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The report of the criticality accident in a uranium conversion test plant in Tokai-mura

Editors Hajime Murata
Makoto Akashi

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National Institute of Radiological Sciences (NIRS)

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PREFACE

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On September 30, 1999, at around 10:35 a.m., the occurrence of Japan's first criticality accident sent shockwaves around Japan, then around the world. The accident cost the lives of two workers, caused many residents concern regarding the impact on their health, and subsequent rumors had both social and economic consequences. Two years and three months later, looking back at the incident through calmer eyes, one can see the significant involvement of large numbers of people and the roles that were carried out on so many levels. The range of reports and books thus far published have ensured that an important records remains for posterity.

We at the National Institute of Radiological Sciences (NIRS) recognize the need for the important role we played and the experience we gained to be recorded as accurately as possible and made available for the sake of future generations. The publication of this report discharges one of our responsibilities in regards to this accident.

On the day of the accident, the NIRS was hosting a visiting nuclear medicine researcher from the US. The formal explanation and tour was called to a halt, and those concerned gathered over lunch to exchange views. I was called away from the discussion to be told that notification had been received that some of those at the Tokai-mura uranium processing plant had been exposed to radiation, and that preparation had been made to admit them. As the aforementioned discussions drew to a close and farewells were exchanged with the departing guest, I recall wondering whether he would sense the abruptness of the departure, or perhaps read later reports and realize the reason. It was at this point that I was intuitively aware of the gravity of the situation.

The unprecedented storm which immediately followed drew in many NIRS staff and continued for a period of months. Even today, with the storm past, those involved spend their days busy with the aftermath. Those outside the NIRS have also lent inestimable assistance. A debt of gratitude is owed to the many who gave their ungrudging cooperation and support through the Network Council for Radiation Emergency Medicine. Yoshiro Aoki, Vice Chairman of the Nuclear Safety Commission, Takayuki Shirao, former Director of the Division of Administration, and all those involved in the establishment of the Network Council have both our respect and thanks for their foresight. Local and overseas organizations were involved in the planning of numerous briefing sessions concerning the JCO accident, and the NIRS was responsible for the organization of seminars and international symposiums convened in December 2000 relating to various aspects of the post-accident response.

The role of many NIRS staff from a wide range of specialist fields in radiation was both diverse and extensive, and involved the medical treatment of the three workers heavily exposed to radiation, support by way of on-site specialists in Tokai-mura and surrounding areas, administration of the resident activity survey and subsequent assessment of radiation dose, explanations to residents, health consultations, allaying the health concerns of those other than residents, and administrative support. This report is a detailed account of the roles that many individuals and groups performed in a range of areas. I also believe that it is a valuable resource for deepening understanding of the realities of the accident and reinforcing the recognition that such an accident must never reoccur.

We pray that the two who lost their lives in this accident may rest in peace, and hope that this report may be useful in preventing the occurrence of future accidents.

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1. Outline of the Accident

On September 30, 1999, at around 10:35, a criticality accident occurred in a uranium conversion test plant of the JCO Ltd., in Tokai-mura, Ibaraki Prefecture, Japan. As two workers (A and B) were pouring uranyl nitrate into a precipitation tank, the solution emitted a flash of blue light and the alarms went off to warn against gamma rays. Another worker (C) who was in the corridor next to the room immediately recognized that a criticality accident had taken place and ordered the two workers to evacuate. They ran to a locker room located in another building. The three workers had been exposed to high doses. Soon after they evacuated the room, Worker A vomited, lost consciousness and showed systemic rigor. Worker B felt numbness. Since Worker A became unconscious and vomited, an ambulance was called.

At about 11:00, the Director of the Division of Radiation Health of the National Institute of Radiological Sciences (NIRS) received the first notice from the fire department of Tokai-mura. The fire department first tried to transfer the patients to the NIRS since the patients were suspected of having undergone high dose exposure to radiation. Since it was reported that there was no contamination and the first aid treatment of the patients was likely to be of the highest priority, the NIRS ordered the fire department to transfer the patients to the National Mito Hospital, which is a large general hospital in the region. Worker A and B vomited and Worker A had diarrhea while they were being transferred to the hospital. The 3 patients received first aid treatment in the National Mito Hospital. However, since the patients showed symptoms of high dose exposure and radioactivities were detected from the surface of their bodies, it was decided that they be transferred to the hospital of the NIRS, which is a Stage 3 Facility of Radiation Emergency. The NIRS established a Command Office for Radiation Emergency and prepared to accept the patients. The institute decided the members in charge, took measures to prevent the contamination of the medical equipment and facilities, which were to be used for the emergency treatment of the exposed patients and checked and prepared medical instruments, tools and medicine. At this point, the scale of the exposure of the accident was not fully understood. At about 14:00, the statement, "There has been an accident in a facility that used uranium hexafluoride. Three persons are severely affected and are possibly contaminated internally" was released. The 1st meeting was held at 14:30. At 14:45, the 3 patients who were accompanied by a physician of the National Mito Hospital, arrived at Toke Heliport, Chiba City, by a helicopter used for disaster prevention belonging to Ibaraki Prefecture. The members of the Section of Radiation Safety of the NIRS waited at the heliport to accompany the patients, who were transferred from Toke to the Medical Care Unit for Radiation Emergency of the NIRS by Chiba City ambulances. At 15:25, they arrived at the NIRS. Patients A and B entered the hospital on stretchers and Patient C on foot. The members of the Section of Radiation Safety examined the helicopter, the ambulances and its crew and concluded that they were not radioactively contaminated.

The members of the radiation emergency medical team, who were prepared for life-saving treatment, quickly examined the degree of exposure and contamination of the patients before starting medical treatment. The medical team attempted to tranquilize the patients, checked their vital signs, secured blood vessels and administered intravenous drip injections to prevent dehydration. At the same time, radiation dosimetry specialists started to estimate the physical and biological doses of the patients exposed. Although it was not then possible to accurately determine the doses, the monitoring of the body surfaces of the patients and a radioactive examination of nasal swabs and clothing suggested that there was almost no external contamination by radionuclides and that there might be the possibility of internal contamination but the degree was likely to be negligible. From the blood cell counts and the clinical symptoms seen at the National Mito Hospital, the patients were presumed to have been exposed to high doses (fatal doses for Patients A and B) and were transferred from the Medical Care Unit for Radiation Emergency to hospital ward of the Charged Particle Therapy (Patients A and B to sterile rooms and Patient C to a low pressure room). The medical team administered steroids to prevent a decrease in blood pressure, antibiotics to prevent infection and cytokines to restore bone marrow. Hours later, the Working Group of Exposure Dose Assessment of the NIRS determined that the accident was a criticality acci-

dent and estimated that Patient A received 18 GyEq (5.4 Gy neutron and 8.5 Gy gamma) or over, when converted into a gamma-ray dose (Gy equivalent to gamma-ray). Patient B was exposed to radiation of 9.3 GyEq (2.9 Gy neutron and 4.5 Gy gamma-rays) and Patient C received a dose of 2.6 GyEq (0.81 Gy neutron and 1.3 Gy gamma-rays) based on clinical symptoms, the amounts of ^{24}Na in vomit and blood specimens, lymphocyte counts and chromosome analyses.

The NIRS contacted and asked for the cooperation of the chairman of the Network Council for Radiation Emergency Medicine, the President of Chiba University, the Director of the Japanese Red Cross Central Blood Center, the Director of the National Cancer Center Hospital, the Ministry of Education, Culture and Sports and the Ministry of Health and Welfare.

Clinical meetings were held periodically from the night of September 30. In the middle of the first meeting, the dose estimation group revealed that ^{24}Na and ^{42}K were detected from the mobile phones and vomit of the patients and they judged that it was a criticality accident. With this information, the medical team decided to focus on the treatment for external exposure by neutrons and other rays. Since Patients A and B were exposed to fatal doses, their prognosis was not optimistic although their general states were stable on the 1st day. The patients showed significantly increased numbers of leukocytes and decreases in lymphocyte numbers, their bone marrow was unlikely to be restored. Therefore, the medical team prepared for transplantation of hematopoietic stem cells. The NIRS decided to call the Network Council for Radiation Emergency Medicine on October 1. With the cooperation of the Ministry of Education, Culture, and Sports and the Ministry of Health and Welfare, the institute obtained the support of nurses and pharmaceutists from other hospitals.

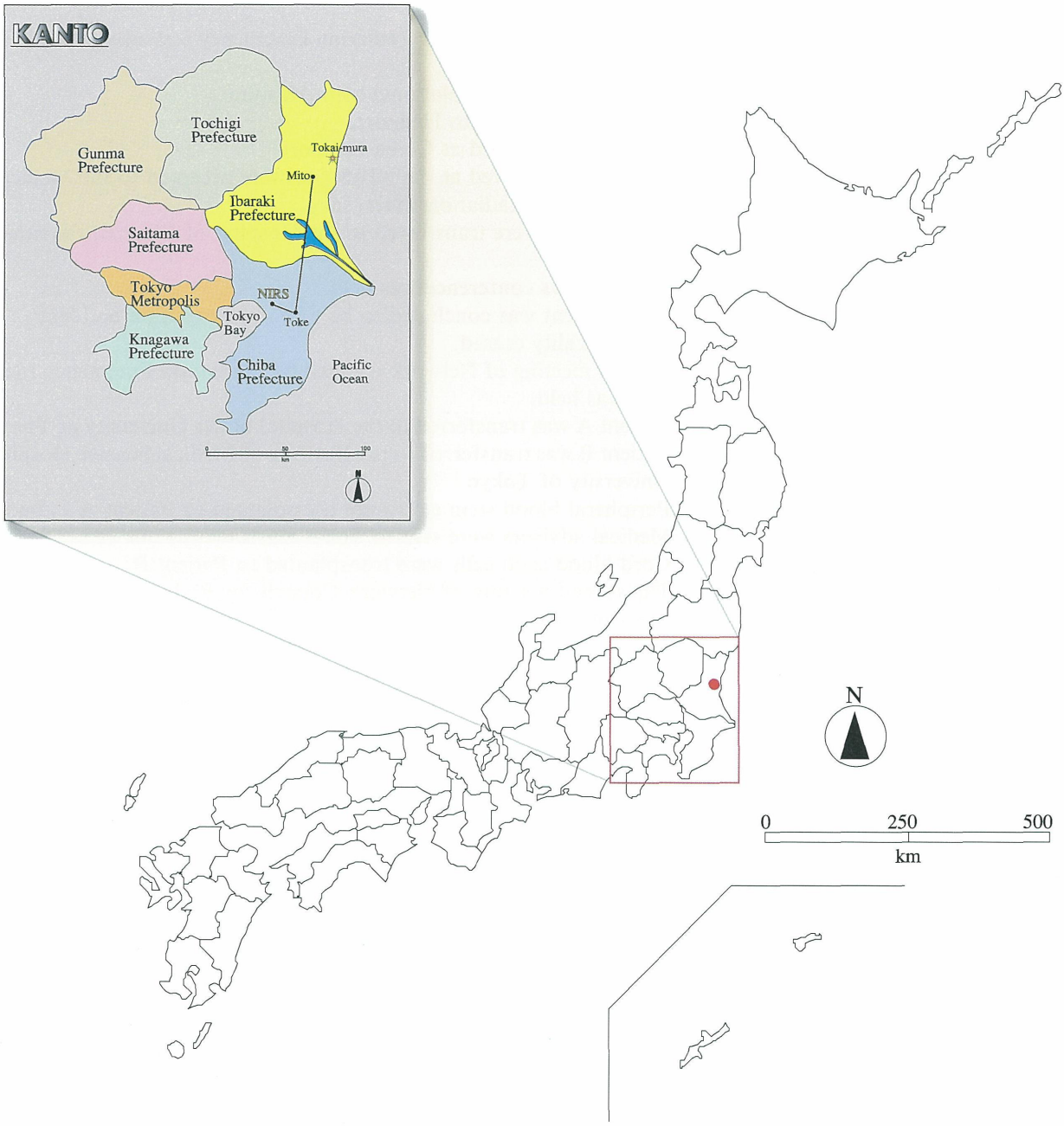
The Network Council for Radiation Emergency Medicine, which was held on October 1, anticipated that Patients A and B would lose their bone marrow functions completely. They concluded that Patients A and B needed transplantation of hematopoietic stem cells and systemic control against the failure of digestive tract, infection and dermal injuries and decided to transfer the patients to the Hospital of the University of Tokyo and the Institute of Medical Science of the University of Tokyo, respectively. It was also decided to continue medical treatment by obtaining cooperation from various medical institutes, such as Kyorin University and Nippon Medical School. Since Patient C was likely to restore his own bone marrow by the administration of cytokines, the network council decided to treat him at the NIRS. Patient A received a transplantation of peripheral blood stem cells from his sister. Patient B received cord blood stem cell transplantation. Despite intensive care, Patient A died on the 83rd day after the accident (December 21, 1999) due to dermal injuries and multiple organ failure, including renal insufficiency. The bone marrow of Patient B was restored and cadaver allografts and cultured autografts were transplanted to treat the skin injuries on the face, legs and arms, which engrafted well. However, Patient B died on the 211th day (April 27, 2000) due to pulmonary and renal insufficiencies and bleeding from the digestive tract. Patient C was treated in a sterile room in the NIRS to prevent infection, administered with cytokines to restore his bone marrow and left the hospital on December 20, 1999. He is to be periodically examined in the NIRS and in a regional hospital. Psychological support was needed for the patients and their families during and after their stay in the hospitals and the help of Chiba University was obtained. Administrative measures by police and prosecutors were necessary as well as medical treatment. Health consultation and lectures have been conducted in order to help the residents to understand radiation and to allay their apprehensions on radiation exposure.

This criticality accident had affects on the administration and led to important revisions. For example, the Basic National Plan for Disaster Prevention of the Central Committee for Preventing Disasters and the Nuclear Disaster Prevention Guidelines for the Nuclear Facilities of the Nuclear Safety Commission were revised and the Special Law on Emergency Preparedness for Nuclear Disaster was enacted. It also changed the consciousness of the public and municipal or local governments on radiation. The NIRS receives increasing numbers of requests for people to give lectures on radiation emergency medicine. Municipal governments that do not have nuclear facilities also feel the necessity for educating their people about radiation. For the NIRS, the criticality accident emphasized the importance of establishing emergency medicine measures against radiation accidents.

Details

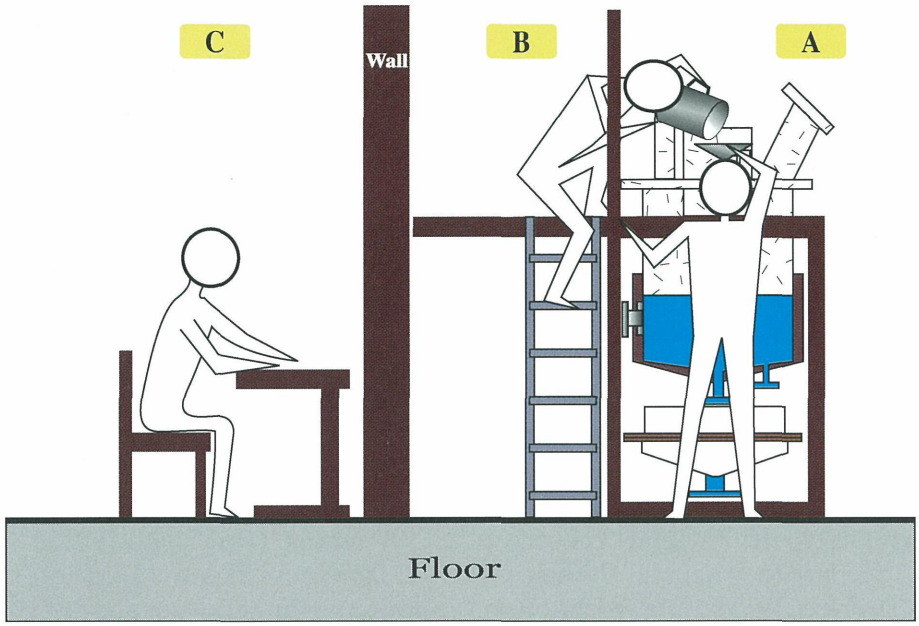
Date and time		Act
September 30, **1999**	10:35	The criticality accident occurred.
	10:43	JCO requested the Tokai-mura fire department to send ambulances.
	about 11:00	The first notice arrived from the Tokai-mura fire department to the NIRS.
	12:07	The patients arrived at the National Mito Hospital.
	about 13:00	The Tokai-mura fire department requested that the NIRS receive the three patients.
		The Command Office for Radiation Emergency was established in the NIRS.
	13:43	The patients left the National Mito Hospital.
	14:16	The patients left Mito Heliport.
	14:45	The patients arrived at Chiba Heliport.
	15:25	The patients arrived at the NIRS and were accepted to the Medical Care Unit for Radiation Emergency.
	16:00	The patients were transferred to the Hospital of Charged Particle Therapy.
	17:00	The 1st news conference was held.
	18:25	The accident was concluded to be a neutron exposure accident.
October 1	about 6:00	The criticality ceased.
		The 1st meeting of Network Council for Radiation Emergency Medicine was held.
October 2		Patient A was transferred to the Hospital of the University of Tokyo.
October 4		Patient B was transferred to the Institute of Medical Science Hospital, University of Tokyo.
October 6 and 7		Peripheral blood stem cells were transplanted to Patient A 2 times.
October 8–		Medical advisors were sent to Tokai-mura.
October 9		Cord blood stem cells were transplanted to Patient B.
October 12		The second meeting of Network Council for Radiation Emergency Medicine was held.
October 16		The NIRS explained the condition and treatment of the patients to the IAEA members who visited the institute.
October 18		Lecturers were sent to an explanatory meeting held in Tokai-mura.
		The NIRS went to IAEA to explain the accident.
October 19–		Physicians were sent for health consultations in Tokai-mura.
October 28 and 29		9 specialists from abroad visited the institute.
October 29		The 3rd meeting of Network Council for Radiation Emergency Medicine was held.
November 20 and 21		Members of the NIRS investigated the movement of the residents on the day of the accident to estimate doses.
December 20		Patient C left the hospital.
December 21		Patient A died.
January 5, **2000**		The 4th meeting of Network Council for Radiation Emergency Medicine was held.
February 9		The 5th meeting of Network Council for Radiation Emergency Medicine was held.
March 25		The 6th meeting of Network Council for Radiation Emergency Medicine was held.
April 27		Patient B died.
December 14 and 15		The international symposium on the criticality accident at JCO, Tokai-mura was held at Chiba-city.

Where did the criticality accident occur ?



The JCO is located in Tokai-mura, Ibaraki, 120 km northwest of Tokyo

Schematic diagram of the workers



This schematic diagram was drawn by the NIRS based on interviews with Patients B and C. This diagram is slightly different from that submitted to the Uranium Processing Plant Criticality Accident Investigation Committee of the Nuclear Safety Commission concerning the position of Patient B's right leg and Patient A's left hand, which were corrected after a similar mock-up experiment conducted at the site.

2. Occurrence of the Accident, Request to Accept the Victims and Communications until the Identification of the Criticality Accident

This section briefly explains the course from the occurrence of the accident until the 3 victims arrived and were accepted at the NIRS.

2-1. Accident and transfer to the NIRS

On September 30, 1999, at about 10:35, at the conversion test facility of JCO's uranium fuel processing plant, a uranyl solution that was poured into a precipitation tank reached criticality, emitting a flash of blue light and a cracking sound[1]. The alarms were sounded to warn against gamma rays. Patient C, who was outside the precipitation tank room, ordered the two workers (Patients A and B) in the room to evacuate. Patients A and B quickly retired to a locker room. Patient A went to the toilet of the locker room, vomited and lost consciousness. Patient B felt numbness all over his body. Another JCO worker hurried to the locker room and asked the 3 victims to evacuate. Patient C replied that a person had fainted, there had been an accident and he could not evacuate. Patient C did not evacuate but asked the worker to call an ambulance. An ambulance was called at 10:43. At 10:46, an ambulance arrived at JCO and started to treat Patient A. A JCO member, who was surveying the site, detected a high radiation level and thus ordered the ambulance crew to retire to a safer place. The ambulance crew carried Patient A on a stretcher to the JCO office and then to the gate even though he was suspected of being contaminated. At 11:27, the ambulance team carried the 3 victims into the ambulance car and asked the Tokai-mura fire department to identify a hospital to accept the patients. The fire department called the NIRS, informed them that there were two people who felt ill at the Tokai-mura facility (the number of patients was first stated as being 2 instead of 3 and the name of the facility was not identified) and asked where they should take the patients. The NIRS suggested checking their vital signs, such as pulse, blood pressure and respiration, as the first priority and then to take them to the National Mito Hospital, which is a Stage 2 facility of radiation emergency and considered to be the most appropriate. The institute also mentioned that it would prepare to accept those patients should it be necessary to do so. After several communications with the fire department, the institute eventually understood that the site was a conversion test facility located on Sumitomo Metal Mining's premises (the name of JCO was not mentioned), the fire department had received the first call at 10:43, the facility used uranium and one person had fainted once after having foamed at the mouth but had soon regained consciousness. By this time, JCO had not yet informed the fire department of what was happening and the NIRS did not know the type of exposure and the possibility of contamination with radionuclides. At about this time, the first notice was sent from JCO to the Science and Technology Agency by facsimile that two people were exposed and it was possibly a criticality accident. However, the NIRS did not receive such information and its Section of Radiation Safety started to prepare the facility for radiation emergency medicine against contamination.

At about 11:33, the Medical Affairs Division of the National Mito Hospital received the 1st notice of the exposure accident from the Tokai-mura fire department, which stated that 1) there had been a radiation exposure accident at JCO, 2) the fire department wanted the National Mito Hospital to accept 3 patients, 3) 2 patients had vomited, and 4) 1 of the 2 patients had lost consciousness once but was conscious again. The director of the Department of Radiology of the hospital replied to the fire department that the patients were likely to have received high doses since they showed symptoms such as vomiting and unconsciousness and it would be better to transfer the patients directly to the NIRS than to carry the patients to the National Mito Hospital. The fire department replied that the NIRS was considering acceptance of patients, so in the meantime, the fire department wanted the Mito Hospital to accept the patients. While this was going on, the NIRS ordered the department to ask the Mito Hospital to give first aid, such as instillation and the NIRS would then give further orders later. The National Mito Hospital thus understood that the NIRS had requested the acceptance of the patients and that the patients were not contaminated internally and decided to accept the patients. At 11:49, the ambulance set off for the National Mito Hospital and arrived at the hospital at 12:07. Since no health physics specialists, such as JCO radiation safety staff, had accompanied the patients, the

National Mito Hospital did not understand 1) what was conducted at JCO and what kind of accident had occurred, 2) why radiation was detected from the bodies of the patients even though all the clinical symptoms showed only external exposure, 3) what were the appropriate protection measures taken by patients suspected of internal contamination by unknown radionuclides of over 30 μSv/h, 4) whether it was possible to accept the patients in ordinary wards and what were the adequate protection measures to be taken while moving and accepting the patients in the hospital and 5) whether it was necessary to administer treatment for internal contamination. The hospital staff felt that the situation increasingly worsened without any solutions being found[4]. The National Mito Hospital decided to transfer the patients to the NIRS since high gamma-ray doses were detected from the body surfaces of the patients and the patients showed severe diarrhea, vomiting and a reduction in lymphocytes.

The NIRS could not grasp the situation just from the information that was communicated from the fire department and asked the Atomic Energy Bureau of the Science and Technology Agency, which did not provide information either. At about 13:00, Mr. Hishiyama, who was the Supervising Research Planner of the Division of Planning and Coordination, made a phone call to the director of the Mito Atomic Energy Office, who informed him that the area monitor went off at JOC at about 10:35 and 2 people were exposed. The facility used 20% to 50% of concentrated uranium. At its peak, a maximum dose of 0.84 mSv/h was detected at the border of the site. JCO is a subsidiary of Sumitomo Metal Mine, and so there might have been a criticality accident.

At about 13:00, the Tokai-mura fire department informed the NIRS by phone that the fire department would transfer the 3 patients from the National Mito Hospital to the NIRS. The NIRS prepared to accept the patients. The Supervising Research Planner took charge of communications after 13:00. From then on, the inquiries from press and other mass media increased. The Ibaraki Prefecture police and Hitachinaka police also made inquiries.

At 13:43, two ambulances left the National Mito Hospital for Mito Heliport. Assuming high dose exposure, the NIRS communicated with the Japanese Red Cross Society about hematopoietic stem cell transplantation and prepared for HLA typing. At about 14:00, the NIRS fully prepared all the necessary equipment for protecting the ambulance crew of the Inage fire department and the medical staff from being contaminated by alpha-nuclides (full-face masks, disposable operation scrubs, aprons, caps and personal dosimeters). Three members of the Section of Radiation Safety carried devices for measuring radiation doses and protective clothing, and left the NIRS for the heliport of the Fire Department of Chiba City (Toke) in fire department ambulances. The ambulances arrived at the heliport at about 14:30 and waited for the patients. The helicopter that left Mito at 14:16 arrived at the heliport of the Chiba Fire Department at 14:45. An immediate survey was urgently conducted on the two patients who showed diarrhea and vomiting. Although alpha rays were not detected, a GM survey meter detected significant counts on the patients and their vomit. Even if there had been some level of contamination by uranium hexafluoride, it was not likely to cause contamination of the medical crew and the members of the Section of Radiation Safety decided not to use full-face masks. The two ambulances left the heliport of the Fire Department of Chiba City at 14:58 and arrived at the NIRS at 15:25.

2-2. Acceptance of the patients to the NIRS and understanding the status of the accident

The NIRS considered the possibility of contamination by radionuclides and physicians and nurses wore full-face masks. The contamination of the body surfaces of the 3 patients was measured in the corridor of the Medical Care Unit for Radiation Emergency using an alpha-ray survey meter and a GM survey meter. Patient A showed approximately 13 kcpm at the head and 26 kcpm at the chest. Patient B showed approximately 15 kcpm at the chest. Patient C showed approximately 6 kcpm at the head and 4 kcpm at the chest (including a background of approximately 100 cpm. See another section for details). Since the patients exhibited intensive sweating and decreases in blood pressure, instillation was administered. After examining the oxygen partial pressure of the arterial blood, oxygen inhalation was administered to the patients. Sodium bicarbonate was also applied since inhalation of uranium was suspected. Methylprednisolone was administered to prevent drops in blood pressure. Since an extra survey meter installed in the corridor showed large gauge movements, contamination was suspected. On the other hand, an al-

pha-ray measurement of the body surfaces showed just background levels and the contamination of the blankets that covered the patients was also low. Since secondary exposure or contamination of the medical crew was unlikely to occur, the NIRS decided to transfer the patients to its hospital ward from the view point that it was the highest priority to save the lives of the patients by maintaining the electrolyte balance and preventing dehydration, which was likely to be advanced by vomiting and sweating. The dose measurements by a whole-body counter and a thyroid monitor at the Medical Care Unit for Radiation Emergency were suspended and the patients were transferred to the Hospital ward of Charged Particle Therapy. The surveys of the ambulance crew and the vehicles detected no surface contamination.

Even at around 16:00, the NIRS still did not fully grasp the status of the accident. The mobile phone of an exposed patient, which showed a very high dose, was analyzed by gamma-ray spectrometry with a germanium detector. The phone showed peaks of ^{24}Na, ^{56}Mn and ^{198}Au. At 16:40, an analysis of Patient A's vomit was conducted, which detected peaks of ^{24}Na and ^{42}K, and at 18:25, it was concluded that there had been exposure to neutron rays.

2-3. Issues

Accurate information is indispensable for allowing appropriate measures to be taken during disaster or accidents. In terms of communicating information, this accident revealed various issues. First, the word "criticality" that Patient C had mentioned immediately after the accident was not communicated to the ambulance crew and thus did not reach the NIRS. If the JCO staff in charge of radiation safety at the site had heard this word, knowing that there was the possibility of a criticality accident, a member of staff would have accompanied the patients to the hospital and correctly explained the accident to the medical staff. Also the NIRS would not have needed to prepare unnecessary masks and the other institutes would not have been so confused. Furthermore, the ambulance crew entered a high dose room even though the gamma-ray alarm went off immediately after the accident and the spatial dose at the site exceeded a certain value. Luckily, the ambulance crew was not exposed to such a high dose that could have affected their health. During such radiation accidents a human's five senses seldom work together to detect danger and the extreme importance of communicating correct information becomes apparent.

September 30, 1999

Time	
10:35	Criticality accident occurred.
10:43	Ambulance was called.
10:46	Ambulance arrived in the entrance hall of the JCO.
11:27	Three patients were carried into the ambulance.
11:49	The ambulance left the JCO.
12:07	The patients arrived at the National Mito Hospital.
13:43	The patients left the National Mito Hospital.
14:16	The helicopter left Mito Heliport.
14:45	The helicopter arrived at Chiba Heliport.
14:58	The patients left the heliport.
15:25	The patients arrived at the NIRS.

References

1) Report of the Uranium Processing Plant Criticality Accident Investigation Committee PII-3, December 24, 1999, The Uranium Processing Plant Criticality Accident Investigation Committee.
2) Ibid as 1), PIV-11.
3) Mitsuyoshi Sugawara: Report of accepting and transferring of the victims and later activities, INNERVISION (in Japanese), 15.2, p. 27, 2000.
4) Hisanori Ariga: Roles of a Stage 2 Medical Facility of Radiation Emergency, the National Mito Hospital, INNERVISION (in Japanese), 15.2, p. 2, 2000.

3. Receiving Patients and Initial Treatments

3-1. Preventing contamination

Immediately after the NIRS received the first notice of the accident, the institute called members of the Division of Radiation Safety, prepared to receive the patients by taking measures to prevent contamination with radionuclides of the Medical Care Unit for Radiation Emergency and performed other tasks, some of which are described below. The institute checked the medical devices necessary for radiation emergency and listed and prepared medicines, equipment and other items necessary for first-aid and life-saving treatment (including the transfer of aspirators since the gas pumping equipment was not functioning). The institute cleaned the room used for treating contaminated patients, the decontamination room and the triage room on the ground (first) floor and the patient ward on the next floor and prepared beds and other necessary items since the facilities were usually used for training.

(1) Decontamination facility of the Medical Care Unit for Radiation Emergency

The institute covered the floor of the entrance, corridors, the triage room, decontamination room, the room used for treating contaminated patients and the evaluation room of the Medical Care Unit for Radiation Emergency to prevent contamination with plastic and polyethylene sheets.

The institute also:

1) checked that the exhaust and purifying devices, exhaust monitor, air conditioner, supply and exhaust device and the plumbing system were functioning correctly,
2) prepared instruments for monitoring radiation and materials and equipment,
3) prepared alpha-, beta-, and gamma-ray survey meters, portable dosimeters, an air sampler, half-face masks, sheets of smear paper, plastic bags and other equipment,
4) covered the stretchers, treatment beds and gurneys that would be used for treating the patients with plastic sheets,
5) prepared plastic buckets installed with plastic bags for collecting contaminated clothing and water,
6) identified the radiation control area, which was prepared for the transfer of the contaminated patients, marked the area by fixing ropes and tapes along the border and strictly limited the entrance and exit of people and equipment (medical supplies and clothes etc).

