Report on the preliminary fact finding mission following the accident at the nuclear fuel processing facility in Tokaimura, Japan

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1999

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
BANGLADESH
BELARUS
BELGIUM
BENIN
BOLIVIA
BOSNIA AND HERZEGOVINA
BRAZIL
BULGARIA
BURKINA FASO
CAMBODIA
CAMEROON
CANADA
CHILE
CHINA
COLOMBIA
COSTA RICA
COTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ESTONIA
ETHIOPIA
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GUATEMALA
HAITI
HOLY SEE
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
LATVIA
LEBANON
LIBERIA
LIBYAN ARAB JAMAHIRIYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITIUS
MEXICO
MONACO
MONGOLIA
MOROCCO
MYANMAR
NAMIBIA
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORWAY
PAKISTAN
PANAMA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
SAUDI ARABIA
SENEGAL
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
THAILAND
THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA
TUNISIA
TURKEY
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VENEZUELA
VIET NAM
YEMEN
YUGOSLAVIA
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

Printed by the IAEA in Austria
November 1999
IAEA-TOAC

REPORT ON THE PRELIMINARY FACT FINDING MISSION FOLLOWING THE ACCIDENT AT THE NUCLEAR FUEL PROCESSING FACILITY IN TOKAIMURA, JAPAN

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1999

EDITORIAL NOTE

FOREWORD

Following the accident on 30 September 1999 at the nuclear fuel processing facility at Tokaimura, Japan, the IAEA's Emergency Response Centre received numerous requests for information about the event's causes and consequences from Contact Points under the Conventions on Early Notification of a Nuclear Accident and on Assistance in the Case of a Nuclear Accident or Radiological Emergency. Although the lack of transboundary consequences of the accident meant that action under the Early Notification Convention was not triggered, the Emergency Response Centre issued several advisories to Member States which drew on official reports received from Japan.

After discussions with the Government of Japan, the IAEA dispatched a team of three experts from the Secretariat on a fact finding mission to Tokaimura from 13 to 17 October 1999. The present preliminary report by that team documents key technical information obtained during the mission. At this stage, the report can in no way provide conclusive judgements on the causes and consequences of the accident. Investigations are proceeding in Japan and more information is expected to be made available after access has been gained to the building where the accident occurred. Moreover, much of the information already made available will be revised as more accurate assessments are made, for example of the radiation doses to the three individuals who received the highest exposures.

Notwithstanding the preliminary nature of this report, it is clear that the accident was not one involving widespread contamination of the environment as in the 1986 Chernobyl accident. Although there was little risk off the site once the accident had been brought under control, the authorities evacuated the population living within a few hundred metres and advised people within about 10 km of the facility to take shelter for a period of about one day.

The event at Tokaimura was nevertheless a serious industrial accident. The results of the detailed investigations and the lessons to be learned will be of importance for other countries also, and in other industries. In this regard, the Government of Japan has assured the IAEA of its commitment to make information about the accident available to the international community. For its part, the IAEA is prepared to co-ordinate an international peer review if so requested by the Japanese Government.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND TO THE IAEA SECRETARIAT TEAM MISSION

On 30 September 1999, at 10:35 local time (01:35 GMT), a criticality[1] accident occurred in the conversion building (auxiliary 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. It 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.

[1] Criticality may be defined as that state of a nuclear chain-reacting medium when the nuclear fission chain reaction just becomes self-sustaining (or critical).

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.

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.

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 [1–25], corroborated to the extent possible by means of interviews conducted by the team with key officials and experts [26–28], and observations and measurements made by the team [29]. 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 is noted in the text. Equally, the direct observations and measurements that were made by the team are also noted.

1.4. STRUCTURE OF THE REPORT

Section 2 provides background information on: the JCO Company Ltd (JCO); the JCO site at Tokaimura; the legislative and regulatory framework in Japan; and emergency preparedness arrangements. Section 3 provides information on the accident, its immediate causes and its mitigation. Section 4 summarizes the environmental monitoring done by the Japanese authorities. Section 5 covers the emergency response actions taken, and Section 6 discusses dose assessments. Section 7 discusses the consequences of the accident for human health and summarizes the medical treatment of the three persons who were severely overexposed. Section 8 presents summary results of the team’s mission and Section 9 presents its preliminary conclusion.

2. BACKGROUND INFORMATION

Tokaimura is a large village 120 km northeast of Tokyo (Fig. 1) in Ibaraki Prefecture [14]. The JCO site in Tokaimura is also close to the town of Naka-machi. There are nine municipalities and about 310 000 inhabitants within a 10 km radius (Fig. 2), and around 150 people live within 350 m of the JCO facility itself (Fig. 3) [14]. 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.

2.1. 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 (Fig. 4) [14]:

— One with an annual capacity of 220 tonnes of uranium per year (t U/a) for low enriched uranium (enrichment[2] of less than 5%);
— One with an annual capacity of 495 t U/a for low 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 U/a for either enriched uranium (not more than 20%) for the production of uranium oxide (U_3O_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 [4]. Its 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_3O_8) powder in nitric acid (HNO_3), homogenization of the solution and precipitation with ammonia to produce ammonium diuranate ($(NH_4)_2U_2O_7$)) [14] (Fig. 5). 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. Its cumulative use has been about two months per year [14].

[2] Enriched uranium is uranium containing a greater mass percentage of the fissile uranium isotope ^{235}U than 0.72%, which is the percentage of ^{235}U by mass that occurs in natural uranium (approximately 99.28% ^{238}U and 0.72% ^{235}U).

2.2. LEGISLATIVE AND REGULATORY FRAMEWORK

Permission for a change in the JCO licensing conditions to encompass the conversion building (Fig. 6) 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 [4, 14]. 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 [4]. 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. EMERGENCY PREPAREDNESS ARRANGEMENTS

The Basic Act on Disaster Countermeasures lays down responsibilities for the State, prefecture and municipality to provide for the formulation of disaster countermeasure plans and basic policies for emergency measures to deal with such disasters as storms, heavy rainfall, heavy snowfall, floods, earthquakes, tsunamis (tidal waves), and explosions, and other specified causes of extensive damage such as accidents causing the release of large amounts of radioactive materials or the sinking of a large vessel [9]. The Central Disaster Prevention Council prepared a national plan which sets out measures to deal with nuclear emergencies that could have off-site effects. The NSC formulated a 'Guideline on Disaster Prevention Measures for a Nuclear Power Plant, etc.' which must be complied with.

The prefectural and municipal administrations had made considerable provisions for the management of general and large scale disasters [26, 27]. These were exercised in 1991, 1993 and 1996. Advanced public information on emergency arrangements was distributed to all households in 1996 and 1997 and stable iodine tablets are stocked in each municipality. Prefectural guidelines for decision making in response to a nuclear emergency recommend sheltering if possible doses may be in the range of 10–50 millisieverts (mSv) and evacuation or sheltering in a concrete building if the possible dose may exceed 50 mSv (on the basis of the whole body dose for a person outdoors).

However, there were no pre-established procedures or specific arrangements for a criticality event such as the one that occurred at JCO [27], which was considered to be an unrealistic scenario. The JCO does conduct a site emergency evacuation drill annually. A radiation alarm system at JCO comprised gamma monitors but no neutron monitors [28].

Under the Basic Plans for Disaster Prevention based on the Basic Act on Disaster Countermeasures, the National Institute of Radiological Sciences (NIRS) is in charge of medical treatment for victims of radiation accidents who cannot be treated by local hospitals, and medical management of overexposed persons. NIRS has four beds for contamination victims, with facilities and staff for decontamination and monitoring. It also runs the Network of the Council for Radiation Exposures in Medical Emergencies, which provides for the treatment of overexposed persons who need medical care [21].

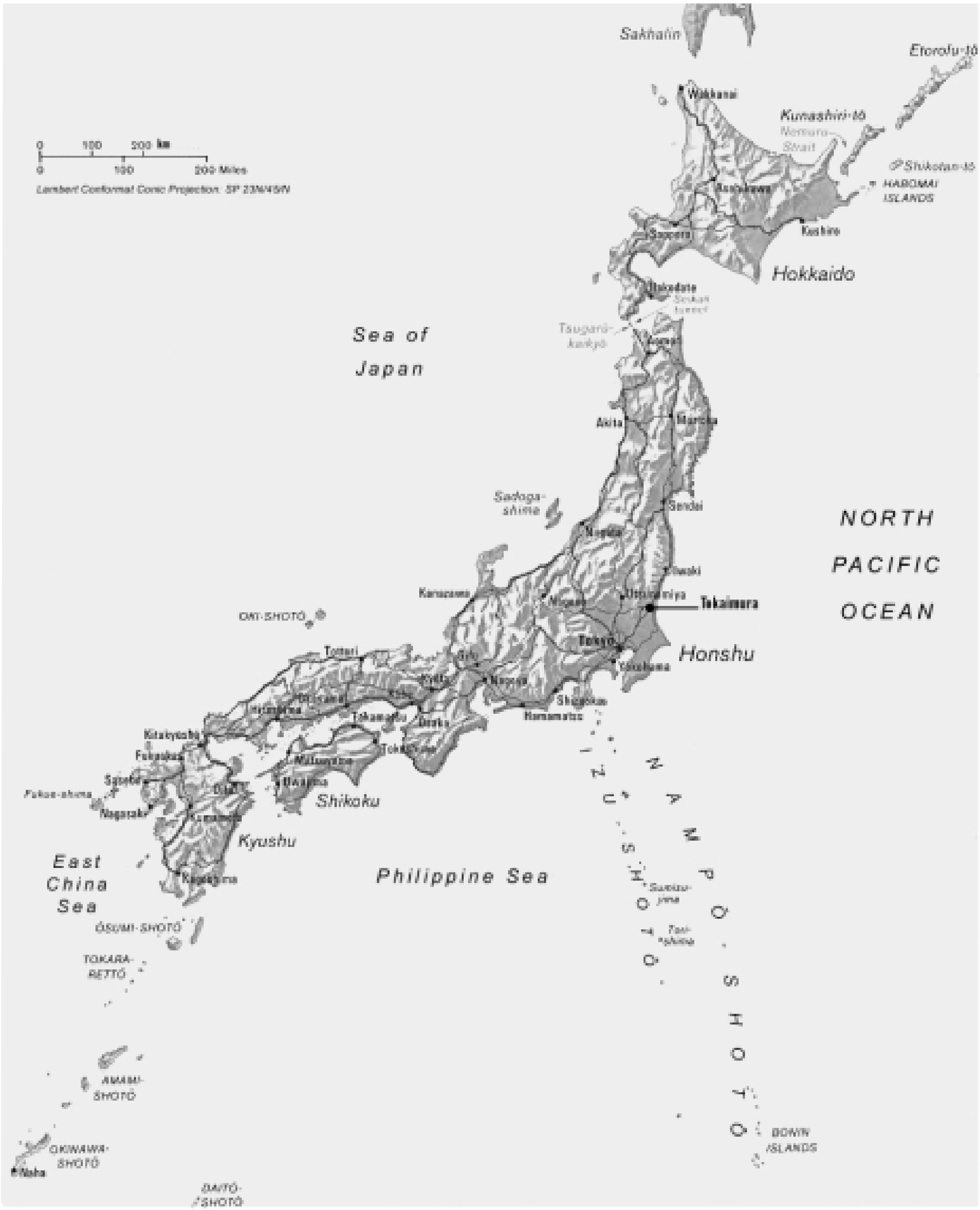

Fig. 1. General map of Japan (courtesy of the University of Texas Library, Austin, TX, USA).

