THE ACCIDENT AT THE NUCLEAR FUEL PROCESSING FACILITY IN TOKAJMURA: THE ROLE OF IAEA

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1. The role of the IAEA

The International Atomic Energy Agency (IAEA):

Membership:	130 countries
Budget:	direct expenses (regular) US $ 225 million Assistance = US $ 90 million extrabudgetary = US $10 million contributions in kind> US $ 15 million
Personnel:	800 professional staff, 900 general support staff
Location:	Wagramer Strasse 5, Vienna, Austria

Within the United Nations family, the IAEA membership consists of nearly 130 States. lt has a total annual budget of more than a quarter of a billion US dollars, a professional staff of about 800 and an administrative support staff of about 900.

1.1 The IAEA’s Main Functions

The IAEA has three main functions, or pillars':

- **Safeguards,** or verification of the peaceful uses of nuclear energy;
- **Technolociy,** or fostering of the transfer of the body of knowledge about nuclear energy and onizing radiation; and
- **Safety,** or - better - the global promotion of an *international safety regime* the least known of the IAEA’s functions.

1.2. The IAEA's Safety Functions

Since its creation in 1957, the IAEA has performed two safety related functions which were provided for by the drafters of its Statute, namely:

- **establishing standards of safety** for the protection of health against the effects of radiation, and
- **providing for the application of those standards** at the request of a State.

With these statutory functions, the IAEA is unique among international organizations.

1.3. The International Radiation Safety Regime: Binding Conventions International Standards Provisions for Applications

In performing its safety functions, the IAEA has contributed to the emergence - in the 1 990s - of what has been termed a *de facto internationaj radiation safety regime.*
The regime includes three key elements:

- **legally binding international undertakings by States;**
- **globally agreed international safety standards;** and
- **international provisions for facilitating the application of those standards.**

I will comment on each of these elements in turn as it relates to our subject.

1.3.1 Conventions

Let us start with the legally binding international undertakings by States or, in legal language, **international conventions.** Under the auspices of the IAEA, four major international conventions have been adopted in recent years, namely:

- the Convention on Early Notification of a Nuclear Accident;
- the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency;
- the Convention on Nuclear Safety; and
- the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the Joint Convention for).

1.3.2. International Standards

Let me now turn to the question ot international safety standards. Over the years the IAEA has developed a corpus of more than 200 safety standards, some jointly with other international organizations. They are published in the Safety Standards Series (formerly the Safety Series) and are grouped into three categories. *Safety Fundamentais,* policy publications for decision makers, present principles, concepts and objectives. The standards proper, the *Safety Requirements:* these are publications with *shall* statements; they are the backbone of the IAEA's corpus of standards. *Safety Guides* are publications with *should* statements recommending how to implement the requirements.

- **Radiation Safety Fundamentals**

One example of the Safety Fundamentals 5 the publication on *Radiation Protection and the Safety of Radiation Sources.* This publication is co-sponsored by six international organizations.

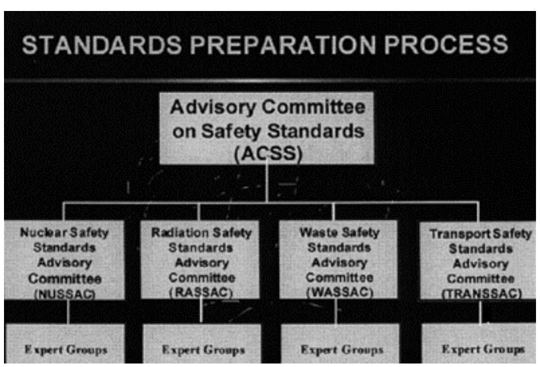
- **Radiation Safety Repuirements; the BSS:**

The publication that establishes requirements in this field is the *International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources* (the BSS). The BSS are also co-sponsored by six international organizations.

- **Radiation Safety Guides:**

A large number of Safety Guides support the BSS. An example of Safety Guide in the context of radioactive residues is the Safety Guide establishing intervention levels for radiological emergencies.

