, Maintenance, Nuclear Fuel Management, Radiological Waste Management, Emergency Measures, Record Keeping, and Reporting.

Officials from the JCO Company were vague in their description of supervisory or management oversight of fuel fabrication and conversion operations. In fact, during the operation in question, there was not a supervisor present. The lead worker had more experience than the other two workers but was not a supervisor.

Relative to the modified JCO Company procedure (described earlier in this report) which was at variance with license conditions, Science and Technology Agency officials indicated that the license required the JCO Company to have a safety committee responsible to review procedure changes and/or facility modifications to ensure such changes were either bounded by existing license conditions or were submitted to the regulatory agency for review and approval. At the time of the information exchange, no record of safety committee review of the revised company procedure could be found.

When asked questions about the criticality safety training provided to workers, JCO Company officials stated that "workers receive training on mass limits. They are not trained on consequences of criticality." Based on this statement and additional discussion with the JCO officials on this subject, the delegation concluded that this meant workers had no training and little knowledge of the fundamentals of criticality accidents, including factors, which can cause criticality accidents and the consequences of such accidents. In this regard, the workers would not know why the required safety controls (including mass limits) and procedure requirements (including appropriate use of equipment) were important to their safety.

7. Conclusions: Probable Causes and Lessons Learned

Based on the information presented, the delegation believes that the cause of this accident was the accumulation of uranyl nitrate, contrary to specified mass limits, directly into a precipitation vessel, contrary to its designed use and contrary to procedure, until a sufficient quantity of intermediate enriched uranium was available to initiate and sustain a nuclear criticality reaction.

These actions appear to have resulted from decisions to facilitate ease of handling the uranyl nitrate solution and to save time. The delegation believes that contributing to this cause were: inadequate worker training and knowledge of fundamentals and consequences of criticality accidents; inadequate procedures and procedure implementation; inadequate supervisory and management oversight; and infrequent regulatory inspection of operations.

The delegation additionally believes that lack of requirements for a planned emergency response, based on assumptions at the time of licensing that criticality was not credible, contributed to the length of time required to terminate the criticality and establish protective measures for members of the public.

The delegation considers the following to be appropriate lessons learned from this accident for operations in the United States:

1. Activities involved in handling fissile materials should ensure involved personnel at all levels have a fundamental understanding of criticality and criticality accidents, including factors which can cause criticality accidents and the consequences of such accidents.
2. Activities involved in handling fissile materials should ensure that criticality safety controls and limits are understood and rigorously followed for operations involving fissile materials. This includes assuring that people performing work understand why the controls and limits are important to their safety.
3. Activities involved in handling fissile materials should ensure sufficiency in monitoring of operations by company supervisory and managerial personnel as well as regulatory inspectors. Company supervisors and managers should ensure performance meets expectations and coach and mentor workers accordingly. Regulatory inspectors should ensure conformance to license conditions during operations.
4. Activities involved in handling fissile materials should ensure that analyses for fissile material operation which conclude criticality is incredible do not rely significantly on worker action.
5. Activities involved in handling fissile materials should ensure existence of a basic public emergency response capability including assuring sufficient instrumentation for perimeter monitoring and protocols with local officials for notification and initial public protective measures. This basic capability should exist even if analyses would suggest accidents are not credible.

During the information exchange, the delegation asked officials fron the Japan Atomic Energy Research Institute what they considered might be appropriate as lessons learned. The officials posed two questions:

(a) To what extent must one be prepared for workers not following any rules?

(b) How does one understand whether a deterioration of one's safety culture is occurring?

The delegation, having contemplated these questions, offers that an answer to question (a) is embodied in the first and second lessons learned relative to workers really understanding why controls and limits are important to their safety. This can be accomplished through ensuring individuals are qualified for the positions they hold, are appropriately trained and receive periodic retraining. Additionally an answer to question (b) is considered to be embodied in the operational awareness of company and regulatory officials (with appropriate feedback), as outlined in the third lesson learned. This can be accomplished by adhering to the Integrated Safety Management tenants associated with the feedback and improvement function.

Attachments

A. Secretary of Energy Charter to Nuclear Expert Team

B. Attendees at the October 18-19 Information Exchange Meetings

C. JCO Company Site Layout

D. Approved and Unapproved JCO Company Conversion Facility Processes

E. Preliminary Personnel Exposures Due to the Criticality Accident

F. Preliminary environmental monitoring data resultant from the criticality accident

G. Criticality Safety Limits for the JCO Company Fuel Fabrication, Storage, and Conversion Facility

The Secretary of Energy
Washington, DC 20585

Information Exchange on the Criticality Accident
at the Fuel Conversion Facility
Tokai-mura, Japan

Following the criticality event that occurred on September 30, 1999, at the fuel conversion facility in Tokai-mura, Japan, and the October 1, 1999, request from the Government of Japan, I am directing that a 3-member delegation of technical experts, Mr. Frank McCoy, Dr. Thomas McLaughlin, and Dr. Leroy Lewis, travel to Japan to exchange information with their Japanese counterparts.

The focus of the delegation is to better understand why the accident happened, including operational aspects and processes that led to the accident. The adequacy of procedures and procedure adherence, understanding of the consequences of the accident to workers and the public, and understanding of the regulatory and oversight regimes in Japan will be addressed. This will help develop lessons learned that can be applied to nuclear operations in the United States. These will include both those operations regulated by the Nuclear Regulatory Commission and the Department of Energy. Another focus of the exchange is to develop a better understanding of the emergency management program and accident response.

The delegation is prepared to share information with the Japanese government and other interested parties on the U.S. government's regulatory and oversight regimes for criticality safety, on initial actions that are being taken by licensees, the Nuclear Regulatory Commission, and the Department of Energy to assure ourselves that operations under our respective purviews are well understood and safe. We are prepared to share information on integrated safety management and specific criticality safety initiatives. These include initiatives designed to enhance the analytical underpinnings of our criticality safety programs; attract and retain qualified criticality safety experts; and provide facilities for generating critical mass data and for providing training for criticality safety practitioners.