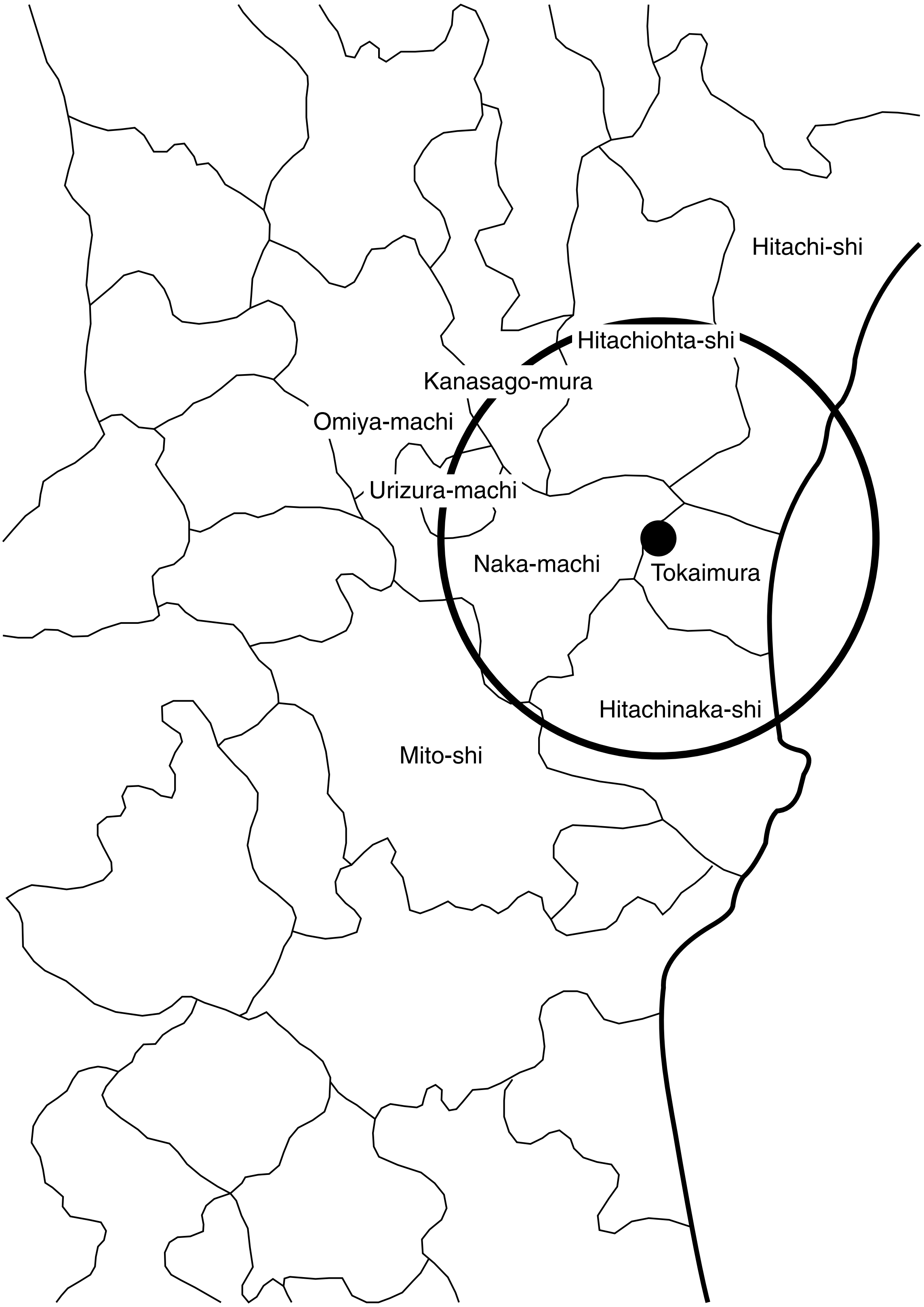

Fig. 2. Regional map of Ibaraki Prefecture. The circle represents the 10 km area within which about 310 000 people were recommended to stay indoors.

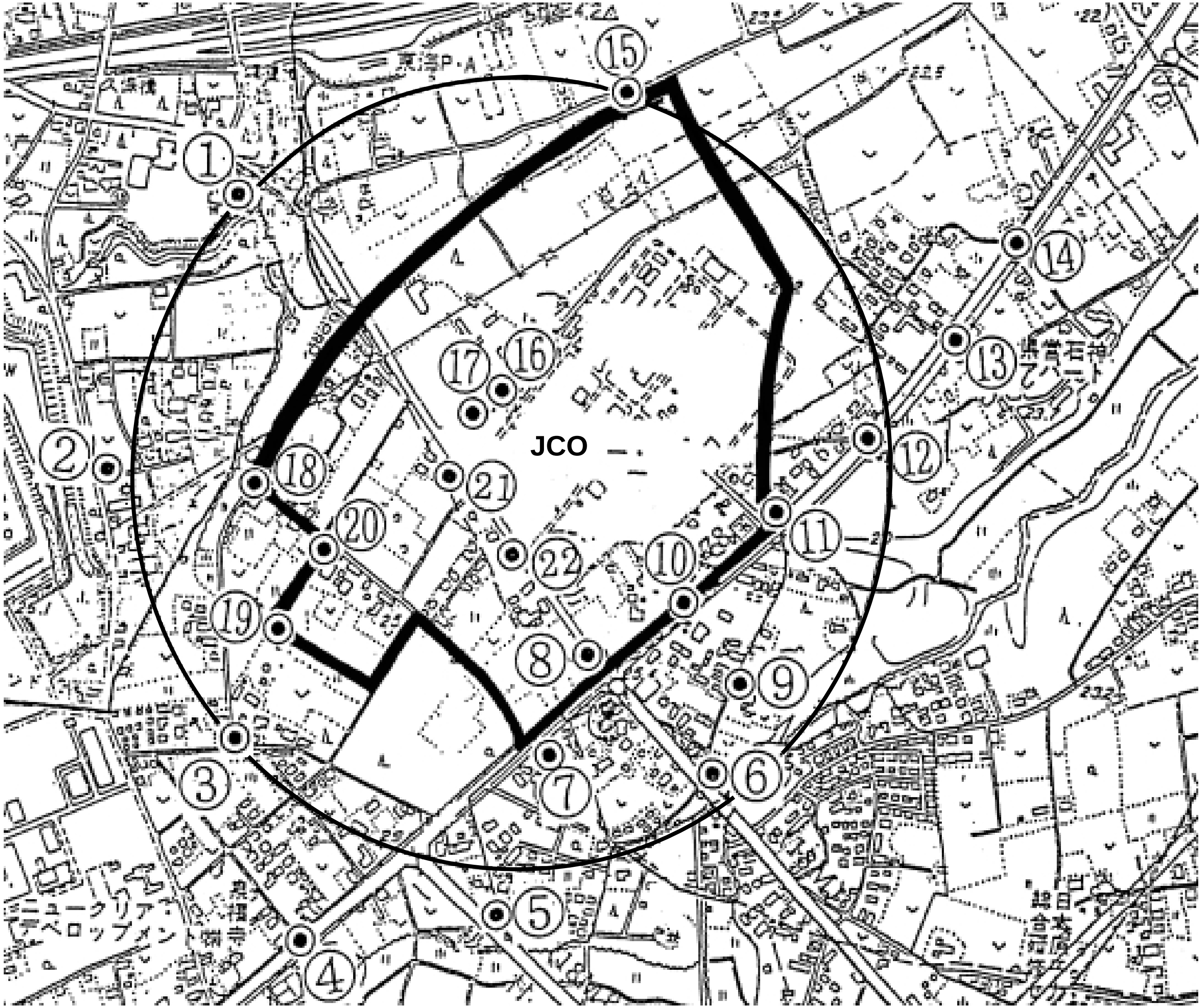

Fig. 3. Local map indicating the area (enclosed by the bold line) within a 500 m radius of the facility (circle) for which evacuation was implemented.

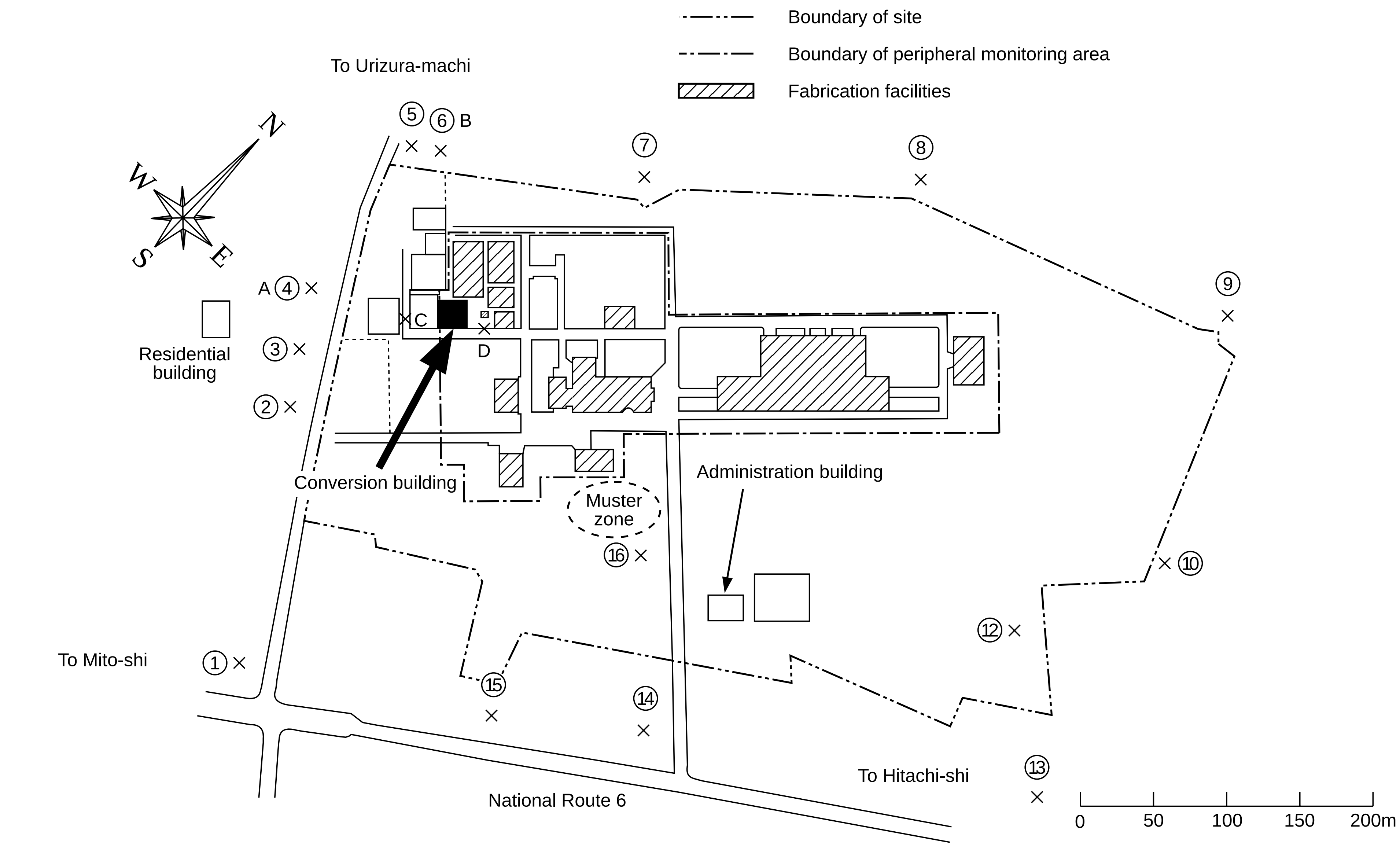

Fig. 4. Plan of the JCO site with location of monitoring points (circled numbers).