(2) Patient ward in the Medical Care Unit for Radiation Emergency (second floor)

Six nurses with a thorough knowledge of radiation emergency medicine were appointed and immediately started preparations to receive the patients. The nurses cleaned the patient ward on the second floor of the Medical Care Unit for Radiation Emergency and transferred the necessary equipment from the Hospital of Charged Particle Therapy. They also cleaned the ground (first) floor of the facility and transferred all the equipment needed for life-saving activities from the Hospital of Charged Particle Therapy.
Tools, devices, and equipment that were transferred to the Medical Care Unit for Radiation Emergency were:

electrocardiographs, pulse counters, counter shocks, respirators, direct patient monitors, oxygen humidifiers, transfusion pumps, syringe pumps, transfusion stands, hemadynamometers, stethoscopes, stretchers, crash carts, sets of first-aid carts, various medicines, 500 l oxygen cylinders (10 cylinders), equipment for sampling blood specimens, medical supplies, disposable sheets, linens, urinals, portable toilet, buckets, plastic bags, items for the gown technique, equipment for collecting smears and equipment for taking records.

Other nurses, nurse assistants and the members of the Administration Division and the Section of pharmacy assisted with the transfer of the equipment into the Medical Care Unit for Radiation Emergency. It took two hours to get everything ready for receiving the patients.

(3) Hospital of Charged Particle Therapy

To prevent radiation contamination, the institute requested the Division of Radiation Safety to cover the floors of the corridors, through

which the patients were to be transferred, sterile rooms and low pressure rooms with polyethylene sheets. Screens were used between the corridor and other parts of the ward while transferring the patients so as not to affect the other patients in the ward. Since the hospital staff were informed that the patients had been severely exposed externally and there was the possibility that the patients might have to be put in sterile rooms, instruction was given to the Hospital of Charged Particle Therapy, which has sterile rooms on the fifth floor, to prepare to receive the patients. The hospital cleaned the rooms and prepared the beds (mattresses were covered with polyethylene sheets to prevent contamination). It also prepared for the gown technique and brought the equipment that was needed for life-saving activities into the sterile rooms.

Equipment that was transferred into the reverse isolating rooms:

electrocardiographs, aspirators, emergency carts, portable toilets, crash carts, pulse counters, transfusion pump, various first-aid medicines, various polyethylene buckets, respirators, syringe pumps, hemadynamometers, urinals, oxygen inhalators, transfusion stands, stethoscopes and plastic bags.

3-2. Protecting the staff from radiation

(1) Principles of radiation protection from the point of disaster prevention activities

People engaged in emergency activities during accidents, such as exposure accidents, including the medical staff, should perform emergency activities following the three principles of radiation protection as far as possible to minimize secondary exposure. When exposure is anticipated, these persons should carry in advance instruments for determining exposure and devices for protecting the body from radiation exposure to minimize the effects of radiation. In other words, in case of exposure accidents, they should perform their duties while monitoring the doses they are exposed to. This is true for both treating radiation- exposed patients and conducting activities at a contaminated site. They should also minimize the time of operation.

(2) Radiation protection of the staff

This section describes the radiation protection measures that were taken to minimize the exposure of the crew in charge of transferring the patients (the staff engaged in transferring the patients from the Class 2 facility of Radiation Emergency to the Class 3 facility: two helicopter pilots, one physician of the National Mito Hospital, one JCO member, six ambulance members of the Fire Department of Chiba City, who transferred the patients to the Class 3 facility and three members of the Division of Radiation Safety, who accompanied the patients to the NIRS) and the medical staff in charge of receiving the patients.

①The group transferring the patients

Members of the Division of Radiation Safety: 3

Members of the Fire Department of Chiba City: 6 (2 ambulance staff, 2 drivers and 2 assistants)

Ambulance cars of the Fire Department of Chiba City: 2

Portable devices, tools and equipment prepared: devices for measuring doses, GM survey meters, portable dosimeters, protective clothing (full sets: full-face masks, disposable operation scrubs, aprons and caps), simplified masks, plastic bags for keeping contaminated matter, applicators for collecting smears and decontamination equipment.

Equipment of the ambulance crew: It was decided in advance that the ambulance crew should wear the necessary clothing for treating infected patients (disposable wear, medical masks, anti-infection rubber gloves). The ambulance crew also wore portable dosimeters.

At 14:00, the three members of the Division of Radiation Safety dressed in their working gear, left the NIRS in ambulances of the Fire Department of Chiba City for the Toke Heliport. They carried the instruments for measuring radiation doses and protective clothing etc. The ambulances arrived at Toke Heliport at 14:30. The crew of the fire department of Inage City wore full sets of protective clothing to shield themselves from the contamination of alpha nuclides (full-face masks, disposable operation scrubs, aprons, caps and personal dosimeters). The staff of the Division of Radia-

tion Safety did not wear their white robes out of consideration of the situation at the site and the apprehension of the patients, but wore their working uniform out of concern for radiation contamination. At 14:40, the disaster-prevention helicopter of Ibaraki Prefecture arrived at the heliport of the Fire Department of Chiba City.

②The group receiving the patients
Medical staff: three physicians and six nurses
Persons in charge of measuring contamination of the patients: six members of the Department of Radiation Safety
Activities: removal of radiation contamination and treatment of the exposed patients
Clothing: middle-scale sets (half-face masks, cotton gloves, rubber gloves, Tyvek suits and over shoes)
Instruments prepared: a GM survey meter, a NaI scintillation survey meter, alpha-ray survey meter and expiratory dust catchers (air snifters)
Clothing of the members of the Division of Radiation Safety: middle-scale sets (half-face masks, cotton gloves, rubber gloves, Tyvek suits and over shoes)

All members of the medical staff (three physicians and six nurses) and the staff in charge of monitoring the doses of the patients (six members of the Division of Radiation Safety) wore personal dosimeters and middle-scale sets (half-face masks, cotton gloves, rubber gloves, Tyvek suits and over shoes) to minimize radiation exposure and waited for the arrival of the patients. The medical members of staff wore double gloves. The edges of the inner gloves were folded outside and were fixed with tape to prevent contamination in case the outer gloves were contaminated or torn. The staff in charge of measuring physical doses wore operation scrubs and prepared to analyze nuclides in specimens that would be collected from the patients and determine exposed doses and waited at their own posts. For each patient, a medical team was formed, which consisted of one physician and nurses. The activities of the nurses were classified into four areas: (1) hot operation (direct contact with the patients), (2) semi-hot operation (supporting {1}), (3) cold operation (supporting (1) and (2) to perform works smoothly) and (4) cold operation (recording data). The members of the Division of Radiation Safety, who were assigned to measure the doses of the patients, were divided into three pairs, depending on their experiences. The members checked the devices for monitoring radiation, GM survey meters, NaI scintillation survey meters, alpha-ray survey meters (which are requisite for accidents in reprocessing facilities) and expiratory dust catchers, measured the back ground radiation level and waited for the patients to arrive.

3-3. Transferring the patients from the heliport of the Fire Department of Chiba City to the NIRS

At about 14:40, the Ibaraki Prefecture helicopter arrived at the heliport of the Fire Department of Chiba City. Two out of the three patients showed symptoms such as diarrhea and vomiting. Dose measurements of the patients with a GM survey meter detected a maximum dose of 12 kcmp in one person (no alpha-rays were detected). Since one of the patients was in a bad state, it was decided to first transfer the patients to the NIRS by ambulance. At about 15:00, the members of the Division of Radiation Safety reported the dose measurements and the conditions of the patients to the Command Office for Radiation Emergency of the NIRS. The three patients, a member of JCO who accompanied the patients, a physician of the National Mito Hospital who was attending the patients and a member of the Division of Radiation Safety set off for the NIRS in two ambulance cars. One of the ambulances transported the most serious patient (Patient A), a physician (of the National Mito Hospital) and a member of the Division of Radiation Safety (who was wearing a film badge and working wear). The other ambulance car transported Patients B and C and a member of JCO. Six members of the Fire Department of Chiba City (two ambulance crew, 2 drivers and 2 assistants) rode separately in two cars.

Two members of the Division of Radiation Safety stayed at the heliport of the Fire Department of Chiba City to measure the radiation contamination of the helicopter and the operators of the disaster-prevention helicopter (to perform decontamination tasks should contamination be detected). Contamination was not detected inside the Ibaraki Prefecture helicopter. They also measured the radiation contamination of the helicopter operators and detected no contamination either.

During the transfer of the patients, a member of the Division of Radiation and Safety checked

the contamination of the patient with a GM survey meter in the ambulance. Approximately ten minutes after the ambulance car left the heliport, the patient vomited. The member kept the vomit in a plastic bag.

At about 15:25, the ambulances arrived at the entrance of the Medical Care Unit for Radiation Emergency of the NIRS. The patients were transferred into the hospital and were measured for radiation contamination. One of the patients showed high values (see Figure 1, which shows the measurements when the patients were accepted to the Medical Care Unit for Radiation Emergency. The maximum value was 26 kcpm at the chest of one patient. Alpha-rays were not detected). Radiation surveys were conducted on the physician who accompanied the patients, the six staff of the Fire Department of Chiba City (two ambulance crew, two drivers and two assistants) and the ambulance cars. The measurements did not detect contamination of the surface of these people and the vehicles. The results of the measurements of the ambulance staff were reported to the Fire Department of Chiba City in written form. The staff in charge of dosimetry started analyzing the nuclides in the clothing and belongings of the patients (working wear, underwear, portable phones, watches, coins, etc.), vomit, and excrement.

3-4. Receiving patients

Patients A and B were carried on stretchers. Patient C, who was less serious than the other two patients, walked into the hospital. For each patient, a two-man team (one person operating a survey meter and another in charge of taking records) measured the contamination of the surface of the patient in the corridor. The survey showed abnormally high values [Patient A: 13 kcpm at the head and 26 Kcpm at the chest, Patient B: 15 kcpm at the chest and Patient C: 6 kcpm at the head and 4 kcpm at the chest (including a background radiation of 100 cpm)]. The contamination of the body surfaces by alpha-rays was below that of the background level. The contamination of the blankets that were used during the transfer of the patients was low. Two out of the three patients showed dehydration, nausea and vomiting. One of the patients showed reduced blood pressure and was treated with emergency measures. The medical team asked for the names, addresses, symptoms, consciousness, fever, respiration, pulse, blood pressure and body weight of the patients and the circumstances of the accident. The team sampled blood specimens and nasal and angulus oris swab specimens and started intravenous drips. The patients' clothing was removed and they were put into test gowns. The clothing, watches, portable telephones, vomit, and applicators that were used to collect smear specimens were placed into separate plastic bags. The samples were marked with the date and names and were handed to each of the analyzers. Although high levels of radiation were detected from the chests of the patients immediately after they arrived at the hospital, the clothing measurement was only 3 kcpm (beta- and gamma-ray values), denying the possibility of external contamination but suggesting internal contamination of the patients. The medical team diagnosed that two patients needed first-aid and life-saving medical treatment and transferred the patients to sterile rooms on the fifth floor of the Hospital of Charged Particle Therapy. The time that was used to check the contamination of the body surfaces and to conduct the initial medical therapy was approximately 35 minutes.

4. Dose Estimation

4-1. Dose Estimation of Whole-Body Exposure from Prodromal Symptoms

Acute radiation syndrome has four stages by the symptoms that appear after radiation exposure. The stage immediately after exposure or within several hours of the exposure, when nausea, vomiting, and fever (prodromes) appear, is called the prodromal period. The IAEA Safety Reports Series No. 2 shows the relationship between the prodromes of acute radiation syndrome and gamma ray doses, which was determined by studying gamma ray victims in the past and analyzing their prodrome appearances and radiation doses. In the rest of this section, dose is expressed as the dose of gamma rays (GyEq). According to the standard, Patient A showed a body temperature of 38.5°C on the day of the accident, suggesting an exposure to at least 6 GyEq. Vomiting within ten minutes of the exposure, and diarrhea within one hour, led to a dose estimation of over 8 GyEq. Previous reports of accidents have shown that unconsciousness was likely to appear for an exposure to over 50 GyEq. Patient A lost consciousness for 10–20 seconds. Vomiting at about one hour

the contamination of the patient with a GM survey meter in the ambulance. Approximately ten minutes after the ambulance car left the heliport, the patient vomited. The member kept the vomit in a plastic bag.

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after the exposure and no diarrhea suggested that Patient B was exposed to 4 to 6 GyEq. Patient C did not show prodromes, except for slight nausea when he was in the helicopter transporting him to hospital, suggesting an exposure to up to 4 GyEq.

4-2. Dose estimation from the reduction curves of blood cells and lymphocytes

The "Effects And Risks of Ionizing Radiation" of ANNEX G, UNSCEAR 1988 Report describes a method for estimating doses using the reduction curves of lymphocytes, neutrophils, and platelets after the exposure to gamma rays of the 0 to 10 GyEq range. Lymphocytes are one of the most sensitive to radiation and show sharp drops in numbers, which are proportional to the dose of exposure. On the other hand, lymphocytes are known to decrease with the application of adrenocortical steroids during medical care or with excess stress. Neutrophils and platelets are ephemeral in the peripheral blood, and thus reflect the reduction of hematopoietic stem cells in the bone marrow.

It was possible to count the number of peripheral lymphocytes of Patient A on the day of the accident and up to the third day. However, we could not estimate the dose from the graph of his lymphocyte number, and therefore estimated the value by using an estimation equation. The dose estimated was over 10 GyEq (16–23 GyEq). Neutrophils showed a transient rise after the exposure, then a linear drop in a log-log plot, and reached 0 on the seventh day after the accident. Platelets also showed a linear log-log drop after the exposure, and the patient needed platelet transfusion from the seventh day.

The reduction curves of neutrophils and platelets are equal to an estimation of over 10 GyEq, which is a dose that kills most of the

Table 4–1 Stages of acute radiation syndrome

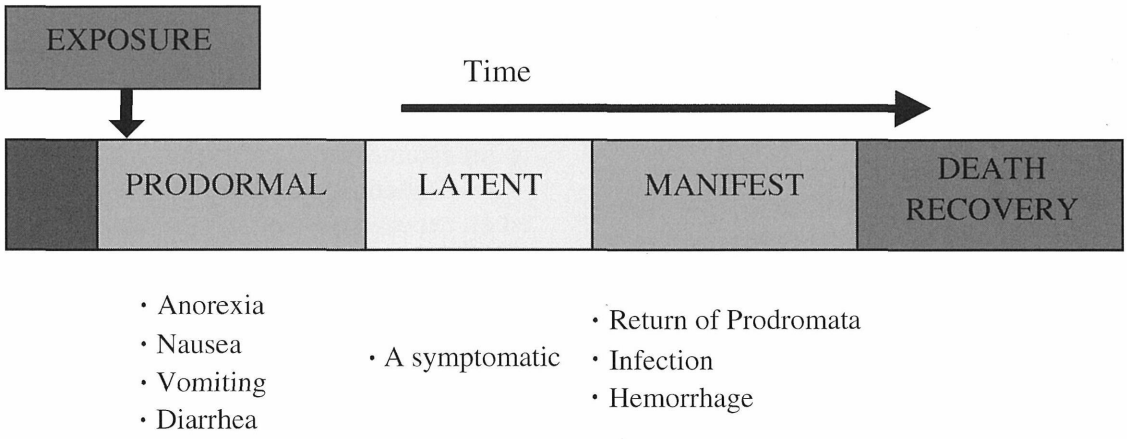


Table 4–2 Latent phase of acute radiation symptom

Dose	1–2 GyEq	2–4 GyEq	4–6 GyEq	6–8 GyEq	>8 GyEq
Latent period (days)	21–35	18–28	8–18	7 or less	0
Principal symptoms	Fatigue Weakness	Fever Infection Bleeding Epilation Fatigue	High fever Infection Bleeding Epilation	High fever Diarrhea Vertigo	High fever Diarrhea Epilation Consciousness dysturbance
Lethality(%)*	0	0–50	20–70	50–100	100

Cited from the IAEA Safety Reports Series No. 2: Diagnosis and Treatment of Radiation Injuries 1998, and modified

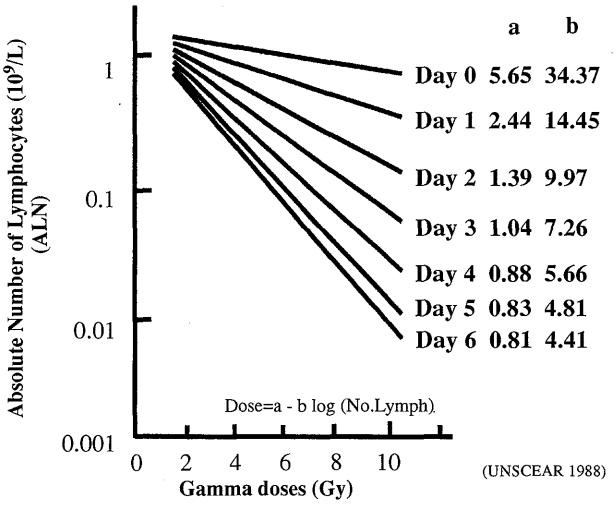
*The percentages are approximate values when no treatment is conducted. Mortality varies depending on the conditions of exposure or treatments.

Table 4-3 Prodromal Phase of Acute Radiation Syndrome

Doses	1-2 GyEq	2-4 GyEq	4-6 GyEq	6-8 GyEq	>8 GyEq
Vomiting (Onset) (%)	2 h or >2 h after exposure 10-50	1-2 h after exposure 70-90	<1 h after exposure 100	<30 min after exposure 100	<10 min after exposure 100
Diarrhea (Onset) (%)	— —	— —	Moderate 3-8 h <10	Severe 1-3 h >10	Severe <1 h 100
Headache (Onset) (%)	Slight ——	Mild ——	Moderate 4-24 h 50	Severe 3-4 h 80	Severe 1-2 h 80-90
Consciousness (%)	Unaffected —	Unaffected —	Unaffected —	May be altered —	Unconsciousness may be (min/sec) 100 (>20 GyEq)
Body temperature (Onset) (%)	Normal ——	Increased 1-3 h 10-80	Fever 1-2 h 80-100	High fever <1 h 100	High fever <1 h 100

Cited from the IAEA Safety Reports Series No. 2: Diagnosis and Treatment of Radiation Injuries 1998, and modified. The doses are mainly gamma ray doses at the time of exposure.

Dose Estimation by Number of Lymphocytes



hematopoietic stem cells.

It was possible to count the number of lymphocytes of Patient B up to the eighth day. The numbers of lymphocytes counted on the first to third days suggested an exposure to over 10 GyEq, but the lymphocyte counted on the fourth to seventh days indicated an estimated exposure to 6-8 GyEq. Platelets showed a linear drop after the fifth day, and the inclination led to an estimation of 6 GyEq.

For Patient C, the lymphocyte count suggested an exposed dose of approximately 1-5 GyEq. Since there was a certain distance between Patient C and the criticality source, Patient C was likely exposed uniformly to radiation. During his stay in hospital, epilation was observed at the head. The numbers of leukocytes and platelets reached a nadir three weeks after the accident, and transfusions of platelets were necessary. This clinical course suggests an exposure to about 3 GyEq.

References
1) IAEA/WHO Safety Series No. 2, Diagnosis and Treatment of Radiation Injuries (1998).
2) UNSCEAR Sources, Effects And Risks of Ionizing Radiation-UNSCEAR 1998 Report.
3) Baranov AE, Guskova AK, Nadejina NM, Nugis Vyu. Chernobyl experience: biological indicators of exposure to ionizing radiation. Stem Cells 13 (suppl 1); 69-77, 1995.

4-3. Physical Methods for Dose Estimation

(1) Analysis of activated biological materials

Three JCO workers were exposed to high radiation of neutrons that were released during the criticality accident. It is possible to estimate the radiation doses by determining the nuclides that were produced during the exposure of neutrons. For this purpose it is necessary to measure the concentrations of radionuclides and related stable elements that were contained in biological samples, such as the blood, urine, and hair. Especially, sodium should be useful to estimate the doses since the production of high ^{24}Na by thermal neutron in blood is expected to be very high due to its high ^{23}Na (stable Na) concentration. This evaluation method that uses ^{24}Na was applied for the criticality accident that occurred in Soarov, Russia, in 1997 (IAEA, 2001[1],). In addition to ^{24}Na, ^{42}K, ^{82}Br, and ^{32}P were also detected, and their measurements are also described in this section. In particular, ^{32}P is useful for evaluating fast neutrons, since ^{32}P was also produced by the reaction of $^{32}S(n, p)\ ^{32}S$.

To determine the production of radionuclides, it was necessary to obtain precise data concerning the concentrations of target stable elements. The results were then used to derive the specific activity (the ratio of the concentrations of radionuclides to the concentrations of stable elements) and to obtain information concerning the doses of neutrons. Therefore, we not only measured the radionuclides but also conducted precise analyses of stable sodium, potassium, phosphorus, and bromine.

①Analysis of activation products (^{24}Na, etc.) and stable elements in blood

(a) Gamma-ray spectrometry (determination of ^{24}Na, etc.)

During the criticality accident, the stable elements that were contained in the bodies of the JCO workers were activated and converted into radionuclides due to the high neutron doses they received. The irradiation of neutrons was likely to especially produce ^{24}Na (half life: 14.96 hours) by the reaction of $^{23}Na(n, \gamma)^{24}Na$. The amount of ^{24}Na produced should be large compared to the other activation products since the sodium is abundant in the body and has a relatively large cross section of 0.53 barn for thermal neutron. Therefore, analysis of ^{24}Na in the blood should be highly effective for estimating the total dose that the body received. In this section, some details on the gamma spectrometry mainly for ^{24}Na in the blood samples obtained from the three workers are described.

Methods

Blood samples used for gamma ray spectrometry were collected on September 30, when the three JCO workers were transferred to the National Institute of Radiological Sciences, and on the next day (October 1). The samples collected from the workers were transferred from syringes to containers for measurement (styrene U8 cylindrical containers of 45 mm in inner diameter), and small amounts of heparin were added to prevent blood coagulation. The gamma rays were measured using three germanium semiconductor detectors. The amount of the blood sample collected on October 1 was 20 ml for each person. On September 30, blood samples were collected immediately after the workers arrived at the National Institute of Radiological Sciences and were used for various medical tests. Therefore, the blood samples that remained in the syringes were also used for gamma-ray spectrometry, which were 6.4 ml, 11.9 ml, and 7.6 ml for Patients A, B, and C, respectively. These samples showed partial coagulation since almost 20 hours has passed after sampling, and were dissolved by adding 2 ml of Solvable (Packard Bioscience).

Results: estimation of ^{24}Na activity concentration during the criticality accident

The blood samples obtained on September 30 were small in quantity and not uniform. Therefore, the sample collected on October 1 were mainly used for the dose assessment. A comparison of ^{24}Na values estimated from the samples of September 30 and of October 1 showed that the samples of September 30 was about 5% smaller for Patient A, about 20% larger for Patient B, and about 12% larger for Patient C. These results suggest that there was a tendency that the ^{24}Na concentrations in blood decreased after one day, although the rate was not so large. The ^{24}Na values determined by the three Ge detectors were very consistent. The measurements showed the following mean ^{24}Na activity concentrations for the times that the blood was sampled.

Table 4-4

Patient A	(Blood sampled at 12:27 on October 1)	47.3 ± 1.4 Bq/ml
Patient B	(Blood sampled at 13:38 on October 1)	24.2 ± 0.5 Bq/ml
Patient C	(Blood sampled at 14:25 on October 1)	5.82 ± 0.28 Bq/ml

These results were used to estimate the concentrations of ^{24}Na during the criticality accident (10:35 on September 30), which are shown in the following table. The physical half-life of 14.596 hours[2], and the biological half-life of 10 days, which is used by the ICRP Publ. 30[3], were used in the estimation.

Table 4-5

Patient A	169 ± 5 Bq/ml
Patient B	91.6 ± 1.7 Bq/ml
Patient C	22.9 ± 1.1 Bq/ml

(b) Measurement of stable elements (Na, P, K, Br)

To estimate the doses using the ^{24}Na that was produced by neutron, the specific activity should be determined by quantifying the stable sodium (^{23}Na), which is contained in the blood. Therefore, we totally decomposed the blood samples with acid, and analyzed the stable sodium using the inductively coupled plasma atomic emission spectrometry (ICP-AES). We also analyzed stable potassium (^{39}K), stable phosphorus (^{31}P) and stable bromines (^{79}Br and ^{81}Br), which were likely effective to estimate the neutron doses. The samples that were used for the analyses were the specimens collected on September 30 and October 1 from the three patients. Since Solvable was added to the specimens of September 30 after sampling, we also analyzed Solvable and investigated the effects on the concentrations of the elements.

Methods

We placed 100 μl of the blood sample from each specimen into a Teflon container for decomposition treatment using micropipettes. Since the blood samples on September 30 were coagulating, we conducted sampling by weighing approximately 100 mg. We added 2 ml of 68 % nitric acid, tightly sealed the container, and heated and decomposed the sample for 1 hour in a microwave oven. After the decomposition process, we heated the sample on a hot plate installed within a clean draft, and dried the samples, which we then dissolved in 1 ml of 68% nitric acid and dried once again. The pellets were transferred to 20 ml polyethylene tubes using 0.5 ml of 27% nitric acid. The specimens were adjusted to 20 ml by measuring the weight, and were used as the stock solution for the analysis (nitric acid concentration: 0.68%, the ratio of dilution to the original blood: 200 times). The samples solutions were further diluted to 2,000 or 10,000 of the original blood, and were used for the analysis (nitric acid concentration: 0.68%). To correct the fluctuation in sensitivity during measurement, yttrium was added as the internal standard to all of the sample solutions and the standard solution (the yttrium concentration: 2 μg/ml). The measurements were conducted using ICP-AES (Seiko, SPS-7700). The wavelengths (nm) and cumulative counting time used for the analysis are listed in table 4-6.

Table 4-6

	Wavelength (nm)	Cumulative time (seconds)
Na	588.995	3
K	766.490	8
P	214.914	10

The analytical curves were drawn by using the multi-element standard solution (SPEX-XSTC-21), which was diluted to 0.1, 0.3, 1.0, 3.0, 10, and 30 μg/ml. We sampled 100 μl of Solvable, which was decomposed and analyzed by the same method used for blood samples. Each sample was decomposed and analyzed two times (three times for some samples) to investigate the deviation of our measurements. Sodium is a very common element in the environment and may enter from the periphery during a series of the decomposition and analysis processes. Therefore, the operation was conducted within a clean room, and a clean draft was used during the decomposition and dilution operations. Highly pure nitric acid (TAMAPURE, AA-100) was used. Pure water was prepared using Milli-

Q SP TOC. The containers for the samples were washed with nitric acid and pure water in advance.

Bromine was analyzed by weighing 50 to 100 μl of the samples in a ceramic boat, adding powder of vanadium pentoxide as the oxidant and solvent, transferring the samples in quartz combustion tubes (inner diameter: 22 mm, length: 50 cm), and heating the samples at 1,000°C with a flow of oxygen gas. The evaporating bromine was trapped with a diluted solution of TMAH (tetramethyl ammonium hydroxide). The solution was further diluted and was used for the measurement with an ICP-MS (inductively coupled plasma emission mass spectrometry). (See Schnetger & Muramatsu: Analyst. 121, 16227-1631, 1996, for the method in detail.)

Results

The sodium concentration in the blood samples obtained on October 1 was 2,050 μg/ml for Patient A, 2,110 μg/ml for Patient B, and 1,860 μg/ml for Patient C. According to ICRP 23, the concentration of stable sodium in the blood for reference man is 10.57 g/5,200 ml = 2,030 μg/ml (Table 108 of ICRP[23]). Our analytical values were very similar to this value. The sodium concentrations in the blood samples collected on September 30 were high, and it is clearly necessary to consider the sodium of Solvable, which was added to the blood specimens after sampling.

The concentrations of potassium and phosphorus in Solvable are both low, and their effects are negligible. There was almost no difference in the concentrations of potassium and phosphorus among the individuals. Their concentrations of potassium in the blood samples of October 1 were 1,390–1,500 μg/ml, and the concentrations of phosphorus were 320–360 μg/ml. These values almost agree with the values of the reference man subject shown in the same table.

(c) Measurement of ^{32}P in the blood

We measured the ^{32}P in the blood using a low-background beta-ray spectrometer.

Preparation of samples

We transferred 20 ml of the blood samples that was used for the ^{24}Na analysis to a plastic container (50 mm in diameter and 60 mm in height), and converted it to freeze-dried powder. The freeze-dried blood sample was transferred on a counting dish (25 mm in diameter and 6 mm deep) so that the thickness was uniform, covered the dish with a piece of thin paper, and used the sample for beta-ray analysis.

Calibration curve

A standard ^{32}P solution was prepared from the ^{32}P standard nucleic acid solution that was purchased on August 24, 1999. On October 25, 2 μl of the solution was sampled and was diluted with 500 ml of diluted water for injection. We further diluted 25 ml of this solution with distilled water for injection and made 100 ml of the substandard ^{32}P solution. The radioactivity of this solution was determined using the new standard solution that was prepared by the Japan Isotope Association, and was 35.4 Bq/ml as for of October 26, 1999. We sampled 100, 200, and 500 μl of the ^{32}P standard solution and used to soak Millipore filter paper in sample dishes, which were then dried and fixed with acetone. These samples were used to draw a calibration curve for determining the efficiency of measurements. In the ^{32}P energy range of 1620 keV to 40 keV, the measurement efficiency was 26.1%.

Decay correction

The ^{32}P measurements were corrected for the attenuation (physical half life: 14.26 days) during the period after exposure (10:35 on September 30).

Results

The results of our measurements of the blood are listed in table 4–7.

②Analysis of activation products and stable elements in urine and vomit

Table 4–7 ^{32}P within in the blood on September 30 (Bq/ml)

Sample obtained	Amount of sample (ml)	Patient A	Patient B	Patient C
October 1, 1999	20	2.36	2.35	1.59

(a) Gamma-ray spectrometry

The urine samples used were the urine of Patient B collected on September 30 (during the period from the arrival at National Institute of Radiological Sciences till the evening) and the urine samples of the three patients collected during the period between the evening of September 30 and the morning (6:00 a.m.) of October 1 (parts were sampled from the daily urine samples). The vomit samples were those of Patients A and B that were collected after they were transferred to the National Institute of Radiological Sciences (or during the transfer to the institute). The radionuclides and stable elements contained in these vomit samples were analyzed. The specimens were one sample of Patient A and two samples of Patient B. Since both Patients A and B had vomited several times before the specimens were obtained, the samples contained no solids and were semi-transparent liquid-like gastric juice.

Methods

The urine specimens were obtained by sampling 100 ml from the total urine samples of the day, and were transferred in containers for measurement. A vomit sample of Patient B was kept in a plastic bag and was in a liquid form, but the other two specimens were soaked in paper towels. Therefore, these specimens were washed out from the paper towels with water. The entire specimen and the total fluid extracted from the paper towels (13–60 ml) were collected in containers for measurement. The nuclides were determined using germanium semiconductor detectors by the method used for the blood samples.

Results

The nuclides ^{24}Na, ^{82}Br, and ^{42}K were detected in the urine samples of all the patients. The samples of October 1 showed that the ^{24}Na value (corrected for the time of the accident) was the highest in Patient B with 178 Bq/ml followed by Patient A with 121 Bq/ml. The value of Patient C was the lowest with 40 Bq/ml. These values show a tendency different from the personal differences revealed by the blood tests. The data of stable elements, which are described in later paragraphs, show that the stable sodium concentration in the urine of Patient A was one half less than those of Patients B and C. This is likely the reason for the low ^{24}Na value in the urine of Patient A. The ^{42}K and ^{82}Br values were higher in Patient A than Patient B, showing a similar tendency with the personal difference in ^{24}Na concentration in the blood. The ratio of ^{24}Na to stable sodium in the urine (specific activity) was similar to the specific activity in the blood for all patients. (Specific activity measurements are described in later paragraphs.)