Following return of the delegation to the United States, I am directing the team to provide me with a report on what occurred and on lessons learned from the accident. I am also directing the delegation to provide, at the appropriate time, an interagency briefing.

Bill Richardson
Secretary of Energy

10/14/99

Attachment A: Secretary of Energy Charter to Nuclear Technical Expert Team

Information Exchange Participants
October 18-19, 1999

DOE Participants in Both Information Exchange Meetings

Frank McCoy	Deputy Manager, Savannah River Site, USDOE
Leroy C. Lewis	Chemist, Idaho National Engineering and Environmental Laboratory
Thomas P. McLaughlin	Criticality Safety Group Leader, Los Alamos National Laboratory

US Embassy Participants in Both Information Exchange Meetings

James Hall	Minister Counselor (Science)
Douglas Morris	Second Secretary
Koichi Uchida	Deputy Representative, DOE Tokyo

Interpreter in Both Information Exchange Meetings

Teruo Fujii

Japanese Government Participants in the October 18, 1999, Information Exchange

Akira Honda	Director, Office of International Relation Nuclear Safety Bureau, Science and Technology Agency (STA)
Uichiro Yoshimura	Director, Nuclear Materials Regulation Division Nuclear Safety Bureau, STA
Masayuki Nakano	Director, International Affairs and Safeguards Division Atomic Energy Bureau, STA
Hiroshi Kataoka	Deputy Director, International Affairs and Safeguards Division Atomic Energy Bureau, STA
Hidetaka Ikeda	Chief of Section, International Affairs and Safeguards Division Atomic Energy Bureau, STA
Kunio Nakamura	Assistant Director, Science and Nuclear Energy Division Foreign Policy Bureau, Ministry of Foreign Affairs (MOFA)

Japanese Government Participants in the October 19, 1999, Information Exchange

Hiroshi Kataoka	Deputy Director, International Cooperation and Safeguards Division Atomic Energy Bureau, STA
Kunihisa Soda	Deputy Director General, Tokai Research Establishment, Japan Atomic Energy Research Institute (JAERI)
Sachio Fujine	Director, Department of Fuel Cycle Safety Research Nuclear Safety Research Center, Tokai Research Establishment, JAERI

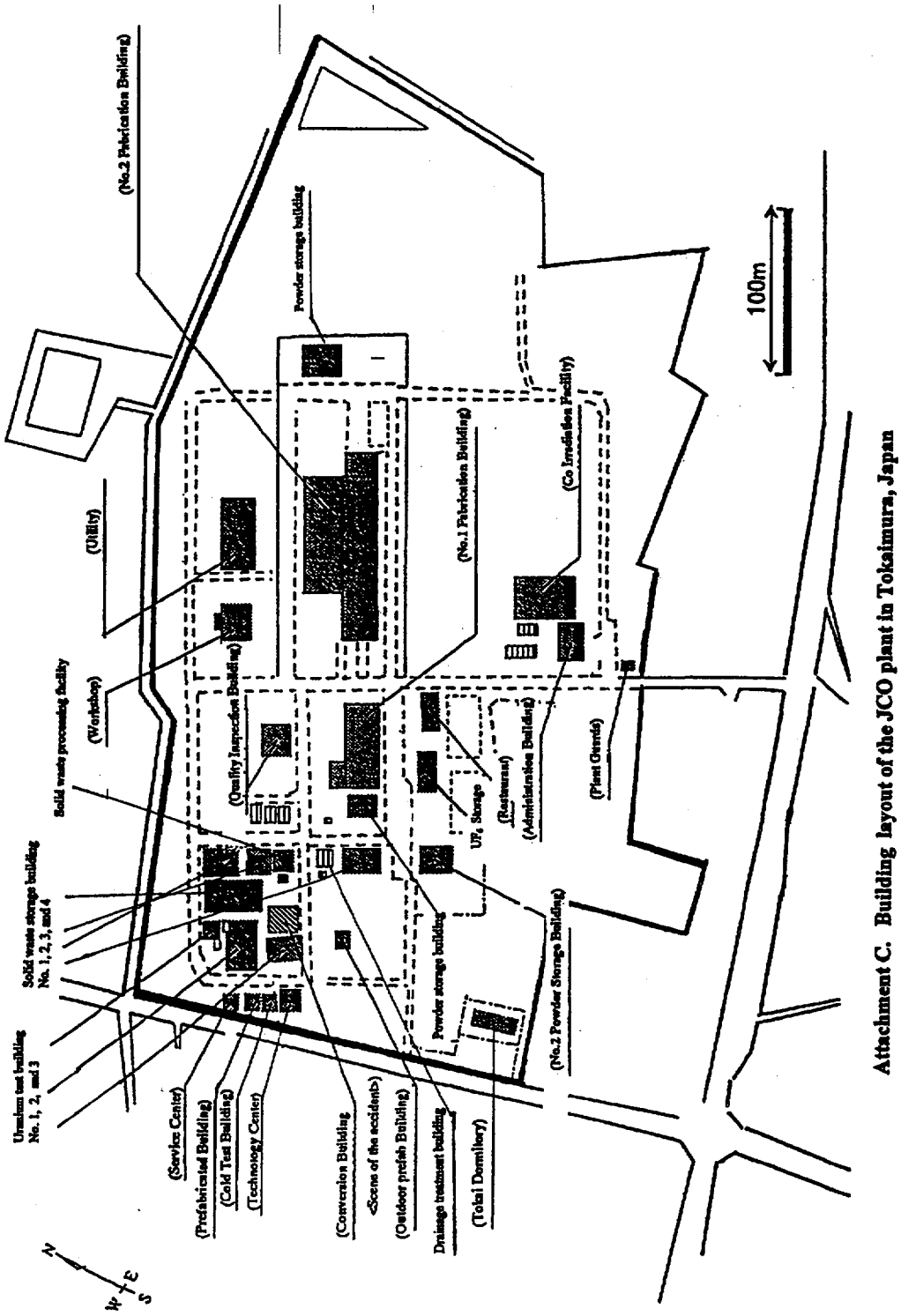
Attachment B: Attendees at the October 18-19 Information Exchange Meetings