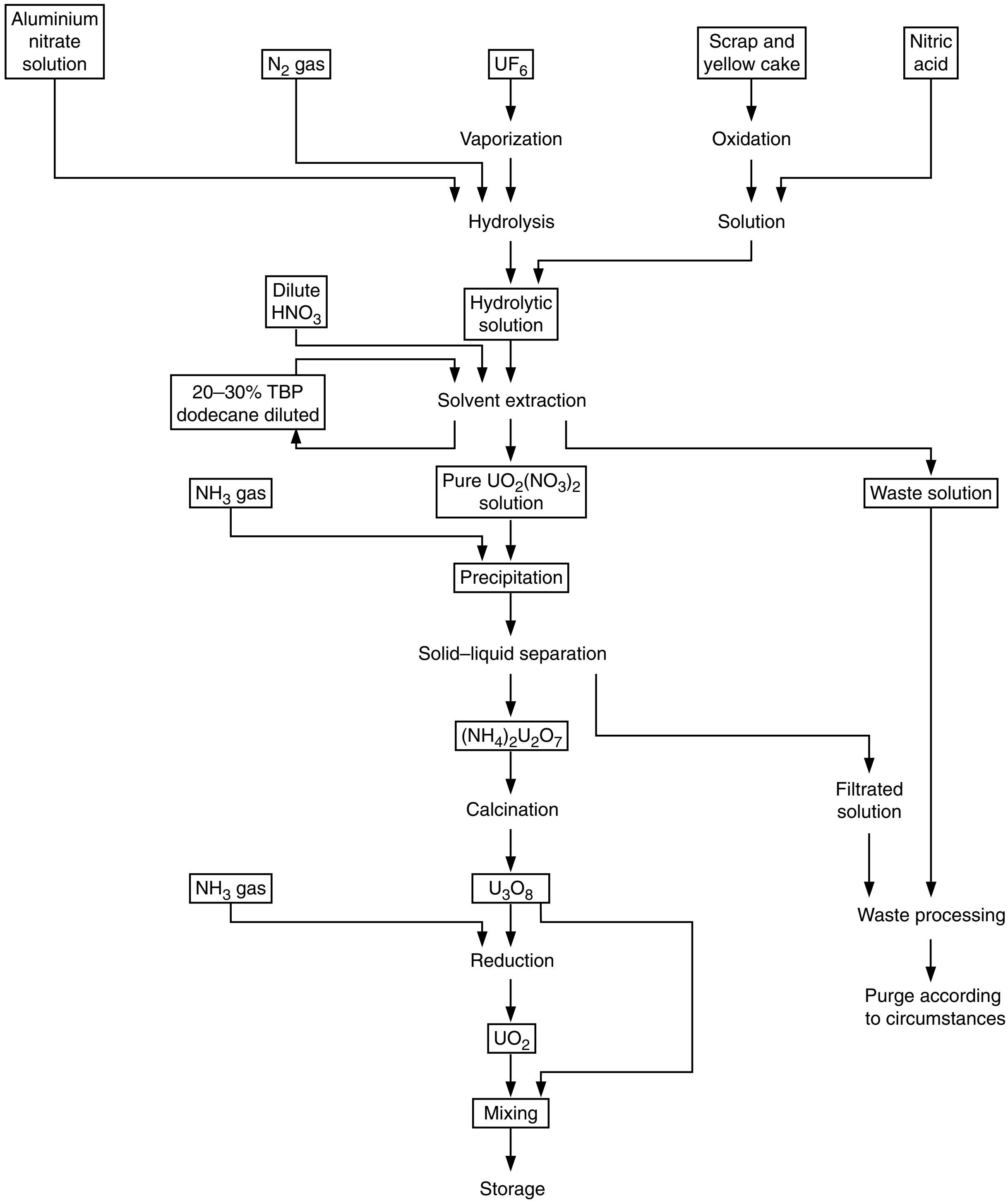

Fig. 5. Schematic diagram of the JCO reconversion process (TBP: tributyl phosphate).

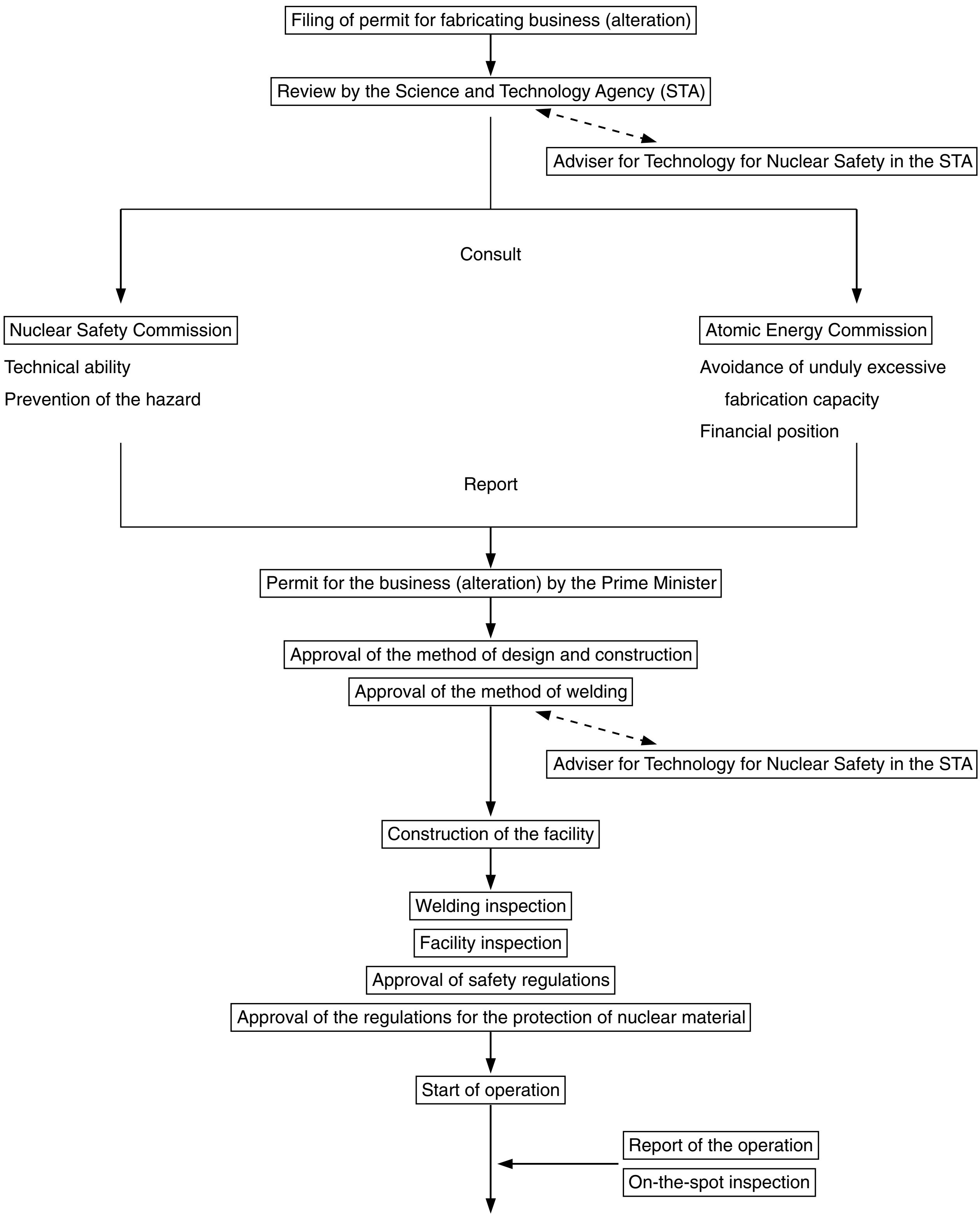

Fig. 6. Schematic diagram of the licensing process for fuel fabrication facilities (procedures from filing for permit to operation).

3. THE ACCIDENT AND MITIGATION OF ITS CONSEQUENCES

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_3O_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 is surrounded by a water cooling jacket to remove excess heat generated by the exothermic chemical reaction (Fig. 7) [4, 14]. 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_3O_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_3O_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, being 450 mm in diameter and 610 mm high (Fig. 8). 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 [28]. 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_3O_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 (Figs 7 and 8).

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 [14]. 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 (Fig. 4).

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 [13]. Six experts from STA were dispatched to this headquarters. With the co-operation of JAERI (some 50 experts), the Japan Nuclear Cycle Development Institute (JNC) (some 60 experts) [4] 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 [4, 13, 14] (Fig. 9). 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 (Fig. 9), which indicated a continuing state of criticality [4, 13].

3.2. MITIGATION OF 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 [14]. 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 [13].

The cooling pump, the valves and the cooling tower were located outside the building, making them easier to access (Fig. 10). 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 (WS4 in Fig. 10) was closed and the drain valve (DR1 in Fig. 10) 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 [14] (Fig. 11).

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 (see later) [14]. 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 close to the building and several microsieverts per hour at the boundary of the site (Fig. 12). Shielding material such as sandbags were placed around the building on the morning of 2 October (Fig. 13). Walls made of concrete shielding material were assembled in some places around the facility (Fig. 14).
— 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 [14] (Fig. 15).

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 [14]. 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}I released to the environment on the basis of exhaust point measurements (see Section 4.2.2) (Fig. 16), it was later decided to stop ventilation and to reinforce the passive confinement provided by the building.

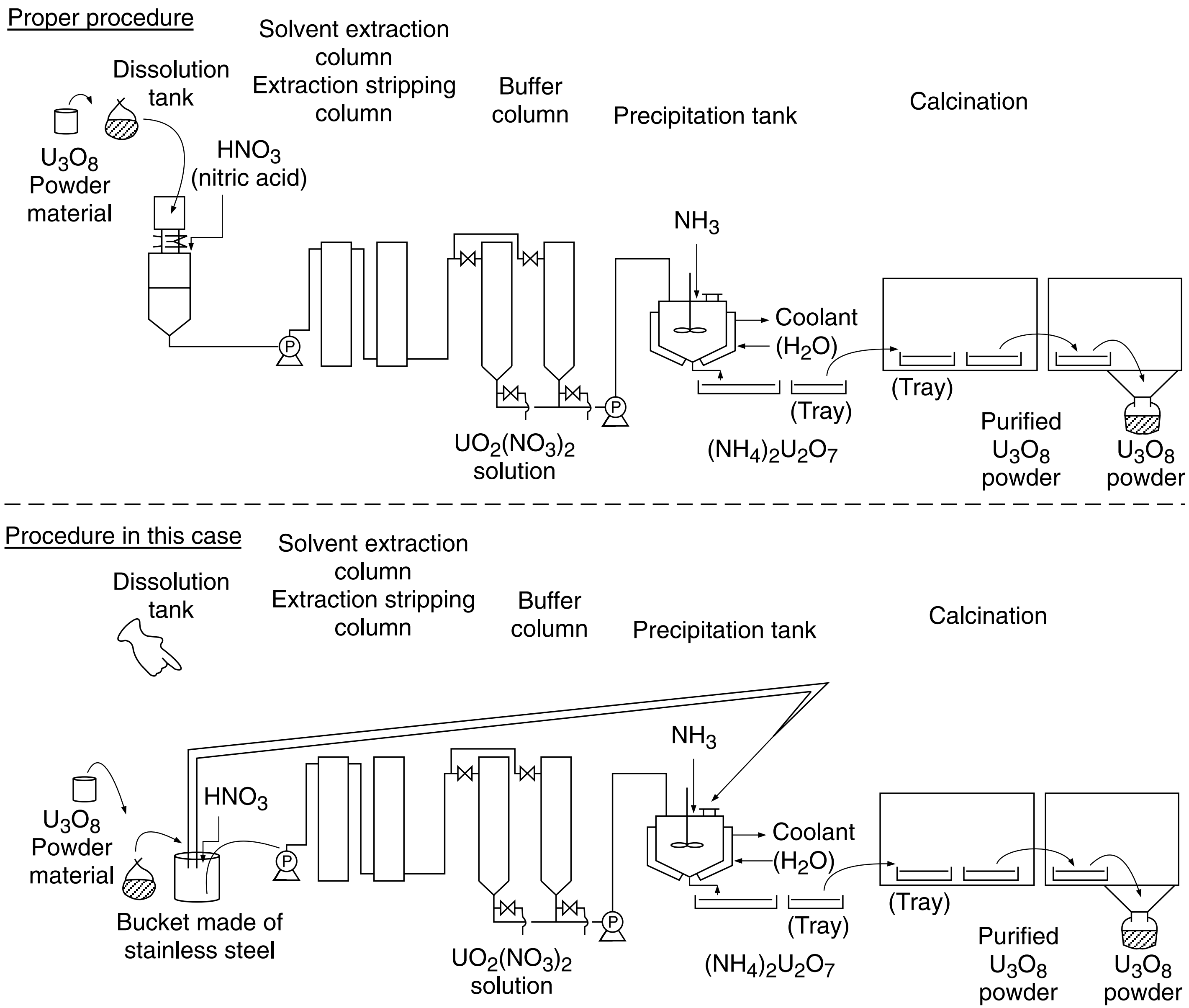

Fig. 7. Schematic diagram of the proper procedure and the actual procedure used in this case for dissolution and precipitation.