The components of the urine were likely affected by fluid injection, and the biological metabolisms of the patients may have been altered due to the radiation exposure. Therefore, the analytical results of urine might cause larger errors than blood when they are used to estimate radiation doses.

Our measurements of gamma ray nuclides in the vomit samples showed that the liquid vomit samples of Patient B contained higher concentrations of ^{24}Na and ^{82}Br than the other samples. This is attributable to the dilution process used for the other samples to wash out the remains from the paper towels. For both Patients A and B, the ratio of ^{24}Na to stable sodium (specific activity) in the vomit samples was similar with or slightly higher than their blood and urine samples.

(b) Measurement of stable elements (Na, P, K, and Br)

To estimate the doses using the nuclides that were activated by neutron irradiation, related stable elements should be quantified. Therefore, we totally decomposed parts of the urine and vomit samples with acid, and analyzed stable sodium, potassium, phosphorus, and bromine. The urine and vomit samples used for the analysis of stable elements were the same samples used for the measurement of gamma-ray nuclides.

Methods

We took 1 ml of urine or vomit sample into a Teflon container for decomposition treatment using a micropipette. We added 2 ml of 68% nitric acid, and heated and decomposed the sample for 1 hour in a microwave oven. The succeeding methods for preparing sample solutions were the same as the aforementioned methods for blood samples. Measurements were conducted using ICP-AES (Seiko, SPS-7700). The wavelengths (nm), cumulative time, the number of repetitions, and the preparation of standard solutions were fundamentally the same with those used for the analysis of blood samples.

As in blood samples, bromine was first heated

and separated within a quartz tube and then measured with ICP-MS.

Results

The sodium concentration in the urine sample of Patient B obtained on September 30 was 3,120 μg/ml. The sodium concentrations in the urine samples of October 1 were 1,390 μg/ml, 3,590 μg/ml, and 2,940 μg/ml for Patients A, B, and C, respectively. These values are smaller than the value of the ICRP 23 reference man subject (4,310 μg/ml), especially the value for Patient A is about one 1/3 of that. These small sodium values in the urine samples were likelyy attributable to the large amounts of intravenous drip injection administered for curative purposes. The potassium concentrations were 900 to 1,120 μg/ml, and the phosphorus concentrations were 17 to 334 μg/ml, both of which were lower than the values of the reference man subject.

Our analysis of the stable elements in the liquid vomit sample of Patient B showed that the sodium concentration was slightly lower than that in his blood sample. On the other hand, the ^{24}Na concentration was slightly higher than in the blood. Both potassium and phosphorus amounts were very small and were under the detection limit of this analytical method.

(c) Measurement of ^{32}P in urine

Introduction

The urine was collected every day from the three JOC workers during their stay in the National Institute of Radiological Sciences, University of Tokyo Hospital, and Institute of Medical Science, and was subjected for radioactivity measurements, which detected ^{32}P. The ^{32}P was likely a result of the activation of phosphorus within their bodies. There is no established method for estimating neutron doses from ^{32}P activity that appeared in the urine. Since this will possibly be an effective method for estimating doses, we measured ^{32}P that appeared in the urine samples.

(i) Measurement of ^{32}P using a low background beta-ray spectrometer

Preparation of samples

We weighed and sampled 50 ml of urine into a plastic container (50 mm in diameter and 60 mm in height), and freeze-dried the sample. Parts of the freeze-dried urine sample were transferred on a counting dish (25 mm in diameter and 6 mm deep) so that the thickness was uniform, covered with a piece of thin paper, and applied for a low background beta-ray spectrrmeter measurements.

Results

The measurements of radioactivity in the urine samples are listed in table 4-8.

Table 4-8 Estimated ^{32}P in the urine for the time of the accident (Bq/ml)

Date of urine sampled	Patient A	Patient B	Patient C
01-Oct-99	20.17	12.16	3.39
02-Oct-99	6.90	2.37	0.71
03-Oct-99		1.02	0.38
04-Oct-99		0.43	
06-Oct-99	0.86		
07-Oct-99	0.89	0.33	
08-Oct-99	0.76	0.44	
09-Oct-99	1.26	0.40	
10-Oct-99	0.81	0.43	
11-Oct-99	0.65	0.28	
12-Oct-99	0.62	0.22	

(ii) Determination of ^{32}P using a liquid scintillation counter

Preparation of samples

Urine samples were prepared by adding 1 ml of distilled water to the freeze-dried urine specimens (200–2,000 mg), and adding tissue solubilizer SOLUENE-350 (1–2 ml) and hydrogen peroxide (0.4–0.8 ml). The samples were then heated for 30 minutes in a water bath at 55°C to remove the remaining hydrogen peroxide. Scintillator (HIONIC-FLUOR, Packard) was added, and the samples were used for liquid scintillation counting.

Counting conditions

Counting was conducted using two channels, which were Channel A (5 keV–1700 keV) and Channel B (50 keV–1700 keV). The measurements of the Channel B were used to eliminate

the radioactivity of nuclides other than ^{32}P. We are tracing the activity of ^{32}P continuously to check and identify nuclides. Since our values are slightly larger than the values determined with the low background beta-ray spectrometer.

③Topics concerning ^{32}P measurements

(a) We measured ^{32}P in the blood, hair, and urine samples, but there is a possibility that we also measured the radioactive nuclides other than ^{32}P. Therefore, we are continuing the analyses and are tracing the half-life to identify the nuclides.

(b) The values determined by the liquid scintillation counter were larger than the values by a low background beta-ray spectrometer, and it was possible that low-energy beta rays were also measured. Therefore, we are continuing the analysis including the investigation of the half-life.

(c) We are investigating a method for estimating radiation doses from ^{32}P contents in the urine by using an ICRP biokinetic model and systems such as Environmental Radionuclides Movement Analysis System (ERMA).

④Specific activity

The amount of activation products that are produced by the irradiation of neutrons is estimated by the amount of the target stable elements and the neutron fluence. Specific activities were determined from the radioactivity of activated biological samples and the analytical data of stable elements, which were described above. In the other words, the specific activity (A/m) was defined by dividing the activity concentration (A) by the concentration of stable elements (m). The results are summarized in the following table. By using the specific activity data, it is possible to directly compare the results of different samples (for example, blood and urine samples).

The specific activity data of ^{24}Na in the blood was used to compare the amounts of neutrons that the three patients received. If Patient A received 1.0, Patient B received 0.52, and Patient C received 0.15. A comparison using the specific activity in the urine samples showed similar ratios of 0.57 for Patient B and 0.16 for Patient C. However, the values of the specific

Table 4-9 Specific activity (Bq/g) of the samples obtained from the three patients
(The values were determined by the analytical values of activity and stable elements. Radioactivity concentrations were corrected for the time of accident using half-life.)

	Specimen (date of sampling)	Bq^{24}Na/gNa*	Bq^{82}Br/gBr	Bq^{42}K/gK
Patient A	Blood (Oct. 1)	8.24E+04	5.9E+04	1.6E+04
	Urine (Sep. 30-Oct. 1)	9.01E+04	5.2E+04	1.4E+04
	Vomit/gastric juice (Sep. 30)	9.24E+04	5.1E+04	
	Hair (Oct. 1)	6.36E+04		
Patient B	Blood (Oct. 1)	4.34E+04	3.0E+04	7.4E+03
	Urine (Sep. 30)	5.40E+04	2.4E+04	7.0E+03
	Urine (Sep. 30-Oct. 1)	5.15E+04	2.7E+04	7.7E+03
	Vomit/gastric juice (Sep. 30)	5.76E+04	2.4E+04	
	Hair (Oct. 1)	3.69E+04	1.5E+04	
Patient C	Blood (Oct. 1)	1.23E+04		
	Urine (Sep. 30-Oct. 1)	1.41E+04	6.5E+03	2.3E+03

*The ^{24}Na values were corrected for the biological half-life (10 days).

activity itself slightly decreased in the order of vomit (gastric juice), urine, and blood, and the values for the hair samples were significantly low (when the samples of a same patient were compared). The specific activities of the blood samples were lower than those in the urine samples. This might be due to the effect of the dilution by stable sodium that was contained in the fluid intravenously given to the patients appeared more clearly in the blood samples than in urine or vomit samples. The especially low values of the hair samples were likely related to their large distances from the neutron source (uranium solution). Two urine samples were measured for Patient B, and the sample obtained on the day of the accident (until the evening of Sep. 30) was higher in specific activity than the sample obtained on the night of October 1 (Sep. 30-Oct. 1). The specific activity dropped likely because ^{24}Na was gradually excreted and stable sodium was added through fluid injection and oral injection.

For ^{82}Br, if the specific activity in blood of Patient A was put as 1.0, that of Patient B was 0.51 (^{82}Br in the blood of Patient C was below the detection limit). The value in urine of Patient B was 0.49 and that of Patient C was 0.13. These ratios were similar to those obtained from ^{24}Na. A comparison of specific activity values determined with the blood, urine, and vomit samples of the three patients shows high values in the order of blood, vomit (gastric juice), and urine. The specific activity of ^{24}Na was low in the blood samples, but the specific activity of ^{82}Br in the blood was similar with or slightly larger than the values of the other samples. This was likely attributable to the small amount of stable bromine in the fluid intravenously given, which caused little dilution effect on the specific activity. The urine samples obtained on the day of the accident (Sep. 30) showed slightly larger specific activity values than the samples obtained on the next day (Sep. 30-Oct. 1). The specific activity of urine dropped because ^{24}Na was gradually excreted and stable sodium was added through instillation intravenous drip and oral ingestion. The specific activity of ^{82}Br in the hair was determined only for Patient B, which was apparently smaller than the specific activity values in the other samples, such as the blood.

Since ^{42}K has a very short half-life of only approximately 12 hours, it was detected only in limited samples. When the specific activity of Patient A was put as 1.0, the value was 0.48 in the blood of Patient B (below the detection limit for the blood of Patient C), 0.50 in the urine of Patient B, and 0.16 in the urine of Patient C. These ratios are similar to those shown by ^{24}Na and ^{82}Br. The specific activity values in the blood and urine samples that were obtained on the same day were similar or slightly higher in the blood samples. As in bromine, the concentration of stable potassium in the fluid intravenously given was likely low and did not reduce the specific activity.

We attempted to estimate the neutron flux using these values. When the number of target atoms was assumed to be N, the activity produced is expressed with the following equation:

$$A = N\Phi\sigma\lambda$$

where, A is the activity of activated nuclides (Bq),

Φ is the neutron fluence (cm^{-2}),
σ is the cross section of nuclear reaction (barn: 1×10^{-24} cm^2), and
λ is the decay constant of the activated nuclide.

By substituting the analytical data of activities and stable elements, it is possible to estimate the neutron fluence (Φ). In this calculation, it is assumed that the target is located only at one point and the value for thermal neutrons is used for the cross section of nuclear reaction (0.534 barn for ^{23}Na). The neutron fluence estimated from the blood of Patient A is as follows.

Calculation using the data of ^{24}Na and ^{23}Na: $\Phi = 4.61\times10^{11}$ (cm^{-2})

The values estimated from the data of bromine and potassium in the blood of Patient A are shown below for comparison:

Calculation using the data of ^{82}Br and ^{81}Br: $\Phi = 1.0\times10^{12}$ (cm^{-2})

Calculation using the data of ^{42}K and ^{41}K: $\Phi = 6.6\times10^{11}$ (cm^{-2})

These values differ from the value estimated using sodium since the activation of bromine and potassium involve high degrees of resonance absorption (the degree is especially high for bromine) due to epithermal neutrons, and the results of calculations greatly deviated from the result determined using only thermal neutrons. On the other hand, dose estimation using ^{24}Na is a little affected by resonance absorption and shows less uncertainty due to this effect. We as-

sumed that target elements were located at one point, but in practice, sodium was distributed throughout the body, and the effects of neutrons in the body need to be evaluated. Detailed dose estimations considering these effects (e.g. body volume, neutron spectrum, etc.) are described in the following section.

References
1) IAEA: The Criticality Accident in Sarov, International Atomic Energy Agency, Vienna, STI/PUB/1106, ISBN92-0-100101-0 (2001).
2) Richard B. Firestone eds. Table of isotopes eighth edition (1995).
3) ICRP, ICRP Publication 30 Part 2, Ann. ICRP, 43/4, Pergamon Press, Oxford (1981).

(2) Estimation of doses based on ^{24}Na measurements in the blood

①Introduction

This section describes our theoretical estimation of doses that the three patients received based on the measurements of ^{24}Na concentration in the blood.

The method for estimating neutron doses is fundamentally the same with the method described in the report of the Oak Ridge National Laboratory[1]. We used the latest data for various parameters that were needed for the estimation, such as neutron energy spectrum, fraction of neutrons captured by a human body, and the conversion coefficient of absorbed dose per unit fluence (flux density) for each tissue.

②Estimation of average whole-body dose by neutrons

(a) Irradiation geometry

We assumed that neutrons uniformly entered from the front of a standing person.

The contents of the works suggest that the workers were likely irradiated from the front. However, Patient B was pouring uranium solution and was not standing straight. There is a possibility that Patient A was irradiated from the right front. However, it is yet technically difficult to conduct analysis assuming complicated postures, and analyses were conducted based on the aforementioned assumption. We are developing analytical methods that reproduce actual postures with more fidelity in cooperation with the Japan Atomic Energy Research Institute and the progress is described in Section 4-4.

(b) Energy spectrum of neutrons

The data calculated by ANISN code, which were provided by the Japan Nuclear Cycle Development Institute, were used as the energy spectra of neutrons.

According to these data, the energy spectrum slightly varies depending on the distance from the solution. However, it was not significant to use different spectra for each patient, because it was impossible to accurately identify the positions of the three patients during exposure, and because the distance of a person to the solution varied by the body parts. Furthermore, the data by ANISN is one-dimensional and cannot express the direction dependency of the spectra. This analysis used the spectrum at 60 cm from the center of the criticality solution, where Patient A was likely to be irradiated, for the three patients as the common spectrum. The mean energy of the energy spectrum used for calculation was 1.0 MeV.

(c) Dose of monochromatic neutrons absorbed by each tissue

The absorbed dose per unit fluence Di (E)(pGy·cm^2) of each tissue i to monochromatic neutrons was obtained from the ICRP Publication 74[2]. The data are the summary of the latest simulation analyses using mathematical phantoms such as MIRD phantom, and is the most reliable among the acquirable conversion coefficients.

(d) Absorbed dose of each issue averaged by spectrum

The absorbed dose per unit fluence Di (E)(pGy·cm^2) of tissue i against the aforementioned energy spectrum φ(E) was determined with the following equation:

$$Di\frac{\int Di(E)\cdot\varphi(E)dE}{\int\varphi(E)dE} \qquad (4\text{-}1)$$

The conversion coefficient of the whole body dose was derived by calculating the weighted mean of the conversion coefficients with the weights of the tissues.

The conversion coefficients that we derived for the principal tissues and the whole body are as follows:

Bone marrow	6.96 (pGy·cm^2)
Colon	9.42 (pGy·cm^2)
Lung	9.97 (pGy·cm^2)

Whole body 9.57 (pGy·cm^2)

(e) Estimation of neutron fluence using the measurements of ^{24}Na in the blood

The activity α of ^{24}Na that is generated per unit weight of stable sodium is approximately expressed with the following equation:

$$\alpha = \lambda/(V\rho) \times (S\Phi) \times (\Sigma Na/\Sigma T) \times \xi \quad (4\text{-}2)$$

where α: activity of ^{24}Na that is produced per 1 gram of ^{23}Na (Bq^{24}Na/g^{23}Na), the specific activity,

λ: disintegration constant (1.28 E-5 s^{-1}),

V: volume of the body, here the value of BOMAB phantom[3]) was used (68280 cm^3),

ρ: Na concentration in the body (g/cm^3),

S: projected area of the body, here the value of the front vertical projection (5690 cm^2) of the BOMAB phantom[3]) was used,

Φ: fluence of irradiated neutrons (cm^{-2}),

ΣT: macroscopic absorption cross section of the human body against thermal neutrons (0.02339 cm^{-1})[4]),

ΣNa: macroscopic capture cross section of ^{24}Na against thermal neutrons, here 0.534 b[5]) was used as a microscopic cross section, and

ξ: mean neutron capture probability, here the value that was calculated by Cross et al. for the BOMAB phantom[3]) filled with diluted salt water was used, and the difference in hydrogen content between water and human tissue was corrected[6]).

The fluence of neutrons incident on the body was calculated from specific activity α (Bq^{24}Na/g^{23}Na) using the following equation:

$$\Phi = 6.9 \times 10^6 \times \alpha \ (cm^{-2}) \quad (4\text{-}3)$$

(f) Conversion coefficients of neutron dose against the specific activity of ^{24}Na

The conversion coefficient for the whole body dose against the specific activity of ^{24}Na was determined by multiplying the conversion coefficient per unit fluence with the neutron fluence calculated by the Equation (4-3).

The whole-body dose Dn was determined using the specific activity α by the following equation:

$$Dn = 6.6 \times 10^{-5} \times \alpha \ (Gy) \quad (4\text{-}4)$$

We compared the conversion coefficient that we determined with the values shown in various references.

For the criticality accident in Sarov, the whole-body neutron dose was estimated form the ^{24}Na concentration in the blood. The conversion coefficient of neutron dose in the table was calculated from the dose and the sodium concentration in the blood of ICRP reference man[9]). The conversion coefficient in Sarov was approximately 1.5 times larger than our coefficient. This difference is probably caused by the difference in neutron spectrum, which is attributable to the difference in the materials and structures of critical assembly.

The ORNL report states the conversion coefficients of neutron dose for critical assemblies of various materials and structures[7]). The value in the table is the average coefficient for the spherical solutions whose radii are 10 cm and 30 cm. The doses in the ORNL report are not the mean values but the maximum values, and the coefficient is much larger than the value derived in this study.

The conversion coefficient by Maruyama is approximately three times larger than our value. This is attributable to the differences in spectrum and various parameters used. The biggest reason is that Maryuyama used not the mean whole-body dose but the first collision dose.

On October 28 and 29, 1999, the National Institute of Radiological Sciences invited nine

Table 4–10 Comparison of neutron dose conversion coefficients in various references

Reference	Sarov*	ORNL[7])	Maruyama[8])	IPSN**	This study
Gy/(Bq/g)	1.02E-4	1.45E-4	2.09E-4	6.8E-5	6.6E-5

*cited from the IAEA, The criticality accident in Sarov, draft report.
** Verbally reported

specialists of medical management and dose estimation from abroad. A participant from the France IPSN (Institute for Protection and Nuclear Safety) verbally presented the value in the table as the conversion coefficient of neutron dose. The value is very similar to the value we estimated.

(g) Measurement of ^{24}Na and stable sodium concentrations in the blood

Blood specimens of 20 cm^3 were collected from the three patients on the next day of the accident. The ^{24}Na and sodium concentrations in the blood specimens were measured.

The measurements of ^{24}Na were done by using Ge semiconductor detectors, and cross-checking by three groups was conducted. The measurements of stable sodium were performed by using ICP-AES. The details of these measurements are described in Section (1) of Chapter 4-2 of this report.

The activity of ^{24}Na during the accident was determined by using a physical half life of 14.96 hours and a biological half life of 10 days[10]. Since Patients A and B suffered diarrhea immediately after the accident and received transfusion before the blood specimens were sampled, the excretion of ^{24}Na was probably accelerated. Therefore, this dose estimation method may cause underestimation.

According to the ^{24}Na whole-body retention against various biological half lives that were estimated using the ICRP model[10], when the biological half life is half of the ICRP model, or is 5 days, the estimated ^{24}Na activated during the accident increases by about 8%.

(h) Estimation of the average whole-body neutron dose

The neutron doses that were estimated using the methods described above are shown in table 4–11.

Table 4–11 Estimated neutron doses

Patient	Specific activity (during the accident)	Mean whole-body absorbed dose
A	8.24E4 Bq/g	5.4 Gy
B	4.33E4 Bq/g	2.9 Gy
C	1.23E4 Bq/g	0.81 Gy

③Estimation of the average whole-body gamma-ray dose

(a) Introduction

To estimate the gamma-ray dose near the precipitation tank, the criticality should be precisely analyzed using models that accurately reproduce the criticality sedimentation tank that caused the accident. The National Institute of Radiological Sciences is conducting more precise analyses in cooperation with the Japan Atomic Energy Research Institute. We have tentatively estimated the following gamma-ray doses based on 1) the neutron dose estimations, which were described in the previous section, 2) the data of environmental monitoring around the JCO site, and 3) the IAEA manual.

(b) Ratio of neutrons to gamma-rays of ambient dose

According to the environmental monitoring near the JCO site at 20:45 on September 30, the neutron: gamma-ray ratio of ambient dose (hereafter referred to as H10 was about 9:1 (Attached Reference 1 of the Report of the Investigation Committee on the Criticality Accident of the Uranium Processing Plant, Science and Technology Agency, December 22, 1999). This ratio was used to estimate the gamma-ray doses of the three exposed patients.

(c) Conversion of H10 to absorbed doses

The ICRP Publication 51 lists the conversion coefficients for estimating H10 from monochromatic neutrons per unit fluence. Using these coefficients and the neutron energy spectra described in the pervious section, we derived the conversion coefficient for H10 per unit neutron fluence. The H10 against neutrons for each worker was calculated by multiplying the conversion coefficient and the neutron fluence that was estimated from ^{24}Na. One ninth of this value was used as the H10 of gamma rays.

The absorbed dose was calculated from the H10 of gamma-rays using the following procedure.

(i) The ICRP Publication 51 shows the conversion coefficient for H10 per unit gamma-ray fluence. The gamma-ray fluence was derived by dividing the H10 by this coefficient.

(ii) The gamma-ray kerma was derived by multiplying this gamma-ray fluence by the air kerma per unit gamma-ray fluence, shown in the ICRP Publication 74[14].

(iii) The absorbed dose of each tissue was derived by multiplying this gamma-ray kerma by the absorbed dose per unit gamma-ray kerma in

Table 4-12 Estimated average whole-body doses of neutrons and gamma rays (Gy)

Patient	Neutrons	Gamma rays	
		Estimated from monitored data	Estimated from IAEA 211
A	5.4	8.5	13
B	2.9	4.5	6.9
C	0.81	1.3	2.0

Table 4-13 Estimated biological gamma-ray equivalent doses (GyEq)

Patient/RBE	1.0	1.2	1.4	1.7	2.0	2.5	3.0	3.5	4.0
A	13.9 (18.4)	15.0 (19.5)	16.1 (20.6)	17.7 (22.2)	19.3 (23.8)	22.0 (26.5)	24.7 (29.2)	27.4 (31.9)	30.1 (34.6)
B	7.3 (9.8)	7.9 (10.4)	8.4 (11.0)	9.3 (11.8)	10.2 (12.7)	11.6 (14.2)	13.0 (15.6)	14.4 (17.1)	15.8 (18.5)
C	2.1 (2.8)	2.2 (3.0)	2.4 (3.1)	2.6 (3.4)	2.9 (3.6)	3.3 (4.0)	3.7 (4.4)	4.1 (4.8)	4.5 (5.2)

Publication 74.[15] The absorbed dose of the whole body was calculated by computing the weighted mean of the tissues.

From the above investigation, we derived the following equation for calculating gamma-ray dose $D\gamma$:

$$D\gamma = 1.03 \times 10^{-4} \times \alpha \text{ Gy} \qquad (4\text{-}5)$$

The IAEA Technical Report Series No. 211[11] shows a plot that may be used to read the estimated gamma-ray kerma/neutron kerma ratio from the criticality solution volume or the atomic ratio of hydrogen to ^{235}U. We also estimated the gamma-ray dose using this plot. The process of the estimation is not described here since the space is limited.

(d) Estimated gamma-ray doses

The gamma-ray doses that we estimated using the methods described above are listed in table 4-12.

④Estimation of biological gamma-ray equivalent doses (GyEq)

Dose estimations that are based on lymphocyte counting and chromosome analysis have derived the biological gamma-ray equivalent doses (GyEq). Therefore, we tried to estimate the biological gamma-ray equivalent doses for various RBE values.

The results of our estimation are listed in table 4-13. Values within brackets denote doses estimated from the gamma-ray doses that were derived based on the IAEA 211.

The ICRP Publication 58[16] summarizes the RBE's of deterministic effects, which were studied using animal experiments. According to this, the RBE's of neutrons of 1 to 5 MeV are 2.8 to 3.7 for the skin, 2 to 3.0 for the gastro-intestinal tissue, and 2.6 for the hemopoietic tissue.

⑤Estimation of doses for each organ

Of the three patients, Patient C was likely to receive relatively uniform irradiation from the front. We estimated the absorbed doses of Patient C for each organ and tissue using the methods described above. The results are listed in table 4-14.

The values show that both the absorbed doses and the contribution ratios of neutron and gamma rays considerably differ depending on organs.

⑥Topics that should be investigated further

The characteristics of the exposure during this accident were 1) coexisting neutrons and gamma rays of different qualities and 2) non-uniform dose distribution. These were likely to affect the clinical progress of the patients. All information

Table 4-14 Absorbed dose for each organ and tissue of Patient C (Gy)

Organ or tissue	Neutron	Gamma ray	
		From monitored data	From IAEA 211
Gonad	1.5	1.5	2.4
Bone marrow	0.59	1.1	1.8
Colon	0.79	1.3	2.1
Lung	0.84	1.3	2.1
Stomach	1.1	1.4	2.2
Bladder	1.1	1.4	2.2
Liver	0.94	1.4	2.1
Esophagus	1.1	1.2	1.8
Thyroid gland	1.3	1.6	2.5
Skin (whole body)	0.97	1.3	2.1
Bone surface	0.62	1.2	1.9
Other tissues	0.78	1.3	1.9

that was acquirable from the conventional dose estimation methods for criticality accidents was the average doses for the whole bodies, and there was no direct information concerning the contributions of neutrons and gamma rays.

Precise analyses of the data of patients, including clinical courses, precise analyses of the radiation field near the precipitation tank, a radiation transportation simulation that accurately reproduce the postures of the workers, and actual measurements of doses using criticality experiment devices are needed to understand the doses in detail.

References
1) Y. Feng, et al.: ORNL/TM-12028, 1993.
2) ICRP: ICRP Publication 74, Ann. ICRP, 26(3/4), 184-198, 1996.
3) W. G. Cross: Health Physics, 41, 105-121, 1981.
4) G. S. Hurst, R. H. Ritchie and L. C. Emerson: Health Phys., 2, 121-133, 1959.
5) ibid to 1), p. 41.
6) IAEA: Technical Report Series No. 211, p142, 1982.
7) ibid to 1), p. 46.
8) R. Maruyama: Nichiihoshi, 27, 1347, 1968.
9) ICRP: ICRP Publication 23, p. 34, p. 314, 1975.
10) ICRP: ICRP Publication 30 Part 2, Ann. ICRP, 4(3/4), p. 3, 1980.
11) ibid to 6), p. 41.
12) ICRP: ICRP Publication 51, Ann. ICRP, 17(2/3), p. 36, 1980.
13) ibid to 11), p. 17.
14) ibid to 2), p. 159.
15) ibid to 2), pp. 160-174.
16) ICRP: ICRP Publication 58, Ann. ICRP, 20(4), p. 11, 1989.

(3) Dose estimation using human counter

①Measurement of the whole-body ^{24}Na dose using human counter

(a) Outline of measurement

The ^{24}Na that was generated within a human body by the (n, γ) reaction of ^{23}Na was quantified using a scanning whole-body counter at the National Institute of Radiological Sciences. The determination was conducted only for Patient C of the three JCO workers who were severely exposed.

(b) Conditions of measurement

i) Date and time when the measurement started: October 2, 1999 at 14:29

(Time after exposure: 51 hours and 54 minutes)

ii) Outline of the measuring devices:

Two NaI detectors (8 inches in diameter diameter × 4 inches) were installed at the upper and lower sides of a horizontal bed in a shielded

room (steel wall of approximately 20 cm thick). The two detectors were movable to the horizontal direction at a constant speed.

iii) Preparation of measurement:

To prevent the contamination of the shielded room, the floor, wall surfaces, bed, and detectors were covered with plastic sheets. In principle, subjects should take a shower before measurements, but the subject in this measurement just wore a clothes' wear for human counter measurements on the gown he was wearing in the sickroom in consideration of his health condition.

iv) Measuring geometry:

The detectors were moved at 10 cm/minute so that the central axes of the NaI detectors would scan the patient from the top of the head to his toes.

v) Duration of measurement: 987 seconds (the height of the patient divided by the speed of the detectors)

vi) Size of the patient;

Before the measurement, the height and the weight of the patient were measured with the gauges installed in the human counter room. The height was 164.5 cm, and the weight was 67.8 kg.

(c) Evaluation of calibration factor

The institute possessed only two calibration phantoms (one phantom was filled with ^{137}Cs solution, and the other was filled with ^{40}K solution). Since the calibration factor varies depending on the energy of the gamma rays to measure, it was necessary to estimate the calibration factor for the energy of either gamma-rays that ^{24}Na emits (1,369 keV or 2,754 keV) by interpolating or extrapolating the values measured with the two phantoms. The calibration factor estimated for 1,369 keV by interpolating the calibration factors of ^{137}Cs (662 keV) and ^{40}K (1,461 keV) was likely to be more accurate than the calibration factor estimated for 2,754 keV by extrapolation. Therefore, we estimated the calibration factor of 1,369 keV by interpolation. To identify the factors for interpolation, we investigated the relationship between the energy and calibration factor per unit photon using four kinds of point radiation sources. We measured the calibration factors by not moving but fixing the detectors at the upper and lower sides of the bed and placing point radiation sources at points that the central axes of the detectors crossed the bed.

The calibration factor EI per unit photon after the correction of gamma-ray emissivity was derived with the following equation:

$$Ei = \frac{Si}{TAili}$$

Ei: calibration factor (cps per photon)
Si: photopeak area
i: target energy (MeV) (i = 0.662, 1.369, 1.461)
T: duration of measurement (seconds)
Ai: activity sealed in the phantom
Ii: gamma ray emissivity

In the above equation, the duration of measurement (T) was 1,943 seconds for both the ^{137}Cs and ^{40}K phantoms, and the activities sealed in the phantoms were A0.662 = 1,359 Bq (^{137}Cs phantom) and A1.461 = 18,477 Bq (^{40}K phantom) when converted for the day of measurement. The measurements of the phantoms were conducted on the same day that the measurement for the patient was conducted. The gamma ray emissivity was I0.662 = 0.851 (^{137}Cs) and I1.461 = 0.107 (^{40}K)[1]. Since there are various ways for determining the photopeak area Si, we compared two methods[2]. Both methods apply the Gaussian constant for the photopeak to determine the area. As the result, the calibration factors of the peak for 1.369 MeV were 0.005405 cps/photon and 0.005270 cps/photon.