Yoshinori Miyoshi	Head, Criticality Safety Laboratory, Department of Fuel Cycle Safety Research, Nuclear Safety Research Center, Tokai Research Establishment, JAERI
Akio Oono	General Manager, Criticality Technology Division Department of Safety Research Technical Support, Nuclear Safety Research Center, Tokai Research Establishment, JAERI
Hiroshi Okuno	Senior Engineer, Fuel Cycle Safety Evaluation Laboratory, Department of Fuel Cycle Safety Research, Tokai Research Establishment, JAERI
Seiichi Mizushita	Deputy Director, Department of Health Physics, Tokai Research Establishment, JAERI
Hiroshi Noguchi	Head, Internal Dosimetry Laboratory, Department of Health Physics, Tokai Research Establishment, JAERI
Masashi Hirano	Acting Manager of International Affairs Nuclear Safety Research Center, Tokai Research Establishment, JAERI
Tadakuni Matsumoto	Senior Engineer, Waste Management and Fuel Cycle Research Center, Tokai Works Japan Nuclear Cycle Development Institute (JNC)
Ichiro Nojiri	General Manager, Technology Developmental Section, Technology Co-ordination Division, Tokai Reprocessing Center, Tokai Works, JNC
Tomohiro Asano	General Manager, Safety Co-ordination Section, Safety Promotion Project, Head Office, JNC
Masayuki Iwanaga	Director, International Cooperation and Nuclear Material Control Division, Head Office, JNC
Junichi Kurakami	Deputy Director, Technology Co-ordination Division, Tokai Reprocessing Center, Tokai Works, JNC
Takeshi Kase	Plant System Design Group, Advanced Fuel Recycle Technology Division, Tokai Works, JNC
Yoshiki Kodani	Co-ordination and Physical Protection Management Section, International Cooperation and Nuclear Material Control Division, Head Office, JNC

JCO Company Participants in the October 19, 1999 Information Exchange

Masatoshi Yoshioka	General Manager, Technical Department The JCO Company
Tetsuya Kondo	Manager, Technical Department, the JCO Company