- **The IAEA Safety Standards Prearation Process**



The IAEA radiation safety standards are established through a process which involves the extensive participation of experts and governmental representatives.

1.3.3. Providing for the Application of International Standards

I will now turn to an area that accounts for a substantial amount of the IAEA's work in radiation safety: providing **for the application of safety standards.**

This aspect of the international safety regime involves:

- providing direct safety assistance to Member States,
- fostering information exchange,
- promoting education and training,
- co-ordinating research and development, and
- rendering safety review services.

Of these activities, two of particular relevance for the subject of this presentation:
rendering services and *in formation exchange.*

Rendering Services

The IAEA offers a wide range of safety review services, which are available to its Member States on request. One purpose of these services 5 to give the requesting State access to a range of expertise and experience available in other IAEA Member States. In recent years, the IAEA has rendered review services to a number of Member States. At the request of the Government of Japan it performed the preliminarv fact-finding mission in Qctober 1999 on the accident at the JCO nuclear fuel processing facility in Tokaimura

Fostering Information Exchange

Another mechanism for providing for the application of safety standards is fostering the international exchange of relevant information. This includes the publication of the report on the preliminary fact-finding mission with the objective that the Member States learn from this accident.

2. The Preliminary Fact-Finding Mission Following the Accident at the Nuclear Fuel Processing Facility in Tokaimura, Japan

2.1. Introduction

2.1.1. Background to the IAEA Secretariat Team Mission

On 30 September 1999, at 10:35 local time (01:35 GMT), a criticality accident occurred in the conversion building (auxiliarv plant) at the uranium conversion facility of JCO Company Limited in Tokaimura, Ibaraki Prefecture, Japan. A solution of enriched uranium (18.8% ^{235}U by mass) in an amount reportedly several times more than the specified mass limit had been poured directly into a precipitation tank, bypassing a dissolution tank and buffer column intended to avoid criticality. This action was reported to have been in contravention of the legally approved criticality control measures. lt resulted in three JCO workers suffering acute radiation syndrome and a number of workers and members of the public receiving radiation doses. Some 161 people were evacuated from within about 350 m of the facility, and some 310,000 people were advised to stay indoors for about 18 hours as a precautionary measure.

Under the terms of the Convention on Early Notification of a Nuclear Accident, Japan had no obligation to notify the IAEA or other States. That Convention applies in the event of any accident from which a “release of radioactive material occurs or is likely to occur and which has resulted or may result in an international transboundary release that could be of radiological safety significance for another State”. The accident at Tokaimura did not result in an international transboundary radioactive release. Notwithstanding this, the Emergency Response Centre set up by the IAEA pursuant to its obligations under the Convention established and maintained contact with the relevant competent authority in Japan to ascertain facts in order to respond to the many requests for information from official Contact Points under the Convention arrangements.

The IAEA Secretariat was notified that Japan had given a provisional rating for the event, on the basis of the overexposure of the workers concerned, of Level 4 on the IAEA's International Nuclear Event Scale, which runs from Level 1 to Level 7. Level 4 denotes an accident without significant off-site risk. On 1 October 1999 (in Japan, 30 September in Vienna), the IAEA Secretariat offered assistance to the Japanese authorities in responding to the accident. This offer was declined because the authorities believed that assistance was not necessary at that time. Subsequently, the Director General of the IAEA, following discussions with the representatives of the Government of Japan, dispatched three experts of the IAEA Secretariat, specializing in the nuclear fuel cycle and its regulation, emergency response and accident consequence assessment, and environmental monitoring and dosimetry, on a fact finding mission to Tokaimura from 13 to 17 October 1999.

2.1.2. Objectives and Scope of the Fact Finding Mission

The objectives of the IAEA Secretariat's fact finding mission were:

- to compile the available information on the accident;
- to render advice to the Japanese authorities should they request it; and
- to prepare for the Director General of the IAEA an authoritative and factual report on the immediate causes, consequences and aftermath of the accident.