(d) Estimation of the amount of ^{24}Na in the body of the patient (for the time of measurement)

Using the spectra of the patient, the net counting rate was derived by dividing the photopeak area (1,369 keV) by the duration of measurement (987 seconds). The error in the calculation of photopeak area by the contribution of ^{40}K and sum peak was only 2%, which was likely negligible. The amount of ^{24}Na in the body of the patient was determined by dividing the photopeak area by the calibration factors, which had been determined as described above. Like the phantoms, two methods were used to determine the photopeak area from the spectra of the patient. Our calculation showed that the amounts of ^{24}Na in the body for the time of measurement were 68,880 Bq and 69,770 Bq.

The effects of the ^{40}K contribution and the sum peak should be subtracted from the aforementioned photopeak area. The photopeak region of ^{24}Na 1,369 keV partly overlaps with the photopeak of ^{40}K, which is present in a

healthy man. From our periodical measurements of several tens of healthy people, we estimated that the photopeak area of ^{40}K that overlapped with the photopeak area of ^{24}Na was about 2,000 to 3,000. The aforementioned photopeak area (S) of 1.369 was only 1% or less of the peak area, although it may include overestimation.

On the other hand, the sum peak (4,123 keV) that was generated by gamma rays of 1,369 keV and 2,754 keV, which simultaneously irradiated a detector, was 2,400 in area. To apply the calibration factors determined for 1,369 keV in (c), the photopeak area (S) of 1.369 should be corrected for the sum peak. As a result of spectrum analysis, the photopeak area (1,369 keV) was underestimated by 9,600 due to the sum peak. However, this underestimation is about 2.6% of the photopeak area S 1.369. Since the area that was overestimated by the contribution of ^{40}K is likely 2,000 to 3,000, the overestimation partly eliminates the underestimation caused by the generation of the sum peak. Therefore, we did not consider the effects and the contribution of ^{40}K and the effects of the sum peak.

The two methods for calculating the photopeak area did not show significant difference (only a difference of approximately 1%). We calculated the mean of the values that were estimated from the two methods and concluded that the amount of ^{24}Na in the body at the time of measurement was likely 69,300 Bq.

②Estimation of specific activity during exposure

(a) Correction of attenuation

Using the physical half life of ^{24}Na (14.959 hours[1]) and its biological half life (10 days[3]), we calculated the amount of ^{24}Na during the time of the accident (10:35 on September 30, 1999) by converting using the amount of ^{24}Na that we derived obtained for the time of in the measurement. Our calculation showed that the amount of ^{24}Na in the body was 896,200 Bq at the time of the accident.

(b) Calculation of specific activity

According to the ICRP reference manreference subject[3], the amount of ^{23}Na contained in one kilogram of human body is 1.4 g. Applying this value to the weight of the patient, the patient contained a total amount of ^{23}Na of 94.9 g, and the specific activity (the activity of ^{24}Na produced per one gram of stable ^{23}Na) was 9,440 Bq/g. However, another reference[4] shows that one kilogram of a human body contains 0.92 to 1.61 grams of ^{23}Na. According to these values, the total amount of ^{23}Na was 62.4–109.2 g, and the specific activity was 8,210–14,360 Bq/g. Kennedy et al.[5] surveyed healthy men at their 40's to 70's and obtained the whole-body ^{23}Na contents of 74.8–99.4 g (83.7 g in average). When these values are used, the specific activity is 9,020–11,980 Bq/g. Either way, the amount of ^{23}Na in the whole body varies depending on person, so is the specific activity value.

③Conversion into dose

In the estimation of dose soon after the accident, we used the conversion factor by Maruyama[6] to derive the exposed dose from the specific activity of ^{24}Na. According to Maruyama, the conversion factor for neutron dose was 0.2092 mGy per unit specific activity (Bq/g). Using the specific activity that we derived based on the ICRP reference man and this conversion factor, we estimated a neutron dose to be 2.0 Gy.

On the other hand, the conversion factor that is based on the latest information is 0.0658 mGy per unit specific activity for neutrons and 0.103 mGy per unit specific activity for gamma rays (See Section Estimation of Doses based on ^{24}Na Measurements in Blood). With these factors, the specific activity of ^{24}Na that was determined with the ICRP reference man (9,440 Bq/g) gives 0.62 mGy and 0.97 mGy for neutrons and gamma rays, respectively. Assuming that the RBE against neutrons is 1.7, the biological equivalent gamma-ray dose for the patient C determined by the human counter measurements was 2.0 GyEq. Therefore, we decided to use the latter evaluation results for dose estimation, which is likely to more closely reproduce the phenomena.

References

1) Firestone, R. B.: Table of Isotopes EIGHTH EDITION, 1996.
2) Noguchi, M.: Gamma ray spectrometry, Nikkan Kogyo Shinbun.
3) ICRP: Report of the Task Group on Reference Man ICRP Publication 23.
4) Sekiguchi M.: Elements necessary for living bodies Rinshokensa 34(11), 1384–1393,: 1990.
5) Kennedy, N. S. et al. Normal levels of total body sodium and chlorine by neutron activation analysis. Phys.

Med. Bio. 28(3), 215–221, 1983.
6) Maruyama, R.: Estimation of dose during an accident 2. Measurement of neutron capture ratio Nihon Igaku Hoshasen Gakkaishi 27(10), 1347–1353, 1968.

4-4. Dose Estimation by Chromosome analysis

Chromosome analysis for dose estimation is performed using peripheral lymphocytes. In the standard method the blood for the analysis is taken from patients later than 24 hours after exposure when the circulating and extravascular pools are mixed well in the body. This time, however, we decided to collect blood first at 9 hours and then 23 and 48 hours after the accident because of the rapid drop in lymphocyte numbers that had been observed.

Already at 9 hours after the accident, the percentage of lymphocytes among white blood cells was as low as 1.9% in Patient A, 2.1% in Patient B and 15% in Patient C. Normal values are 25–48%. For Patients A and B, it was likely impossible to collect a sufficient number of lymphocytes to make chromosome preparations using the conventional method since most of the lymphocytes would probably be lost during the culturing and harvesting processes. Even if it were possible to make chromosome slides, it would be difficult or impossible to analyze them because the frequency of metaphase would be extremely low due to mitotic delay caused by high dose radiation.

To overcome these difficulties, we used two new techniques which had been developed by us as part of the Nuclear Cross Over Research Project by the Science and Technology Agency: A high yield chromosome preparation method (Hayata et al., 1992) and easy biodosimetry for high-dose radiation exposure using drug-induced, prematurely condensed ring chromosomes (PCC-R) (Kanda et al., 1999). The former method was developed to prepare chromosome specimens suitable for analysis with automatic devices. This method concentrated the lymphocytes, increased the recovery rate of the sedimentary cells by centrifugation, and raised the frequency of analyzable cells considerably. The latter method was developed for detecting chromosome aberrations in interphase nuclei instead of metaphase chromosomes. After exposure to high-dose X or gamma rays (over 10 Gy), few cells are able to enter mitosis when cultured and so are harvested at metaphase having been arrested by a mitotic inhibitor such as Colcemid. On the other hand, Okadaic acid effectively induces prematurely condensed chromosomes even in lymphocytes exposed to 20 Gy. Since this PCC-R method uses only ring chromosomes as an indicator of dose, it enables a rough, but quick dose-estimation compared to the conventional method of scoring dicentrics (a multicentric chromosome within centromeres is counted as n-1 dicentric chromosomes), ring chromosomes and fragments. Therefore, the PCC-R analysis is a practical method of biodosimetry especially for high-dose estimation.

Chromosome analysis for the present dose estimation was performed according to the method described below:

Chromosome preparation and observation

(1) Lymphocytes were separated from 8 ml of peripheral blood and mixed with 12 ml of a culture medium consisting of 9.6 ml of RPMI 1640 solution, 2.4 ml of calf serum, 0.72 mg of Kanamycin and 0.24 ml of PHA, and then divided into two centrifuge tubes for tissue culture.
(2) One tube was processed for the scoring of PCC-R, and the other was used for conventional analysis. Both were cultured for 48 hours at 37°C. The former was treated with 500 nM Okadaic acid for the last hour of the culture. The latter was supplemented with 0.3 μg of Colcemid at the start of the culture.
(3) The lymphocytes were treated and fixed according to a high yield harvesting method. Air-dried slides were densely stained with Giemsa's solution.
(4) Chromosome aberrations were scored under a microscope. All of the cells carrying aberrations were photographed.

Dose estimation and the calculation formula

A dose estimation using the PCC-R method was made by comparing the observed data with the experimentally obtained values in the dose response of the PCC-R against 200 keV X-rays (Figure 1). The estimation based on the dicentrics and rings in Patient C was made according to the standard method outlined in IAEA Technical Report Series No. 260 based on an equation for calculating ^{60}Co gamma rays: $Y = (2.31 \pm 0.88) \times 10^{-2}D + (6.33 \pm 0.25) \times 10^{-2}D^2$

(M. S. Sasaki, unpublished). The doses of radiation for Patients A and B were higher than the dose that can be estimated with this formula, which is only suitable for doses below 6 Gy. Therefore, estimates were made by a direct comparison of the observed frequencies with those obtained in a study of 1.9 MeV X-rays (the quality factor = 1) by Norman and Sasaki (1966) (Figure 2).

Results

Table 4–15 The results of dose estimation by PCC-R analysis using samples obtained 9 hours after the accident

Patient A	75 PCC-R/50 cells	>20 GyEq*
Patient B	38 PCC-R/50 cells	7.8 GyEq*
Patient C	13 PCC-R/50 cells	2.6 GyEq*

Note: Doses (GyEq*) were estimated by using the dose-response curve of PCC-R obtained in experiments conducted at theNational Institute of Radiological Sciences.

1) Dose estimation by PCC-R analysis

It is essential to estimate the dose as quickly as possible in cases involving exposure to high doses of radiation. Therefore, we first examined the frequencies of PCC-R in the samples obtained 9 hours after the accident, by which we could quickly, though crudely, estimate the radiation dose. The PCC-R analysis to estimate the doses of 3 patients took approximately one hour. The results are listed in Table 4–15.

2) Dose estimation by the analysis of dicentrics and ring chromosomes

Since this was the world's first attempt to estimate exposed dose by analyzing PCC-R, we needed to promptly check the results shown in Table 1 by comparing them with the doses estimated by the conventional method of scoring dicentrics and ring chromosomes (Dic + Rc). However, the scoring of Dic + Rc in Patients A and B was very difficult, or impossible in short-term due to the very low mitotic index (1/100 to 1/1000 of the corresponding normal value) and complicated morphology of aberrant chromosomes. Therefore, at first, the analysis of Dic + Rc to check the PCC-R results was performed only for Patient C. The analysis of 50 cells of Patient C took approximately 1 hour. The estimated value was 2.4–3.2 GyEq***, fairly consistent with the result of the PCC-R analysis.

The doses estimated by PCC-R analysis for 3 patients and the result for Patient C obtained by the conventional method were reported at the meeting to plan clinical treatment held at 10:25 am on October 3, 3 days after the accident.

Thereafter, we concentrated on the analysis of Dic + Rc, which gives a more precise estimation of dose than the PCC-R analysis. We started with Patient B, but the analysis took a long time because dividing cells were scarce and several complicated aberrant chromosomes were observed per cell. While conducting this difficult analysis, we simultaneously had to prepare chromosome slides from the 23- and 48-hour samples of the 3 patients and had to plan a chromosome analysis for the residents of Tokai-mura, who were, or suspected of being, exposed to low doses of radiation. Therefore, at the meeting to plan clinical treatment held on the morning of October 7, we could report the results of only 13 cells in the 9-hour sample of Patient B. The dose estimated from the results for these 13 cells was higher than 6 GyEq, consistent with the result of the PCC-R analysis in this patient also.

Between October 7 and 13, we could finish the analysis of 15 cells in the 9-hour sample of Patient A, 40 cells in the 9-hour sample of Patient B, and 100 cells in the 23-hour of sample of Patient C. In the sample from Patient A, it was not rare to find a chromosome with several centromeres, and it was not always possible to identify all 46 centromeres in each cell. As well, ring chromosomes with (Rc) and without (Ra) a centromere could not be distinguished. So, an overall count of ring chromosomes (R) was made for Patient A. The number of dicentrics (Dic) was scored conservatively and as a result, the estimated dose for Patient A would be lower than the dose actually received. The estimated dose was 24.5 GyEq using the analysis of Dic + R for Patient A. On the 13th day after the accident, this time-consuming but precise estimation of dose by conventional metaphase analysis as shown in Table 4–16 confirmed that all the values for the three patients obtained by PCC-R analysis are reliable.

3) Final results of the estimated dose

After much effort, we succeeded in analyzing all the 9-, 23- and 48-hour samples from the 3 patients by the conventional metaphase method. In addition, we analyzed 50 more cells per sample in the PCC-R preparations to increase the reliability of these results. The results are shown

Table 4-16 The estimated dose by conventional analysis until October 13, 1999

The samples obtained 9 hours after the accident		
Patient A	158 Dic+R/15 cells	24.5 GyEq**
Patient B	160 Dic+Rc/53 cells	8.3 GyEq**
Patient C	28 Dic+Rc/50 cells	2.4-3.2 (median: 2.8) GyEq***
The sample obtained 23 hours after the accident		
Patient C	64 Dic+Rc/100 cells	2.7-3.3 (median: 3.0) GyEq***

Note: The doses (GyEq**) were estimated by a direct comparison of the observed frequencies with those obtained in a study of 1.9 MeV X-rays by Normal and Sasaki (1966). Dose (GyEq***) estimation was made using a calculation of dose-response for ^{60}Co gamma rays: $Y=(2.31\pm0.88)\times10^{-2}D+(6.33\pm0.25)\times10^{-2}D^2$.

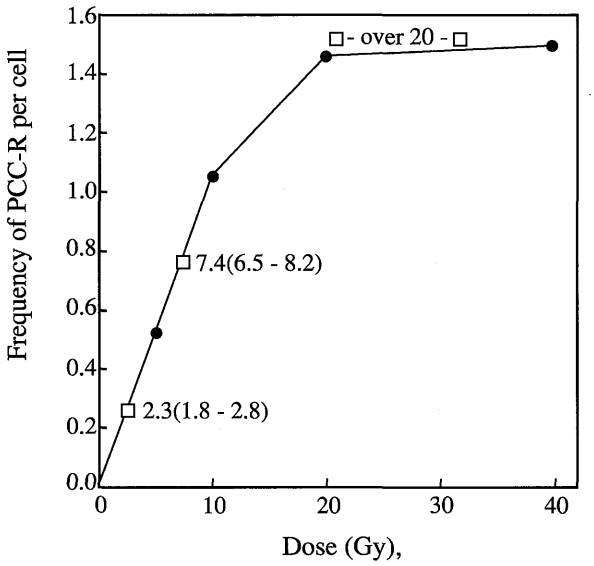


Figure 1: Dose-response curve of PCC-R. (cited from Hayata et al., J. Radiat. Res., 2001)

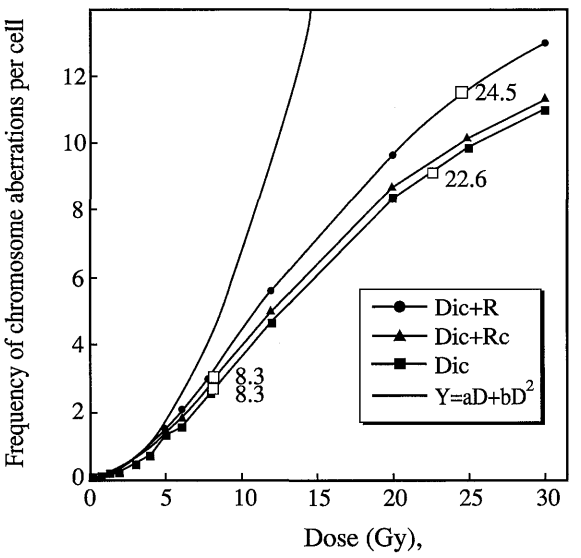


Figure 2: Dose-response curves of dicentrics and ring chromosomes, and the estimated doses of Patients A and B. (cited from Hayata et al., J. Radiat. Res., 2001)

Table 4-17 Frequencies of chromosome aberrations in lymphocytes and estimated doses in 3 patients after the accident

Patient	Indicator	9-hour	23-hour	48-hour	Total	Estimated dose
A	PCC-R	150/100	—	—	150/100	>20 GyEq*
	Dic	445/50	197/20	73/8	715/78	22.6 GyEq**
	Dic+R	563/50	250/20	90/8	903/78	24.5 GyEq**
B	PCC-R	77/100	—	—	77/100	7.4 (6.5-8.2) GyEq*
	Dic	199/75	127/50	153/50	479/175	8.3 GyEq**
	Dic+Rc	224/75	147/50	166/50	537/175	8.3 GyEq**
C	PCC-R	24/100	—	—	24/100	2.3 (1.8-2.8) GyEq*
	Dic+Rc	63/100	64/100	64/100	191/300	3.0 (2.8-3.2) GyEq***

in Table 4-17 and Figures 1 and 2 (Hayata et al., 2001).

Acknowledgments

The present results of dose estimation conducted by us, I. Hayata, R. Kanda and M. Minamihisamatsu, were confirmed by Professor M. S. Sasaki, Kyoto University, to whom we sent the chromosome slides for analysis of dicentrics and rings. We express our deep grati-

tude to Professor Sasaki for his valuable advice and information concerning dose estimation.

References
1. Hayata, I., Tabuchi, H., Furukawa, A., Okabe, N., Yamamoto, M. and Sato, K.: Robot system for preparing lymphocyte chromosome. J. Rardiat. Res., 33 Suppl., 231-241, 1992.
2. IAEA Technical Reports series 260. Biological dosimetry: Chromosome aberration analysis for dose assessment. IAEA, 1986.
3. Kanda, R., Hayata, I. and Lloyd, D. C.: Easy biodosimetry for high-dose radiation exposures using drug-induced prematurely condensed chromosomes. Int. J. Radiat. Biol., 75: 441-446, 1999.
4. Norman, A and Sasaki, M. S.: Chromosome-exchange aberrations in human lymphocytes. Int. J. Radiat. Biol., 11, 321-328, 1966.
5. Hayata, I., Kanda, R., Minamihisamatsu, M., Furukawa, A. and Sasaki, M. S. Cytogenetical dose estimation for 3 severely exposed patients in the criticality accident in Tokai-mura. J. Radiat. Res., 42, Suppl., 2001.

Response measures taken for chromosome analysis of the three victims of the criticality accident in Tokai-mura

September 30, 1999

10:30 A criticality accident occurred at Tokai-mura

15:25 Three victims were transferred from Mito to the National Institute of Radiological Sciences by helicopter and ambulance.

16:00 The media and agents for culture were newly prepared.

19:30 Blood samples, each of 9 ml, were collected. The lymphocyte separation was started (at 9 hours after the accident).

20:30 The first culture was started.

October 1, 1999

9:30 The blood samples for the second chromosome analysis were collected (at 23 hours after the accident).

10:30 The second culture was started.

October 2, 1999

10:30 The blood samples for the third chromosome analysis were collected (at 48 hours after the accident).

11:30 The third culture was started.

19:30 Okadaic acid was added to the 3 tubes of the first culture.

20:30 The harvesting of the first culture was started.

21:30 The harvesting of the first culture was completed. The fixed cells were kept in a freezer.

23:30 Air-dried slides were prepared, stained with Giemsa's solution, and embedded.

October 3, 1999

1:00 Microscopic observation was started.

2:00 The PCC-R analyses for the 3 patients were completed, and doses were estimated (at 53.5 hours after blood sampling, or 62.5 hours after the accident).

3:00 Chromosome slides for the Dic + R analysis were prepared again since they were found to be fixed insufficiently.

5:30 The Dic + R analysis for Patient C was completed, and dose was estimated (at 57 hours after blood sampling, or 66 hours after the accident).

9:30 Okadaic acid was added to the 3 tubes of the second culture.

10:25 The estimated doses were reported at the meeting to plan clinical treatment. They were based on the results of the PCC-R analysis for the 3 patients, and those of the Dic + R analysis for Patient C.

10:30 The harvesting of the second culture was started.

11:30 The harvesting of the second culture was completed. The fixed cells were kept in a freezer.

October 4, 1999

10:30 Okadaic acid was added to the 3 tubes of the third culture.

11:30 The harvesting of the third culture was started.

12:30 The harvesting of the third culture was completed. The fixed cells were kept in a freezer.

October 13, 1999

10:30 The Dic + Ring analyses confirmed the doses estimated in three patients by PCC-R to be accurate. The doses of the three patients were reported at the meeting to plan clinical treatment.

4-5. Precise Analysis of Dose Distribution

(1) Introduction

In the accident in Tokai-mura, within a very short time after the uranium solution reached the criticality, vast amounts of neutrons and

prompt gamma rays were generated and released as a result of nuclear fission, which also caused a mass release of secondary gamma rays by neutron capture. Three workers who were operating around the precipitation tank were heavily exposed. The workers were transferred to the National Institute of Radiological Sciences, and the radiation doses to which they were exposed were estimated by analyzing blood components such as lymphocytes, chromosomal aberration, and ^{24}Na in the blood to present a guidance on the medical treatment plans.

The characteristics of the exposure in this accident were:

1) the victims were simultaneously exposed to neutrons and gamma rays which have different quality factors and attenuation coefficients within the human body, and

2) the two persons who were pouring the uranium solution were unevenly exposed.

These were likely to have affected the clinical symptoms of the patients. However, the methods described so far estimate the mean doses for the whole body and are not useful to estimate the dose distribution and the respective contributions of neutrons and gamma rays.

In cooperation with the Japan Atomic Energy Research Institute, we are estimating both the neutron and gamma-ray doses for each section of the skin and deeper parts of the bodies by conducting a Monte Carlo simulation of radiation transportation, which reproduces the position and posture during a radiation exposure, and performing reproduction experiments using an experimental criticality facility. The results, which will be used in comparative studies with clinical symptoms, should contribute to an understanding of the effects of severe radiation exposure on the human body and the progress of curing methods.

An outline of the study is described in this section.

(2) Dose estimation by computational simulation

①Introduction

This method estimates the dose absorbed by each section of the skin and deeper parts of the body by positioning numerical phantoms that reproduce the positions and postures of Patients A and B around the precipitation tank, and simulating the criticality reaction and the process of radiation transportation.

②Calculation method

The criticality and the radiation transportation were calculated by using a Monte-Carlo code of MCNP-4B. FSXLIB-J3R2 was used for the cross section library of the neutrons. As a numerical phantom, we used a humanoid phantom with movable arms and legs, which was developed in the Japan Atomic Energy Research Institute[2]. The numerical phantom is MIRD phantom, but with arms and legs that are independent from the body, and have spherical joints at the shoulders, elbows, and hip. This phantom can reproduce the posture at the time of the accident. The phantom is 170 cm high and 73 kg in weight, which is relatively similar to the body sizes of Patients A and B.

③Process of investigation

Calculation is being conducted using the following procedure:

[Step 1: Spatial dose distribution by using a model of the precipitation tank]

Before the doses of the workers were calculated, the neutron flux, gamma-ray flux and their energy spectra around the precipitation tank were calculated using the computational simulation method. The resultant radiation field was used to calculate the tissue absorbed doses of microscopic volume elements by using the kerma factor for neutrons and the mass energy absorption coefficients for gamma-rays[3], and to estimate the dose distribution in the space around the precipitation tank. The result of the calculation is shown in Figure 4-1. The Y axis represents the absorbed dose per 1×10^{17} nuclear fission. The number of nuclear fissions during the initial pulse of criticality burst was estimated to be $(4\text{-}10) \times 10^{16}$ when the three patients were exposed[4].

The principal points that were revealed by Step 1 are:

(a) Figure 4-1 shows that the absorbed gamma-ray dose is slightly higher (18%–35%) than the neutron dose at 115 cm in height.

(b) Figure 4-1 shows that the dose varied much, depending on the position around the precipitation tank. For example, the dose at a distance 10 cm away from the tank is double that of the dose at 20 cm away from the tank. Also, for vertical distance, the dose at 115 cm in height and 10 cm away from the tank is about

2.5 times larger than the dose at 165 cm in height.
(c) Although not shown in the figure, the side and upper surface of the precipitation tank did not show significant differences in neutron spectrum.
(d) Although not shown in the figure, the gamma-ray spectrum has a broad peak around several hundreds keV and is similar to the spectrum of nuclear fission gamma rays. Since the peak that is attributable to neutron capture by hydrogen (2.2 MeV) is not shown on the gamma-ray spectrum, nuclear fission gamma-rays were likely to be accounted for the majority of the dose.

[Step 2: Analysis using slab phantoms]
Two slab phantoms (170 cm high, 20 cm thick, and 40 cm wide) were positioned around the precipitation tank to simulate Patients A and B. The radiation doses that were absorbed into the phantoms, and the generation of ^{24}Na, were determined for different distances and angles between the phantoms and the precipitation tanks. This analysis clarified an outline of the dose distribution over the skin and a dose decrement in the deeper parts of the body, and we succeeded in establishing the conditions that are necessary for the next step of the calculation, such as the optimum fractionation of the skin surface and the optimum size of the hexahedron for estimating the doses in the deeper parts of the body.

The principal points that were revealed by Step 2 are:
(a) The mean neutron absorbed dose of the whole body per unit specific activity of ^{24}Na (Bq/gNa) agreed well with the dose conversion factor that is described in Section 4-2 (6.6×10^{-5} Gy/(Bq/gNa)).
(b) When the distance between a slab phantom and the center of the precipitation tank was 55 cm, the mean whole-body neutron dose changed -10% to $+15\%$ by moving the position of the phantom for 5 cm.
(c) The attenuation of the neutron dose within the slab phantoms was sharp. The dose at the back of a phantom was less than 1/10 of the dose at the front and was even less than 1/100 in some sections. On the other hand, the attenuation of gamma rays was about 1/3 to 1/5.

[Step 3: Precise dose estimation by using humanoid phantoms with movable arms and legs]
Both the neutron and gamma-ray doses absorbed by each section of the skin and the deeper parts of the body are calculated by positioning humanoid phantoms with movable arms and legs around the precipitation tank to reproduce the positions and postures of the patients during the exposure.

The results of Steps 1 and 2 show that the dose highly depends on the positions and postures during exposure. To conduct Step 3, it is indispensable to estimate accurately these positions and postures. Therefore, we interviewed Patient B, and Patient C, and attempted to reproduce the operation using a mock-up facility built inside the site of JCO with the help of the members of the National Institute of Radiological Sciences, who are as tall as Patients A and B. A photograph of this experiment is shown in Figure 4-2.

Based on the positions and postures estimated by this simulation experiment, we have determined the most possible positions of the two patients by conducting preliminary calculations and checking that the ratio of the computed ^{24}Na values between Patients A and B does not contradict with the measurements, and with the dermatological diagnoses of Patients A and B.

An interim model that we established to perform our analyses is shown in Figure 4-3.

Since the skin was seriously injured, the skin dose needed to be precisely determined. The head, body, arms, and legs were divided in a 5 cm meshes along the vertical axes, and the head and body were divided along the circumference into sections of 22.5 degrees. The legs and arms were divided into sections of 45 degrees along the circumference. The dose is to be determined for each meshgrid. The dose distribution toward the deeper parts of the body will be analyzed by determining the dose for each hexahedron section of 1 cm × 1 cm × 2 cm.

(3) Investigation of the depth dose distribution using a criticality experiment reactor TRACY

①Introduction

The Nuclear Fuel Cycle Safety Engineering Research Facility of the Japan Atomic Energy Research Institute has a transient experiment critical facility (TRACY) that uses uranyl nitrate as the fuel, like the precipitation tank that caused the criticality accident. A phantom filled with water was positioned in the reactor room of TRACY, and the dose distribution inside the

phantom was measured using cavity ionization chambers, when the reactor was operated at low power. We quantitatively analyzed the attenuation of the neutron and gamma-ray doses inside the phantom.

②Experimental methods

A schematic diagram of the facility is shown in Figure 4-4.

The core of TRACY is a cylinder of 50 cm in outer diameter with a cylindrical cavity of 7.6 cm in diameter for inserting a safety rod. The reactor is operated by filling the tank with 110 l of 9.98% uranyl nitrate solution. There is no jacket of cooling water. On the other hand, the uranyl nitrate solution that was poured into the JCO precipitation tank was 18.8% in concentration, and reached the criticality with approximately 40 l of the solution.

The used phantom was an elliptic cylinder of 30 cm wide, 20 cm thick and 50 cm high, which was made of 5 mm-thick acrylic resin, and was filled with tap water. The phantom was positioned 46.1 cm from the surface of the core tank.

The dose was measured by inserting a pair of cavity ionization chambers, which are largely different in neutron sensitivity, and scanning the inside of the phantom using a three-dimensional driving device. In order to correct the power fluctuation of TRACY, we placed a cavity ionization chamber in front of the phantom and monitored the fluctuation in power during the measurement. The each sensitivity of the cavity chambers against neutrons and gamma-rays was derived by weighting the sensitivity with the energy spectrum that was obtained by computational simulation.

③Results

Our measurements of the dose distribution toward the deeper parts of the phantom along the central axis are shown in Figure 4-5. The doses along the horizontal direction crossing the central axis and along the height direction crossing the central axis, were almost the same regardless of the position, which suggested that the irradiation was uniform.

As Figure 4-5 shows, the neutron dose showed an exponential attenuation along with the change of the depth. The apparent attenuation coefficient was 0.204 cm^{-1}. The attenuation of the gamma rays was less remarkable and a build-up of doses occurred. For the doses extrapolated to the depth 0 cm the gamma-ray dose was about twice of the neutron dose, but was 10 times of the neutron dose in the depth of 100 mm. According to Step 1 of the computational simulation described in the previous section, the neutron and gamma-ray doses were not significantly different on the surface of the tissues. TRACY, which contained approximately 3 times larger volume of the solution than the JCO precipitation tank, was likely to cause larger attenuation of neutrons, produce more captured gamma-rays in the tank, and, consequently, cause gamma-ray doses to become higher than the JCO precipitation tank.

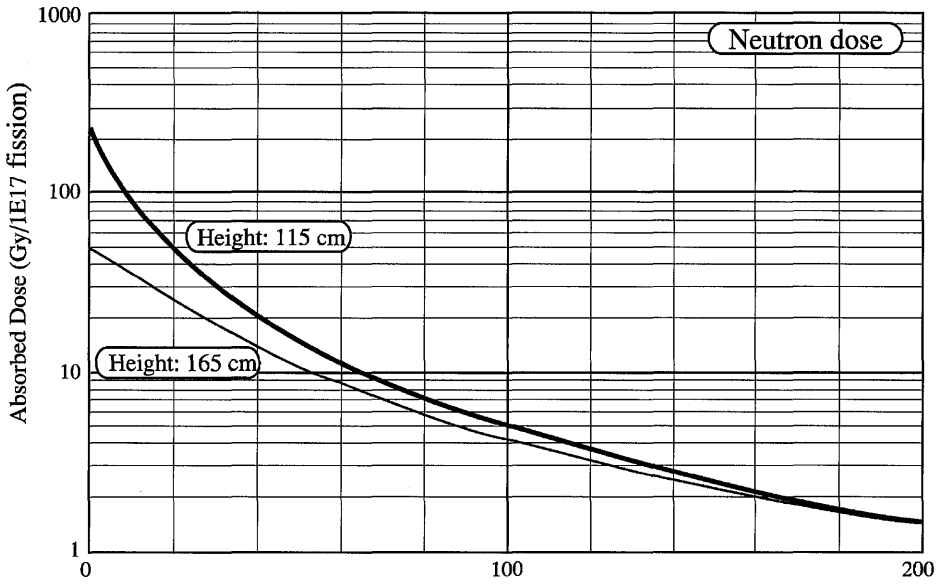
(4) Conclusion

To use the experiences of this accident for future emergency medical care, the dose must be fully clarified. At present, we are estimating the neutron and gamma-ray doses absorbed in each section of the skin and in the deeper parts of the body. We are almost finished with the estimation. The computational simulation described here uses models of the positions and postures of exposed persons, which is an unprecedented trial. Further development of this method should lead to the new methodologies for precise dose estimation of exposure accidents.