Attachment B: Attendees at the October 18-19 Information Exchange Meetings



Attachment C. Building layout of the JCO plant in Tokaimura, Japan

Attachment C: JCO Company Site Layout

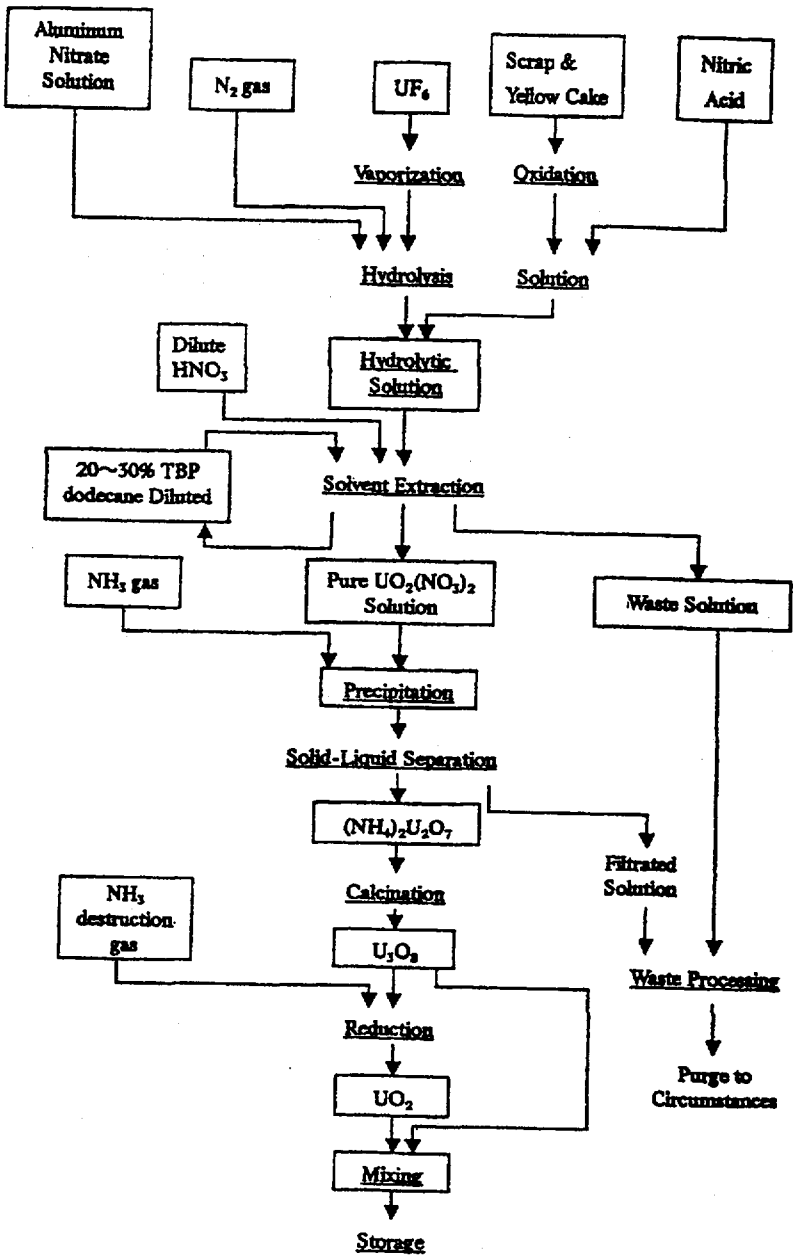


Figure 1. A schematic diagram of the JCO conversion process

Attachment D: Approved and Unapproved JCO Company Conversion Facility Process

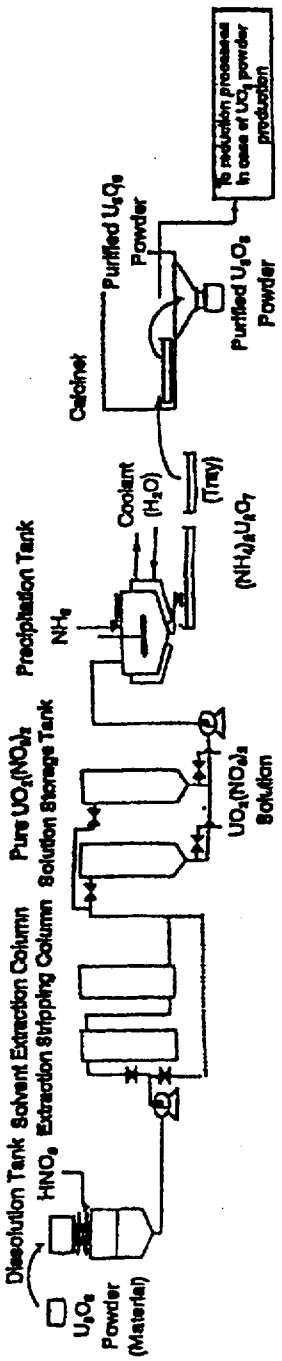


Figure 2. The JCO conversion process as it was permitted under the license granted in 1984. This license permitted the dissolution of 2.4 kg U_3O_8 when the enrichment was between 16 and 20 %. It allowed the option of taking off $UO_2(NO_3)_2$, U_3O_8, and UO_2 as products. It also allowed the feed to be from either the hydrolysis of UF_6 up to 20% enriched, or from the direct dissolution of U_3O_8 up to 20% enriched or of scrap up to 50% enriched.

Attachment D: Approved and Unapproved JCO Company Conversion Facility Process

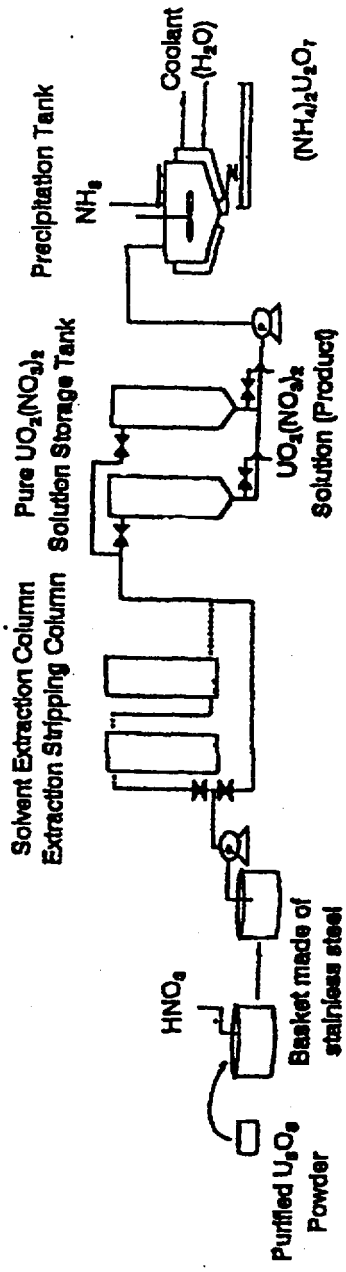


Figure 3. The modified procedure that allowed the use of a stainless steel bucket as a dissolution vessel. The resultant solution was to be pumped into the system for storage in the geometrically favorable solution storage tanks.

Attachment D: Approved and Unapproved JCO Company Conversion Facility Process

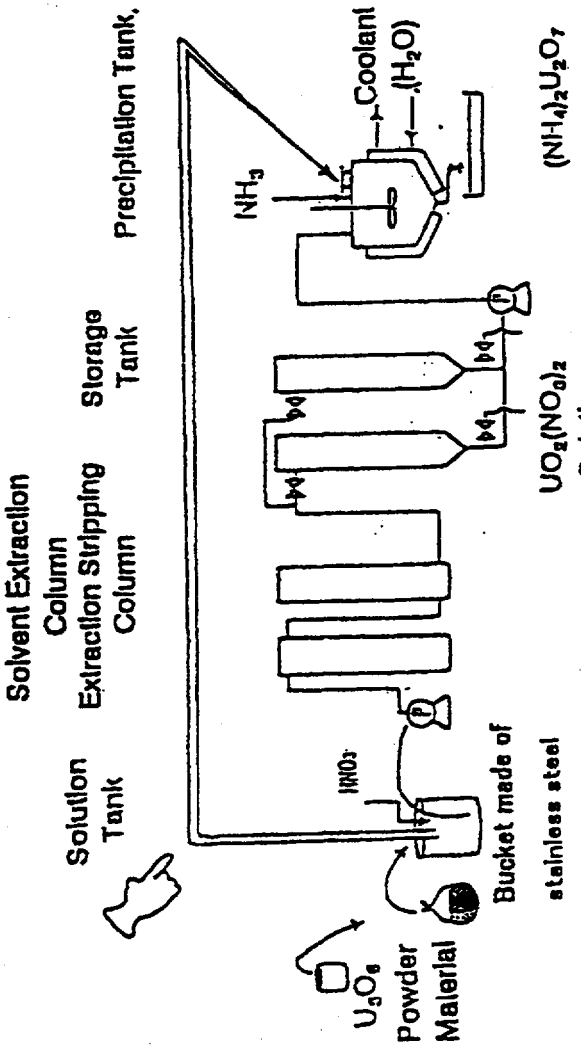


Figure 4. The procedure that was used at the time of the criticality accident. Batches containing 2.4 kgU_3O_8 were dissolved in a stainless steel bucket. The batch was then transferred to a 5-liter beaker and then physically transported to the precipitation tank where it was poured through a funnel into the tank. Seven batches of solution were added to the tank before it went critical.