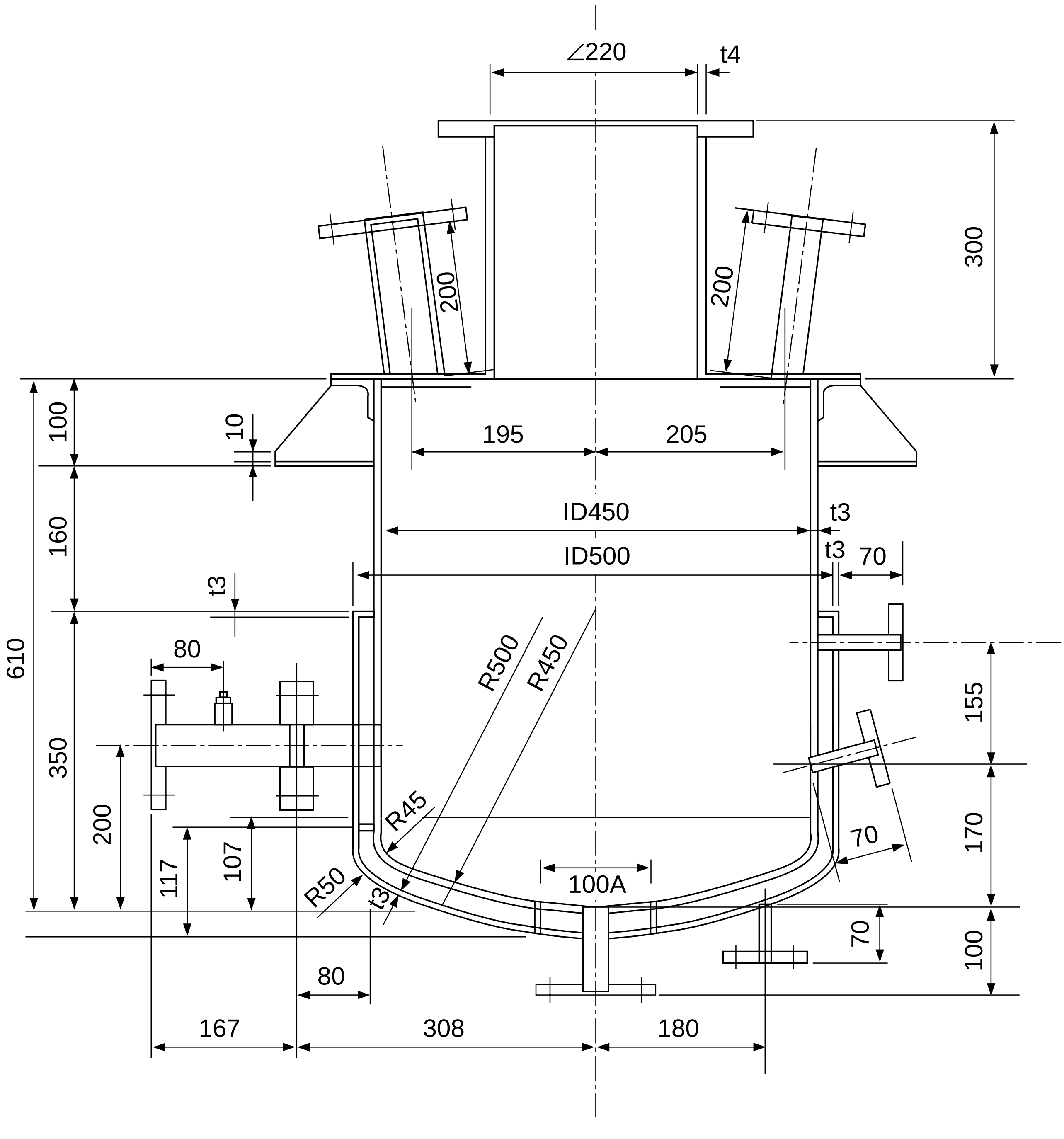

Fig. 8. Cross-section of the precipitation tank indicating dimensions (in mm).

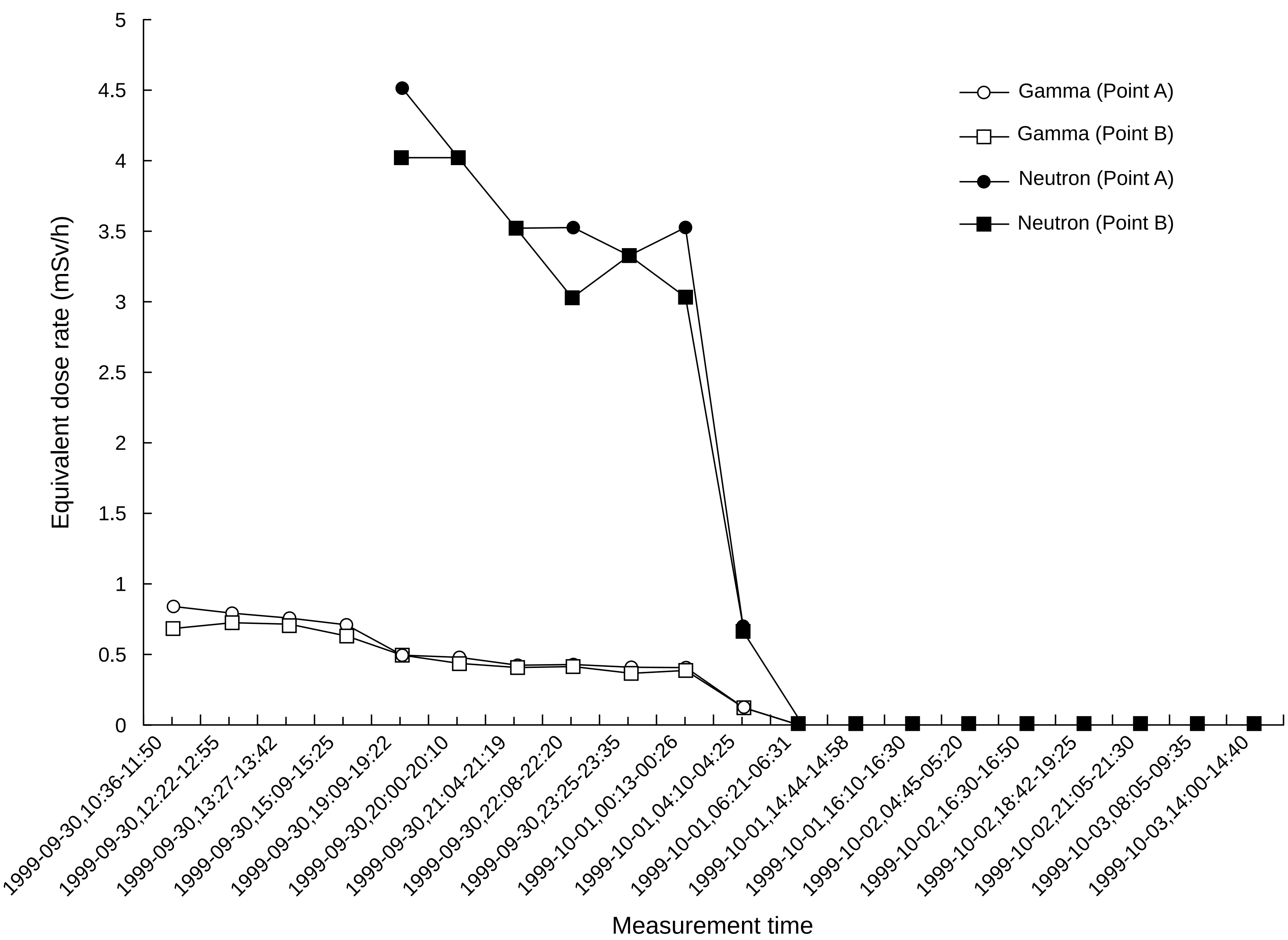

Fig. 9. Gamma and neutron dose rates at monitoring points A and B (see Fig. 4).

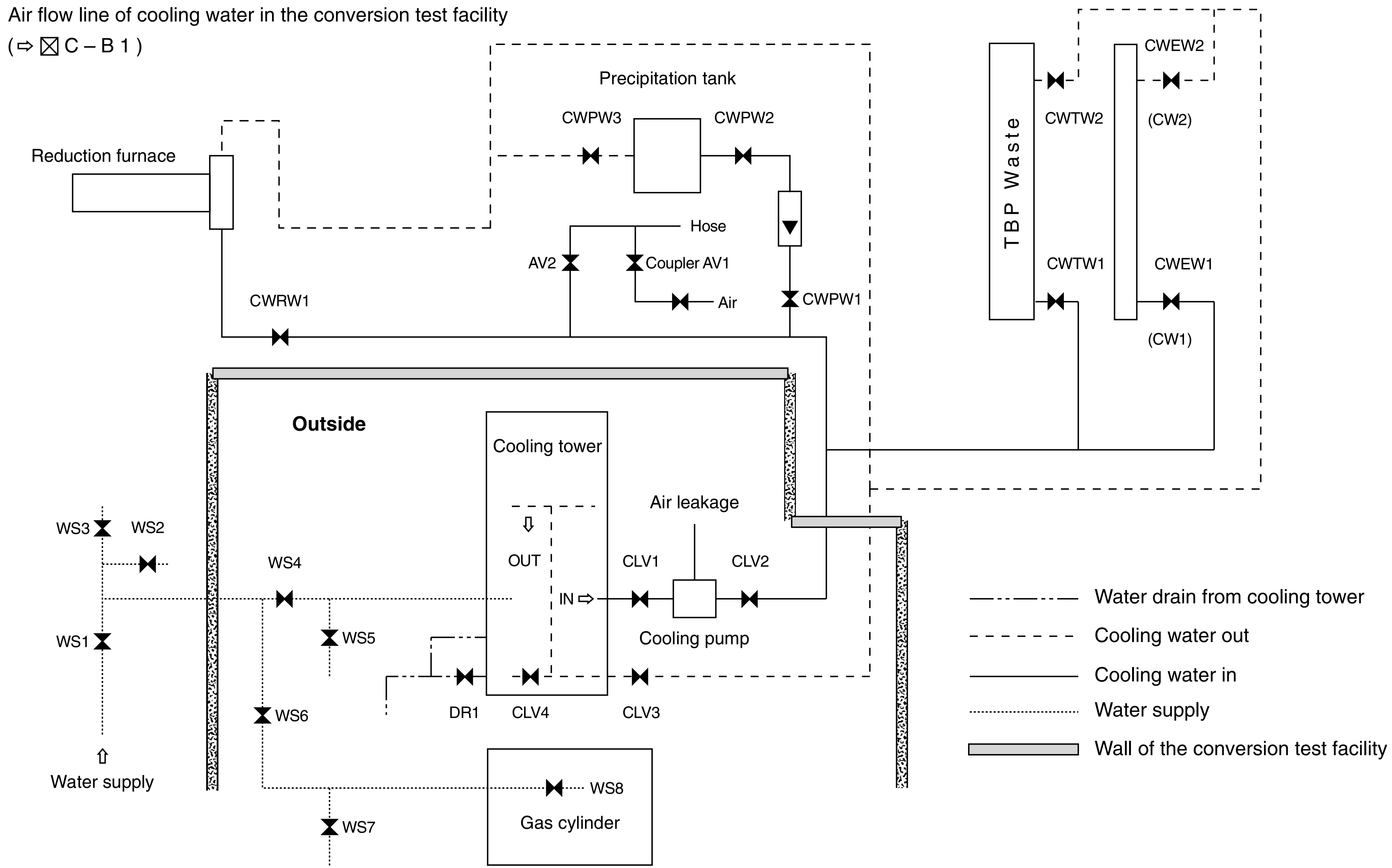

Fig. 10. Schematic diagram of the cooling system for the conversion building (TBP: tributyl phosphate).