The scope of the fact finding mission was restricted to:

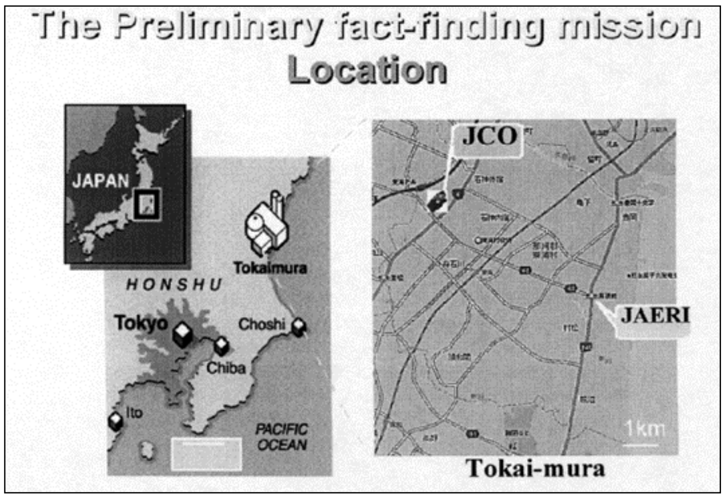
- the events leading up to the accident;
- the criticality event itself and the mitigation of its consequences;
- the radiological consequences in terms of radiation doses to the persons exposed, and the radiation and radioactive materials released to the environment;
- the conditions of the exposed persons and their medical treatment; and
- the emergency response and actions taken to protect workers and the public.

The IAEA Secretariat team was also to take some corroborative measurements of radiation levels in the environment.

2.1.3. Objectives and Scope of the Report

The objectives of this report are to assist in the dissemination of information on the accident and its consequences, and to set out established facts. The report is limited to a summary of information collected during the mission on the accident, its immediate causes, the response to it and its immediate consequences. An investigation into the accident has commenced in Japan. A Japanese Governmental Investigative Committee under the Nuclear Safety Commission (NSC), which is advisory to the Prime Minister, is undertaking its own investigation into the accident and is still collecting information and evaluating the facts. The information presented here derives primarily from source materials provided by Japanese authorities and institutes, corroborated to the extent possible by means of interviews conducted by the team with key officials and experts, and observations and measurements made by the team. Some of the information provided to the team was clearly of a provisional nature and has therefore not been reproduced here; nevertheless, this information was useful in gaining a technical understanding of the accident and its consequences. Where there are questions concerning the accuracy of the information reported, this 5 noted in the text. Equally, the direct observations and measurements that were made by the team are also noted.

Tokaimura is a large village 120 km northeast of Tokyo in Ibaraki Prefecture. The JCO site in Tokaimura is also dose to the town of Naka-machi. There are nine municipalities and about 310,000 inhabitants within a 10 km radius, and around 150 people live within 350 m of the JCO facility itself. The nearest residence is within 200 m of the conversion building in which the accident took place. There are several nuclear installations operating in Tokaimura, including the Japan Atomic Power Company (JAPCO) nuclear power plant and other nuclear reactors, the Japan Atomic Energy Research Institute (JAERI) establishment, and a fuel reprocessing plant.



2.2.1. JCO and the Nuclear Fuel Processing Facility

The operating company, JCO, wholly owned by Sumitomo Metal Mining Company Ltd, operates three conversion facilities at this site:

- One with an annual capacity of 220 tonnes of uranium per year (t Ula) for 10w enriched uranium (enrichment of less than 5%);
- One with an annual capacity of 495 t UIa for bw enriched uranium (less than 5%); and the one in which the accident took place – in a conversion building whose annual capacity is up to 3 t Ula for either enriched uranium (not more than 20%) for the production of uranium oxide (U_30_8) powder from uranium hexafluoride (UF_6), or for enriched uranium (not more than 50%) for the production of uranium oxide powder from scrap.