Attachment D: Approved and Unapproved JCO Company Conversion Facility Process

Personal Monitoring at JCO Criticality Accident

Environment and Safety Division

Tokai Works

Japan Nuclear Cycle Development Institute(JNC)

Na-24 Activity in Whole Body and Estimated Dose(JCO employees) (1/2)

ID No.	Criticality Accident Start	Measurement Start	Time after Exposure [h]	Measured Activity(WBC) [Bq]	Corrected Activity in Whole Body [Bq]	Estimated Dose[mGy] (neutron+gamma)*1)
1	1999/9/30 10:35	1999/9/30 19:19	08:44	5.1E+03	7.7E+03	3.9 ~ 23
2	1999/9/30 10:35	1999/9/30 19:34	08:59	2.3E+03	3.5E+03	1.8 ~ 11
3	1999/9/30 10:35	1999/9/30 19:51	09:16	1.8E+03	2.8E+03	1.4 ~ 8.4
4	1999/9/30 10:35	1999/9/30 21:01	10:26	2.6E+02	4.3E+02	0.2 ~ 1.3
5	1999/9/30 10:35	1999/9/30 21:18	10:43	1.6E+02	2.7E+02	0.1 ~ 0.8
6	1999/9/30 10:35	1999/9/30 21:52	11:17	<D.L.*2)	-	-
7	1999/9/30 10:35	1999/9/30 22:15	11:40	1.1E+02	1.9E+02	0.1 ~ 0.6
8	1999/9/30 10:35	1999/9/30 22:32	11:57	<D.L.	-	-
9	1999/9/30 10:35	1999/9/30 22:54	12:19	<D.L.	-	-
10	1999/9/30 10:35	1999/9/30 23:11	12:36	<D.L.	-	-
11	1999/9/30 10:35	1999/9/30 23:26	12:51	2.2E+02	4.1E+02	0.2 ~ 1.2
12	1999/9/30 10:35	1999/9/30 23:41	13:06	2.0E+02	3.7E+02	0.2 ~ 1.1
13	1999/9/30 10:35	1999/10/1 00:29	13:54	3.2E+03	6.2E+03	3.1 ~ 19
14	1999/9/30 10:35	1999/10/1 00:45	14:10	2.6E+03	5.1E+03	2.6 ~ 15
15	1999/9/30 10:35	1999/10/1 02:35	16:00	4.0E+02	8.6E+02	0.4 ~ 2.6
16	1999/9/30 10:35	1999/10/1 02:46	16:11	4.1E+02	8.9E+02	0.4 ~ 2.7
17	1999/9/30 10:35	1999/10/1 02:54	16:19	<D.L.	-	-
18	1999/9/30 10:35	1999/10/1 03:02	16:27	2.6E+02	5.7E+02	0.3 ~ 1.7
19	1999/9/30 10:35	1999/10/1 03:10	16:35	3.6E+02	7.9E+02	0.4 ~ 2.4
20	1999/9/30 10:35	1999/10/1 03:17	16:42	9.3E+02	2.1E+03	1.0 ~ 6.2
21	1999/9/30 10:35	1999/10/1 03:24	16:49	3.4E+02	7.6E+02	0.4 ~ 2.3
22	1999/9/30 10:35	1999/10/1 03:32	16:57	5.5E+02	1.2E+03	0.6 ~ 3.7

*1) Na-24 1Bq(Whole Body)=0.5~3μGy(IAEA Technical Report Series No.211)

*2) D.L Na-24:150 Bq

Na-24 Activity in Whole Body and Estimated Dose(JCO employees) (2/2)

ID No.	Criticality Accident Start	Measurement Start	Time after Exposure [h]	Measured Activity(WBC) [Bq]	Corrected Activity in Whole Body [Bq]	Estimated Dose[mGy] (neutron+gamma)*1)
23	1999/9/30 10:35	1999/10/1 03:38	17:03	1.7E+03	3.8E+03	1.9 ~ 11
24	1999/9/30 10:35	1999/10/1 03:45	17:10	9.4E+02	2.1E+03	1.1 ~ 6.4
25	1999/9/30 10:35	1999/10/1 03:52	17:17	7.5E+02	1.7E+03	0.9 ~ 5.1
26	1999/9/30 10:35	1999/10/1 03:59	17:24	3.9E+02	8.9E+02	0.4 ~ 2.7
27	1999/9/30 10:35	1999/10/1 04:06	17:31	3.4E+02	7.8E+02	0.4 ~ 2.3
28	1999/9/30 10:35	1999/10/1 04:14	17:39	4.7E+02	1.1E+03	0.5 ~ 3.3
29	1999/9/30 10:35	1999/10/1 04:21	17:46	1.9E+03	4.4E+03	2.2 ~ 13
30	1999/9/30 10:35	1999/10/1 04:28	17:53	6.1E+02	1.4E+03	0.7 ~ 4.3
31	1999/9/30 10:35	1999/10/1 04:40	18:05	2.6E+03	6.1E+03	3.1 ~ 18.4
32	1999/9/30 10:35	1999/10/1 04:53	18:18	4.3E+02	1.0E+03	0.5 ~ 3.1
33	1999/9/30 10:35	1999/10/1 05:00	18:25	1.7E+02	4.1E+02	0.2 ~ 1.2
34	1999/9/30 10:35	1999/10/1 05:07	18:32	1.8E+02	4.3E+02	0.2 ~ 1.3
35	1999/9/30 10:35	1999/10/1 05:15	18:40	3.6E+02	8.8E+02	0.4 ~ 2.6
36	1999/9/30 10:35	1999/10/1 05:22	18:47	9.6E+02	2.3E+03	1.2 ~ 7.0
37	1999/9/30 10:35	1999/10/1 05:28	18:53	2.5E+02	6.1E+02	0.3 ~ 1.8
38	1999/9/30 10:35	1999/10/1 05:38	19:03	1.8E+02	4.5E+02	0.2 ~ 1.3
39	1999/9/30 10:35	1999/10/1 05:53	19:18	<D.L.*2)	-	-
40	1999/9/30 10:35	1999/10/1 06:00	19:25	4.9E+02	1.2E+03	0.6 ~ 3.7
41	1999/9/30 10:35	1999/10/1 07:27	20:52	7.0E+02	1.9E+03	0.9 ~ 5.7
42	1999/9/30 10:35	1999/10/1 07:36	21:01	4.3E+02	1.2E+03	0.6 ~ 3.5
43	1999/9/30 11:10	1999/10/1 10:23	23:13	<D.L.	-	-