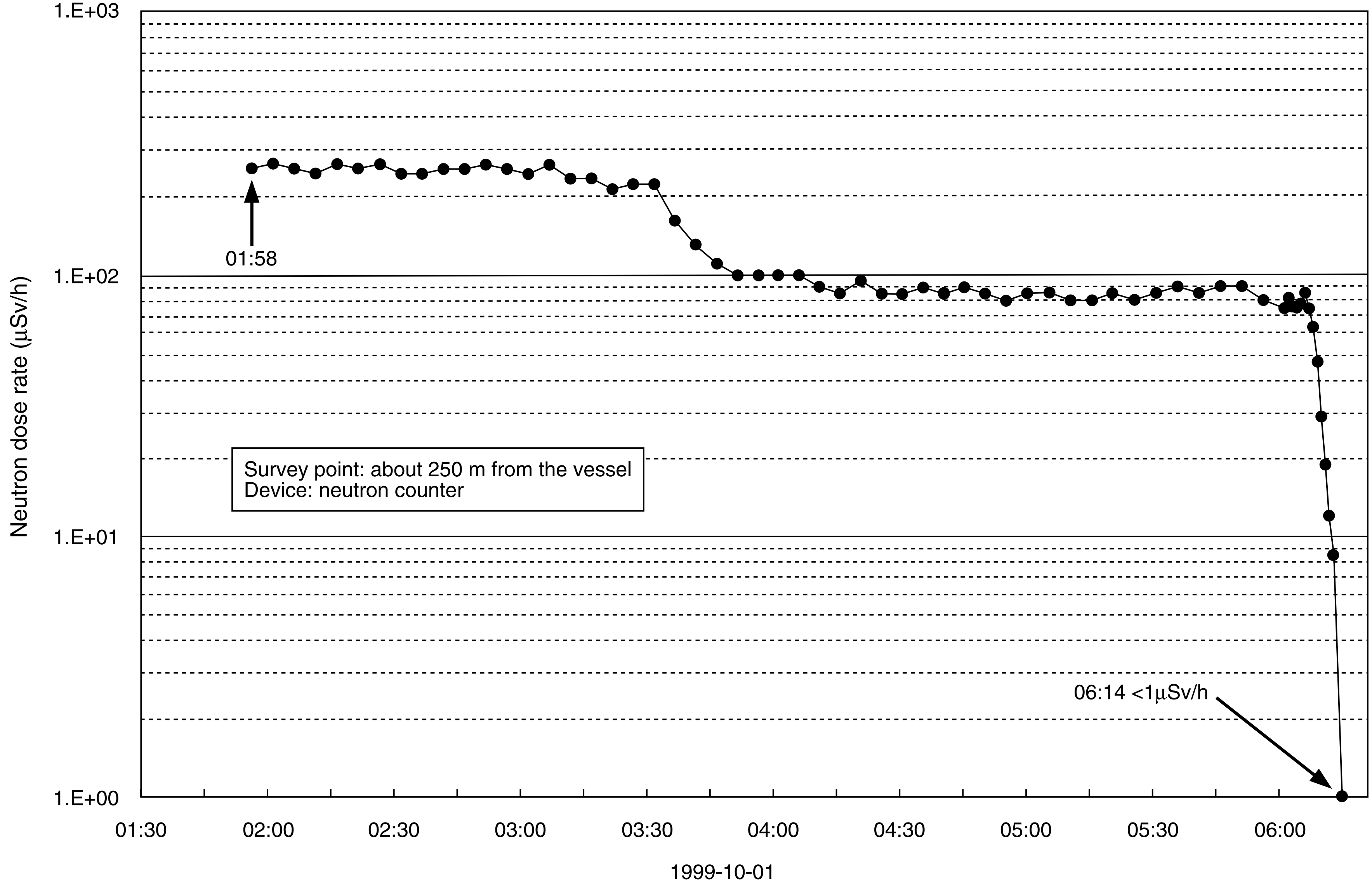

Fig. 11. The trend of neutron dose rate during mitigation (measured by JNC).

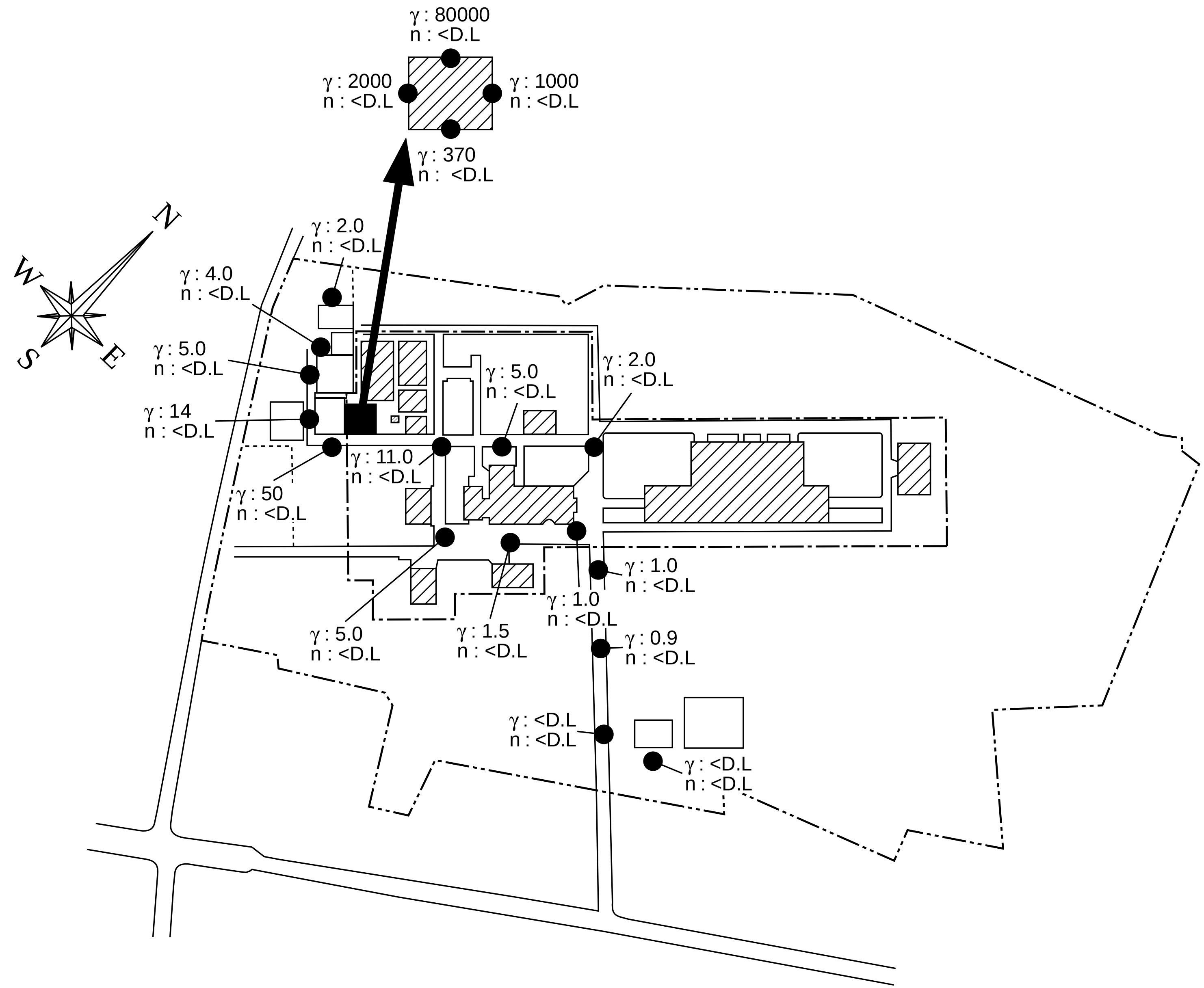

Fig. 12. Gamma and neutron dose rates after the end of criticality (units: μSv/h). The measurements were made by JNC at 06:20 on 1 October 1999.

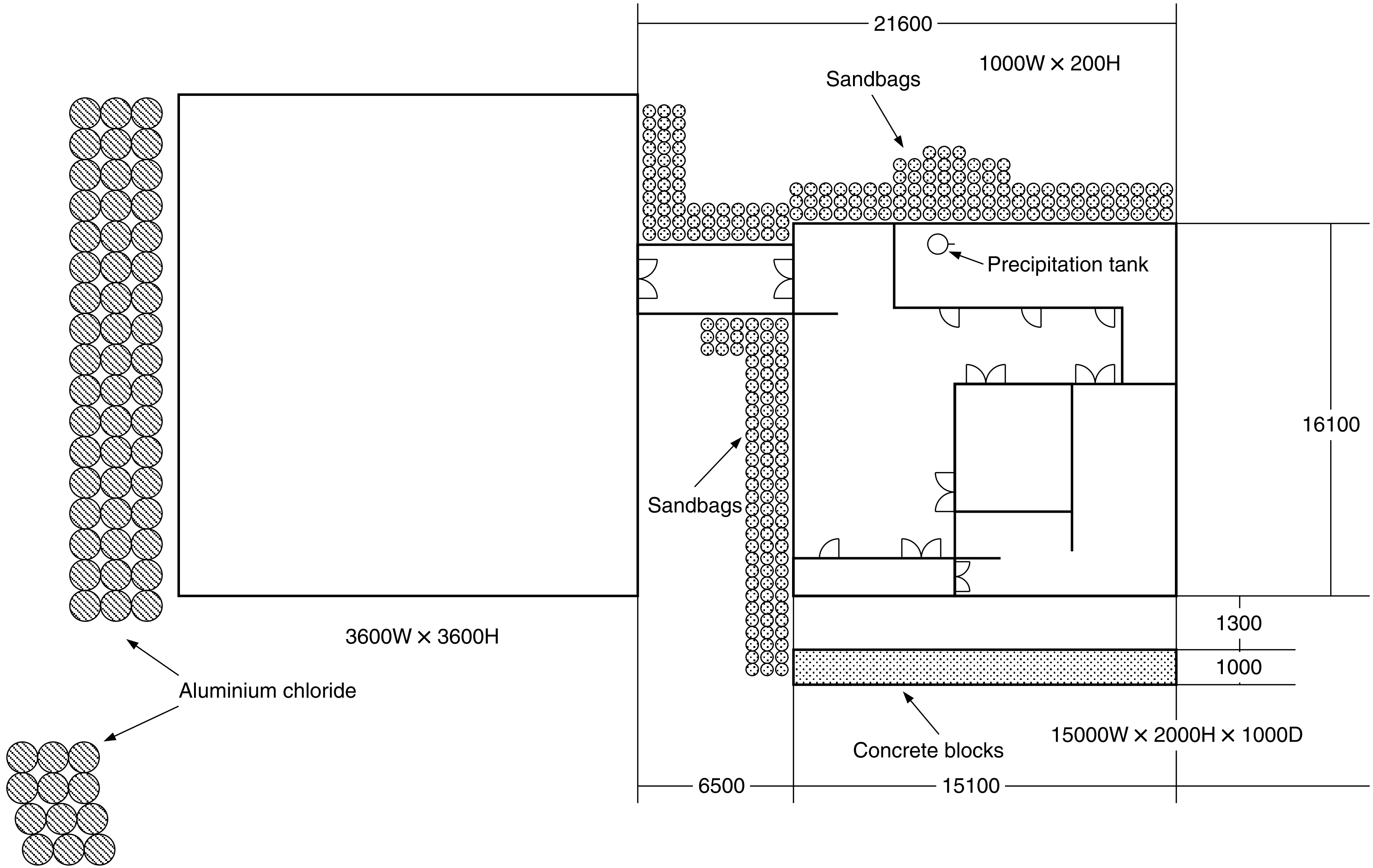

Fig. 13. Detailed plan of the conversion building indicating supplementary shielding arrangements (dimensions in mm).

Fig. 14. The conversion building with supplementary shielding in place.

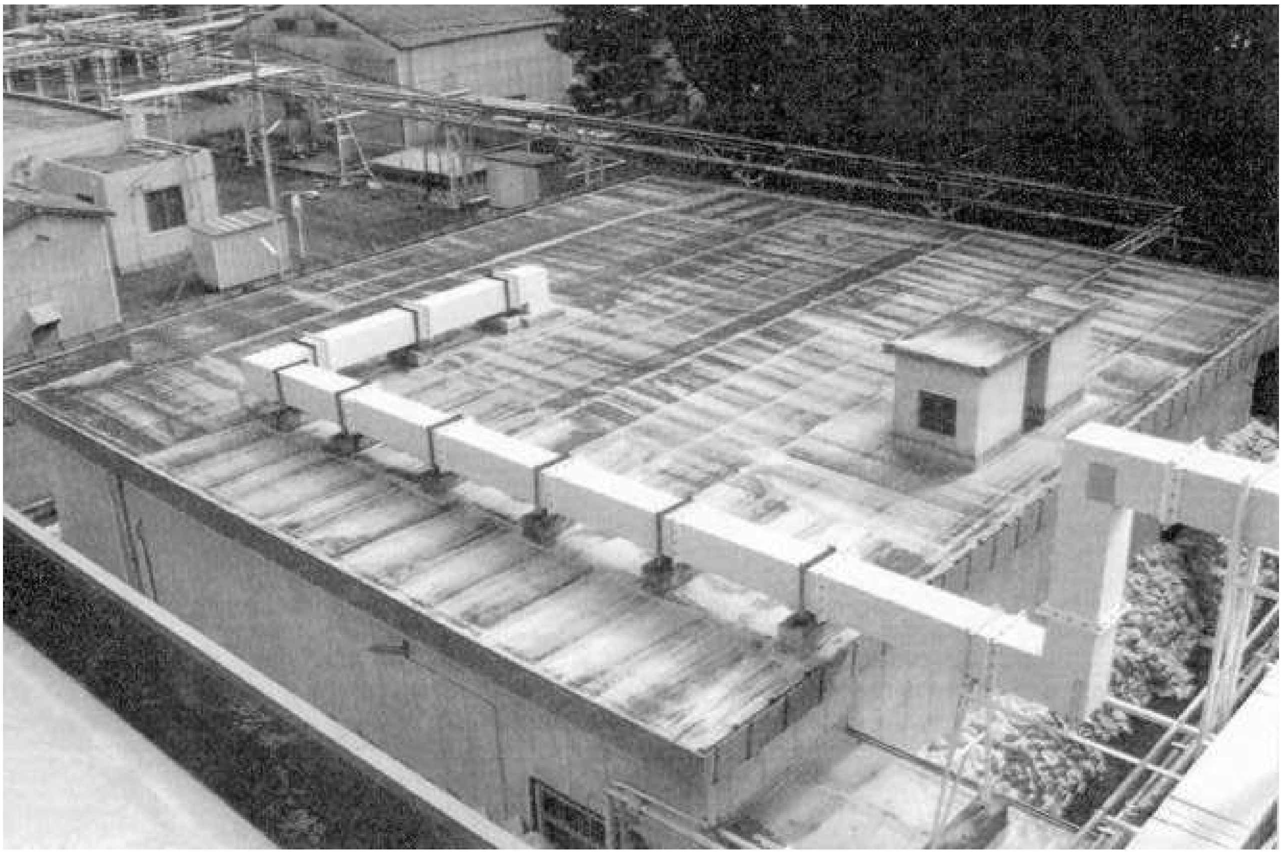

Fig. 15. The roof of the conversion building.