The conversion building is on the western side of the site, near its western boundary and the municipalities of Tokaimura and Naka-machi. lts purpose is the production of uranium oxide powder or uranyl nitrate solution from uranium hexafluoride (UF_6), uranium yellow cake or scrap. One process involves the dissolution of uranium oxide (U_30_8) powder in nitric acid (HNO_3), homogenization of the solution and precipitation with ammonia to produce ammonium diuranate ($((NH_4{>}_2U_20_7))$). The facility is not operated continuously but is used for immediate and short batch production (30-200 kg U with an average of around 100 kg U), produced mainly for the Joyo fast research reactor. lts cumulative use has been about two months per year.

2.2.2. Legislative and Regulatory Framework

Permission for a change in the JCO licensing conditions to encompass the conversion building was given on 20 June 1984 by the Prime Minister after review by the Japanese Science and Technology Agency (STA) and in consultation with the NSC and the Japan Atomic Energy Commission. The licensing conditions stipulated a mass limitation of 2.4 kg U in the conversion facility for an enrichment level of between 16 and 20%. Also, a constraint on the geometric shape of the buffer column was applied. An inspection was carried out on the basis of the approval on 20 June 1984 and certification was issued by the STA in December 1984 covering the entire conversion building.

A change in the capacity of the products storage room was approved on 6 October 1994. An inspection by STA in March 1995, on the basis of the approval of the change on 6 October 1994, covered only the storage facility in the conversion building. In Japan, periodic inspection during operation seems not to be a legal requirement for facilities of this type.

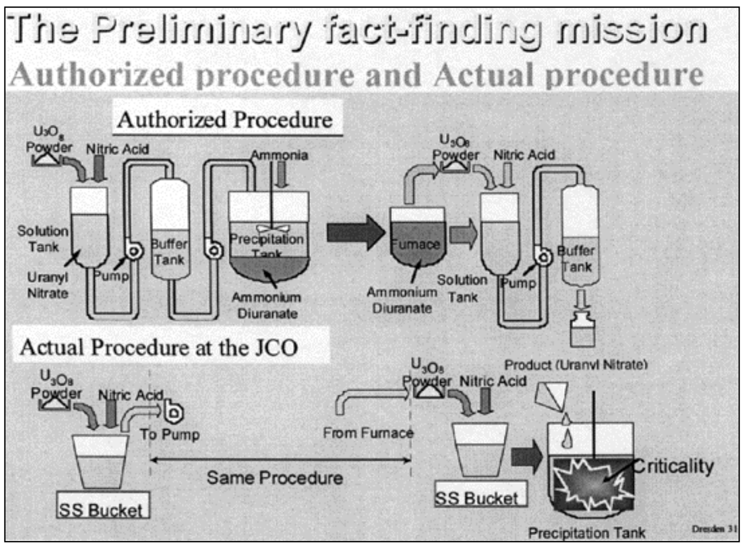
2.3. The accident and mitigation of its consequences

2.3.1. The Criticality Event and Its Immediate Causes

The approved nuclear fuel conversion procedure specified in an internal document involved the dissolution of uranium oxide (U_30_8) powder in a dissolution tank, then its transfer to a pure uranyl nitrate solution buffer column for homogenization by nitrogen (N_2) gas purge and mass control, followed by transfer to a precipitation tank which 5 surrounded by a water cooling jacket to remove excess heat generated by the exothermic chemical reaction. The prevention of criticality was based upon the general licensing requirements for mass and volume limitation, as well as upon the design of the process, including use of a column with a criticality-safe geometry as a buffer to control the amount of material transferred to the precipitation tank.

The work procedure was modified in November 1996, without permission for the modification having been given by the regulatory authorities, to allow the dissolution of uranium oxide (U_30_8) to be performed in stainless steel buckets. According to the information provided at the meetings with the IAEA Secretariat team, this new procedure had been followed several times before this accident occurred.