The studies described in Section 4-4 are conducted under the joint-study contract entitled "Dose Reconstruction of Patients Exposed by the JCO Criticality Accident" which was agreed upon by the National Institute of Radiological Sciences and the Japan Atomic Energy Research Institute on February 1, 2000.

References

1) K. Kosako, et al.: FSXLIB-J3R2: A Continuous Energy Cross Section Library for MCNP based on JENDEL-3.2, JAERI-Date/Code 94-020, 1994.
2) Y. Yamaguchi: FANTOME-90: Shishikado Jintai Mokei wo Mochiita Koshi Gaibu Hibaku Senryo Keisan Kodo (Codes for calculating the externally exposed photon doses using humanoid models with movable arms and legs), Hoken Butsuri, 27, 143-148, 1992.
3) ICRU: ICUR Report 46: Photon, Electron, Proton, and Neutron Interaction Data for Body Tissues, 1992.
4) Nuclear Safety Commission: Committee Report of the JCO Criticality Accident, III-17, 1999. (In Japanese)



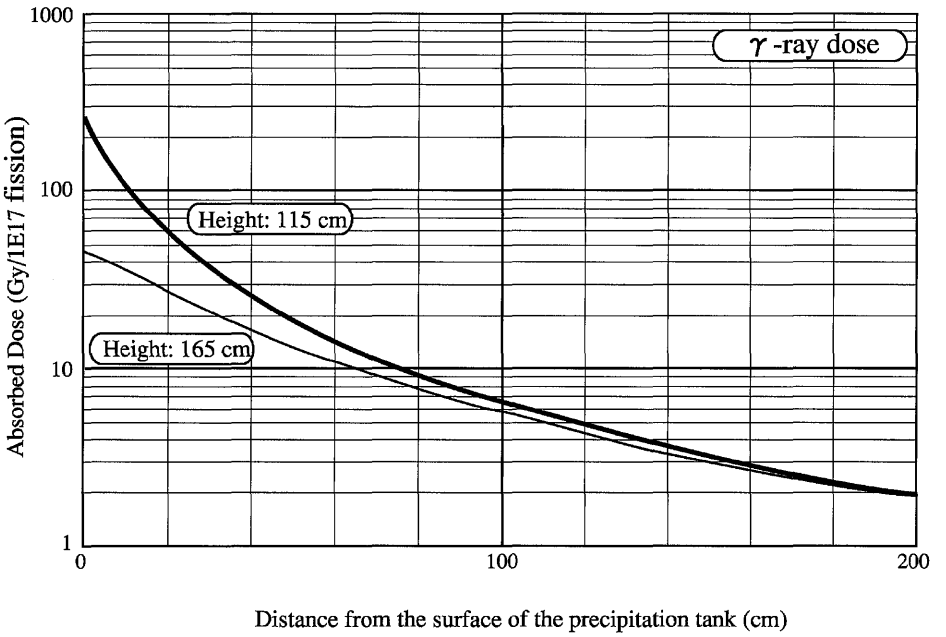


Figure 4-1 Tissue absorbed dose distribution in the space around the precipitation tank

Figure 4-3 Interim calculation models

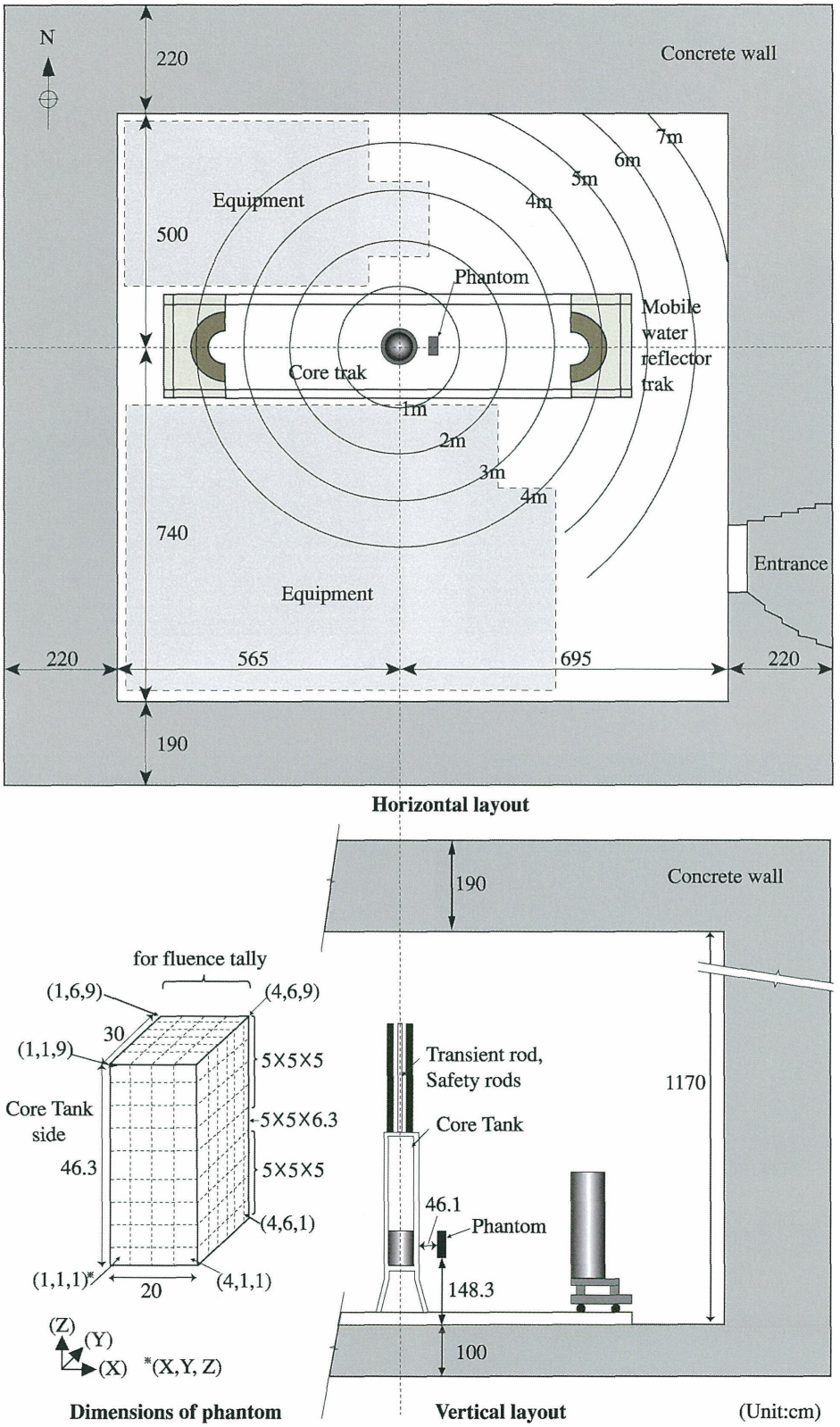


Figure 4-4 Layout drawing of the experimental devices

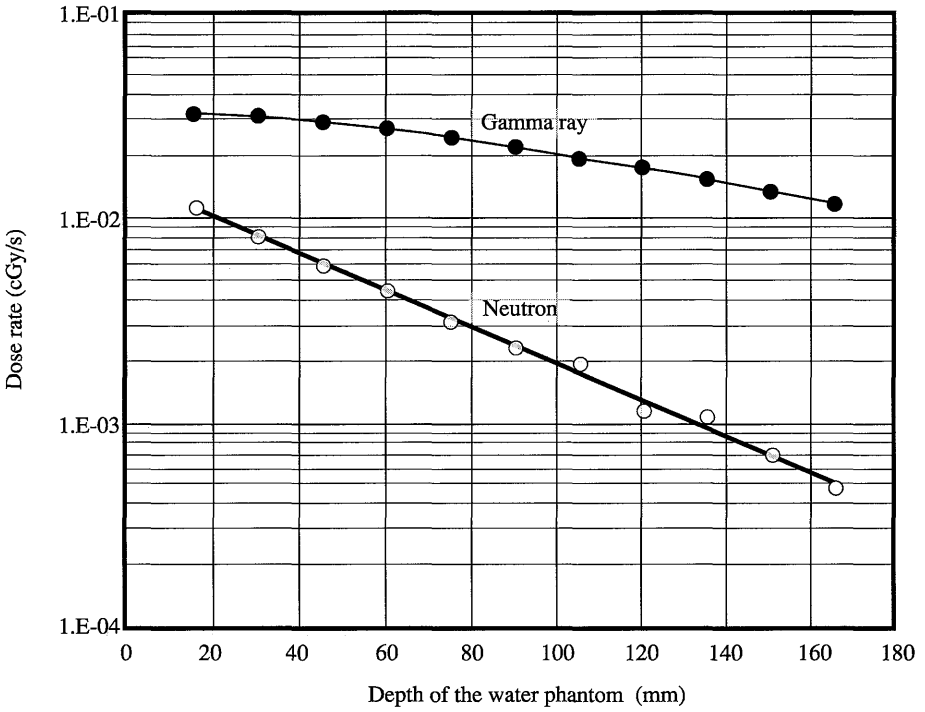


Figure 4-5 Measurements of the dose distribution to the deep part of the phantom

4-6. Dose Estimation of Interoral Tissues by the Dental Metals Activated due to the Neutron Exposure

After two patients (Patients A and B) were transferred, respectively, to the Tokyo University Hospital and the Institute of Medical Sciences of the University of Tokyo, both of the medical doctors reported that the patients had the severe inflammation of their interoral mucous tissues around some dental metals and questioned that these symptoms might be an acute radiation injury due to induced radio activities by thermal neutrons in the critical accident. They therefore requested NIRS to investigate the possibility of its irradiation. If it were the case, they would remove the metal as soon as possible. Dr. Nishizawa, Section head of the Human Radiation Environment Division, and Mr. Yoshida, Vice section head Technology and Safety Division, from NIRS visited the hospitals and measured the expose doses of each patient. The doses of interoral tissue were then estimated based on the measured results using some theoretical assumptions[1),2)].

Assuming that the irradiation was even on the whole body, neutron induced radio activities in the dental metals were estimated using thermal neutron fluences for each patient evaluated from ^{24}Na activity in their blood (91.3 Bq/ml for Patient B and 169 Bq/ml for Patient A)[3)]. The amount of sodium in the blood was assumed to be 1.9 mg per 1 g (1 ml) of blood.

(1) Metals within the oral cavity and nuclides that might have generated

Since the contents of each metal were not known, the average values of common fillers were used.

Table 4-18 Metal crowns on the lower right No. 5, 6, and 7 teeth of Patient B
The total amount of metals was assumed to be 15 grams.

Composition and ratio			Nuclides that were suspected for generation
Au	12%	1.8 g	^{198}Au
Ag	52%	7.8 g	^{108}Ag, ^{110}Ag, ^{110m}Ag
Pd	20%	3.0 g	^{109}Pd
Cu	17%	2.6 g	^{64}Cu

Table 4-19 Amalgam filling in the upper right No. 6 tooth of Patient A
The amount of amalgam was assumed to be 0.33 grams.

Composition and ratio			Nuclides that were suspected for generation
Hg	55.6%	0.183 g	^{197}Hg, ^{203}Hg
Ag	26.5%	0.087 g	^{108}Ag, ^{110}Ag, ^{110m}Ag
Sn	12.2%	0.041 g	
Cu	5.7%	0.019 g	^{64}Cu

(The radioisotope of Sn were not considered since the amount of their production was expected to be very small.)

(2) Exposure to gamma rays

It was assumed that the radioisotope existed as a point source at the centers of the teeth covered with the metals. The absorption by the teeth and the metals themselves were neglected. The doses were calculated at a specified distance from a point source. The tissue air ratio was assumed to be one.

①Calculation result for Patient B

·The calculation was performed only for ^{64}Cu, ^{198}Au, ^{110}Ag, and ^{110m}Ag using their emission rates and energies.
·The thickness of the tooth was assumed to be 10 mm and the dose estimation was conducted for a position of 5 mm away from a point source.

Table 4-20 Gamma-ray dose to which the interoral tissue of Patient B was exposed

Initial radioactivity		Half life	Air collision kerma-rate constant	Initial dose rate at 5 mm	Cumulative dose
MBq			μGy·m^2/h/MBq	mGy/h	mGy
^{64}Cu	3.24E-01	12.07d	0.0250	0.324	5.64
^{110}Ag	1.42E+04	24.57s	0.0041	2330	22.9
^{110m}Ag	8.12E-04	250.4d	0.3510	0.0114	98.7
^{198}Au	4.35E-01	2.7d	0.0547	0.952	88.8

②Calculation result for Patient A

Since the amalgam filling was at the cheek side of the tooth, the dose estimation was done for a position of 1 mm away from a point source.

Table 4-21 Gamma-ray dose to which the interoral tissue of Patient A was exposed

Initial radioactivity		Half life	Air collision kerma-rate constant[2)3)]	Initial dose rate at 5 mm	Cumulative dose
MBq			μGy m^2/h/MBq	mGy/h	mGy
^{64}Cu	4.33E-03	12.70 h	0.0250	0.108	1.968
^{108}Ag	2.30E+01	2.37 m	0.0023	52.6	2.99
^{110}Ag	2.94E+02	24.57 s	0.0041	1178	11.60
^{110m}Ag	1.70E-05	250.4 d	0.3510	0.006	51.5
^{197}Hg	3.81E-03	64.14 h	0.0079	0.030	2.78
^{203}Hg	6.88E-05	46.61 d	0.0308	0.002	3.41

(3) Exposure to beta rays

(a) The following tooth model was used for dose calculation

·Patient B: The teeth were assumed to be rectangular parallelepiped (10.8 mm depth, 11.4 mm wide and 7.9 mm height), The metal crown was supposed to cover the five faces of the rectangular parallelepiped except the bottom. The interoral tissue was assumed to contact with one of the faces. (Figure 4-7).

·Patient A: The teeth were supposed to be rectangular parallelepiped and the amalgam filling was assumed to be 3×3×1.5 mm. (Figure 4-8).

(b) The metal section that caused the exposure of the interoral tissue was assumed to be the side that was adjacent to the tissue with a thickness of the maximum range of beta rays within the metal. It was supposed that the internal tissue has absorbed half of the beta-rays emitted from this section. The absorbed energy was determined by calculation using the average energy of beta rays (Figure 4-6).

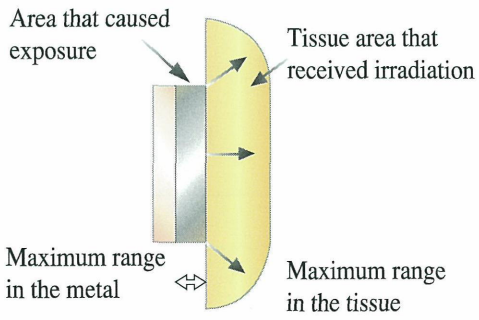


Figure 4-6 Calculation model for Patient B
Radiation source region and the area of the tissue that was exposed.

(c) The section of the tissue exposed to beta rays was assumed to be the region from the side that was adjacent to the metal and to the maximum range of beta rays in the tissue. The weight of the affected tissue was determined from the volume of this section assuming that the density was one (Figure 4-6).

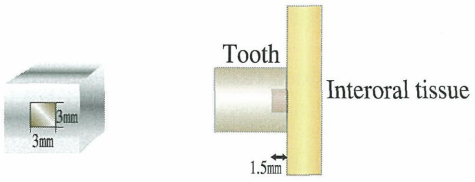


Figure 4-7 Calculation model for Patient A

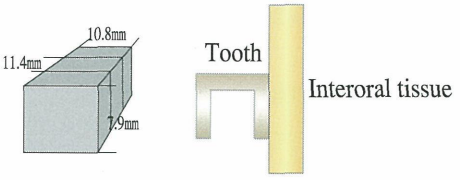


Figure 4-8 Calculation model for Patient B

(d) The absorbed dose [Gy = J/kg] was determined by dividing the absorbed energy [J] by the weight of the exposed tissue [kg].

(e) Results

Table 4-22 Estimated absorbed dose for Patient B

Cumulative activity		Half life	Maximum range in the metal	Maximum range in the tissue	Absorbed energy	Exposed region	Cumulative dose
Bq·s			cm	cm	J	kg	Gy
^{110}Ag	5.02E+11	24.57 s	0.137	1.44	9.92E-03	1.37E-02	0.73
^{108}Ag	2.25E+11	2.37 m	0.073	0.76	1.36E-03	3.37E-03	0.40
^{198}Au	1.46E+11	2.696 d	0.037	0.39	2.52E-04	9.24E-04	0.27
^{110m}Ag	2.53E+10	250.4 d	0.016	0.17	4.45E-06	2.51E-04	0.018
^{64}Cu	2.03E+10	12.70 h	0.022	0.23	7.99E-06	3.82E-04	0.021
^{109}PD	1.44E+10	13.46 h	0.040	0.42	2.97E-05	1.09E-03	0.027

Table 4-23 Estimated absorbed dose for Patient A

Cumulative activity		Half life	Maximum range in the metal	Maximum range in the tissue	Absorbed energy	Exposed region	Cumulative dose
Bq·s			cm	cm	J	kg	Gy
^{110}Ag	1.04E+10	24.57 s	0.059	1.44	3.16E-04	8.25E-03	0.038
^{108}Ag	4.70E+09	2.37 m	0.031	0.76	4.29E-05	1.54E-03	0.028
^{110m}Ag	5.29E+0.8	250.4 d	0.007	0.17	1.43E-07	5.25E-05	0.0027
^{203}Hg	3.99+08	46.6 d	0.002	0.05	2.46E-08	6.69E-06	0.0037
^{64}Cu	2.85E+08	12.70 h	0.009	0.23	1.67E-07	9.26E-05	0.0018

*^{197}Hg does not emit beta rays.

(4) Conclusion

The absorbed dose for interoral tissue of Patient A and B were summarized in the following table. Since many assumptions were used for the calculation, the results are likely to have large errors. The assumptions were made so as to derive higher doses. This calculation was urgently quickly conducted for the medical treatments, to examine whether high-level exposure was still continuing from the activated dental metals. The estimation was first conducted by using the various data that were available at that time. Later on more accurate data could be available and radiation doses were reconstructed using those data presented in the report by Kawachi et al.[3] The results shown here are the total doses summed up until all radioactive isotopes decayed. The weights of the dental metals were estimated based on the advice of dentists. Since most radionuclides were presumed to be short half-life, high-dose radiation exposure was likely to have occurred immediately after the accident, and radiation dose delivered later would not likely affect the medical care in the hospitals.

Table 4-24 Total dose

	Beta rays	Gamma rays	Total
Patient B	1466	216	1682
Patient A	74.2	74.2	148.4

(mGy)

References
1) Murakami, Y. et al. ed.: Hoshasen deta bukku (Radiation data book), Chijin Shoten, Tokyo, 1982.
2) Japan Isotope Association ed.: Aisotopu techo (Isotope handbook), Maruzen, Tokyo, 1996.
3) Kawachi, K. et al. ed.: Uran kako kojo rinkai jiko kanja no senryo suitei chukan hokoku (Intermediate report on the dosimetry of the exposed patients by the criticality accident at Uranium processing plant, National Institute for Radiological Sciences, 2000).

5. Making Decisions for Therapeutic Strategies

In Japan, the radiation emergency medical preparedness has three categories of facility which are primary medical facility, big general hospitals in the region, and a definite care hospital specialized for radiation emergency which is the National Institute of Radiological Sciences (NIRS). Victims with internal contamination with radionuclides or high dose-exposure are to be transferred to NIRS. As described, the Basic Plan for Preventing Disasters by the Central Disaster Prevention Council requires that the NIRS be in charge of organizing a network of advanced and specialized medical institutes, such as university hospitals, and should always be ready for radiation emergency and provide advanced medical treatments. The most important information for the treatment of victims of radiation exposure is the dose, the types of the exposure (whether it is only external exposure, or involves external or internal contamination), and the radionuclides. For example, the NIRS identified nuclides, such as ^{24}Na and others in the vomit and blood and investigated the belongings such as watches or mobile phones of the victims and clarified that it was in fact a criticality accident and that there was no contamination of radionuclides. One of the most important roles of the NIRS is to identify the type of exposure and examine contamination with radionuclides. Based on the estimation of doses and comprehensive evaluation of clinical diagnoses and the data of radiation accidents in the past, we are to predict the prognosis of patients, and draw up therapeutic policies.

Therapeutic policies for a victim of a radiation exposure accident should be drawn up by estimating the dose, the type of exposure, and the radioactive nuclides, which may cause further contamination. As described in the previous section, in the Tokai-mura accident, the dose rates on the surface of the victims' body were very small and the possibility of secondary radiation exposure of the medical staff was very low. In addition to this, since the patients showed prodromes of acute radiation injury, the medical staff decided to treat them in the general ward. The group in charge of estimating the physical doses found the existence of ^{24}Na from the belongings and vomit of the patients, analyzed the causes of the radiation that was found on the body surface, and concluded that it was very likely to be neutron exposure. This was a very significant factor for determining their therapeutic policies. It signified that it was possible to select treatments and medical facilities freely since there was no danger of causing further contamination. On October 1, which was the day after the accident, the NIRS called the Network Council for Radiation Emergency Medicine, and the first meeting was held at the institute. As described in detail in another section, the dose of Patient A who was exposed to the highest dose, was presumed to be, at least, over 10 Gy when converted into gamma rays. Since such a high dose suggested that self-recovery of bone marrow was difficult, the institute started to test his human lymphocyte antigens (HLA) immediately after he arrived in the hospital. Severe dermal injuries and failure of the digestive tract were likely to develop. Since systemic control was considered to be necessary, including treatment against increased vascular permeability, it was decided at the clinical meeting that was held at the NIRS in October 2 to transfer the patient to the hospital of the University of Tokyo, which can provide hematopoietic stem cell transplantation and intensive care. Members of the Network Council also attended the meeting.

In the morning of October 4, a meeting was held to discuss the treatment of the bone marrow injury of Patient B, which was suspected due to the high dose he was likely to have received, following Patient A. Since the estimated dose was not higher than 10 Gy, the discussion focused on the possibility of self-recovery and the indication of the transplantation of hematopoietic stem cells. The medical staff concluded that his bone marrow may recover, and even if the transplanted cells were consequently rejected, the transplantation is significant since the transplanted cells play a bridging role to prevent infection and bleeding, during the period when his own marrow was not yet active. Since there was cord blood stock that had relatively large number of cells and matched to Patient B's HLA, he was transferred to the Institute of Medical Sciences of the University of Tokyo, which has thorough knowledge of transplanting stem cells of cord blood. As with Patient A, Patient B also was likely to develop dermal injuries and failure of the digestive tract, and to

need systemic control. Therefore, physicians from Kyorin University and Nippon Medical School cooperated in the medical care as well as the physicians of the Institute of Medial Sciences.

The 3rd patient (Patient C) could recover his own bone marrow, and was not likely to show serious dermal injuries or failure of the digestive tract. Therefore, it was decided to treat him in a reverse isolating room at the NIRS using cytokine and other therapeutic methods. Considering that he was in a responsible position at the operation site, it was decided to provide mental and psychological treatment by psychiatrists.

6. Cooperation With the Network Council for Radiation Emergency Medicine and Other Medical Facilities

6.1. Network Council for Radiation Emergency Medicine

In May 1997, a chapter for nuclear accident countermeasures was added to the Basic National Plan for Disaster Prevention authorized by the government. Based upon the directive "The National Institute of Radiological Sciences (NIRS) shall establish a cooperative network to facilitate cooperation with external specialists in the area of radiation emergency medicine, and through this network shall improve everyday and emergency treatment systems by means of the exchange and dissemination of information, joint research, and the exchange of personnel", NIRS established the Network Council for Radiation Emergency Medicine in July 1998, and the first session was held in January 1999. The second session was held in July 1999 and deliberated upon a system of emergency medicine.

Immediately following the JCO accident, the Dr. Sasaki, Director-General of NIRS contacted Kazuhiko Maekawa, professor at the School of Medicine, University of Tokyo, Network Council Chairman, to enlist the assistance of the Network Council. Dr. Maekawa immediately came to NIRS and provided medical care for the patients. On October 1, the day following the incident, the NIRS convened the first meeting of Network Council for Radiation Emergency Medicine at the NIRS. To this meeting, other specialists of no member joined. Following this, reports were presented on the condition, assessment and treatment outcomes of the three radiation victims who had been transferred to the NIRS, and valuable assistance and advice were received through the meeting.

At a clinical meeting held at NIRS on the morning of October 2, in which members of the Network Council also participated, it was determined that the most critical of the patients needed a stem cell transfusion. The decision was made to transfer the patient to the University of Tokyo Hospital, where the transfusion and intensive treatment could be undertaken.

On the morning of October 4, it was decided at the clinical meeting to perform a cord blood cell transfusion on the next most critical patient. The patient was subsequently transferred to the Hospital of the Institute of Medical Science, The University of Tokyo, which specializes in transplant technology. The treatment was a cooperative effort between doctors from The Institute of Medical Science, Kyorin University, and Nippon Medical College.

The second meeting of Network Council for Radiation Emergency Medicine including specialists of non member was convened on October 12, at which time reports were presented on the course of treatment of the three patients, and on radiation dose evaluation conducted at NIRS. The third meeting of Network Council was convened on October 29, and the treatment and future treatment plan of the three patients was discussed. This session also saw the participation of specialists from the US, Russia, France, and Germany.

The new year saw the convening of the fourth meeting of Network Council on January 5, 2000, and the fifth one on February 9. At these sessions, the progress of the three patients was reported, and the public release of medical data was debated. On March 25, the sixth meeting of Network Council was convened, and the transfer of the patient undergoing treatment at the Hospital of the Institute of Medical Science, The University of Tokyo was discussed.

That such concerted cooperation between different medical facilities was possible was arguably the result of already existant lines of communication via the Network Council. Some reports were critical of the decision by NIRS, a tertiary treatment facility, to transfer the patients. However NIRS is primarily a hospital of radiation oncology and does not have the capacity, to conduct intensive treatment, and reliance on other facilities lent further strength to the construction of the network. Roles of NIRS in radiation emergency will be described later in this text.

6.2. The System of Cooperation with Other Medical Facilities

The damage caused by whole body exposure to radiation is not restricted to a single organ, but is complex in nature. The symptoms of acute radiation syndrome manifest within a period of weeks following exposure and affect the whole

body. Symptoms including bone marrow sicknesses, digestive tract dysfunction, damage to circulatory organs, and damage to the central nervous system appear respective of the radiation dose received. In addition, although not typical of acute radiation syndrome, damage to skin and eyes may also manifest. Exposure to radiation in excess of a certain dose often results in the manifestation of pneumonia after a period of months. Even at highly specialized facilities such as university hospitals, the treatment of high dose radiation victims is difficult. Furthermore, a medical remedy for the fear concerning high-level radiation exposure is important. For these reasons, the treatment of victims of high dose radiation exposure requires the cooperation of specialists from a various fields of disciplines. Recognizing the need for the cooperation of other highly specialized medical facilities, the Network was constructed and treatment performed cooperatively.

With the Department of the Emergency Medicine, The University of Tokyo Hospital, treatment was undertaken cooperatively with an entire hospital, and excreta of a patient and radiation protection for ward staff was managed based upon direction by the NIRS's Division of Radiation Safety. In addition, the possibility of exposure to radiation from dental crowns was considered. Estimation of radiation doses was performed by NIRS researchers and Division of Radiation Safety staff.

At the Hospital of the Research Institute of Medical Science, The University of Tokyo, Network members from Kyorin University Hospital and Nippon Medical School worked cooperatively in the treatment of skin damage and general body management. As was also the case at the University of Tokyo Hospital, the possibility of exposure to radiation from dental crowns and estimation of radioactive doses was determined by NIRS researchers and Division of Radiation Safety staff.

Since after the three patients arrived at NIRS, many other treatment facilities made available to the NIRS assistance in the form of personnel and equipment. The goodwill of the Teikyo University Ichihara Hospital and the Chiba Cancer Center provided monitors and other such medical equipment. The assistance provided by personnel other than doctors, including nurses and pharmacists, is discussed in other sections and thus will not be elaborated upon here. Treatment of bone marrow including the management in a reverse isolating room was undertaken by Nippon Medical College's Department of Internal Medicine III, evaluation of circulatory organs was performed by Chiba University's Department of Internal Medicine III, care of oral aspects such as gingivitis was the responsibility of Tokyo Medical University, and examinations and advice concerning mental care were provided by visiting doctors from the Department of Psychiatry, School of Medicine, Chiba University.

6.3. Cooperation from the Ministry of Health and Welfare and the Ministry of Education

On September 30, the three patients received high dose of eternal radiation were admitted to the NIRS. As the NIRS was not equipped to deal with the nursing and treatment of three such critical patients simultaneously, it experienced a shortage of nursing and pharmaceutical staff. On the request of the director of the Division of Radiation Heath (also Director of Division of Radiation Medicine), on October 1, Director of Division of Administration, and Section Head of General Affairs requested the assistance of the Ministry of Health and Welfare, and the Ministry of Education.

The responses of the two Ministries were both rapid and positive. The Ministry of Education, Culture, Sports, Science and Technology enabled the transfer of twelve nurses and one pharmacist from Chiba University Hospital, and the Ministry of Health and Welfare organized the immediate transfer of twelve staff from the National Hospital of Tokyo Disaster Medical Center. Following further efforts, the Ministry of Health and Welfare dispatched a further eight staff from the National Hospital Tokyo Disaster Medical Center, and another four nurses from the International Medical Center of Japan. The Ministry of Education, Science and Culture was also requested to dispatch an additional four nurses and one pharmacist from Chiba University Hospital.

Following the subsequent transfer of two of the patients to the University of Tokyo Hospital and the Hospital of the Institute of Medical Science, The University of Tokyo, the nurses and other transferred staff returned to their regular places of work. To enable 24-hour nursing of the most critical patients, large numbers of nurses were required. As a result of the rapid

responses of both the Ministry of Education, Science and Culture, and the Ministry of Health and Welfare, an adequate nursing system was maintained. As the timing of accidents cannot be foreseen and the dispatch of staff from their regular duties is indispensable, a system which provides for the highest level of cooperation is necessary.

6-4. Cord Blood Bank Network

The Japanese Cord Blood Bank Network was established in August 1999 from the 9 cord blood banks all over Japan (the Central and Fukuoka Red Cross Blood Centers, Tokai University Blood Bank, and the Hokkaido, Tokyo, Tokai, Hyogo, Chugoku-Shikoku, and Kanagawa Cord Blood Banks) aiming at always maintaining 20,000 cord blood stock available in 5 years, and setting its goal as the unitary control of the HLA data throughout Japan, which are necessary for cord blood transplantation, and performing all tasks necessary for safe and fair transplantation. The network, when it acquires the targeted number of blood, will be able to provide cord blood cells to 90 to 95% of patients waiting for blood stem cell transplantation. Up to the present, the network has over 3,000 stock.