Fig. 16. The exhaust for the ventilation system.

4. ENVIRONMENTAL MONITORING

The main parameters for the evaluation of off-site consequences of the accident are twofold: the neutron and gamma irradiation associated with the nuclear fission reaction, and the ‘source term’ for the traces of radioactive elements released to the environment from the facility (the source term may be defined as the amount and isotopic composition of material released (or postulated to be released) from a facility).

With regard to irradiation, at the time of the visit by the IAEA Secretariat team, no accurate data were available on the level of the neutron flux or on the neutron energy spectrum for the initial criticality peak. The radiation dose rates in the building were too high for the operators to re-enter it. Therefore, it had not yet been possible to take samples of the uranium solution that gave rise to the criticality. Such a sampling was planned in order to determine the amount and composition of fission products with a view to estimating the amount of fission that had occurred [14]. Assessments reported to the team at the meeting with representatives of JAERI concluded that the total number of nuclear fission reactions that had occurred over the approximately 20 hours during which the state of criticality persisted (from 10:35 on 30 September to 06:30 on 1 October) may have been of the order of 5×10^{17} to 5×10^{18}.

Gaseous releases to the environment occurred mainly through the building’s ventilation system. Definitive data on these releases were not available at the time of the visit by the IAEA Secretariat team. An appreciation of the consequences can therefore be made primarily on the basis of measurements performed around the facility and environmental monitoring.

4.1. METEOROLOGICAL CONDITIONS AT THE TIME OF THE ACCIDENT

Meteorological observations were made by the Japanese authorities at stations located about 1.5 km south of the JCO site for wind measurements and about 3.5 km south–southeast of the JCO site for precipitation measurements. The wind direction was from the southeast and wind speed was about 1.3–2 m/s between 10:00 and 11:00 on 30 September. By 16:00, the wind direction was from east to east–southeast with a speed 3–3.5 m/s. The wind direction then became erratic with a wind speed of 1–2 m/s until 00:00 the next day. Precipitation of 16.5 mm was recorded at around 18:00 on 30 September. The wind direction was north between 01:00 and about 03:00 on 1 October, and then changed to northeast or east–northeast after 04:00. The wind speed was low at this time, but settled at 3–5 m/s after the wind direction stabilized at 06:00 [23].

4.2. ENVIRONMENTAL RADIATION MONITORING BY THE JAPANESE AUTHORITIES [23]

In order to evaluate any possible radiological effects on residents or environmental effects, STA and Ibaraki Prefecture began emergency monitoring after they were notified of the accident, in co-operation with JAERI, JNC, JAPCO and other organizations. Monitoring included measuring gamma dose rates at fixed monitoring stations and posts, and from moving vehicles. Atmospheric dust, soil, leafy vegetables and other samples collected in the vicinity of the JCO were measured for gamma emitting radionuclides. Gamma dose rates and the concentrations of gamma emitting radionuclides in soil, leafy vegetables and other samples were measured along the radius of a 10 km zone in 16 directions around the JCO. Tap water, well water, water from precipitation, dairy products, sea water and sea products were collected and monitored for radioactivity.

4.2.1. Radiation dose rates measured around the JCO site during and after the accident

The criticality in the precipitation tank in the conversion building is considered to have continued for about 20 hours, from 10:35 on 30 September to about 06:30 on 1 October. In this period, the neutron dose rates at the site boundary (Fig. 4), measured at point A (about 90 m southwest of the conversion building) and point B (about 110 m northwest of the conversion building) fell from 4.0 and 4.5 mSv/h at the start of measurement at these locations (19:09–19:22 on 30 September) to below the detection limit when the criticality ceased. Gamma radiation dose rates decreased over time from the first gamma measurement between 11:35 and 11:50 on 30 September recorded at point A (0.84 mSv/h) to 0.001 mSv/h when criticality ceased. The neutron dose rates at around 20:45 on 30 September were found to decrease steadily with distance from the conversion building. The neutron dose rate decreased from about 3 mSv/h at 100 m from the JCO site to about 0.02 mSv/h at 500 m, a factor of about 100. The reduction factor with distance was similar for the gamma dose rate (Fig. 17). The neutron dose rate was several times to ten times higher than the gamma dose rate in the vicinity of the JCO site up to a distance of at least 800 m [23].

Once criticality had ceased, neutron dose rates fell below the detection limit and gamma dose rates decreased to almost normal levels after sandbags were piled around the conversion building on 2 October. The IAEA Secretariat team's measurements of the gamma dose rate confirmed that levels were normal outside the JCO site boundary and dose rates on the site were slightly higher [29], e.g. 0.84 μSv/h at about 12 m east–northeast of the conversion building (point D), with no concrete blocks or sandbags along the line-of-sight between the detector and the conversion building (Fig. 4).

4.2.2. Radiation dose rates in districts around Tokaimura

Just after the accident occurred on 30 September, the gamma dose rate was measured at 0.40 μGy/h 1.5 km south of the JCO site, but it then returned to the normal background level of 0.04 μGy/h. Similar dose rates were measured at 2 km to the northeast and 2 km to the east–southeast. At about 11:30, about one hour after the start of the accident, at 7 km west of the JCO site, the gamma dose rate increased to a maximum of 0.24 μGy/h, continuing for about 20 minutes before returning to the normal background level at about 11:50. At about 16:00, when the wind direction began to change, enhanced gamma dose rates were observed at 38 monitoring stations and posts of the Prefecture and of other operators. The maximum dose rate of 3.1 μGy/h was observed 1.5 km south of the JCO site, and dose rates of over 0.1 μGy/h were observed at the other points.

Intermittent increases in gamma dose rates were also observed at MP-1 and MP-2 monitoring posts at the JAERI Naka site after the accident and continued until 00:00 on 1 October (see Fig. 18). The JAERI experts considered that the increase in the gamma dose rate immediately after the accident began was due to direct gamma radiation associated with the criticality reaction, and the subsequent peaks were due to gamma radiation from the plume borne by the wind, which may have contained radioactive noble gases and iodine released into the atmosphere from the conversion building during the criticality event [23].

The vehicle measurements made on 30 September showed dose rates in the range of 0.03–440 μGy/h from a distance of 4 km to the boundary of the JCO site. The gamma dose rate on 1 October showed normal levels at all points in 16 directions from a 0.5 to 10 km radius from the JCO site.

4.2.3. Measurements of activity in environmental samples

The activation products and fission products that were detected in air samples were ^{24}Na, ^{56}Mn, ^{91}Sr, ^{131}I, ^{133}I, ^{135}I and ^{138}Cs. The concentrations of all these short lived radionuclides just outside the monitoring zone set within the JCO site were below the regulatory limits for concentration in air. After 7 October, measurements were made of the concentration of iodine in air at the exhaust of the building ventilation system (Fig. 16) and at the site boundary. A maximum concentration of 2.7×10^{-5} Bq/cm^3 of ^{131}I was measured at the exhaust of the ventilation system. The ^{131}I concentrations in air at the site boundary ranged from 1.6×10^{-9} to 44×10^{-9} Bq/cm^3, well below the Japanese concentration limit of 1×10^{-5} Bq/cm^3.

In the first monitoring programme conducted immediately after the accident, the isotopes ^{24}Na, ^{56}Mn, ^{131}I and ^{133}I (and ^{137}Cs considered to derive from global fallout from atmospheric nuclear weapon tests) were detected in some soil samples collected in the region of 10 km radius from the site boundary. The concentrations of ^{24}Na and ^{56}Mn, whose half-lives are 15 h and 2.6 h respectively, were extremely low. Among 138 samples, ^{131}I and ^{133}I were detected only in one sample from the vicinity of the JCO, where the concentrations were 0.000 45 and 0.0016 Bq/g, respectively, which are extremely low and radiologically insignificant. Among 115 leafy vegetables collected within the 10 km radius, radioactive iodine (^{131}I, ^{133}I and ^{135}I) was observed in only 15 samples that originated from within 2 km of the site. The maximum concentration of ^{131}I was 0.037 Bq/g, well below the Japanese intervention level prescribed for foodstuffs, which is for example 2 Bq/g for vegetables. No radioactivity associated with the accident was detected in farm produce (milk, eggs, beef, pork) or marine samples (seaweed, fish, shellfish) collected in Ibaraki Prefecture.

No radioactivity that could be associated with the accident was detected in samples of lake water, tap water, rain water, reservoir water or sea water within 10 km of the JCO site. The uranium concentration measured in water was well below the Japanese quality standard for tap water (i.e. 0.002 mg/L) and considered to be of natural origin. No uranium that could be associated with the accident was detected in water or in air dust. A survey on 1 October of the ground surface within a 700 m radius showed no contamination, and a survey on 2 October of window glass in dwellings within a 350 m radius showed no radioactivity that could be associated with the accident.