*1) Na-24 1Bq(Whole Body)=0.5~3μGy(IAEA Technical Report Series No.211)

*2) D.L Na-24:150 Bq

Na-24 Activity in Whole Body and Estimated Dose (Residents)

ID No.	Criticality Accident Start	Measurement Start	Time after Exposure [h]	Measured Activity(WBC) [Bq]	Corrected Activity in Whole Body [Bq]	Estimated Dose[mGy] (neutron+gamma)*1)
1	1999/9/30 10:35	1999/9/30 20:06	09:31	8.5E+02	1.3E+03	0.7 ~ 4.0
2	1999/9/30 10:35	1999/9/30 20:14	09:39	1.0E+03	1.6E+03	0.8 ~ 4.7
3	1999/9/30 10:35	1999/9/30 20:22	09:47	1.7E+03	2.7E+03	1.4 ~ 8.1
4	1999/9/30 10:35	1999/9/30 20:35	10:00	1.9E+03	3.1E+03	1.5 ~ 9.2
5	1999/9/30 10:35	1999/9/30 20:44	10:09	1.9E+03	3.1E+03	1.5 ~ 9.2
6	1999/9/30 10:35	1999/9/30 23:56	13:21	4.7E+02	8.9E+02	0.4 ~ 2.7
7	1999/9/30 10:35	1999/10/1 00:12	13:37	1.1E+03	2.1E+03	1.1 ~ 6.3

*1) Na-24 1Bq(Whole Body)=0.5~3μGy(IAEA Technical Report Series No.211)

*2) D.L Na-24:150 Bq

Na-24 Activity in Whole Body and Estimated Dose (Tokaimura fire fighters)

ID No.	Criticality Accident Start	Measurement Start	Time after Exposure [h]	Measured Activity(WBC) [Bq]	Corrected Activity in Whole Body [Bq]	Estimated Dose[mGy] (neutron+gamma)*1)
1	1999/9/30 10:35	1999/10/1 01:32	14:57	5.0E+02	1.02E+03	0.5 ~ 3.1
2	1999/9/30 10:35	1999/10/1 01:49	15:14	6.4E+02	1.32E+03	0.7 ~ 4.0
3	1999/9/30 10:35	1999/10/1 02:05	15:30	6.1E+02	1.28E+03	0.6 ~ 3.8

*1) Na-24 1Bq(Whole Body)=0.5~3μGy(IAEA Technical Report Series No.211)
*2) D.L Na-24:150 Bq

2-8-1

Environmental Monitoring after the JCO Criticality Accident

Oct.15 1999

Environmental Monitoring after the JCO Criticality Accident

1. Introduction

In order to understand the effects of the criticality accident of the nuclear fuel processing facility at J.C.O. Tokai Office (thereafter referred to as "JCO") on September 30, 1999, on people's health and environment, the national government (Science and Technology Agency) and the Prefecture of Ibaraki (Pollution Technology Center) began emergency environmental monitoring immediately after the accident. This effort is being carried out with the cooperation of the Japan Atomic Energy Research Institute (JAERI), Japan Nuclear Cycle Development Institute (JNC), Japan Atomic Power Company (JAPCO), and other organizations.

2. Environmental Monitoring Program

As the emergency response, after the accident, the radiation dose rate was more carefully monitored at the fixed monitoring stations, in addition, the atmospheric radiation dose rate was also measured by mobile monitoring vehicles, etc. After these initial immediate activities, air dust, soil, leaves, and plants were collected and analyzed within 10-kilometer radius of the facility. Although no dispersion of radionuclides to the marine environment was expected based on the conditions of this accident, seawater and marine products were also collected and analyzed. In this monitoring, gamma-ray emission nuclides with short half-lives were focussed since these are most likely to have been generated by the criticality accident.

3. Results of Environmental Monitoring

(1) Meteorological Conditions

The meteorological conditions observed at the Prefecture's Funa-Ishikawa Station (located 1.5 km south of the facility), are as follows (only the precipitation information is from the Prefecture's Oshinobe Station, located 3.5 km south-southeast of the facility):

- The wind was from the southeast from 10 to 11 A.M. on September 30, with a speed of 1.3 to 2 m/s.
- After that, until about 4 P.M., the wind was from the east-southeast, with a speed of 3 to 3.5 m/s.
- The wind began to swirl around starting about 5 P.M.; the wind direction was not clearly fixed until about the midnight. During this time, the wind speed was little—between 1 to 2 m/s. The air stagnated in the downstream of the wind. Also, during this time, rain was observed; in particular, 16.5 mm of precipitation was recorded around 5 P.M.