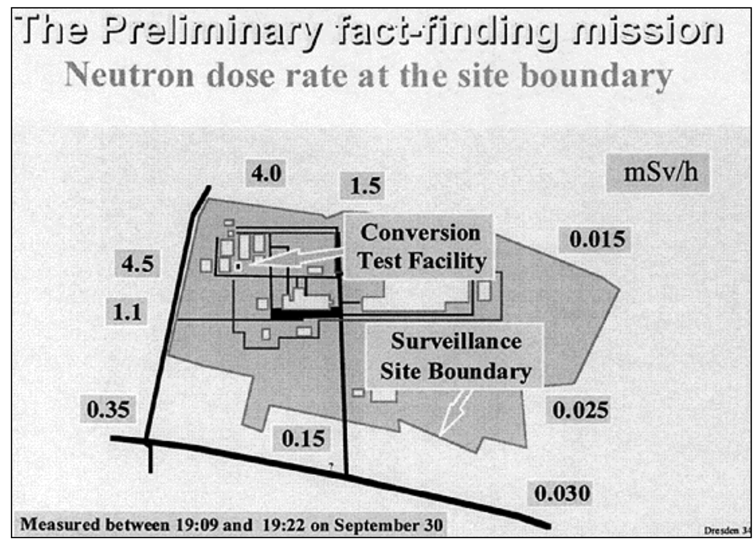
Furthermore, when the criticality event occurred, homogenization of uranium oxide was being performed by mechanical stirring in the precipitation tank instead of in the mass control equipment. This was done by pouring uranyl nitrate solution (made by dissolving uranium oxide (U_30_8) in nitric acid) directly from the steel bucket into the precipitation tank. The tank was not designed with a geometry conducive to preventing criticality, bei ng 450 mm in diameter and 610 mm high. This means of homogenization in the precipitation tank is not even described in the revised procedure and was a further deviation from the approved procedure.



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

Thus, for the preparation of fuel for the Joyo fast research reactor in late September 1999, workers dissolved U_30_8 powder in nitric acid in stainless steel buckets and poured the solution directly into the precipitation tank. About 26 L of the solution, with uranium enriched to 18.8% ^{235}U by mass, had been poured into the precipitation tank in four batches on 29 September. In the morning of 30 September, the workers continued to prepare uranyl nitrate solution and poured three additional batches into the precipitation tank.

At around 10:35 on 30 September (all times are local times unless otherwise stated), when the volume of solution in the precipitation tank reached about 40 L, equivalent to about 16 kg U, a critical mass was reached. At the point of criticality, the nuclear fission chain reaction became self-sustaining and began to emit intense gamma and neutron radiation. The area gamma monitoring device detected a high level of gamma radiation and the area alarms sounded. The three workers concerned evacuated the building (there was apparently no explosion). They were subsequently given assistance by emergency service workers. The other workers on site assembled in the muster zone.



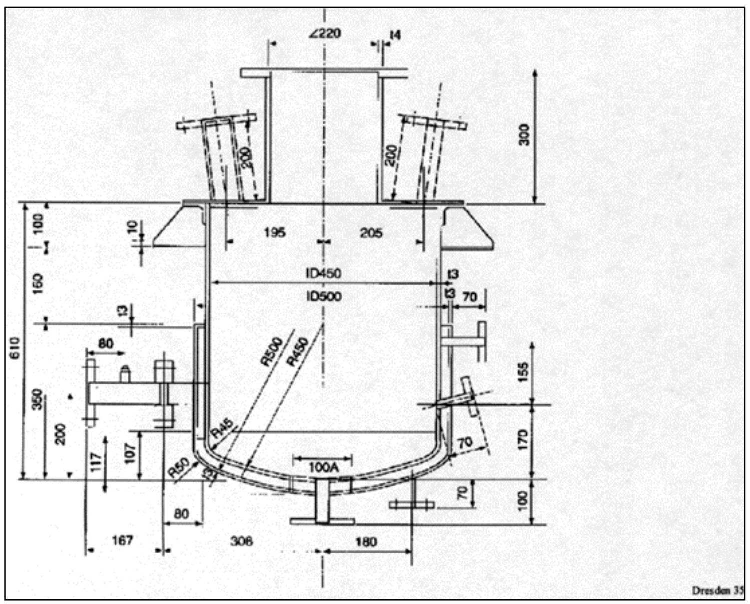
The STA received the first report of an accident from JCO at 11:19 on 30 September. Later the same day it set up a Local Countermeasures Headquarters (LCH) in the Tokai Research Establishment of JAERI. Six experts from STA were dispatched to this headquarters. With the cooperation of JAERI (some 50 experts), the Japan Nuclear Cycle Development Institute (JNC) (some 60 experts) and electricity companies, STA began to gather information on the situation at the site and give advice.