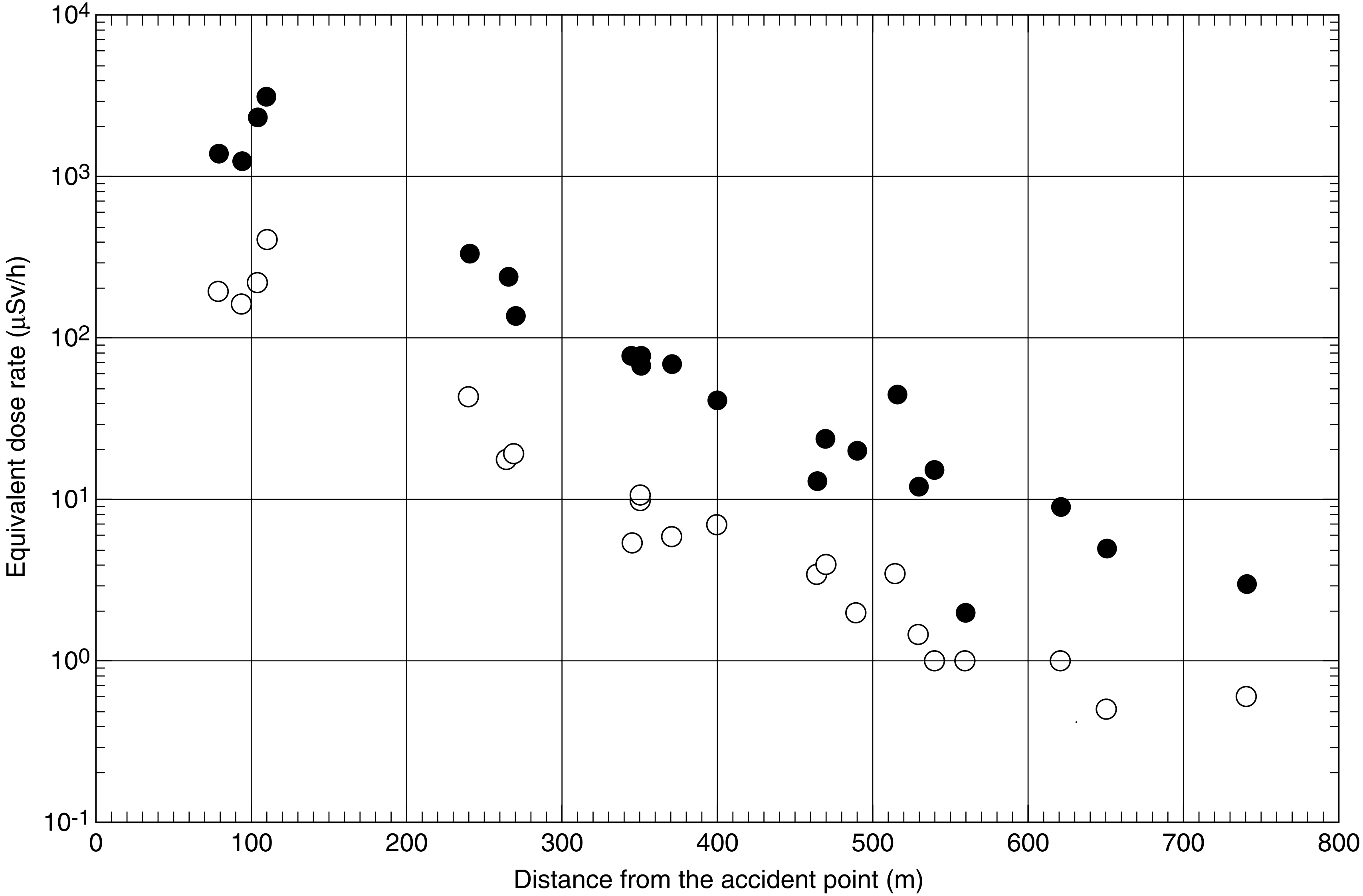

Fig. 17. Gamma and neutron equivalent dose rates around JCO at about 20:45 on 30 September 1999 at the monitoring posts indicated in Fig. 3 as a function of distance.(●: neutron; ○: gamma).

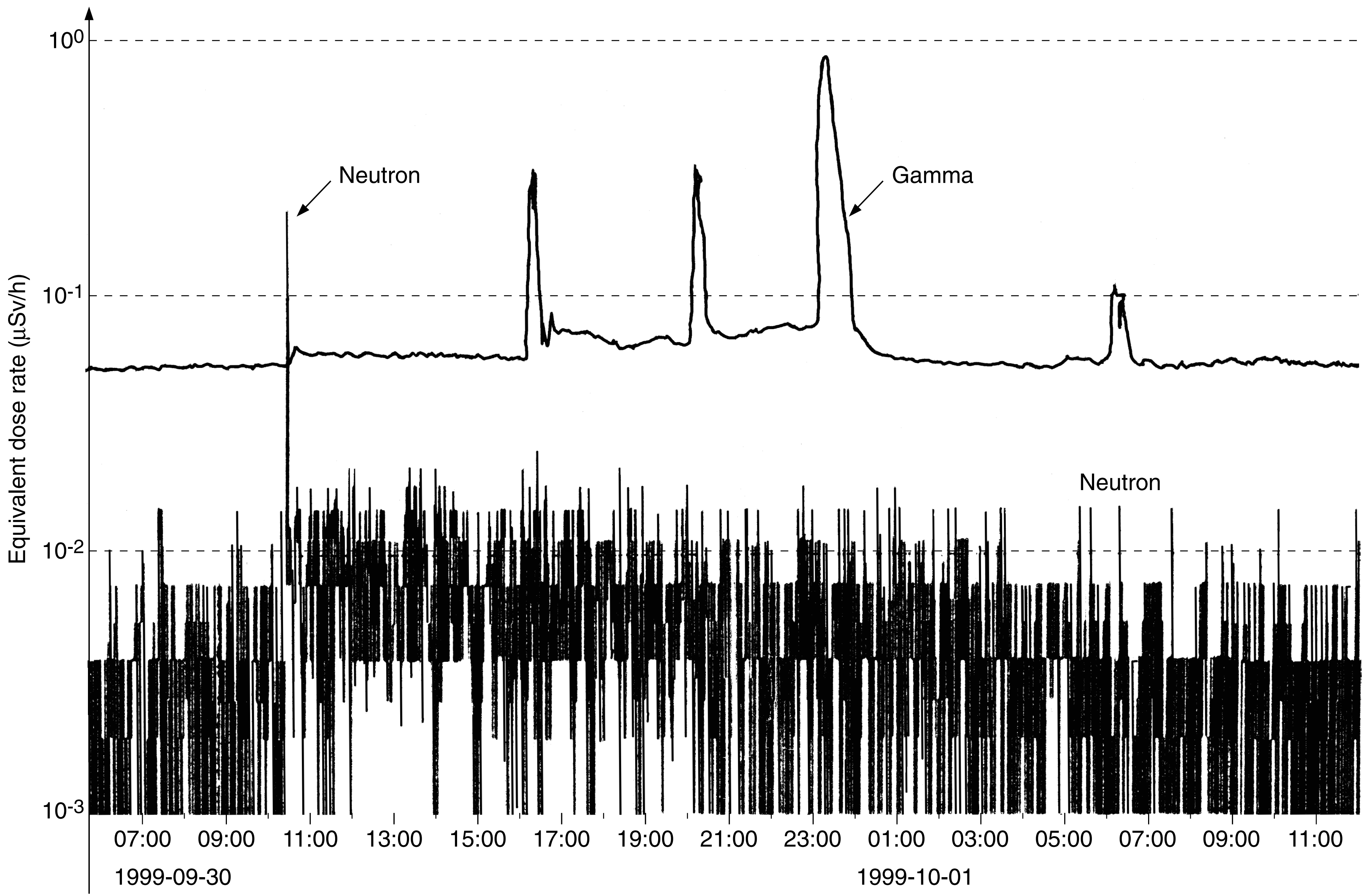

Fig. 18. Gamma and neutron equivalent dose rates at JAERI Tokai Site monitoring post MP-1 (1.7 km from the conversion building).

5. EMERGENCY RESPONSE MEASURES TAKEN

The following chronology is based on provisional information. Given the number of organizations and communications concerned, it will take some considerable time to derive an authoritative picture of the timings of events.

At 10:35, the three workers A, B and C were present in the conversion building as the accident happened (see Sections 3.1 and 7). Area alarms sounded in the conversion building triggered by the gamma radiation generated as the criticality occurred. Local emergency services were notified by JCO staff at 10:43 and three emergency service staff arrived at 10:46, reportedly not knowing the nature of the accident and without dosimeters. At around 11:19, the accident was reported by JCO to the STA. The local municipality of Tokaimura was notified at around 11:34 by JCO. Subsequently, at around 12:00, a report was made to the Chief Secretary of the Cabinet, and then to the NSC at around 14:00. After receiving the first report from JCO at around 11:19 on 30 September, STA dispatched personnel to the LCH [13].

At around 11:40, a maximum dose rate of 0.84 mSv/h was measured at point A on the map (see Fig. 4 and Section 4.2.1). At around 13:40, the Nuclear Material Regulation Division of STA requested the dispatching of emergency monitoring staff. At around 14:00, the Mito Atomic Energy Office of STA began monitoring [13].

At around 14:30, the STA established its countermeasures headquarters (see Section 3.1). At 15:00, the establishment of the GACH headed by the Minister for Science and Technology and with representatives from the relevant ministries and agencies was decided upon [13]. The STA collected results of environmental surveys performed by Ibaraki Prefecture, JAERI, JNC and the Mito office of STA. This information was transmitted to the local government. After this, the STA convened the LCH, headed by the State Secretary for Science and Technology, in the Tokai Research Establishment of JAERI.

At around 15:00, evacuation of residents living within 350 m of the facility was initiated by the Mayor of Tokaimura [13]. This decision was based on three factors: a request from JCO to evacuate people from a specific area; on a report that JCO personnel had been evacuated from the site; and on the gamma dose rate of 0.84 mSv/h measured at the site boundary. By around 17:00, 86 persons had been evacuated, reportedly with little panic or confusion. The last person was evacuated at 20:10, making a total of 161 people from 39 households within 350 m range of the JCO facility. It was reported that traffic control was effected smoothly by Ibaraki Prefecture authorities [26, 27].

At around 17:05, the first dose rates of neutrons were measured by JNC at the site boundaries and these indicated that criticality was continuing [13].

At around 18:00, the NSC convened an Emergency Technical Advisory Body and decided to dispatch a group of experts, including NSC members, to Tokaimura [13].

The Government Task Force for the Accident, headed by the Prime Minister, was established and met at around 21:00. The Task Force discussed and decided on measures to be taken by the Government [13].

At around 22:30, residents living within a 10 km radius of the facility were advised by Ibaraki Prefecture, through public information means, to stay indoors. This was reported to be a precautionary measure, and most people were indoors at this time of the evening. Although the dose rate was below the emergency action level [10], dose rates measured 7 km from the site were above the normal background level, and it was possible that criticality was still continuing. Advice was given to the parties concerned, such as commercial and industrial associations, to discontinue the collection of rain water for drinking.

At around 01:30 on Friday 1 October, the Governor of Ibaraki Prefecture requested the closure of schools within a 10 km radius of the site, requested residents to avoid unnecessary use of hospitals within the 10 km radius, and requested the suspension of harvesting of crops and vegetables.

After the water had been drained from the cooling jacket of the precipitation tank and neutron dose rates had fallen to below detection limits (see Section 3.2) at 09:20 on 1 October, the NSC stated that “the criticality had ended for the time being”. At 15:30, all traffic controls were lifted. At around 16:40 that day the recommendation to residents within the 10 km radius of the facility to stay indoors was lifted by Ibaraki Prefecture. On 2 October at around 18:30, following the placing of sandbags and other shielding material around the facility in order to reduce gamma dose rates, the decision was made by Tokaimura municipality, after consultation with the GACH and the Emergency Technical Advisory Body, that the evacuation be ended for residents within the 350 m range [13].

Water supplies and agricultural produce were monitored to reassure the population. The suspension of harvesting was announced as having been lifted at 18:30 on 2 October. Contamination checks had been conducted at 18 points in Ibaraki Prefecture for 74 633 residents as of 12 October; a health consultation programme was established as a telephone ‘hotline’; counsellors were made available for pregnant women and parents of children; a training session was held for schoolteachers; and one million copies of a pamphlet dated 15 October were printed and distributed to every household in the Prefecture.

6. RESULTS OF PRELIMINARY DOSE ASSESSMENTS

Retrospective dose assessments by JAERI, JNC and STA for residents in the region, including detailed plans on the exact methodology to be used, were still continuing at the time of the IAEA Secretariat team's visit. The results will be provided to the Governmental Accident Investigation Committee for evaluation and release. Exposure (mainly to neutron irradiation) of the JCO workers, the emergency service workers who responded and the resident workers in the vicinity at the time of accident was confirmed by means of film badges and whole body counting to measure ^{24}Na (neutron activated) levels in the body. The doses to the three radiation workers were estimated separately by blood sample analysis for ^{24}Na in the National Institute of Radiological Sciences, Chiba.

6.1. NUMBER OF PERSONS EXPOSED AND ESTIMATED DOSES AS OF 15 OCTOBER 1999

The 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 adjoining 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[3] for patient A, 6–10 GyEq for patient B and 1.2–5.5 GyEq for patient C (see Table I). 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 [5]. It 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.

In addition to patients A, B and C, a further 56 persons at the JCO facility were confirmed to have been exposed to gamma and neutron irradiation on the basis of measurements made by whole body counting of ^{24}Na and their film badges. Furthermore, seven workers who were assembling scaffolding on a construction site near the western boundaries of the JCO were confirmed to have been exposed to gamma and neutron irradiation on the basis of ^{24}Na measurements made by whole body counting. The three members of the Tokaimura emergency services who took the three JCO workers (Group 1) to hospital were also confirmed to have been exposed to gamma, neutron and other irradiation on the basis of ^{24}Na measurements made by whole body counting. The total number of persons confirmed to be exposed as thus defined was 69 as of 15 October 1999.

At the time of the accident, there were 123 workers who were engaged to work under conditions of managed radiation exposure (radiation workers) at the JCO site. A total of 108 film badges were recovered and by 14 October measurement data had been obtained from 93 film badges. A total of 43 unrecovered film badges remained in the Sumitomo Metal and Mining Co. Ltd facility at the site. Twenty-two film badges worn by workers at the time of the accident permitted dose estimates to be made. The effective dose from gamma radiation ranged from 0.1 mSv to 6.2 mSv (the maximum), and most were in the range 0.1–1.0 mSv.