Attachment F: Preliminary Environmental Monitoring Data Resultant from the Criticality Accident

- Between 1 and 3 A.M., the wind was from the north; afterwards, it was from the northeast or east-northeast, starting around 4 A.M. The wind speed was extremely small when the direction varied; after 6 A.M., the wind direction got settled, with a speed of 3 to 5 m/s.

(2) Radiation Dose Rate

(i) Conditions around the facility

Radiation dose rate, measured in the vicinity of the facility, from 11:36 A.M., Sept. 30, to the end of the fission, was 0.001 to 0.84 mSv/h. The dose rate for the neutron was measured after the evening of September 30, and it was 0.0015 to 4.5 mSv/h. Neutron was detected until the completion of the fission.

After the completion of the fission at 6 A.M. on October 1, neutron ray got down below the detection limiting value; gamma-ray began to decrease after the evening of October 2, when shielding such as soil were built near the facility. Currently, both levels are returning to their respective normal levels.

(ii) Conditions in the Tokai Area

Among the monitoring stations established by the Ibaraki Prefecture or other organizations, the following three stations confirmed a change of radiation dose rate immediately after the accident: the Prefecture's Funa-Ishikawa Station (1.5 km south of the facility), the Prefecture's Ishigami Station (2 km northeast of the facility), and the JNC's Funa-Ishikawa Station (2 km east-southeast of the facility). At the Prefecture's Funa-Ishikawa Station, the level of 0.40 micro Gy/h was observed immediately after the accident (this is a 2-minute value, about 10 times the level before the accident). However, this value returned to the normal level immediately afterwards. The monitoring station inside the JAERI's Naka Center (1.7 km west of the facility) also observed both the gamma ray and the neutron ray instantaneously.

After that, at the Prefecture's Kadobe Station (7 km west of the facility), the gamma-ray dose rate increased around 11:26 A.M., approximately one hour after the accident had occurred; it achieved a maximum level of 0.24 micro Gy/h (a 2-minute value), where the level stayed for about 20 minutes, and it got back to its normal level about 11:50 A.M. Further, starting around 4 P.M., when the wind direction began to change, an increase in the gamma-ray dose rate was observed at 38 fixed observation stations established by the Prefecture of Ibaraki or other organization. A maximum level of 3.1 micro Gy/h (a 2-minute value) was observed at the Prefecture's Funa-Ishikawa Station; elsewhere, radiation dose rates exceeding 0.1 micro Gy/h were also observed.

In addition to the data obtained by monitoring stations, survey of gamma dose rate using monitoring vehicle was done on September 30 in the vicinity of the premises up to about 4 km away from the facility. The resulting levels varied from 0.03 micro Sv/h to 0.44 micro Sv/h.

Around 6 A.M., October 1, when the fission was completed, the gamma-ray dose rate had returned to its normal level at all fixed observation stations.

Attachment F: Preliminary Environmental Monitoring Data Resultant from the Criticality Accident

The cumulative dose for the atmospheric gamma-ray dose rates observed at these 38 fixed stations between 10 A.M., September 30, and 6 A.M., October 1, was 0.8 - 3.0 micro Sv. (These values include the increase due to natural radiation from precipitation.)

The following two reasons can be considered as an explanation for the increase in the atmospheric gamma-ray dose rate in such a large area (numerous locations) between the accident and the completion of the fission:

- Since the instantaneous peak-level immediately following the accident was detected in various numerous stations in different directions (the Prefecture's Funa-Ishikawa Station, the Prefecture's Ishigami Station, JNC's Funa-Ishikawa Station, and JAERI's Naka Center), it is likely to be the prompt gamma ray generated by the fission.
- Various peak levels observed following the accident, until the completion of the fission, were due to inert gasses and iodine generated mainly by the continued fission and carried away by the wind.

(3) Environmental Samples Analysis Results
The radaionuclides detected in the emergency environmental monitoring after the accident are the following types with short half-lives:

Na-24 (half-life: 15 hours):	radioactive substance generated by neutrons
Mn-56 (half-life: 2.6 hours):	radioactive substance generated by neutrons
Sr-91 (half-life: 9.5 hours):	decay product of Kr-91 (inert gas) generated by nuclear fission
I-131 (half-life: 8 days):	generated by nuclear fission
I-133 (half-life: 21hours):	generated by nuclear fission
I-135 (half-life: 6.6 hours):	generated by nuclear fission
Cs-138 (half-life: 32 minutes):	decay product of Xe-138 (inert gas) generated by nuclear fission

Among these nuclear species, iodine (I-131, I-133, I-135) is generated by nuclear fission whereas strontium (Sr-91) and cesium (Cs-138) are decay products of inert gasses (such as Kr and Xe) generated by nuclear fission. Therefore, it appears that neither inert gasses nor iodine were radiated as substances from the facility in this nuclear accident. Since no particle-type products of nuclear fission were detected here, it can be concluded that these substances were probably filtered out via HEPA filters installed in the ventilation system of the facility, thus hardly affecting the environment.

On the other hand, sodium (Na-24) and manganese (Mn-56) are likely to have been activated by neutrons with the non-radioactive substances Na-23 and Mn-55 contained in the natural soil.

Below are the results for each item measured in this monitoring process.

(i) Atmospheric Dust and Iodine in the Atmosphere
Dust and iodine were collected from the atmosphere, and their radionuclide activity was measured. Out of the 109 samples collected, one sample collected at the Prefecture's Funa-

Ishikawa Station (1.5 km south of the facility) contained Sr-91; eleven samples collected at the JAERI's Naka Center (their ground, 1 km west of the facility), at JAPCO's Nakamaru Station (3 km south-southeast of the facility), and in the vicinity of the facility contained Cs-138; and two samples collected in the vicinity of the facility contained I-133 and I-135. No other samples contained radioactive substances.