At 11:40, a maximum gamma dose rate of 0.84 mSv/h was measured in an area around the facility. At around 14:00, the Mito Atomic Energy Office of STA started monitoring gamma dose rates. The results were provided to the LCH and to the Government Accident Countermeasures Headquarters (GACH) which had been established at 15:00.

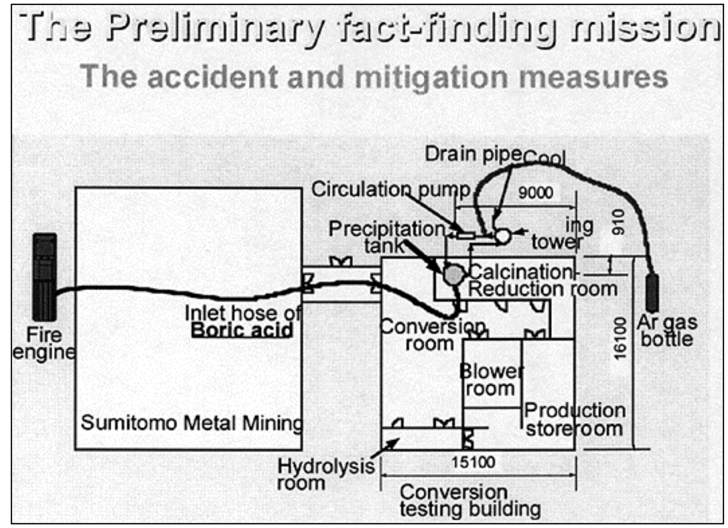
After 17:00, the maximum neutron dose rates at the site boundaries were measured to be around 4 mSv/h, which indicated a continuing state of criticality.

2.3.2. Mitigation oh the Accident's Consequences

An investigation was made by the LCH by means of criticality modelling, which took about an hour. This computer modelling led to the conclusion that the removal of water from the cooling jacket could help to terminate the state of criticality.

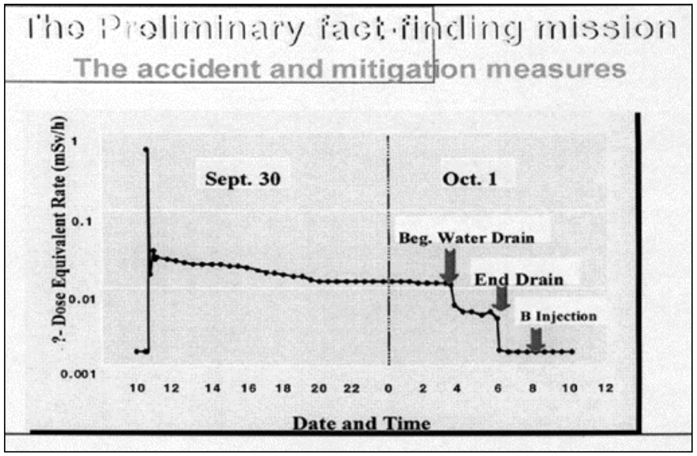


The cooling jacket acted as a neutron reflector, thereby enhancing nuclear fission. At the second meeting at the GACH, held at 23:15 on 30 September, it was concluded that the cooling water should be drawn off from the water jacket surrounding the precipitation tank in order to end the state of criticality and thereby terminate the self-sustaining nuclear chain reaction.