6.2. PLANNED DOSES IN THE OPERATION TO DRAIN COOLING WATER

Ten teams, each consisting of two workers, and one driver were engaged in the operation to drain cooling water from the precipitation tank, which comprised 2–3 minute approach–work–retreat procedures. The total number of persons engaged was 21. Their doses ranged from below 1 mSv to 112 mSv for neutron irradiation and from 0.1 to 7.9 mSv for gamma irradiation on the basis of the readings of the gamma and neutron dose rate meters that they wore.

Six persons in three teams of two were engaged in injecting boric acid water into the precipitation tank. The

[3] A criticality accident is associated with mixed radiation fields (neutron and gamma), which have different penetration and absorption properties, as well as differing effectiveness at producing biological harm. The GyEq is 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.

doses from gamma irradiation for these six persons ranged from 0.034 to 0.61 mSv for their actions, which lasted 6–12 minutes. They did not wear neutron dosimeters because it had been considered before the operation that the criticality had already been terminated on the basis of the fall in the neutron dose rate.

TABLE I. NUMBER OF PERSONS EXPOSED TO EXTERNAL GAMMA PLUS NEUTRON IRRADIATION AND ESTIMATED DOSES AS OF 15 OCTOBER 1999.

Persons/ groups	Activities being conducted at the time of the criticality accident	Number	ID	Range of estimated doses ($\gamma + n$): preliminary values	Ref.
JCO employees[a]: Group 1	JCO workers A and B adding uranium oxide solution in nitric acid to the precipitation tank in the conversion building; worker C next door	3	A	10–20 GyEq[b]	[6]
			B	6–10 GyEq	[6]
			C	1.2–5.5 GyEq	[6]
JCO employees[a]: Group 2	21 JCO workers engaged in the operation to drain water from the cooling jacket	(21)		0.04–119 mGy[c]	[27]
JCO employees[a]: Group 3	Six JCO workers engaged in the operation to feed boric acid into the precipitation tank	(6)		0.03–0.61 mSv	[27]
JCO employees[a]: Group 4	Other workers at the site	56		0.1–23 mGy	[6, 27]
Tokaimura emergency service workers	Three Tokaimura emergency service workers who took workers A, B and C (JCO Group 1) to hospital	3		0.5–3.9 mGy[d]	[27]
Public	Local workers assembling scaffolding on a construction site just beyond the western boundary of the JCO site	7		0.4–9.1 mGy[e]	[27]
	Total number of persons confirmed to have been exposed (*excluding* JCO employees incurring planned exposures, JCO Groups 2 and 3)	69			[27]

[a] Employees of associated companies are included.
[b] GyEq: Gy equivalent.
[c] Group 2 doses were updated to 0.05–120 mSv on 22 October [29].
[d] Updated to 0.5–4.1 mGy on 22 Oct [29].
[e] Updated to 0.5–9.4 mGy on 22 Oct [29].

7. HEALTH CONSEQUENCES OF THE ACCIDENT AND MEDICAL TREATMENT OF OVEREXPOSED PERSONS

Since the IAEA Secretariat team did not include a medical doctor, the information presented here is limited to issues of a general nature.

Workers A, B and C were present in the conversion building at around 10:35 as the criticality event occurred and they reported seeing blue-white flashes. A few minutes later, worker A lost consciousness at the decontamination and changing room and began to vomit. The Tokai Fire Department received an emergency call from JCO at about 10:43 informing it of the accident, and an ambulance was despatched and arrived on the site at around 10:46. Patient A recovered consciousness after about 70 minutes and started to have diarrhoea at about the same time before being taken into the ambulance. After a discussion of the most appropriate destination for treatment, the ambulance departed at 11:49 and brought the three workers at 12:07 to the regional National Mito Hospital.

At this time, 1.5 hours after the initial exposure, patient A was conscious but was vomiting and had diarrhoea and fever. After a preliminary check and initial medical intervention, it was decided to transfer the patients to NIRS for treatment, where they arrived by helicopter at around 15:30 on 30 September [13]. The isotope ^{24}Na was detected in a vomit sample from patient A [13], confirming that he had been exposed to neutron irradiation.

On 2 October 1999, patient A was admitted to the hospital of the University of Tokyo, and on 4 October patient B was transferred to the hospital at the Institute of Medical Science of the University of Tokyo (IMSUT). Patient C was treated at NIRS. The team visited the hospitals on 16 October 1999 and saw patients A and B [13, 17].

It was reported that patient A had a markedly reduced lymphocyte count and marked hypocellular bone marrow. A fully matched donor (sister) was found and peripheral blood stem cell transplantation was effected on 5 October 1999. Thus he had survived for 16 days (until the IAEA Secretariat team’s visit) in a critical condition, which for doses reported in other cases had led to a fatal outcome within two weeks. At the time of going to press, he was reported to remain in a critical condition with a very poor prognosis.

It was reported that patient B had vomited about one hour after exposure and also had a markedly reduced lymphocyte count and marked hypocellular bone marrow. It was reported that on admission to NIRS he was alert and complaining only of mild nausea and pain in the right hand, and that his general condition was good although the skin of his face, neck, upper thorax and right arm was reddened. The right hand and forearm were reported to have been diffusely swollen and very painful. Since his bone marrow was severely damaged, haematopoietic stem cell transplantation was planned. Since no appropriate related donors were found, though, it was decided that transplantation of umbilical cord blood cells should be performed, and foetal stem cells taken from his umbilical cord were infused on 8 October 1999. It was reported that his prognosis remained uncertain.

Patient C was almost asymptomatic after exposure, with a moderately reduced lymphocyte count and hypocellular bone marrow. He has received cytokines for bone marrow stimulation and supportive care. It was reported that his prognosis for full recovery seemed good, although he would be expected to be subject to an increased risk of incurring cancer or leukaemia at a later date.

8. SUMMARY RESULTS OF THE MISSION

The Japanese authorities provided the IAEA Secretariat team with information on the accident and its causes and consequences, as was available at the time of the team's visit and subsequently updated. They also gave answers to questions posed by the team members. The team was also granted access to provisional information that permitted a better understanding of events and the corroboration of published material. The team was able to confirm independently that there was no apparent damage to the structural integrity of the JCO conversion building, and in particular that the roof appeared to be intact, and that gamma dose rate levels outside the JCO site were normal.

9. PRELIMINARY CONCLUSION OF THE MISSION

At this preliminary stage of assessment, the accident at the JCO nuclear fuel processing facility at Tokaimura seems to have resulted primarily from human error and serious breaches of safety principles, which together led to a criticality event. It 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 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 health consequences for the three severely overexposed workers. It will most probably also have implications for the regulatory regime and safety procedures and safety culture at the JCO facility. Investigation of the accident is continuing in Japan, and it is clear that much of the information that is currently provisional may need to be modified as additional information becomes available. For example, when the conversion building can be re-entered and adequate samples taken from the precipitation tank, it will be possible to make better estimates of the nuclear fission yield. These estimates are expected to enable revised dose assessments to be made for the radiation workers and nearby residents. Moreover, it will take time to review the causes of the accident in detail.

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.*

ACKNOWLEDGEMENTS

The IAEA would like to express its gratitude to all those people who provided information and who made arrangements for the mission and for the preparation of this report. The IAEA is also grateful to the Japanese authorities concerned for permission to reproduce the figures used in the report. In particular, the team expresses its deep thanks to the following individuals in Japan for the information provided:

Ibaraki Prefecture: I. Nagamine

Institute of Medical Science of the University of Tokyo: S. Asano, Y. Beck, T. Iseki, K. Misawa, H. Nagayama, T. Nakamura, N. Shirafuzi, Y. Yamada, N. Yamashita, K. Yoshikawa, K. Tani

Japan Atomic Energy Research Institute: S. Fujine, M. Hirano, H. Mineo, Y. Miyoshi, S. Mizushita, H. Noguchi, Y. Nomura, A. Oono, K. Soda, K. Suyama, T. Suzuki, M. Tsunoda

Japan Nuclear Cycle Development Institute: N. Hayashi, M. Iwanaga, H. Katagiri, J. Kurakami, T. Matsumoto, K. Miyabe, I. Nojiri, N. Tsujimura, T. Wakabayashi, H. Watanabe

JCO: T. Kondo, M. Yoshioka

Ministry of Foreign Affairs: K. Nakamura

National Institute of Radiological Sciences: M. Akashi, Y. Hishiyama, H. Murata, Y. Sasaki, M. Shimo, G. Suzuki, H. Tsujii,

Nuclear Safety Commission: K. Sato

Science and Technology Agency: A. Honda, H. Ikeda, H. Kataoka, M. Nakano, N. Oki, U. Yoshimura

Tokaimura: T. Murakami

University of Tokyo Hospital: K. Maekawa

REFERENCES

[1] Schedule of visit by the IAEA Secretariat Team, Science and Technology Agency, 14 October 1999 (provisional).

[2] Agenda for meeting, Science and Technology Agency, 14 October 1999 (provisional).

[3] List of participants at STA, Science and Technology Agency, 14 October 1999 (provisional).

[4] Materials for Briefing, Science and Technology Agency, 14 October 1999 (provisional) (in English).

[5] Materials distributed at the first meeting of the Accident Investigation Committee (I-1 to I-17), Science and Technology Agency, 14 October 1999 (in Japanese).

[6] Laws for the Regulation of Nuclear Activities, Science and Technology Agency, 14 October 1999 (in Japanese).

[7] Press release by JCO of 2 October 1999, Science and Technology Agency, 14 October 1999 (in Japanese).

[8] Nuclear Law, Science and Technology Agency (in Japanese).

[9] Disaster Countermeasures: Basic Act, Science and Technology Agency (English translation).

[10] Basic Plans for Disaster Prevention, Science and Technology Agency (English translation).

[11] Ibaraki Prefecture, Chronology of events, Science and Technology Agency (in Japanese).

[12] List of Participants: JNC, STA, JAERI, 15 October 1999.

[13] Chronology of the Accident at the Conversion Building, JNC STA JAERI, 15 October 1999.

[14] JCO, Fuel Fabrication Business (translation of A5/I-2), Accident at the Conversion Test Facility (translation of A5/I-6) JCO; Operation Manual (Translation of A5/I-7); Report by JCO to Minister of STA (translation of A5/I-8); Monitoring in the JAERI Naka site; Radiation exposure and Environmental Impacts (translation of A5/I-12); Planned Doses and Actions in the JCO Criticality Accident (translation of A5/I-13); JCO, Science and Technology Agency, Japan Atomic Energy Research Establishment, 15 October 1999 (in English).

[15] Agenda, Science and Technology Agency; Japan Atomic Energy Research Establishment, 15 October 1999.

[16] Radiation Measurement Data for the JCO Criticality Accident, Japan Nuclear Cycle Development Institute (JNC), 15 October 1999.

[17] Diagram indicating where the water pipe was broken, Japan Nuclear Cycle Development Institute (JNC), 15 October 1999.

[18] Summary of the Criticality Accident at the JCO Site, JCO, 15 October 1999 (in Japanese).

[19] Introduction to Tokaimura, Science and Technology Agency, Japan Atomic Energy Research Establishment, brochure (in English).

[20] Background material on NIRS, National Institute of Radiological Sciences, 16 October 1999 (brochure).

[21] Medical Preparedness for Radiation Accidents in Japan, National Institute of Radiological Sciences,16 October 1999 (in English).

[22] Documents, National Institute of Radiological Sciences, Japanese Association for Medical Management of Radiation Accidents, 16 October 1999 (in Japanese).

[23] All documents presented to the Second Accident Investigation Meeting (Index and 2-1 to 2-14), Science and Technology Agency, 16 October 1999 (in Japanese).

[24] Description of Disaster Message Dialling System, Science and Technology Agency, 16 October 1999, brochure (in Japanese).

[25] All documents presented to the Third Accident Investigation Meeting (Index and 3-1 to 3-19), 22 October 1999 (in Japanese).

[26] Interview with the Director General, Department of Civil Affairs and the Environment, Ibaraki Prefecture, 14 October 1999.

[27] Interview with the Mayor of Tokaimura, 14 October 1999.

[28] Meeting with the staff of JCO Company Ltd, 15 October 1999.

[29] Record of measurements made by IAEA Secretariat team at JCO and surroundings, 15 October 1999.

99-04542