Each cord blood bank collects cord blood, freezes and maintains the blood, determines blood types, performs blood tests, HLA tests, infection tests, and sterile tests, prepares a waiting list of patients for blood stem cell transplantation, controls data, collection and transportation of cord blood, and provides information concerning cord blood banks and blood stem cell transplantation.

Along with the establishment of the network, a computer system has been set up to integrate and share information concerning cord blood stock (HLA, cell numbers, and results of infection tests) which used to be independently controlled at each bank. With this system, physicians and medical institutes in charge of the patients who are waiting for stem cell transplantation can obtain the necessary information.

At present, the Japanese Cord Blood Bank Network has a web site with a page of "Open retrieval", which lists the banks that have available cord blood stock and informs about the number of available cord blood cells just by inputting the HLA and body weight of a patient.

The victims of the accident in Tokai-mura were suspected of severe exposure since they arrived at the NIRS. Therefore, the institute immediately communicated with the Japanese Cord Blood Bank Network. The system mentioned above informed the institute that the Tokai Cord Blood Bank had available cord bloodstock, and it has been transferred to the hospital of the Institute of Medical Science of the University of Tokyo for transplant to one of the patients.

7. Emergency Importation of Medical Supplies

Emergency importation of medical supplies was undertaken as a result of necessary medications not being approved in Japan, and due to short supply of other approved medications. In the wake of this incident, the following medical supplies were procured.

(1) Pentoxifylline (Trade Name Trental)

On October 2, Dr. Suzuki, former Section Head in the Division of Radiation Health, discussed with the Division of Planning and Coordination his need for a supply of the circulation agent Pentoxifylline. Approval for this medication had previously been revoked, and it had been withdrawn from the market. Information to the effect that the drug company Hoechst Japan had stored stocks of Pentoxifylline (trade name Trental) following its withdrawal from the market was obtained, and a request was made for its transfer to the NIRS. In addition, a request for assistance in obtaining the product was made of the Ministry of Health and Welfare through the Science and Technology Agency. The result of the kindness of Hoechst Japan and the cooperation of the Ministry of Health and Welfare and the Science and Technology Agency was the transfer of the Trental from Hoechst Japan to the NIRS.

The Trental transferred from Hoechst Japan were an oral medication, however due to further development of symptoms, the oral administration of medication became difficult, and on Friday, October 8, an injectable form of medication became a necessity. As no injectable form of Pentoxifylline was available in Japan, an inquiry was made by Dr. Akashi, Section Head in the Division of Radiation Health, to Hoechst Japan which resulted in the knowledge that both Hoechst Thailand and Hoechst Korea had stocks of the product. As the product had not yet been approved, it was necessary for individual doctors to take responsibility for the importation and use of the product, thus its importation by Hoechst Japan was not possible. As a result, the NIRS contacted the local corporations directly. Dr. Akashi attempted to contact Hoechst Korea, however contact was not possible due to the company being closed for a public holiday. Next, Hoechst Thailand was contacted. Following discussions, it was learned that they carried stocks of the injectable medication which they were happy to provide.

As the product was needed urgently, the establishment of importation means and the acceleration of paperwork was problematic. Concerning the means of importation, Mr. Hishiyama, Supervising Research Planner of the Division of Planning and Coordination, contacted the Ministry of Transport and received an introduction to a member of Japan Air Lines' (JAL) Administration Division. After discussing the situation, it was agreed that the product be transported by a JAL aircraft. As transportation of the product from Hoechst Thailand to JAL's airport counter would have to be undertaken, a request was made of Mr. Muto, Chairman of the Bangkok office of the National Space Development Agency of Japan, who readily offered his services.

Concerning the importation formalities, the Science and Technology Agency contacted the monitoring division of the Ministry of Finance's Customs and Tariff Bureau and the monitoring and guidance division of the Ministry of Health and Welfare's Pharmaceutical Affairs Bureau to request the most rapid clearing of formalities possible. Both Ministries gave their utmost support, promising to arrange for the immediate clearance of the product upon touchdown of the JAL aircraft. The product was carried on JAL flight 718 departing Bangkok at 10:30pm on October 8 and arriving at Narita airport at 6:20am the following day. As legalities required the product be collected by a doctor, Dr. Akashi departed for Narita airport early on the morning of October 9.

Obviously, no manual can be prepared for the emergency importation of pharmaceuticals, thus the process was undertaken by trial and error. This process was only made possible with the assistance of the Ministry of Health and Welfare, the Ministry of Finance, the Ministry of Transport, Japan Air Lines, the Science and Technology Agency, Hoechst Thailand, the National Space Development Agency of Japan, and others and we take this opportunity to express our gratitude to all those mentioned. In addition, in response to this incident, it was clear that government agencies worked together in unison, thus enabling the operation to be undertaken in an exceptionally smooth manner.

In November, more Trental was purchased from Korea's Handok Pharmaceutical Co., Ltd., following which further supplies were provided by Germany's Hoechst Marion Roussel. The Trental thus provided was not only given to the NIRS's Patient C, but also to Patient A, who had been transferred to the University of Tokyo Hospital, and Patient B, who had been transferred to the Hospital of the Institute of Medical Science of the University of Tokyo. In addition, the informed consent of the patients was obtained for the use of the drug.

(2) Cytokines

①Recombinant human GM-CSF (Granulocyte Macrophage Colony-Stimulating Factor) (Leukomax)

The Hospital of the Institute of Medical Science of the University of Tokyo team imported 50 vials of recombinant GM-CSF (400 microgram vials) from Ireland's Schering-Plough to be administered to Patient B for the treatment of radiation induced stomatitis. The product is used as an oral rinse. Leukomax is not yet approved in Japan, but has been approved in Europe and the US. However the pros and cons of oral administration of the product as utilized in this instance is still undergoing clinical trials in both Europe and the US.

②Recombinant human thrombopoietin (KRN9000)

The Hospital of the Institute of Medical Science of the University of Tokyo team organized the urgent supply and use of fourteen 50 microgram vials from Kirin Brewery Co., Ltd., in order to stimulate the patients' thrombocyte production. This drug is not currently approved in Japan, and is in the clinical trial stage.

In addition to this, the Hospital of the Institute of Medical Science of the University of Tokyo team also organized the urgent supply of Recombinant IL11 (YN294) (Yamanouchi Pharmaceutical) and stem cell factor (AMJ-9302) (Amgen Pharmaceuticals), however ultimately these were not used. Currently these two products have not been approved in Japan and are undergoing clinical trials.

8. Treatments and Progress

In the criticality accident at Tokai-mura three workers suffered from severe acute radiation syndrome and skin injuries. Patient A (35 years old, male), Patient B (39 years old, male), and Patient C (54 years old, male) were likely to have received whole body doses of 18 GyEq, 8.5 GyEq, and 2.6 GyEq, respectively (see the sections on dose estimation). Sympsoms also suggested exposure to high doses during the time of the accident. The patients were first transferred to National Mito Hospital and then to the NIRS. The first diagnoses and treatments of the patients were conducted after they arrived at the NIRS. Both Patients A and B were exposed to high doses throughout their bodies, and some parts of their bodies were likely to have received even higher doses. Patient C was exposed to a lower dose than the other two patients, and more uniformly throughout the body. The difference in doses led to great difference in prognosis. The two patients who were especially severely affected were treated by transplanting hematopoietic stem cells, intravenously applying high doses of L-glutamine (which enhances the growth of intestinal epithelial cells), applying pentoxifylline (Japanese name, Trental) to prevent lung injury caused by radiation, and using all other measures that were considered the best treatment at that time. The patients showed injuries attributable to high dose exposure. Although the patients accepted the stem cells that were transplanted, they were suspected of GVHD (graft-versus-host disorder), and showed complications such as globuliferous syndrome and ineffective erythropoiesis. These two patients showed characteristics of non-uniform exposure. The times that they showed skin injuries and their degrees, correlated with the doses to which they were exposed.

There has been no report of victims who survived for a long period of time after whole-body exposure during a criticality accident (9 days for the longest). In the criticality accident in Sarov, Russia, in 1997, a survivor died 66 hours after exposure. In exposure accidents other than criticality accidents, the only case was a patient who survived for 113 days after exposure to 10 Gy of ^{60}Co. Therefore, textbooks seldom describe medical treatments for patients who are exposed to over 10 Gy of radiation. We needed to treat the patients by responding to their conditions, which were changing day by day. The experience of treating the two severely exposed patients revealed that highly intensive care is needed, which requires a vast amount of human and material resources. It is difficult to decide to what extent we should apply medical treatments to a victim who is so severely exposed that he cannot survive. We hope there will be further debate about treatment of high-dose exposure victims.

Whole-body exposure to high doses causes acute radiation syndrome such as disorders of multiple organs. The therapeutic strategies for patients who are exposed to high radiation doses are changing with the progress of medicine. Bone marrow failure and skin injuries were considered to be the principal factors determining the prognosis. Transplantation of stem cells, such as cord blood transplantation, and skin grafts demonstrated more basic, but hidden factors. Even if the bone marrow and skin are successfully rebuilt, the disorders of the digestive tract and lungs must be cured to save victims of high-dose exposure. For the organs that cannot be restored, clinical methods such as transplantation and regeneration are indispensable. It was revealed that, to save such patients, complete restoration of the functions of the bone marrow, early diagnosis of skin injuries, prevention of fibrosis, and the introduction of effective measures to prevent fibrosis in the lungs are indispensable.

In the examination after transfer to the NIRS, all the three patients showed hypoxemia and hyperamylasemia six hours after exposure, and the two severely affected patients also showed hyperuricemia. The high activity of amylase, which is produced in the salivary glands, was likely attributable to radiation injury to the salivary gland. The causes for the hypoxemia and hyperuricemia are not known. Further studies are required. This section outlines the clinical courses of the three patients based on the published results. Please refer to papers published or to be published by the institutes in charge for more precise data.

8-1. Cases

(1) Patient A (35 years old, male)

Preliminary dose-estimation of this patient was performed immediately after he arrived at the NIRS, and it was determined that he required immediate transplantation of blood stem cells and intensive care of the whole body in a sterile environment. The patient was transferred to the Hospital of the University of Tokyo on the second day after exposure. The entire Hospital of the University of Tokyo was organized to support the medical care for this patient. On the third day after exposure, the number of peripheral lymphocytes reached 0. On the seventh and eighth days, the peripheral blood stem cells were transplanted from a family member with the identical HLA. On the 17th day after exposure, a marrow biopsy showed that the transplanted cells had been accepted. However, the patient needed transfusions of over 4,000 ml per day from the day of exposure. Hypoxemia that was attributable to pulmonary edema advanced, and on the tenth day after exposure, an endotracheal intubation was performed in the trachea for artificial ventilation. The skin injury was serious throughout the body. The radiation damage was so severe that the corium was exposed, secreting a large amount of body fluid. As an injury of the digestive organs, heavy diarrhea started on the 26th day and continued until his death, involving bleeding from the lower digestive tract from the 47th day and also from the upper digestive tract from the 50th day. Due to massive loss of body fluid from the skin and heavily bleeding from the digestive tract, the patient needed fluid therapy and transfusions of over 10,000 ml per day and precise control of the body fluid. Although the patient was immunologically deficient, complication by infection was totally controlled except on the last days. However, the bleeding from the digestive tract was fatal, which was attributable to the exfoliation of the entire intestinal mucosal layer. Although the patient needed a respirator until he died, the lungs had no apparent radiation injuries. The patient suffered complications of respiratory insufficiency, renal insufficiency, hepatic failure, and intestinal bleeding, and died on the 83rd day.

What we particularly noted in this case was the onset of gastrointestinal injury, which was anticipated, from the radiation dose, to have occurred much earlier. According to our knowledge at that time, an exposure to over 10 Gy should have caused the injuries of the digestive tract to appear four to five days after exposure. Our endoscopic biopsies of the upper (four times) and lower (six times) digestive tract showed a regeneration-like activity of the mucosa of the upper digestive tract on the 14th day and a regenerated mucosa in the seventh week. Although the effect of different radiation quality is unknown and neutrons may have special characteristics, the body received over 10 Gy of gamma rays during the accident, which should have been sufficient, in itself, to cause immediate injuries of the digestive tract. We should further investigate the effects of various therapeutic methods, such as sterilization of the digestive tract, administration of amino acids, and transplantation of peripheral blood stem cells.

(2) Patient B (39 years old, male)

The dose estimation suggested that the patient was likely to suffer severe bone marrow failure. We decided that the patient needed transplantation of hematopoietic stem cells. On the fifth day, the patient was transferred to the Institute of Medical Science of the University of Tokyo, and received cord-blood stem cell transplantation. The emergency medical staff of the Kyorin University, as well as the staff of the Institute of Medical Sciences, organized to support the radiation burn treatment and intensive care throughout the period of the treatments. This patient did not need the intensive care that was required in the case of Patient A. On the seventh day, the number of peripheral lymphocytes reached 0, and cord-blood stem cells were transplanted into the patient on the tenth day. To treat the bone marrow failure, cytokines were also applied, such as G-CSF (granulocyte colony stimulating factor), GM-CSF (granulocylte/macrophage colony stimulating factor),TPO (thrombopoietin), and EPO (erythropoietin) in addition to transplanting the blood stem cells. The transplanted stem cells were accepted, but the marrow of the patient was still functioning. The blood was in a chimera state, in which the blood of the patient and the donor co-existed, and consisted of almost 100% self blood cells two months after the accident. On the 153rd day, the patient suffered a complication of pneumonia by MRSA, which caused respiratory insufficiency. Bleeding from the digestive tract also started on

the 145th day and did not stop until his death. A temporary activity of cytomegalovirus was also observed. The patient, who survived the acute symptoms, showed disorders of lymphocyte activation and abnormal lymphocyte subsets. The patient was always immune deficient and needed a sterile environment. On the 194th day, the patient was transferred to the Hospital of the University of Tokyo.

Radiation burns such as redness and blistering were observed on the hands, face, and legs from the fourth week, slowly worsened during the subsequent two months, and caused the exfoliation of 67% of the skin by 70th day after the accident, which corresponded to a Class II burn. Therefore, we transplanted skin to the lesions that were judged unlikely to cure by themselves: the forearms and the lower legs. On the 80th day, we performed cadaver allograft to the forearm sections of a Class IId burn (15%). On the 88th day, we transplanted his own auto graft, which had been cultured and provided by Dr. Inoguchi of Tokai University Hospital, on the lower leg lesions of a Class IId burn (20%). Both the allografts and autografts engrafted well (over 90%), and notably improved the condition of the whole body. On the 120th day, autograft was performed on the face, which almost entirely covered the wound in one month. These engrafted skin layers were not rejected and remained until he died. However, strong fibrosis and sclerosis appeared on the skin throughout the body during the subsequent subacute period.

After the 150th day, the patient showed enlargement of the pharynx, which made it difficult for him to swallow. Although his acute respiratory insufficiency temporarily became better, the respiratory condition progressively worsened from the 200th day. The irreversible hypoxemia was fatal despite of all efforts, and the patient died on the 211th day in the Hospital of the University of Tokyo due to multiple organ failure.

(3) Patient C (54 years old, male)

When the criticality accident occurred, Patient C was sitting in the corridor with a thin wall screening the precipitation tank. Although the tank was out of the sight, he saw "a flash of blue light" reflecting on the machine panels, heard the warning alarm to γ-rays, and was aware of the accident. After Patients A and B were evacuated, Patient C remained at the site for approximately five minutes trying to make emergency calls and peeped into the precipitation room several times. Since he was walking in various directions around the place during this five-minute period, we imagine that he was likely to have been relatively uniformly exposed throughout his body.

During the period between the accident and the time he arrived at the NIRS, Patient C felt no symptoms except a mild nausea when he was in a helicopter. In the NIRS, the patient showed reduction in the number of lymphocytes, rises in serum amylase value, and drops of the oxygen partial pressure in the arterial blood. Since our dose estimation suggested that marrow failure was the most serious issue for him, we immediately applied granulocyte-colony stimulating factor (G-CSF), sterilized the digestive tract to prevent infections from the tract, applied an antiviral agent as a preventive measure, dosed L-glutamine to enhance the regeneration of the gastrointestinal epithelium, and administered pentoxifylline to improve the circulation of the peripheral blood. As a result, the number of leucocytes and platelets showed a constant and self-sustaining recovery after October 20, which marked the bottom. From October 19 to 27, the patient was put under reverse isolation. The patient needed transfusion of platelets several times. He did not show serious infection or complications such as bleeding. Temporal epilation and fragile oral mucosa were observed but were not serious. The patient steadily recovered and left the hospital on December 20. We obtained the cooperation of ophthalmologists, dermatologists, and cardiologists and diabetes specialists from Chiba University, and dentists from Tokyo Dental College. The patient received periodical counseling by Chiba University psychiatrists.

8-2. Nursing system

(1) Nursing of the patients

Patients A and B, who were severely exposed, were sent to reverse isolating rooms, and Patient C was received in a low-pressure room. Since the patients needed to be cared for by nurses who were familiar with radiation emergency medicine, the nursing system was changed from three shifts to two shifts, as is stated in the radiation emergency manual.

The patients needed care as patients with internal contamination since high dose exposure

to neutrons induced the stable elements in their bodies to activate. Excrements, specimens, instruments, tools, linens, and garbage were kept and treated following the orders of the Division of Radiation Safety. The nurses were always aware of the three principles of radiation protection, and wore film badges and portable dosimeters during the care. The patients received frequent and first aid treatments and tests to save life and to estimate the doses.

Tests and treatments:
Electrocardiogram, Chest X-P, Blood sampling, Gas analysis of the arterial blood, Blood cell count, CT, MRI, Bone marrow aspiration, Ensuring the transfusion line, Inserting the IVH line, Inserting the urinary catheter, Withdrawing urine, Controlling supplemental oxygen, Measuring oxygen saturation in the blood, Measuring central venous pressure, Transfusion, Blood transfusion, Controlling the IVH line, Controlling transfusion and syringe pumps, Collecting and sampling urine specimens (submitted to the Division of Radiation Safety), Sampling oral and nasal swab (submitted to the Division of Radiation Safety)

Nursing activities:
On the day of the accident, the nurses helped with and conducted the aforementioned tests and treatments until midnight. Tests and treatments were similarly conducted on the next and subsequent days.

The nurses also performed:
Vital sign check (every hour) using the observation charts for serious patients, blood transfusion, preparation and control of transfusion preparation of internal medicines, assistance with taking the medicines assistance with taking sterilized food, assistance with taking water, assistance during urination and evacuation (checking occult blood in excrements) Wiping (Many towels, bath towels, and test wears were necessary since they were kept in the Division of Technology and Safety.) Changing linens, Cleaning the rooms, Controlling and keeping sterilized items

The emergency treatments that were required in ICU were conducted, such as checking the vital signs every hour, and observing and treating the radiation injuries of the patients. Patient A, especially, was suffering such severe diarrhea that a portable toilet was useless, and diapers were used. The nurses wiped the patient clean every time he evacuated. As well, the patient had the strong apprehension of most patients about radiation injuries, strong sentiments for the family, and discontent about frequent tests, so we asked him to cooperate by giving explanations many times, and providing repeated mental support. The nurses communicated to the families of the patients by telephone, arranged the schedules for the visits of family members, and attended while the police asked questions.

On the day of the accident, physicians, experts of radiation protection, radiation experts, and members of the Division of Radiation Safety entered and left the rooms until midnight. The next morning, diagnoses by the Director General and other physicians were begun. The nurses assisted the doctors.

On October 2, at 15:30, Patient A was transferred to the hospital of the University of Tokyo for hematopoietic stem cell transplantation.

At the network meeting on October 1, it was decided that the number of nurses be increased, and three new nurses joined from the second shift on October 2. At 20:30, Patient B was temporarily transferred to a low-pressure room since the reverse isolating room was to be disinfected by a company. After disinfections, at 3:00, Patient B returned to the reverse isolating room. Thereafter, the hand-washing procedures equivalent to those for operation rooms were needed to enter the sterile rooms. The nurses assisted many physicians, experts of radiation protection, and other nurses to wear gowns. The second group of new nurses arrived at 23:00, once they had received the training program that was given by the Division of Radiation Safety.

On October 4, Patient B was transferred to the Institute of Medical Science of the University of Tokyo to receive cord blood transplantation.

Only Patient C remained in the NIRS. Semi-sterile control and a number of treatments and tests were continuously conducted. Three weeks after exposure, Patient C was transferred to a reverse isolating room, since the activity of his bone marrow had dropped to the lowest level. Patient C entered in the reverse isolating room after bathing in iodine solution. The patient continuously received the counseling of a specialist, and the nurses attended the sessions.

Mental care was necessary not only for the patients but also for their families.

(2) Working systems

As described above, the working shift was changed from three shifts to two shifts according to the radiation emergency manual. At least two nurses were needed for care in the reverse isolating rooms on the day of the accident and the next day, but only one nurse was available due to a shortage of nurses. General ward nurses provided care to the patient in the low-pressure room.

Nurses sent through the Ministry of Health and Welfare
- Three nurses from the National Hospital of Tokyo Disaster Medical Center October 2–5
- Four nurses from the National Tokyo Medical Center October 3–8
- Four nurses from the International Medical Center of Japan October 4–8

After the new nurses arrived, a nurse of the NIRS and a new nurse formed each team and cared for the patients. Two-shift rotations in tense situations were very tiresome for the nurses, and this continued for one week. Thereafter, the rotation reverted to the ordinary three shifts. The nursing teams for the patients continued even after the support nurses returned to their hospitals, and were finally released on October 27. Each nurse worked 12 to 13 night shifts in October.

(3) Care of patients in the other wards

On October 2, the Director of the Division of Radiation Health and the general chief nurse explained the situation to the other patients in the hospital to relieve them from apprehensions, and asked for their cooperation. The institute asked the Chiba-Prefecture Nurse Association to send volunteer nurses. Two nurses arrived and helped the general patients to and from their various tests and provided mental support to the general patients by communicating with them.

(4) Summary

This accident made us consider requirement of a nursing system equivalent to one for internal contamination, since high-dose neutron exposure induced activation of elements in the body, including ^{24}Na. Exposure of medical staff to the activation was negligible, and it was possible to treat the patients as externally exposed patients. Therefore, the patients were cared for in a general ward. The nurses obtained the cooperation of the general ward nurses, but the number of night shifts greatly increased. The support of the nurses sent by the Ministry of Health and Welfare and the Ministry of Education was a big help.

A network of nurses should be established to deal with emergency treatment of radiation exposed patients. The nurses executed their work, always aware of the three principles of radiation protection. Adequate instructions by the radiation protection experts led to smooth and rapid execution of the nursing.

In nursing of exposed patients, it is important to observe and treat the acute radiation syndrome and to provide mental care to the patients, who feel apprehensions about their disorders and their prognosis and are experiencing anguish about the causes of the accidents. All nurses and staff members of the NIRS should be trained, and thereby acquire the knowledge and skills necessary to qualify the Institute to act as a Class 3 facility for radiation emergency.

8-3. Radiation injuries

(1) Radiation burns

Injury to the skin by radiation is called a radiation burn. This is a factor determining the prognosis of a victim, especially when the victim received a whole body exposure. The accident in Chernobyl in 1986 caused severe skin injuries to 56 persons. Of these 56, 13 showed radiation burns on over 50% of the total body surface. This accident and the accident in Goiania caused burns to the shallow skin layers by nuclides emitting beta-rays and burns to the deeper skin layers by gamma-ray nuclides. The combined effects of beta- and gamma-rays made the skin injury very difficult to cure. These accidents also revealed that the degrees of burns vary depending on the thickness of the skin.

①Radiation burns and thermal burns

Radiation burns are different from thermal burns in various aspects (Table 8–1). Thermal burns cause prompt pain, severe inflammatory response, death of the affected cells, and destruction of the tissue. On the other hand, radia-

tion burns cause no prompt pain, and we know the death of the cells and tissues are not apparent until the epidermis exfoliates due to the cessation of cellular regeneration. Thermal burns usually involve injury of all types of cells and tissues within a certain range. However, the effect of radiation is not uniform and depends on the sensitivity of the cells that constitute the skin. In both types of burns, the degree of injury is determined by the total amount of energy deposited in the tissue, rate of energy deposition, and the area of the skin lesion that is affected. When radiation burns and thermal burns are compared, heat needs 10 to 100 times more energy than radiation to cause a similar degree of injury. For example, heat of 4 Cal/cm^2 delivering the skin at a depth of 1 mm from the surface causes Class 2 burns. A gamma-ray dose of approximately 30 Gy is needed to cause a similar burn, which is equivalent to 0.0126 Cal/m^2 of heat. A very high temperature causes proteins to coagulate, flames to oxidize carbohydrates, lipids and proteins, and water to evaporate. The effects of radiation on living tissues are more non-specific. Radiation causes both acute and latent injuries of the subcutaneous and dermal tissues and causes disorders of blood vessels.

Table 8-1 Radiation burns and thermal burns

	Thermal burns	Radiation burns
Symptoms	Prompt pain Severe inflammatory reaction Death of the all types of cells Destruction of the tissue	No prompt pain (before the epidermis exfoliates after cessation of regeneration of the cells)
Damage	Damage to all cells and tissues Damage due to high temperatures	Non-uniform damage (sensitivity varies by cell) Non-specific damage
Energy (Class 2 burns)	High (4 Cal/cm^2)	Low (0.0126 Cal/cm^2 (30 Gy))

②Symptoms of radiation burns

The initial symptom is redness (erythema), which is usually transient (Table 8-2). Redness usually appears after an exposure of over 2 Gy. Itching, stiffness, pinching, or stretching skin may follow this, all caused by the swelling of the skin. Injured cells produce substances which cause dilatation of vessels and release chemicals that enhance permeability, causing redness and edema of the skin. These initial symptoms occur prior to changes in the skin and the vasculature. The victims of the JCO accidents also mentioned such feelings on the skin. As time progresses, various symptoms appear, such as depilation, pigmentation, desquamation, blistering, cellular death, and algetic ulceration, which is caused by the inhibition of the growth of the epidermal cells, although the symptoms vary depending on the dose. Radiation sometimes causes damage to the cells of the basal layer, which undergo active cell division.

When the endothelial cells of the affected lesion are damaged, inflammation reactions prolong, endothelial cells swell, vessel porosity increases, and clots are formed. Finally, the endothelial cells of the small arterioles and capillary vessels proliferate. However, these symptoms, except for redness and edema, appear only after atrophy of the tissue, healing failure, and tissue failure due to diminished circulation. It is possible to estimate the dose which a patient received if sufficient information is provided about the exposure and symptoms of the patient. However, most locally exposed patients are not aware of the exposure until symptoms appear, and in such cases there is little information about when they were exposed, to what kind of ray they were exposed, to how much they were exposed, and for how long they were exposed.

Table 8-2 Dermal reactions by radiation and treatments

	Class 1	Class 2	Class 3	Class 4
Typical symptoms	Redness, Epilation (slight erythema)	Strong Erythema	Blistering, Erosion	Ulceration
Dose (Gy)	Less than 3-4	6-15	20-25	Over 30
Period until symptoms appear	3 weeks	2 weeks	1 week	2-7 days
Duration	3-4 weeks	4-5 weeks	6-7 weeks	Continuous
Initial reactions	Dry	Congestion, Erythema, Swelling, Epilation	Strong erythema, Swelling, Blistering, Erosion	Deep red erythema, Blistering, erosion, Non-regenerating ulcers
Late reactions	Pigmentation, Recovery of depilation	Pigmentation, depilation, desquamation	Destruction of the sebaceous and sweat glands, Etrophy of the skin, Dilatation of capillary vessels, Easy to form ulcers	Cicatrisation accompanied by pigmentation, Dilatation of the capillary vessels at the periphery, Ulcers that are difficult to cure in the central lesion
Treatments	Conservative treatments	Conservative treatments and Symptomatic treatments	Treatments for Class 3 thermal burns	Skin grafts, Plastic surgery

③Injury by the different quality of radiation

The corneal layer protects the basal layer from alpha-rays. For example, alpha-rays of plutonium penetrates only a distance of approximately 0.04 mm within soft tissues, and do not reach the basal cell layer of the epidermis. However, exposure cannot be neglected since the skin possibly absorbs the contamination of the alpha emitters and there is a possibility of exposure to beta- and gamma-radiations of the daughter nuclides. Loose contamination with alpha-emitters on skin may result in an ingestion and inhalation hazard. Most beta-ray radiation is reduced while they pass through a tissue 1 mm thick, and the amount of beta-ray that reaches the subcutaneous tissue from the surface is small, but causes damage to the basal layer. This is the beta-ray burn, which was seen among victims of the Chernobyl accident.

On the other hand, X-rays, gamma-rays, and neutrons, which are penetrating rays, reach and cause damage to the epidermis, subcutaneous tissue, muscles, and even the bones. Damage to the muscles may involve myoglobulinemia. Exposure of the skin to high doses of beta-, X- or gamma-rays (of over several Gy) leaves damage to the capillary vessels within the dermis.

④Blood circulation in the skin after radiation exposure

Exposure to radiation, especially to penetrating radiations, hinders the blood circulation at the affected skin lesions due to various reasons. The tissue is swollen, which compresses the capillary vessels; released chemical substances cause the vaso-constriction. The blood circulation is further reduced by occlusion of vessels by damaged cells or multiplied cells. Circulation of

the blood is sensitive to temperature; it decreases at low temperatures. Low temperature accelerates the formation of shunts, and reduces the amount of blood flow that circulates and nurses the skin surface. Blood circulation is also decreased by apprehension and stress since the sympathetic nerve system releases epinephrine, which causes vaso-constriction of the skin. The circulation at the radiation-exposed skin lesion is also affected by smoking (nicotine causes blood vessels to constrict), diabetes, several kinds of anemia (such as sicklemia), and diseases of the peripheral blood vessels.

References
1) Berger ME, Hurtado R, Dunlap J, Mutchinick O, Velasco MG, Tostado RA, Tostado RA, Valenzuela J, Ricks RC. Accidental radiation injury to the hand: anatomical and physiological considerations. Health Physics. 72(3): 343–348, 1997.
2) Management of Accidentally Contaminated with Radionuclides. NCRP Report No.65, 1993.

(2) Blood stem cell transplantation

There are three methods that are widely used to transplant hematopoietic stem cells: bone marrow transplantation, peripheral blood stem cell transplantation, and cord blood transplantation. Bone marrow transplantation is the method that has the longest history among these three, and can be thought to be the most established method. The procedure is to aspirate the bone marrow fluid from the donor and inject the cells into the veins of the recipient. However, this method greatly affects the donor, who should be under general anesthesia during bone marrow aspiration. Transplantation of peripheral blood stem cells is a relatively new method. The procedure of this method is to collect blood stem cells in the peripheral blood of the donor by administering granulocyte colony stimulating factor (G-CSF: a factor that stimulates hemopoiesis) for several days, separate the fraction that contains many hematopoietic stem cells, and inject the fraction into the vein of the recipient. Compared to the bone marrow transplantation, this method has various advantages, such as 1) the number of hematopoietic stem cells provided to the recipient is large, 2) it takes a shorter time for the transplanted cells to graft, and 3) the donor is less affected. However, the donor may experience severe bone pains during the period of G-CSF administration and other side effects. Stem cell transplantation from cord blood is also a new method. The procedure is to collect the stem cells from the umbilical cord after the birth of a baby, identify the HLA type, keep the blood in a cord blood bank, and inject the cells which match patient's HLA into the vein of the recipient. Cord blood is known to contain high concentrations of hematopoietic stem cells. Theoretically, there are as many donors as there are numbers of newly born babies. Another advantage of this method is the slight GVHD (graft-versus-host-disease). However, this method has disadvantages, such as 1) the number of hematopoietic stem cells is relatively small, 2) it takes long for the cells to graft, 3) the past history of the donor is unknown, 4) it is costly to establish and maintain cord blood banks, and 5) in some cases, there are moral restrictions to handling cord blood. From these hematopoietic stem cell transplantation methods, a method is selected considering the availability of donors and policies of the medical facilities.