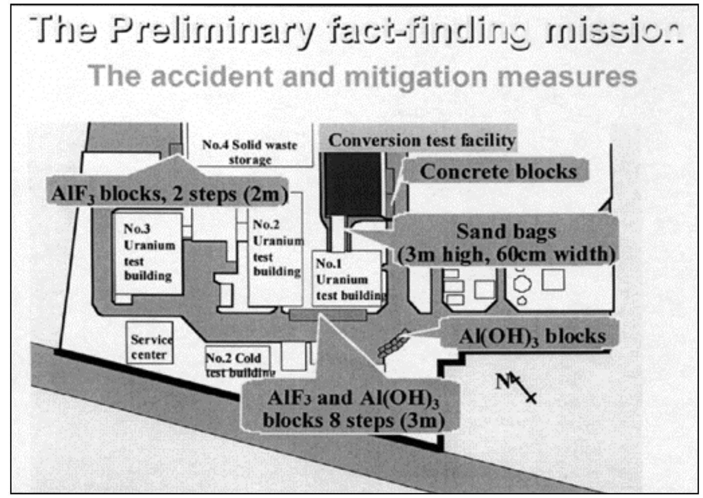
The cooling pump, the valves and the cooling tower were located outside the building, making them easier to access. Attempts to drain the water were made between 02:35 and 06:04 on 1 October. Ten approaches were made, the purpose of the first being to photograph the cooling tower and pump area. First the cooling tower feed valve was closed and the drain valve was opened. At this stage, only a little water was drained, but the neutron dose rate decreased somewhat. The water pipe was then broken and cut to drain the water. Finally, at around 06:15, argon gas was pumped into the water pipe to force out much more water. At around 06:30 the neutron dose rate was below the detection limit.

In parallel with the removal of water, preparations were made for the injection of aqueous boric acid in order to ensure that the state of the precipitation tank was and would remain subcritical. No boric acid was available at the JCO site, so it was brought from the Oarai Establishment in JAERI, 10 km away from the JCO site. The boric acid feeding Operation began at 08:19 on 1 October. A fire engine was used for the boric acid feed, which was reported to have been completed at 08:39 with a total volume of 17 L of solution with 25 g of boron per litre having been fed into the precipitation tank. A photograph was taken of the precipitation tank to ensure that aqueous boric acid had been adequately injected. The photograph showed that no damage had been caused to the tank or to its surroundings. After inspection the operation was deemed to be completed at 09:18.



After the termination of the state of criticality, the immediate remaining safety issues were the need for shielding from gamma radiation resulting from the fission products generated in the precipitation tank and held within the confinement of the building:

- With regard to the remaining radiation fields, gamma radiation dose rate measurements were performed at 06:20 on 1 October. These measurements yielded gamma dose rates of several millisieverts per hour dose to the building and several microsieverts per hour at the boundary of the site. Shielding material such as sandbags were placed around the building on the morning of 2 October. Walls made of concrete shielding material were assembled in some places around the facility;
- With regard to radioactive releases, the operator reported that there had been no explosion in the building and there was no overpressure in the ventilation system. The visual check carried out by the workers who fed the boric acid into the precipitation tank showed that there had been no mechanical damage to the installation, and the integrity of the equipment, rooms and building in general had been maintained. During its mission, the IAEA Secretariat team observed that there was no apparent physical damage to the structural integrity of the conversion building. The team examined the roof of the conversion building from two opposite viewpoints (northwest and southeast) and confirmed that it in particular had not been damaged.



The high efficiency particulate air (HEPA) filters in the conversion building had filtered out particulates collected by the building's ventilation system, whose exhaust is connected to a general ventilation system that also serves other buildings. It had been reported by the workers who injected the boric acid into the precipitation vessel that an underpressure had been maintained, since air flow into the building was found. A smoke test on 5 October confirmed that there was an underpressure and that the ventilation system was working. The integrity of the building confinement had therefore been provided primarily by active maintenance of an underpressure by the ventilation system and by the HEPA filters. However, owing to the detection of ^{131}1 released to the environment on the basis of exhaust point measurements, it was later decided to stop ventilation and to reinforce the passive confinement provided by the building.