Sr-91 has a short half-life of 9.5 hours, decaying very rapidly. The concentration of Sr-91 detected was 2.1×10^{-8} Bq/cm^3, significantly lower than the atmospheric concentration limit (5×10^{-4} Bq/cm^3) for the peripheral monitored area established by law (thereafter, simply referred to as the "atmospheric concentration limit").

(ii) Soil

Sample soil was collected in the area covering the immediate vicinity of the facility (80 m south, adjacent to the premises) as well as the 10-km-radius of the facility. Some of the samples contained Na-24, Mn-56, I-131, I-133, and Cs-137.

Na-24 was detected at several locations around the facility, and Mn-56 was found at two locations near the facility as well. It seems to generate by neutron activation. A very small amount of Na-24 was also found in the soil collected at Nukata Elementary School in the town of Naka-machi, 3 km northwest of the facility. The soil, leaves, and plants were then collected near this site and analyzed, but none of these samples contained any Na-24 in them; therefore, it appears that the Na-24 generated by radioactive reactions around the facility was carried over by the wind to some spots, where the product was detected.

The concentration levels of both Na-24 and Mn-56 detected in these samples were extremely low. Furthermore, the half-live of Na-24 is 15 hours while that of Mn-56 is 2.6 hours. They both decay very quickly, and thus the effects of these species on the heath of the general public and on the environment are considered insignificant.

Out of the 138 samples collected, only one sample near the facility contained I-131 and I-133. Their concentration levels were 0.00045 Bq/g and 0.0016 Bq/g, respectively; both of these levels are quite low, and there is hardly any effect on the heath of the public and on the environment.

Cs-137 had been found on a regular basis as a result of past nuclear experiments, and the level of this substance in the sample was also normal. Hence, it is concluded that the Cs-137 found in this study is a result of nuclear experiments.

(iii) Leaves and Plants

Leaves and plants (including weeds) were collected in the area covering the immediate vicinity of the facility (90 m south, adjacent to the premises) as well as the 10-km-radius of the facility. Out of the 115 samples, fifteen of the samples collected within the 2-km radius of the facility contained radioactive iodine (I-131, I-133, and I-135). These are thought to have been dispersed by the accident and deposited on the surface of leaves and plants by means such as rain.

The maximum level of I-131 was 0.037 Bq/g, about 1/50 of the intervention level for vegetable (2 Bq/g). The levels for I-133 and I-135 are also extremely low, and their half-lives are 21 hours and 6.6 hours, respectively. Hence, these substances decay rapidly, and the effects of these elements on the health of the public and on the environment are considered sufficiently small.

(iv) Livestock and Marine Products

Milk, chicken eggs, beef, pork, seaweeds, fishes, and shells were collected at various locations within the prefecture and analyzed; none of the samples had any radioactive elements.

(v) Miscellaneous Samples (Land Water and Sea Water)

As miscellaneous samples, land water (lakes and swamps, drinking water, rain water, tap water supply (reservoir water)) and sea water were collected in the 10-km radius of the facility and analyzed. None of the sample had any radioactive elements.

4. Summary and Future work

A summary of the results thus far of the emergency environmental monitoring is as follows:

Gaseous matters (inert gasses and iodine), thought to have been generated by nuclear fission, were dispersed to a large area, increasing the radiation dose rate at numerous locations. The environmental sample analysis showed that some samples contained decay products (Sr-91 and Cs-138) of iodine and inert gasses with short half-lives; these are considered to have been generated by the fission. Na-24 and Mn-56 were also found in some samples; these are considered to have been activated by neutrons.
The increase in the gamma-ray dose rate due to the gaseous matters dispersed from the facility was only several micro Gy/h at the highest level, and it was seen only for a brief period of time. Further, the level of each radionuclides found in the environment after the accident was very insignificant, and the nuclear species found are those which decay very rapidly. Therefore, we conclude that they affect neither the health of the public nor the environment.

In order to quantitatively evaluate and study the effects of the accident on the health of the public and on the environment, a second-phase monitoring process shall be conducted soon; this will include the evaluation of the exposure ray dose of radioactive substances found in the environment due to the accident.

Attachment F: Preliminary Environmental Monitoring Data Resultant from the Criticality Accident

Table 6-1 Nuclear limit values for UF_6 cylinder

(No.1 Fabrication Facility, No.2 fabrication facility building, UF_6 storage building)

	Nuclear limit values		
Cylinder	Enrichment	H/U	Mass limit values
30-inch cylinder	less than 5%	less than 0.088	less than 1,539 kg U
12-inch cylinder	less than 5%	less than 0.088	less than 141 kg U
8-inch cylinder	less than 5%	less than 0.088	less than 78.2 kg U

Table 6-2 Nuclear limit values for UF_6 cylinder

(Conversion Facility)

	Nuclear limit values		
Cylinder	Enrichment	H/U	Mass limit values
8-inch cylinder	less than 12.5%	less than 0.088	less than 78.2 kg U
5-inch cylinder	less than 20%	less than 0.088	less than 16.86 kg U

Table 7 Mass limit values in Conversion Facility

Nuclear limit values		
Enrichment	H/U	Mass limit values
less than 5%	No limitation	less than 16 kg U
5-10%		less than 6.0 kg U
10-12%		less than 4.7 kg U
12-16%		less than 3.2 kg U
16-20%		less than 2.4 kg U
20-30%		less than 1.4 kg U
30-50%		less than 0.78 kg U

Table 8 Volume limit values in Conversion Facility

Nuclear limit values		
Enrichment	H/U	Volume limit values
less than 20%	No limitation	less than 9.5 l

Attachment G: Criticality Safety Limits for JCO Company, Ltd. Fuel Fabrication, Storage and Conversion Facility