There are several significant differences between ordinary hematopoietic stem cell transplantation and transplantation to a victim in a radiation exposure accident. First, for ordinary hematopoietic stem cell transplantation, administration of immuno-suppressants and whole-body irradiation to a recipient is required. On the other hand, there is no clear consensus on how to use immuno-suppressants for the patients of radiation exposure. Moreover, it is very difficult for victims in radiation accident to be treated with whole-body irradiation. Unlike planned irradiation, a whole-body exposure during an accident is always non-uniform. Therefore, victims who are exposed to such high doses as cause bone marrow failure possibly retain parts of their own hematopoietic tissues. The degree of GVDH is thus difficult to estimate, and the rejection of transplanted cells is frequent. It is also highly possible that the patients show radiation injuries other than bone marrow failure.

Therefore, there is an opinion among specialists that victims of such a high dose exposure as requires blood stem cell transplantation usually die due to failures of organs other than the bone marrow and that transplantation is useless to save the patients.

Hematopoietic stem cell transplantation has been conducted for victims of several radiation accidents in the past. In the accelerator accident in Pittsburgh in 1957, bone marrow was transplanted to a victim from his identical twin

brother, and the patient survived. However, there is no clear evidence that the transplanted cells were actually taken. In the Chernobyl accident in 1986, thirteen victims received bone marrow transplantation, and five received fetus hepatocyte transplantation. Only two patients survived, while they rejected the transplanted cells.

There is no clear record in history that the blood stem cells that were transplanted to victims of radiation accidents actually settled in the bodies of the patients and caused them to survive. These transplantation attempts were made a long time ago, as a whole, and the methods used were either fetus hepatocyte transplantation or bone marrow allograft transplantation. The principal histocompatibility matching was likely insufficient in most of these attempts.

The IAEA Safety Reports Series No. 2 (1988) describes the effectiveness of bone marrow transplantation to radiation exposed patients as limited and states that bone marrow transplantation should be a choice for patients who are uniformly exposed to 8–12 Gy and who do not show severe skin injury, internal contamination, or other complications. The report does not mention other transplantation methods. In conclusion, there is no consensus that the latest methods of bone marrow stem cell transplantation are effective for patients of radiation exposure accidents since transplantation medicine is rapidly progressing. Transplantation may be conducted with an awareness of the possibility of rejection, and could be a go-between procedure aiming to temporarily support the immune system of the patient until the bone marrow of the patient restores, and to make it highly possible for the patient to overcome failure of the digestive tract and skin injuries.

(3) Failure of the digestive tract

High-dose exposure to the whole body or the abdominal part of the body causes disorders of the digestive tract within several days to two weeks. The dose range that causes failures of the digestive tract in humans is believed to be 6–10 Gy or more. Following the prodromal period, the patient shows anorexia that reduces or inhibits drinking and eating, diarrhea, paralytic ileus, nausea, vomiting, abdominal flatulence, reduction of intestinal absorption, dehydration, and electrolyte unbalance. Severe cases may show complications of acute renal failure and circulatory failure. Bone marrow failure, which is caused by a lower-dose exposure, causes the digestive tract to bleed easily and become infected. If not properly controlled, the symptoms advance to gastric bleeding and septicemia, which are fatal.

Radiation injuries of the digestive tract are attributable to the reduction of epithelial cells within the digestive tract. The reduction is caused by the stem cells of the intestinal crypt losing their regeneration ability due to high dose exposure. In other words, new matured cells are not supplied to the villi, which are constantly supplied with the cells in a normal state. The epithelia cells remain on the intestinal villi for only three to four days. When the supply from the stem cells stops, a drop in the number of epithelial cells starts on the third to fourth day, and the symptoms appear. Judging from past cases, the symptoms appear after the fourth day of an exposure to over 10 Gy, and after the seventh day with 6 to 10 Gy.

According to the law of Bergonie-Tribondeau, the higher the frequency of cell division, the higher the sensitivity of the cell against radiation. In the intestinal mucous membranes, the stem cells of the crypt divide most frequently. Thus, it can be thought that these cells are highly sensitive against radiation. Cells lose their regeneration abilities depending on the dose they receive. An autopsy of a monkey (over 15 Gy) showed that ulcers and atrophic mucous membranes of the stomach and colon were the most notable abnormalities.

Therapy for digestive tract failures should be conducted along with the treatments for bone marrow failure. Patients should be controlled under sterile conditions and with total parenteral nutrition (central venous nutrition, elementary diet, etc). When necessary, such things as wide-spectrum antibiotics, antifungal agents, anti viral agents, cytokines, transplantation of blood stem cells, transfusion of blood components, or correction of the metabolisms should be given. Animal tests show that an exposure to over 6 Gy causes intestinal bacteria to invade the body. Accordingly, selective intestinal sterilization should be conducted on human patients who are exposed to doses of over 6 Gy soon after the exposure. Mass application of L-glutamin has been reported to be effective to promote the regeneration of the intestinal mucous membranes. However, patients who were exposed to over 8 Gy of radiation have shown a very poor

prognosis. This is because the failure of the digestive tract was not the only cause of the death, but various factors, such as bleeding and infection, affected the whole body severely. The other organs are also prone to suffer failure. After the acute period of the digestive tract failure, the lungs are frequently affected by a dose of over 8 Gy, which is another cause of death.

References
1) Radiation Emergency Medicine-from RI facilities to nuclear power plants. I Nakao, Editor, Soft Science Co. Ltd., Tokyo (In Japanese)
2) UNSCEAR Sources, Effects And Risks of Ionizing Radiation-UNSCEAR 1988 Report
3) REACT/TS, Handling of Radiation Accidents by Emergency Personnel (Reference Manual)

(4) Mental care

①Victims of a radiation accident

The mental states of the victims of radiation accidents are very peculiar in several respects. Firstly, in accidents within facilities, such as was the criticality accident in Tokai-mura, the patients may not only be the victims of the accident but also the persons responsible for the accident, and are put in a difficult social position. The patients are affected by the interest of the public in the accident, which may cause a more serious effect than the exposure itself. The patients may suffer from factors other than radiation. Many physicians and other persons concerned visit the patients, which means they are forced to endure unpleasant visits every day against their will. Members of the press and other communication media often go too far, reporting incorrect information, and sensationalizing the accident, which are very frequent in reports soon after accidents. It is a big issue to protect the patients of radiation accidents from such meaningless stress.

Besides these stresses due to the uniqueness of the condition, the patients suffer from apprehension about their own physical states, since acute radiation syndrome is very unique and is difficult to understand even if physicians explain them in detail. Therefore, sufficient consideration and measures should be taken to reduce the apprehension and fear caused by the rapidly progressing symptoms and drastically changing environment. A fiduciary relationship should be created between the patient and the physician in charge. It may be effective to limit visits to only those that are indispensable, and to separate the patients from mass communication media. Advice and consultation of psychiatrists are also important.

②Effects of radiation on the mind and the nerve system

Nerve cells belong to the least sensitive to radiation. Textbooks state that an exposure to a dose of over 20 to 30 Gy causes immediate acute prodromes and various mental and nerve disorders, such as emotional torpor, lethargy, excitement, tremor, spasm and walking disability, and that the victims suffer circulatory collapse and die early. This description is based on the several criticality accidents in the 1950s and 1960s. Since no pathological abnormality of the nerve system was observed even in the cases that showed nerve disorders, these mental and nerve syndromes are likely to be the secondary effects of insufficient circulation of the entire body and edema. Animal experients showed that an exposure to much higher doses causes direct damage to the central nerve system, but there is no record of such a high dose exposure for humans. However, there may have been such cases among victims of the Hiroshima and Nagasaki bombings who were hit very near the blast center.

9. Protection from Radiation in Medical Facilities

(1) Radiological survey in facilities

The three patients who were transferred to the NIRS were determined for radioactivity thoroughly out the body at the Medical Care Unit for Radiation Emergency (alpha-, beta- and gamma-rays). The activities were also determined from the belongings of the patients. The patients were received in sterile rooms of the Hospital of Charged Particle Therapy. Visitors to the sterile rooms were restricted. Radiactivities were also measured in the vomitus and excrement of the patients, devices that were used to transport the patients, and persons engaged in first-aid treatment of the patients (members of the NIRS, attendants, a physician of the National Mito Hospital, and the ambulance staff of Fire Department of Chiba City).

To prevent physicians, nurses, and persons concerned (including the families of the patients) from being exposed to radiation, scintillation survey meters were installed 1) near the body surfaces of the patients (on the blankets), 2) in front of each sterile room, and 3) antiroom, the preparation room, the hall, and near the boundary of the area (Figure 9-1). Survey meters and portable dosimeters were kept on hand at the entrance of the area, and persons entering the area were requested to wear the devices to understand their exposure (Figure 9-2). The cumulative doses were measured in and near the rooms using TLD's (Figure 9-3).

The radiactivities of medical wastes, linens (sheets, covers, and pajamas), and excrement were measured each time they were collected. The wastes and linens were temporarily kept in the Medical Unit for Radiation Emergency, and the excrement was kept within a freezer of the radiotoxicology building to prevent decomposition.

(2) Management of the blood, excrement, and wastes

The vomitus and excrement of the patients, which were collected during transportation, and the excrement that was produced in the hospital were also temporarily kept in a freezer of the radiotoxicology building since they would be used for a long period of time as specimens for estimating doses, etc. Since long-term observation was anticipated, the specimens were frozen. The excrement of the three patients (several liters of urine per day per person) was collected at least once every day and kept separately for each patient.

Approximately one month after exposure, the amount of specimens that accumulated was 1) approximately 1.5 m^3 of medical waste, 2) about 3.0 m^3 of waste for safety control, 3) approximately 1.5 m^3 of linens, and approximately 3.0 m^3 of excrements.

Our experience revealed the necessity for preparing sufficient room for keeping wastes, specimens, and other matters since they may need to be kept for a long period of time and there may be more patients. Reduction of the volume and efficient storing methods should also be considered.

When the patients were transferred to the Hospital of the University of Tokyo and the Institute of Medical Science of the University of Tokyo, members of the Division of Radiation Safety of NIRS accompanied to read survey meters and portable dosimeters and explain the methods of measuring doses with the devices. They also explained that the blood and excrement of the patients had to be handled as the wastes of nuclear medicine (kept frozen for use as specimens).

Dose measurements in and around the sickrooms of the patients
Date of measurement: October 1, 1999, 09:40
Gauge: Scintillation survey meter (Aloka TCS-161)
Unit: μSv/hr
Note: Na in the bodies of the patients were activated by neutrons, producing ^{24}Na.

Dose measurements in and around the sickrooms of the patients

Date of measurement: October 1, 1999, 09:40

Gauge: Scintillation survey meter (Aloka TCS-161)

Unit: μ Sv/hr

Note: Na in the bodies of the patients were activated by neutrons, producing ^{24}Na.

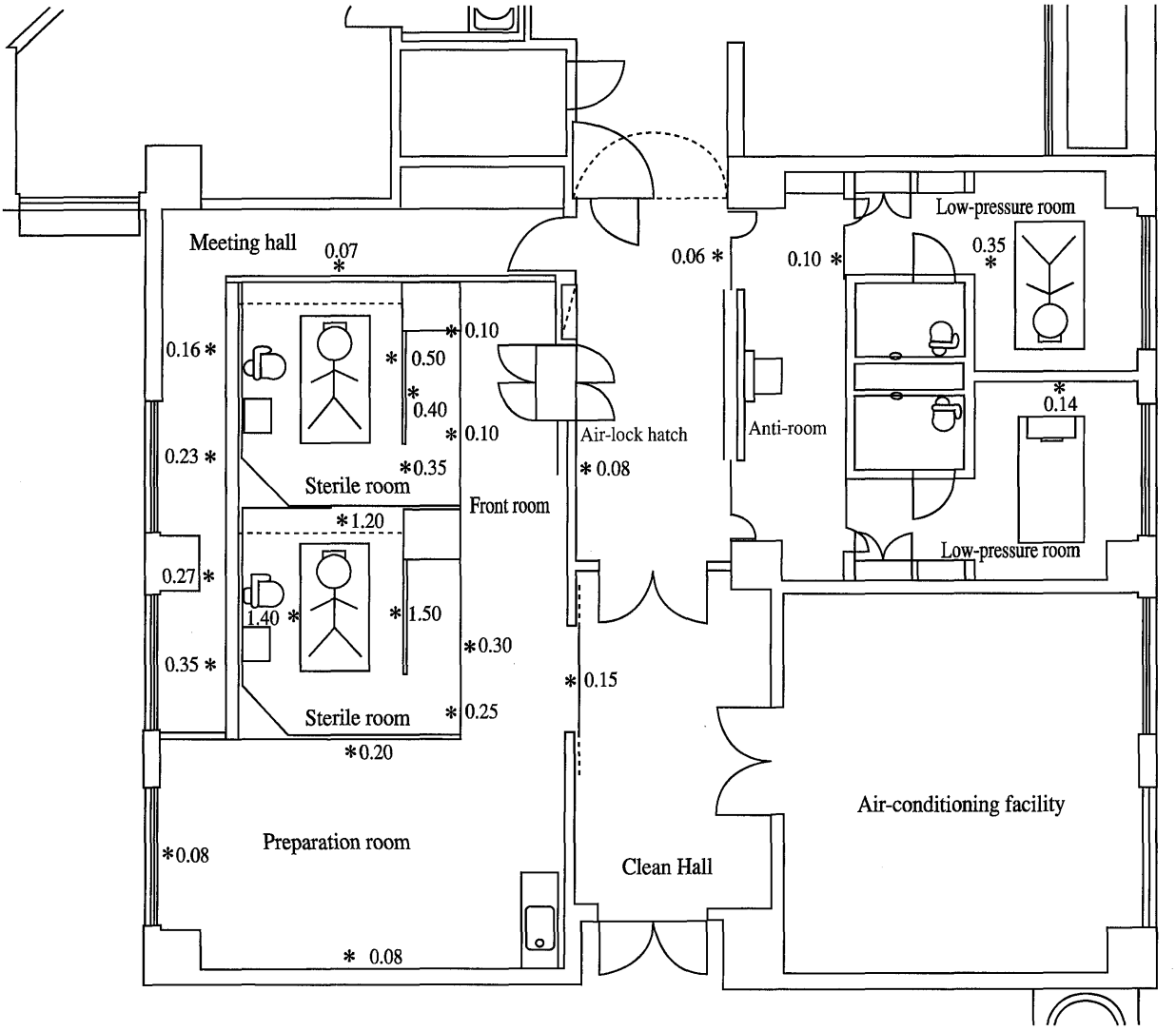
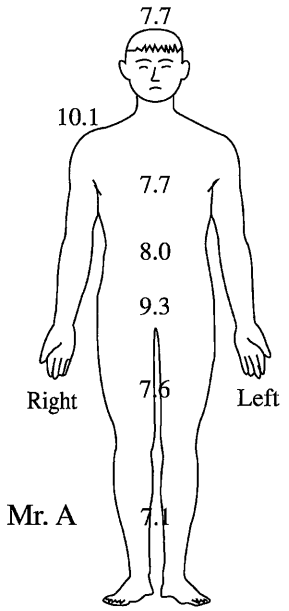


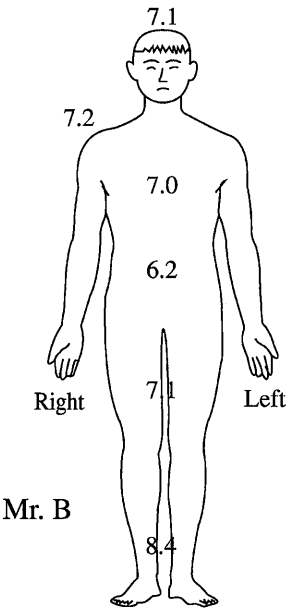
Figure 9-1

Table 9–1. Dose record of persons who entered the area

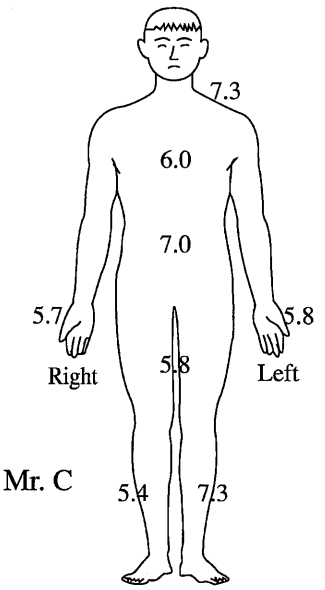
Name of the person	Date of wearing the dosemeter	Time of wearing the dosemeter	Date of returning the dosemeter	Time of returning the dosemeter	Dose (μSv)	PDNo.
A	October 1	17:00	October 2	10:20	4	R-5
B	October 2	8:30	October 2	16:30	0	R-10
C	October 2	9:00	October 3	3:00	0	R-8
D	October 2	10:00	October 2	21:00	0	R-7
E	October 2	17:25	October 2	20:50	0	R-6
F	October 2	17:25	October 3	3:55	0	R-4
G	October 2	17:25	October 3	3:55	0	R-3
H	October 2	17:25	October 3	3:55	0	R-5
I	October 2	17:30	October 3	10:30	0	P-61
J	October 2	17:30	October 3	9:30	0	R-2
K	October 2	20:15	October 2	20:45	No record	R-9
L	October 2	20:15	October 2	20:45	No record	P-63
M	October 3	8:00	October 3	18:00	3	R-3
N	October 3	8:30	October 3	18:45	0	R-2
O	October 3	8:30	October 3	17:30	1	R-9
P	October 3	8:35	October 3	17:35	0	P-63
E	October 3	8:35	October 3	19:30	0	R-5
Q	October 3	8:40	October 3	17:50	0	P-62
R	October 3	8:41	October 3	17:50	0	P-64
S	October 3	9:55	October 3	17.5	0	P-67
T	October 3	9:55	October 3	17:35	No record	P-66
U	October 3	9:55	October 3	17:35	0	P-65
D	October 3	10:00	October 4	2:00	1	R-1
V	October 3	10:45	October 3	17:30	No record	P-68
H	October 3	17:15	October 4	2:45	0	R-7
G	October 3	17:20	October 4	2:45	0	R-3
W	October 3	18:00	October 4	9:00	1	P-70
X	October 3	18:45	October 4	10:00	0	P-61
T	October 4	0:30	October 4	9:45	0	P-65
P	October 4	1:30	October 4	10:18	0	P-62
S	October 4	8:45	October 4	18:00	0	P-61
R	October 4	9:30	October 4	18:00	0	P-61
Y	October 4	10:47	October 4	18:00	0	P-62
Z	October 4	10:47	October 4	18:00	0	P-63
E	October 4	16:30	October 4	20:00	0	R-3
A2	October 4	20:00	October 5	8:45	No record	P-62
R	October 5	2:30	October 5	8:45	No record	P-61
Y	October 5	9:30	October 5	18:50	0	P-61
P	October 5	17:53	October 6	1:20	0	P-62
Z	October 5	17:55	October 6	1:20	0	P-63
Y	October 6	0:30	October 6	9:00	0	P-61
T	October 6	9:05	October 6	17:00	0	R-10
B2	October 6	9:05	October 6	17:00	1	R-5
S	October 6	17:00	October 7	0:50	0	P-61
R	October 6	17:00	October 7	0:50	0	P-62
S	October 7	9:50	October 7	18:00	0	P-61
V	October 7	9:50	October 7	18:30	No record	P-62
Y	October 7	18:45	October 8	1:00	0	P-63
P	October 8	1:00	October 8	9:00	0	P-63



TLD measurement (μ Sv)
16:53 October 1, 1999
(Wearing time: 30 minutes)



TLD measurement (μ Sv)
16:51 October 1, 1999
(Wearing time: 30 minutes)



TLD measurement (μ Sv)
17:05 October 1, 1999
(Wearing time: 30 minutes)

Patient A Left

Part of the body	Measurement (μ Sv)
Head	7.7
Right shoulder	10.1
Chest	7.7*
Abdomen	8.0*
Lower abdomen	9.3*
Thigh	7.6*
Leg	7.1*

Patient B Middle

Part of the body	Measurement (μ Sv)
Head	7.1
Right shoulder	7.2
Chest	7.0*
Abdomen	6.2*
Thigh	7.1*
Leg	8.4*

Patient C Right

Part of the body	Measurement (μ Sv)
Left shoulder	7.3
Chest	6.0
Abdomen	7.0
Left hand	5.8
Right hand	5.7
Thigh	5.8*
Left leg	7.3*
Right leg	5.4*

* Installed on the blanket

Figure 9-2 TLD records
Date of measurement: October 1, 1999 (Friday) at sterile rooms
Note: Since it was not possible to directly install the TLDs on the patients, the devices were installed on the blankets. The patients were not always wearing the blanket throughout the measurement.

10. Response to Nearby Residents of the Uranium Processing Plant

One characteristic of this incident was the fact that exposure to radiation affected not only JCO employees, but also residents of the surrounding area. Of serious consequence is the fact that radiation leaked outside the nuclear facility and resulted in members of the general public being received radiation exposure. According to a Nuclear Safety Commission Health Management Committee report, the influence of radiation in this accident is as follows.

①Regarding deterministic effects, the radiation dose level was not sufficient to affect any influence.

②Regarding stochastic effects, the possibility of any radioactivity induced effects is extremely remote, and the detection of any effects is not possible[1]. Despite this, as far as residents were concerned, they had been unnecessarily exposed to radiation, and were considerably concerned. Researchers conducting surveys of residents' actions reported that residents with children had concerns, and some residents felt a sense of self condemnation.

In such a situation, although the NIRS did provide assistance on the ground in Tokai-mura, its response was perhaps not as thorough as warranted as a result of its concentration on those victims of high dose radiation exposure. The NIRS not only provided medical treatment to those victims of high dose radiation exposure, but also became deeply involved in the medical problems of other residents. In addition to the Division of Radiation Health of NIRS, other researchers were involved in a variety of ways. However as the managing of residents' medical problems had not been envisaged as part of emergency drills, there was little choice but to deal with them on a trial and error basis. Furthermore, as this took place over a considerable period of time, and not all of the medical problems could be explained as the result of radiation exposure, this is an issue which should be delved into in terms of internal cooperative systems.

1) Nuclear Safety Commission Health Management Committee Report p.35, 27 March, 2000, Nuclear Safety Commission Health Management Committee

10-1. Dispatch of the Medical Advisor to the Mayor of Tokai-mura

On October 8, the Director of the Research Center for Charged Particle Therapy, Dr. Murata, was dispatched as medical advisor to the mayor of Tokai-mura. One week after the criticality accident, although a degree of calm had returned, the Command Office for the JCO Criticality Accident which had been established in the civic center was constantly attended, first by Mayor Murakami, the head of the office, then by others. While Mayor Murakami, Mr. Ono, the Science and Technology Agency's Director for Safety Administration of Nuclear Fuel Cycle Facilities, and Dr. Murata, had immediately established a plan of action, at that point in time the radiation dose received by nearby residents was not yet known, the outcome of the health examinations conducted by Ibaraki prefecture between the second and fourth of October had not been announced, and the major concerns of the village authorities were whether there was adverse effects to the health of residents or not as a result of the criticality accident and the calming of residents' mental shock. In this respect, the expectations by the village populace of the NIRS were not insignificant. The following two items were proposed to and accepted by the mayor.

(1) A "Resident Health Forum" given by specialists from the NIRS. (Held on October 18 and chaired by Dr. Kawachi, the Deputy Director-General, and Dr. Akashi, Section Head of the Division of Radiation Health. (To be discussed at a later stage.)

(2) The "Establishment of a Medical Advice Office" to assuage the health related concerns of residents.
(Held a total of 17 times between October 19 and December 21 at the village civic center. In addition to doctors from the Division of Radiation Health, assistance was received from the Division of Advanced Technology for Medical Imaging and former NIRS doctors. To be discussed at a later stage.)

Results of blood testing including lymphocyte number conducted by the authorities of Ibaraki

prefecture for 1,800 residents residing within a 500 meter radius of the accident site were made available on October 12. According to these tests, "None of them have an evidence of harm as a result of radiation exposure". Around this time, the health test results were formally announced to the mayor of Tokai-mura, and the presence of the medical advisor to interpret the data from a medical viewpoint was of utmost importance.

Subsequently, the external radiation dose to which general employees and members of the Tokai-mura Fire Department were exposed, estimated by means of ^{24}Na radioactivity in the body, was announced. These results showed that this accident gave little effect on residents' health, however these information, in addition to health consultations with doctors, did not quickly assuage the concerns of residents.

Dr. Murata visited Tokai-mura a total of 8 times in the period to December 21.

10-2. Resident Health Forums

From October 8, requests were conveyed via Mayor Murakami's medical advisor, Dr, Murata, for the convening of a "Resident Health Forum" in Tokai-mura and for the dispatch of lecturers from the NIRS. Upon receipt of this request, the NIRS sent Dr. Kawachi, the Deputy Director-General, and Dr. Akashi, Section Head of the Division of Radiation Health, to perform this role.

The forum was held between 2:00pm and 5:00pm on Monday October 18, 1999 at the Tokai-mura Culture Center. Dr. Kawachi, explained types of radiation and their qualities, units used to express radiation and radioactivity, and radiation half-life and its influence. Dr. Akashi explained acute radiation sickness, methods for measuring radiation dose, and the effects of exposure to radiation. This was followed by a question and answer session.

For the benefit of those who could not be present, a video was made of the proceedings and was made available for borrowing. In addition, an outline was published in local notices. Enabling the recording of the video and the publication of the notices was an administration which was closely tied to the populace.

Public forums were held on Saturday November 13, 1999 at Nakamachi and on Sunday November 14, 1999 at Tokai-mura. Types of radiation and their qualities were explained by Dr. Kawachi, and the effects on human health of radiation were explained by Dr. Akashi. These forums were convened to allow the Science and Technology Agency to announce the results of its radiation evaluations and to explain the steps it planned to take thereafter, and specialists from the NIRS were requested by the Agency as representatives for this purpose. Subsequent to the convening of the forum, health discussions were held, with Dr. Akashi and the Senior Researcher, Dr. Hirama presiding.

10-3. Health Consultations at Tokai-mura

(1) Cooperation With the Sponsored by Tokai-mura Health Consultation Office

The NIRS became involved with the Health Consultation Office on a number of levels. Initially, the NIRS offered support for health consultations conducted by Tokai-mura, which were held on Tuesdays and Thursdays each week beginning on October 19. At first, Dr. Tanada, Director of the Division of Advanced Technology for Medical Imaging, Dr. Ikehira, Senior Researcher, Dr. Suhara, Senior Researcher, and Dr. Watanabe, Researcher, attended in rotation. Mid-way through the series, former NIRS members Dr. Nakao and Dr. Tateno also attended. Later, Dr. Tanosaki, Senior Researcher at the Division of Radiation Health, and Dr. Kuroiwa, a researcher, were dispatched.

The Health Consultation Office in the early stages dealt with large numbers of residents and a great deal of pressure was placed upon the attending doctors. However, after the initial rush, the number of residents seeking consultations was less than predicted at around only 1-2 per day. The content of most consultations concerned issues of uneasiness and distrust which the residents concerned were not able to ask in the presence of large audiences at the forums. Rather than medical issues, cases in which concerns would be best dealt with by a psychologist or counselor were prevalent.

(2) Telephone Consultations

The results of the evaluation of radiation doses received by local residents were released to the press by the Science and Technology Agency on November 4. In order to establish a telephone consultation office at the Tokai-mura civic center, the Science and Technology Agency requested the NIRS provide one medical doctor

and one researcher with knowledge of the effects of radiation on the human body as consultants. With the treatment of hospitalized patients and participation in the Health Consultation Office to consider, sparing an additional doctor was not an easy task, however the circumstances being such as they were, it was determined to send the doctors from the Division of Radiation Health in rotation. Furthermore, how many researchers with knowledge of the effects of radiation in the human body who were also able to perform a consultative role were resident at the NIRS was unknown. It was understood that there were virtually no researchers who were experienced in advising the general public. A decision was made to send the Division of Radiation Health's Senior Researcher Dr. Hirama, Researcher Dr. Kuroiwa, and Researcher Dr. Nakagawa to Tokai-mura in rotation. In addition, to fulfill the request for the dispatch of researchers, Dr. Hachiya, Senior Researcher at the Division of Radiation Health and Dr. Yukawa, Senior Researcher at the Division of Human Radiation Environment Division were sent.

Although initially for the purpose of telephone consultation, large numbers of residents visited the office. Reporters entered the consultation booths to photograph consultations in progress and to photograph the board on which questions and contacts were displayed, the result of which was a great deal of confusion. Reports were received to the effect that the right to privacy of those seeking advice was not being respected, and that the response to reporters had not been appropriately planned. Such problems existed in the initial stages only, and were soon dealt with.

Based upon the results of the survey of residents' actions conducted in December, measurement of radiation doses received by residents was performed, the results of which were explained to residents individually by NIRS researchers on January 29 and January 30, 2000. As a follow-up, the Science and Technology Agency requested the presence of NIRS staff at the Health Consultation Office. Researchers were dispatched from the central research facility and the Nakaminato research facility, however contrary to predictions, the number of residents requiring consultations was small.

(3) Cooperation with the Health Examination carried out by the Ibaraki Prefecture

Based upon a report by the Nuclear Safety Commission Health Management Committee, and at the request of the Science and Technology Agency, Ibaraki prefecture conducted health examinations on Saturday May 13, Sunday May 14, and Sunday May 21, 2000. Prior to this, health consultations were held on Tuesday April 25, Wednesday April 26, and Thursday April 27, 2000. Participants included Dr. Akashi (Section Head), Dr. Hirama (Senior researcher), Dr. Kuroiwa (researcher), and Dr. Nakagawa (researcher) from the Division of Radiation Health, Dr. Ogyu (Supervising researcher of Low Dose Radiation Risk and Carcinogenesis Research Group), and Dr. Watanabe (researcher of Division of Advanced Technology for Medical Imaging). In addition, as the Health Consultation Office was to be opened on the day of the health examinations, Dr. Hirama, Dr. Kuroiwa, and Dr. Nakagawa were dispatched from the Division of Radiation Health.

As the health examinations are to continue, it is expected that the cooperation of the NIRS will continue to be sought.

10-4. Cooperation with Hitachinaka City

(1) On Friday October 1, a request was received from Hitachinaka city for assistance in measuring the radiation doses for residents. In response, the Laboratory for Radioecology, Nakaminato, sent six personnel on October 1 (Friday), eight on October 2 (Saturday), and eight on October 3 (Sunday), and conducted screening by means of survey meters.