2.4. The accident's consequences

Three JCO employees A, B and C were severely overexposed in the conversion building, where two were engaged in the Operation of transferring uranyl nitrate solution into the precipitation tank and the third was in an adioming room. After the accident occurred, all three were taken to the NIRS at Chiba. Patient A was transferred to the Hospital of the University of Tokyo on 2 October and patient B was transferred to the Hospital of the Institute of Medical Sciences of the University of Tokyo on 4 October. Their doses were estimated by four methods: measurement of

^{24}Na in blood; analysis of chromosomal aberrations; lymphocyte counting; and for patient C measurement of ^{24}Na by whole body counting. The preliminary estimated doses were from 10-20 Gy equivalent (GyEq) to gamma radiation* for patient A, 6-10 GyEq for patient B and 1-4.5 GyEq for patient C. The doses estimated by measurement of ^{24}Na in blood were 18 GyEq for patient A, 10 GyEq for patient B and 2.5 GyEq for patient C. lt would seem that these estimated doses must all be considered preliminary owing, among other things, to the inhomogeneous (i.e. uneven) exposures of the workers' bodies.

- **One worker died as a result of a severe overexposure (16 to 20 Gy)**
- **A second worker suffered very acute radiation syndrome (6 to 10 Gy)**
- **A third worker was also seriously overexposed (1 to 4.5 Gy)**
- **Overexposure of several workers involved in the mitigation measures**
- **Overexposure of some members of the public**

2.5. Conclusion

The accident at the JCO nuclear fuel processing facility at Tokaimura seems to have resulted primarily from human error and serious breaches of safety principles, which together led to a criticality event. lt resulted in the overexposure of several workers, two of whom had as a consequence reportedly suffered very severe acute radiation syndrome, and one other to a moderate degree. The most exposed worker died in December 1999. The accident was classified by the Japanese authorities as Level 4 on the IAEA International Nuclear Event Scale (INES), indicating an event without significant off-site risk.

The accident was essentially an irradiation' accident; it was not a ,contamination' accident as it did not result in a radiologically significant release of radioactive materials.

For some 20 hours after the onset of criticality at Tokaimura, radiation was generated in the conversion building and could be measured at some distance. However, only trace amounts of noble gases and gaseous iodine escaped from the building itself. After the criticality had been terminated and shielding was emplaced, radiation levels beyond the JCO site returned to normal.

Only trace levels of radionuclides were detected in the area shortly after the accident. The half-lives of the radionuclides detected are relatively short, so there is no residual contamination by this accident. Such traces of radioactive material would not be expected to have any detectable radiological effect on the health of local residents or their offspring or on environmental conditions. Products from the area would have been as normal and entirely safe throughout. Radiation levels measured by the team in residential areas were at the normal background levels.

It was reported that local industries and businesses had been indirectly harmed by the accident, and that this was perhaps because many people had mistakenly associated the accident with radioactive contamination, although only radiation exposure and no radioactive residues resulted from it. There were also reports that some people had been concerned about the effects of the accident on real estate prices, and that the prices of agricultural products had fallen.

The accident was significant from the point of view of the consequences on one of the workers and on the health consequences for the two other severely overexposed workers. It will most probably also have implications for the regulatory regime and safety procedures and safety culture at the JCO facility.

An extensive investigation of all the circumstances of the accident will be necessary, covering considerations relating to:

- *(a) The criticality event itself, including a detailed description of the sequence of events and their consequences;*
- *(b) The JCO facility, including its safety related design aspects, managerial provisions and operational matters;*
- *(c) Regulatory control, including licensing and inspection;*
- *(d) Emergency preparedness and response; and*
- *(e) The medical care of the three severely overexposed workers.*

* A criticality accident is associated wjth mixed radiation fields (neutron and gamma>, which have different penetration and absorption properties, as well as differing effectiveness at producing biological hann. The GyEq 5 used here to indicate that the estimated neutron doses have been weighted to account for their relative biological effectiveness in order to make the doses comparable with that for gamma rays.