(2) A request was received from Hitachinaka city for assistance in measuring the radioactivity of marine produce. On October 1 and October 4 samples were analyzed, and a report titled "Concentrations of Radioactive Caesium 137 in Seaweed and Shellfish from Hitachinaka City's Isozaki and Hiraiso" was presented to the city planning division on November 12.

(3) On January 24, the city assembly's committee members visited and were shown around the site, following which informal discussions were held and understanding was sought for the NIRS's research concerning environmental radioactivity.

10-5. Resident Behavior Survey

Following receipt of a request from the Science and Technology Agency to evaluate the radiation doses received by residents in the vicinity of the uranium processing facility, the construction of behavior survey formatted sheet, consideration of radiation dose calculation methodology, and consideration of survey procedure including the construction of a survey consent form were undertaken and the decision was made to conduct the survey on Friday November 19 and Saturday November 20 jointly by the Science and Technology Agency, the NIRS, Ibaraki Prefecture, Tokai-mura, and Nakamachi. The intention to perform the survey was released to the press by the Science and Technology Agency on November 4. Following the advice of the Nuclear Safety Commission Health Management Committee, the measurement of radiation doses was conducted on the forty-eight families and workers present on September 30 at 18 businesses located within the evacuation area, a total of 265 people. A total of 28 surveyors, consisting of 13 members of the NIRS's Human Radiation Environment Division, 4 members of the Division of Radiation Research, 4 members of the Division of Accelerator Physics and Engineering, 4 members from the Laboratory for Radioecology, Nakaminato, and 3 members of the Environmental and Toxicological Sciences Research Group participated. Surveys were conducted by groups of two surveyors in conjunction with Ibaraki Prefecture community nurses. The surveys of workers at the various businesses were conducted in the presence of staff from the Labor Standards Bureau. Prior to the survey being conducted, the NIRS convened two meetings for the purpose of instructing surveyors on the method by which surveys should be completed, and on the content of explanations to residents. The survey consent form was sent to residents on November 15.

Over the two day period, the surveying of all of the necessary Nakamachi residents, all bar five of the necessary Tokai-mura residents, and all of the businesses was completed. The five Tokai-mura residents who were not surveyed over the two day period were surveyed by staff of the Nakaminato Center on November 21 (Sunday) and November 22 (Monday). Those staff of the businesses included in the survey who missed being surveyed in the initial two day period were interviewed by telephone the following days. Thus surveys were completed by all of those required.

The survey which was conducted was not merely an assessment of the residents' activities, but also paid attention to the emotional state of the residents, and explained in detail the estimated radiation dose of the residents at that time, the attributable risk due to the exposure, and the degree of that risk. Time was also taken to answer the questions and assuage the concerns of those surveyed. As a result, 1-2 hours was allowed to survey each family. With one or two exceptions, the response of the residents was overwhelmingly positive, and as mentioned in press reports, the fears of many residents were laid to rest by the careful explanations of the specialists.

With the exception of a few who came into contact with the press, the surveyors recognized the residents' need for careful explanations, and achieved a great sense of satisfaction from the residents' responses.

This survey with the care taken concerning the emotional state of the respondents has demonstrated the importance of the NIRS.

Following is the assessment of radiation doses based upon the results of the behavior survey.

(1) Residents:

Category	Families/businesses surveyed	Individuals surveyed	Those who did not come within 1 km from the site in the 20 hours immediately after the accident	Those for whom radiation dose assessment was carried out	Notes
Tokai-mura	39 families (43 families)	138 (152)	48 (—)	89* (—)	Excluding overlap from businesses (Including overlap from businesses)
Naka-machi	9 families	34	10	24	
Businesses	18 businesses	93	Not included in survey	86*	
Total	—	265	58	199*	

*One member who was the emergency team, and seven workers inside the evacuation zone whose dose had been assessed using a whole body counter were excluded from the survey.

(2) Criteria Used in Radiation Dose Evaluation

◆Radiation dose at the location
Cumulative radiation dose provided at 30 minute intervals as a function of distance from the JCO Conversion Test Building's precipitation tank (outdoor cumulative radiation dose provided every 30 minutes at 10 meter intervals).

◆Duration of time
Residents' movements recorded according to survey responses.
Data constructed every 30 minute intervals.

◆Shelter from housing
Relevant homes were divided into eleven categories based upon the recommendations of a construction specialist and the results of the activity survey. Various walls were assigned transmission according to the component materials.

Type	Urizura-sen (Prefectural road)	Route 6 (National road)	Examples of a side road
Shortest distance	70 m	270 m	230 m
Automobile (10 m/s)	0.5 min.(16.1 sec)	1 min.(44.6 sec.)	1 min.(39.96 sec.)
Motorcycle/bicycle (4 m/s)	1 min.(40.2sec.)	2 min.(111.4 sec.)	2 min.(99.66 sec.)
On foot (1 m/s)	3 min.(160.8 sec.)	8 min.(445.7 sec.)	7 min.(398.56 sec.)
Consideration for time spent stationary as a result of traffic congestion at Niken-jaya intersection (automobiles only)	260 m +0.5 min.	280 m +1 min.	N/A

(The neutron transmission of houses varied between 0.94 for glass and 0.14 for concrete).

◆Movement
Consideration for transport type and path traveled based upon information gleaned from interview surveying.

As shown in the table on the previous page, equivalent time upon the shortest distance was estimated.

(3) Preconditions

◆Variation in radiation dose according to the direction from JCO (directional dependency)
According to the measurement results of Japan Atomic Energy Research Institute survey group, with the exception of some of the data, it has been shown that directional dependency is conspicuously absent.
Consideration for directional dependency was therefore excluded from this survey.

◆Dose Variation according to location within houses

As is evident in the above examples of transmission, the radiation dose varies greatly depending upon the location inside the house. In reality, instances in which the exact location in the house cannot be pinpointed, or cases in which variation exists even between houses of the same type can be conceived. In addition, glass or storm shutters is considered as a shelter if a resident is situated near a window. Thus these variations in the house were not considered, and only the transmission assigned to different house types were used.

◆Angle of incidence of radiation on the body.
For safety reasons, the angle of incidence is assumed to be from the front.
Effective radiation dose from the side or rear is less than that from the front.

◆Inclination of walls in relation to JCO
For safety reasons, walls are assumed to face JCO directly.
As the incident angle of the scattered radiation that attribute more than 80% of incident radiation is distributed mainly in the upper front

Timber mortar (two story structure with 5 rooms)	:0.36～0.63
Steel frame sidings (two story structure with 8 rooms)	:0.27～0.70
Ferroconcrete (two story structure with 8 rooms)	:0.046～0.11

direction, the inclination of walls in relation to JCO was discounted.

◆Multi-layering of surrounding houses.
As the intensity of scattered radiation coming from above is greater than that of direct radiation, the multi-layering of surrounding and neighboring houses has not been awarded consideration.

◆Distance greater than 1 km
Radiation doses at distances of greater than 1 km were not included.

◆Calculation example
As showen in page No. 72.

(4) Estimated Radiation Dose

In order to adequately estimate radiation dose, a number of parameters were selected. Ambiguous points such as location within the house and movement were assumed to be overestimation. Therefore, the estimated radiation dose may have been overestimated, while it is believed that no underestimations were made.

(5) Reporting of Results

Using the results outlined above, the affected area was visited on both January 28 and 29. Each household and business was visited and the results explained. Care was taken that individuals results would not be leaked to others. On January 25, 2000, prior to the reporting of results, residents were informed of the second visits and arrangements were made at the convenience of the residents. A total of 20 surveyors took part, with groups of two surveyors accompanied by Ibaraki Prefecture community nurses. Of the 20 participants, eleven were from the Human Radiation Environment Division, three

Household number	T**	September 30														
Name of head of household		25 min. intervals following the incident	11:00 –11.30	11:30 –12:00	12:00 –12:30	12:30 –13:00	13:00 –13:30	13:30 –14:00	14.00 –14.30	14:30 15:00	15:00 –15:30	15:30 –16:00	16:00 16:30	16:30 –17:00	17:00 –17:30	17:30 –18:00	18.00 –18:30
Number	T**-1		7													
Name		1	0.68	0.68	0.68	0.68	0.82	0.82	0.82	0.82	0.68	0.68	1				
Radiation dose (mSv)	1	1	0.81	0.81	0.81	0.81	0.9	0.9	0.9	0.9	0.81	0.81	1				
0.65	Neutron dose	1.5E-05	6.5E-05	6.2E-05	5.9E-05	5.7E-05	5.2E-05	5.0E-05	4.8E-05	4.6E-05	4.6E-05	4.4E-05	4.0E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00
0.16	Gamma ray dose	3.1E-06	1.7E-05	1.6E-05	1.6E-05	1.5E-05	1.3E-05	1.2E-05	1.2E-05	1.1E-05	1.2E-05	1.1E-05	8.5E-07	0.0E-00	0.0E+00	0.0E+00	0.0E+00
0.81	13.5	1.8E-05	8.2E-05	7.8E-05	7.5E-05	7.2E-05	6.4E-05	6.2E-05	5.9E-05	5.7E-05	5.8E-05	5.6E-05	4.8E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00
		0.03	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.033				
	Distance (m)	230	280	280	280	280	300	300	300	300	280	280	230				
	Movement	1	0	0	0	0	0	0	0	0	0	0	1				
	1.Automobile 2. Bicycle 3. Foot	1											1				
	Direction	Went back home before 11o'clock (Not at the time of the burst)															
	Indoors/outdoors (0/1)	1	0	0	0	0	0	0	0	0	0	0	1				
	Roof type		1	1	1	1	2	2	2	2	1	1					
	Construction material		2	2	2	2	Slate	Slate	Slate	Slate	2	2					
	Floor		1	1	1	1	2	2	2	2	1	1					
	Wall thickness (window glass) cm		0.2	0.2	0.2	0.2					0.2	0.2					
	Wall thickness (clay/mortar) cm																
	Wall thickness (concrete) cm																
	Wall thickness (concrete) cm																
	Wall thickness (ALC) cm																
	Wall thickness (paneling) cm																
	Wall thickness (plaster board) cm																
	Wall thickness (other) material						Slate	Slate	Slate	Slate							
	Wall thickness (other) cm						3	3	3	3							
	Inclination of wall°		30	30	30	30	30	30	30	30	30	30					
	Inclination of body°																

Estimated Radiation Dose for on Individual Residents in Surrounding Areas				
Measured radiation dose (mSv)	Tokai-mura residents excluding workers at businesses	Naka-machi residents	Workers at businesses	Total
Less than 5 (greater than 1 mSv)	77(35)	24(0)	78(56)	179(91)
Greater than or equal to 5 but less than 10	7	0	8	15
Greater than or equal to 10 but less than 15	4	0	0	4
Greater than or equal to 15 but less than 20	0	0	0	0
Greater than or equal to 20 but less than 25	1	0	0	1
Total	89	24	86	199

from the Division of Radiation Research, two from the Division of Accelerator Physics and Engineering, three from the Laboratory for Radioecology, Nakaminato, and one from the Fourth Research Group. As was the case on previous occasions, a total of 1-2 hours was allowed for careful explanation to each household.

Surveyors

Human Radiation Environment Division
Kenzo Fujimoto, Masahide Furukawa, Shinji Tokonami, Yoshikazu Nishimura, Yoshito Watanabe, Hisao Kawamura, Kunio Shiraishi, Shinzo Kimura, Hidenori Yonehara, Sarata Kumar Sahoo, Kanae Nishizawa, Masaki Matsumoto, Tetsuo Ishikawa, Yasuhiko Yoshimoto, Shinji Yoshinaga.

Division of Radiation Research
Yutaka Noda, Sadao Shibata, Kaname Omata, Akifumi Fukumura.

Division of Accelerator Physics and Engineering
Yukio Sato, Yasuyuki Futami, Shin-ichi Minohara, Koji Kawano.

Laboratory for Radioecology, Nakaminato
Kiyoshi Nakamura, Shigeki Hirano, Ryoichi Nakamura, Teruhisa Watanabe

Environmental and Toxicological Science Research Group
Masahiro Doi, Yoshihisa Kubota, Keiko Tagami

(Those whose names have been underlined participated in both November and January.)

10-6. Response at the NIRS

(1) Telephone Consultations

Immediately following the incident, the NIRS received one telephone query after another. A response manual and list of predicted questions was distributed to each person involved. The content of the conversations concerned the following topics.

○ The effect of radiation exposure on those who passed through the area around the accident site

and surrounding localities.
○whether or not items such as table salt from residences was safe for consumption.
○whether clothing or washing that was wet as a result of the accident was safe to wear.
○whether areas outside of the indicated 10 km radius danger zone were completely safe.
○concerns regarding decontamination (a university)
○whether the waters surrounding Chiba and Shonan could be considered safe for weekly bodyboarders.
○means for the purchase of iodine drugs
○requests for radiation dose measurement

(2) Questions From Regional Authorities

○what should be done in the case of an accident (a prefecture with nuclear power facility)
○what response should be made to question concerning iodine drugs
○the scale of equipment and facilities used for pollution removal, and management plans.

(3) Measurement Requests From Residents

Requests for radiation dose measurements were received from 42 people, most of whom were in Tokai-mura or drove through Ibaraki Prefecture on the day of the incident. On a case by case basis, all were predicted to show reading within normal ranges, however for the peace of mind of the general public the tests were conducted.

Using survey meters for alpha, beta, and gamma rays, measurements were taken of the individual's body and of clothing and personal effects worn or carried on the day. Before performing the test, the subjects were interviewed concerning their movements on the day in question, the location of their place of work (in relation to the accident site), and the hours they worked.

Of the 42 subjects, none showed abnormal readings from body scans. In addition, of the 13 who were tested for evidence of internal radioactivity, none showed abnormal readings.

A breakdown of the subjects is as follows.

Helicopter pilots associated with the mass media - 11 people
Transport workers - 7 people
Construction workers - 13 people
People who passed through areas surrounding the accident site - 9 people
Others - 2 people

*A human counter is a scanning type whole body counter which takes the form of two NaI detectors (4 inches × 8 inches in diameter) fixed to the top and bottom of a room shielded with iron (of approximately 20 cm thickness).

To perform a full body scan, in order to scan the subject from the top of the head to the tip of the toes along the central axis of the NaI detectors, the detectors are driven at a speed of 5 cm/min. For a fixed chest measurement, the detectors are fixed so the central axis of the NaI detectors is in the region of the subject's chest, and measurements are taken without scanning.

10-7. Dose Estimation by Chromosome Analysis of Neighbors and Low-dose Exposed Persons

(1) Circumstances leading up to dose estimation by chromosome analysis for 43 people

Before we had finished preparing the chromosome specimens of the three patients who were taken to the NIRS after the accident, we were informed that several dozen people at the JCO facility and in its neighborhood were confirmed to have been exposed slightly on the basis of measurements made by whole body counting of ^{24}Na. We judged that chromosome examination would be necessary for these people, and prepared special sets of reagents and tools to perform low-dose estimation by chromosome analysis for 100 people. On October 4, Professor Sasaki, of the Radiation Biology Center (RBC) at Kyoto University, who was also the president of the Japan Radiation Research Society, explained the necessity for academic investigations of both environmental radiation and its influence on human health to the members of the Research Aid Division, Ministry of Education, Science, Sports and Culture (MESSC). He proposed them practical methods and also asked the Nuclear Safety Commission (NSC) for cooperation. Based on the advice of Dr. Sumita and Dr. Aoki, Nuclear Safety Commissioners, the Science and Technology Agency (STA) formulated the policy that chromosome analysis would be applied for those persons found to be exposed to low dose of radiation. Simultaneously, Professor Sasaki and we designed a concrete

Results of Internal Measurements Using Human Counters

No.	Measurement Date	Age	Sex	Relevant Details	Measurement Results	Measurement Method
1	01.10.1999	28	Male	On the evening of 30.09.1999, the subject was transporting a load inside the 10 km radius danger zone. He carried out his work in the rain. After returning home, he showered and changed his clothing.	No radiation detected	Whole body scan
2	01.10.1999	34	Male	On 30.09.1999 the subject worked for one hour at a location 5.8 km from the accident site. He left by car and returned to his home in Chiba, after which he showered.	No radiation detected	10 minute fixed chest measurement
3	04.10.1999	51	Male	On 30.09.1999 the subject was aloft in a helicopter for less than 15 minutes for the purpose of collecting information on the accident.	No radiation detected	10 minute fixed chest measurement
4	04.10.1999	43	Male	On 30.09.1999 between the hours of 2:00pm and 3:00pm, the subject rested at the Tokai PA. Between the hours of 5:00pm and 6:00pm, he worked in the rain at a location approximately 5 km from the accident site.	No radiation detected	10 minute fixed chest measurement
5	06.10.1999	48	Male	On 30.09.1999, the subject flew in a helicopter twice for the purpose of collecting information on the accident.	No radiation detected	10 minute fixed chest measurement
6	06.10.1999	32	Male	On 30.09.1999, the subject flew in a helicopter for the purpose of collecting information on the accident.	No radiation detected	10 minute fixed chest measurement
7	06.10.1999	37	Male	On 30.09.1999, the subject flew in a helicopter twice for the purpose of collecting information on the accident.	No radiation detected	10 minute fixed chest measurement
8	06.10.1999	34	Male	On 30.09.1999, the subject flew in a helicopter for the purpose of collecting information on the accident.	No radiation detected	10 minute fixed chest measurement
9	07.10.1999	47	Male	On 01.10.1999, the subject flew in a helicopter for the purpose of collecting information on the accident.	No radiation detected	10 minute fixed chest measurement
10	07.10.1999	29	Male	During the night of 30.09.1999, the subject made a delivery close to the accident site.	No radiation detected	10 minute fixed chest measurement
11	08.10.1999	47	Male	On 30.09.1999, the subject flew in a helicopter for the purpose of collecting information on the accident.	No radiation detected	10 minute fixed chest measurement
12	08.10.1999	18	Male	Between Sep.27-30, the subject carried out work on the premises of the Japan Atomic Energy Research Institute.	No radiation detected	10 minute fixed chest measurement
13	21.10.1999	38	Male	On 30.09.1999 between the hours of 3:30pm and 4:30pm, the subject was in the vicinity of the Niken-jaya intersection on Highway 6. As the subject had already undergone a body scan, he requested that only in internal scan be undertaken.	No radiation detected	10 minute fixed chest measurement

plan for this with nation-wide support by related specialists; that was within one week of the accident. By the same time, the National Radiation Protection Board (NRPB) in Britain, Institut de Protection et de Surete Nucleaire (IPSN) in France and the Laboratory of Industrial Hygiene in China, which had experience in estimating dose by chromosome analysis, sent us e-mails saying that they are willing to offer their expertise. The nation-wide cooperation was essential to this investigation, because at least 1000 cells (46,000 chromosomes in total) needed to be examined per person. This means the dose estimation of 100 people would require the examination of over 4.6 million chromosomes one by one under the microscope. The analysis of such a huge number of chromosomes at one time was only possible with the cooperation of specialists in institutes other than the NIRS.

On October 2, 3 and 4, lymphocyte counts were made at the Ibaraki Prefectural Hospital for 1,844 people living near the JCO facility. The results revealed 8 persons with abnormally low values (below 910 cells/$\mu\ell$). On October 12, Dr. Okura, Vice-Director of the hospital, contacted the NIRS about possible chromosome analyses for these 8 persons. We replied that such an analysis would only be useful if the blood specimens could be sampled within four weeks of exposure. In addition we said that we could culture less than 15 samples at one time because low-dose estimation requires very accurate control of the conditions of culturing and harvesting the blood cells, and that it would take some time to obtain results. The NIRS selected members to be sent for an on-the-spot blood sampling in Ibaraki, and waited for a formal request for chromosome analysis from the Ibaraki Prefecture's Government.

On October 13, the NIRS explained to the STA that it was necessary to sample the blood of the people exposed to low-dose radiation as well as the 8 individuals having abnormally low lymphocyte counts as soon as possible in order to accurately estimate the dose by chromosome analysis.

On October 14, the Ibaraki Prefectural Government formally requested the chromosome analysis for these 8 persons. On October 15, Mr. Kawarada, Atomic Energy Bureau, STA, Mr. Okamoto, Nuclear Safety Bureau, STA, and Hayata, NIRS, visited the Tokai-mura Office and the Ibaraki Prefectural Office to make arrangements for collection of blood.

On October 18, blood samples were collected from seven of the individuals having abnormally low lymphocyte counts by the staff of Ibaraki Prefectural Hospital at the old Tokai-mura Office in the presence of members of the Department of Health and Welfare of the Ibaraki Prefectural Government. The other one was a baby, for whom chromosome analysis was not performed. The seven persons were elderly people and/or individuals who had blood disorders or chronic disease before the exposure. For each of them, the purpose of chromosome analysis was explained at length and informed consent was obtained. Information on their health and exact location at the time of the accident was inquired. Therefore, it took more than two hours to obtain the blood samples from seven persons. The NIRS researchers (Hayata, Kanda and Minamihisamatsu, Division of Radiobiology and Biodosimetry, and Kawase, Division of Radiation and Health) were in charge of the blood sampling, making of blood smear slides and mixing of the blood with the medium for preservation in a sterilized tube. The blood samples and the smear slides were brought to the NIRS. The lymphocytes were separated from the blood, and cultures were started within eight hours of sampling. Blood smear slides were prepared for examining blood cells in the case that chromosome analysis was impossible due to diseases or some unexpected event, but in the end were not needed.

On October 20, officers in charge of Tokai-mura, Dr. Murata, Director of the Research Center of Charged Particle Therapy, NIRS, Mr. Ohno of the Nuclear Safety Bureau, STA and Hayata had a consultation about executive arrangements for chromosome analysis of the residents near the JCO plant.

On October 21 and 22, second and third blood samplings were conducted at the National Mito Hospital. With the cooperation of Dr. Ariga, Director of the Department of Radiology of this hospital, 7 persons working near the JCO site, 26 JCO employees and 3 firemen came to the hospital to have their chromosomes checked. These 36 persons had been confirmed having been exposed to radiation on the basis of whole body measurements of ^{24}Na. There were no elderly among them. By virtue of advance requests for the cooperation of the National Mito Hospital from the Ministry of Health and Welfare (MHW), STA, and Dr. Sasaki, Director-General of NIRS, we could perform the blood

sampling quickly with the full cooperation of the members of the hospital. The 36 persons were divided into four groups to receive an explanation about chromosome analysis, and to undergo blood sampling after obtaining informed consent. These procedures took a relatively short time. We explained using the results of a study in our own laboratory and a collaborative study with an institute in China that 1) it is possible to estimate the exposed dose by chromosome analysis, 2) we are always being exposed to natural radiation even when there is no accident, 3) residents of areas with a high level of natural radiation in China were exposed to more radiation than these persons might have been exposed to in this accident, with no increase in the frequencies of cancers and leukemia,[4] majority of chromosome aberrations were found to be induced by factors other than radiation such as chemical mutagens in those residents in China, 5) and therefore the effect of radiation on the induction of chromosome damage is insignificant in such low dose level. In answer to questions from the persons, we further explained that this investigation was aimed not at gene analysis but at the counting of injuries caused by radiation to estimate dose.

Blood samples were taken from 24 and 12 persons on October 21 and 22, respectively, and brought back to the NIRS in sterile tubes containing the medium for preservation. The separation of lymphocytes from the blood was conducted twice and once on October 21 and 22, respectively, and lymphocyte cultures were set up within eight hours of blood sampling.

On October 29, Hayata attended a Meeting on the Health Effects of the JCO Criticality Accident on Residents organized by the municipal government of Ibaraki Prefecture (Mito). He explained the progress of chromosome analysis and its future schedules.

We thus took blood specimens from a total of 43 persons with the cooperation of all concerned at Tokai-mura, Ibaraki Prefecture, Ibaraki Prefectural Hospital, the National Mito Hospital, NIRS, STA, MHW, MESSC and NSC.

(2) The preparation of chromosome slides for low-dose estimation

The chromosome slides were prepared according to method that have been developed at the NIRS and used for chromosome analysis of residents in areas of high level of natural radiation in Guangdong, China (Hayata et al., 2000). A brief description is given as follows:

1) Approximately 3 ml of heparinized (about 10 Units/ml) peripheral blood was taken with a sterilized syringe and poured into a lymphocyte separation tube containing the preservative medium, that is 0.8 ml of RPMI 1640 culture medium plus 0.2 ml of calf serum and 0.24 mg of Kanamycin. These tubes were transferred on ice to a culture room within eight hours of blood sampling.
2) In the culture room, lymphocytes were separated, mixed with 6 ml of culture medium consisting of 4.8 ml of RPMI 1640 solution, 1.2 ml of calf serum, 0.36 mg of Kanamycin, 0.12 ml of PHA, and 0.3 μg of Colcemid, and stirred by pipetting.
3) The mixture was poured into a 15-ml centrifuge tube for cell culture and warmed in a water bath at 37°C. The cap was loosened and the cells were cultured in an incubator under a 5% CO2 atmosphere for 48 hours.
4) The lymphocytes were collected by centrifugation and treated with hypotonic (0.075 M) KCl solution for 20 minutes at 37°C.
5) The mixture, to which approximately 50 μl of methanol-acetic acid (3:1) was added, was stirred by pipetting and centrifuged.
6) The lymphocytes were fixed with methanol-acetic acid (3:1) twice and kept at under −20°C for at least 3 hours.
7) Air-dried slides were made in the box under warm (27–30°C) and humid (about 80%) conditions, and stained with Giemsa.

(3) Analysis of chromosomes

Through the efforts of Professor Sasaki, a corroborative study group involving the STA, MESSC and MHW was made to estimate the exposed doses by chromosome analysis. There were five research institutes participated: the RBC (Prof. Masao Sasaki), Radiation Effects Research Foundation (Dr. Yoshiaki Kodama), Research Institute for Radiation Biology and Medicine of Hiroshima University (Prof. Nanao Kamada), School of Pharmaceutical Science of Nagasaki University (Dr. Seiji Kodama) and the NIRS (Dr. Isamu Hayata) (the name within brackets is the representative of the institute). The first group meeting was held on November 5 at the NIRS and the details of chromosome

analysis and data recording were discussed. It was decided that five chromosome slides would be prepared for each of the 43 persons at the NIRS, and a set of slides (a total of 43 slides) sent to each of the five institutes. Each institute was to analyze at least 200 cells for each subject and to photograph all cells that were suspected of having abnormalities. Any points and comments and the analytic results were to be sent to the others via e-mail. The same program (Microsoft Excel) was used to handle the total data so as to facilitate the comparison and summing up of the results. On March 6 and 7, a second group meeting was held at the RBC where photographs of all abnormal chromosomes and chromosomes suspected of aberration were brought from the five institutes for final judgment. Therefore, it can be said that this analytical data is very precise and reliable. Doses were estimated using the final analytical results by a method described in the following section (Sasaki, M. S., 2001).

Persons in charge of chromosome analysis (*: persons who made final judgment)

RBC of Kyoto University: M. Sasaki*

Radiation Effects Research Foundation: Y. Kodama*, M. Miura and T. Matsumoto

Research Institute for Radiation Biology and Medicine of Hiroshima University: N. Kamada and K. Tanaka

School of Pharmaceutical Sciences of Nagasaki University: S. Kodama*

NIRS: I. Hayata*, M. Minamihisamatsu, R. Kanda, A. Furukawa, S. Suzuki, Y. Yamagishi, Y. Morimoto, K. Kawase

(4) Estimation of exposed dose

The analysis of a total of 67,879 cells (approximately 3.12 million chromosomes), or an average of 1,579 cells (approximately 73,000 chromosomes) per subject, detected a total of 107 dicentrics plus centric rings (Dic+Rc). Of these 107, 87 aberrations accompanied fragments, which were used for dose estimation. We estimated the dose of each person using the following equation.

$$Y = C + aD + bD^2$$

where, Y is the yield of Dic+Rc accompanying fragments, C is the spontaneous frequency, D is dose, and a and b are coefficients.

For the spontaneous frequency (C) of Dic+Rc of healthy Japanese and of subjects having low lymphocyte counts, the data of Tonomura et al. (1983) and of Prof. Sasaki (unpublished) were used, respectively. For the coefficients a and b, we used the values obtained in the ^{60}Co γ-ray experiment by Prof. Sasaki ($a = 2.31 \pm 0.88$, $b = 6.33 \pm 0.25$).

The average absorbed dose (Gy-equivalent) which is calculated directly from the results of chromosome analysis, means the γ-ray dose equivalent on the basis of chromosome aberrations (Rech, Roentgen equivalent chromosomal) and does not necessarily correspond to Sievert (Sv) which is generally used as the standard measure of risk. Supposing the mean RBE of several mGy of neutrons to be 50, the directly calculated dose to be D and the mean kerma ratio between γ-rays and neutrons to be 1:1, the neutron dose that contributed to kerma (A) is expressed as $D = A + A \times 50$. Since the neutron RBE is generally accepted to be 10 in terms of radiation protection, the dose equivalent in Sv (D') is expressed as $D' = A + A \times 10$. Therefore, D' was estimated from the equation ($D' = D \times 11 \div 51$).

After deducting the spontaneous frequency of chromosome aberrations, we detected no increase in the frequency of chromosome aberrations that was likely attributable to accidental exposure among the seven persons who had abnormally low lymphocyte counts and attended the first blood sampling. However, 18 persons out of the remaining 36 showed a rise in chromosome aberration frequency (Fig, 10-1). The median dose values estimated by chromosome analysis were 5 mSv or less for 13 subjects, 6–10 mSv for 3 subjects, and 11–16 mSv for 2 subjects.

(5) Conclusion

In early May, the seven persons with reduced lymphocyte counts were notified of the estimated dose by physicians and the other persons by mail. Since we had explained to the people that they would be notified of the results by the end of March at the earliest, we received inquiries from three persons from mid to late April. Two others asked about the results after they received the notice.

It has been reported that a rise in the frequency of chromosome aberrations can be detected through dose estimation by chromosome analysis, following exposure to 20 mGy of X or

gamma rays of low-LET radiation. Since the neutron's RBE for the induction of chromosome aberrations is over 20 for the dose range up to 10 mGy, even an exposure of 1 mGy or less would cause a detectable rise in the frequency of chromosome aberrations. The collaborative investigation by five institutes, which was very precise and large-scale, made it possible to show this small effect by an extremely little amount of neutron in the Tokai-mura criticality accident.

It is a matter of concern that there are few skilled cytogenetists among the younger generation in the research institutes in Japan now. One solution to this problem may be to train technicians in a commercial laboratory for chromosome analysis to learn this special technique.

References

1. Hayata, I., Wang, C-Y., Zhang, W., Chen, D-Q., Minamihisamatsu, M., Morishima ,H., Yuan, Y-L., Wei, L-X. and Sugahara, T.: Chromosome translocation in the residents in high background radiation area, the south China. J. Radiat. Res. 41 Suppl., 69–74, 2000
2. Tonomura, A., Kishi, K., Saito, F.: Types and frequencies of chromosome aberrations in peripheral lymphocytes of general populations. In: Radiation-Induced Chromosome Damages in Man, Eds. T. Ishihara and M. S. Sasaki, pp606–616, Alan Liss Inc., New York (1983)
3. Sasaki, M. S., Hayata, I., Kamada, N., Kodama, and Y., Kodama, S.:Chromosome aberrations analysis in persons exposed to low-level radiation from the JCO criticality accident in Tokai-mura. J. Radiat. Res. 42, Suppl. (2001)

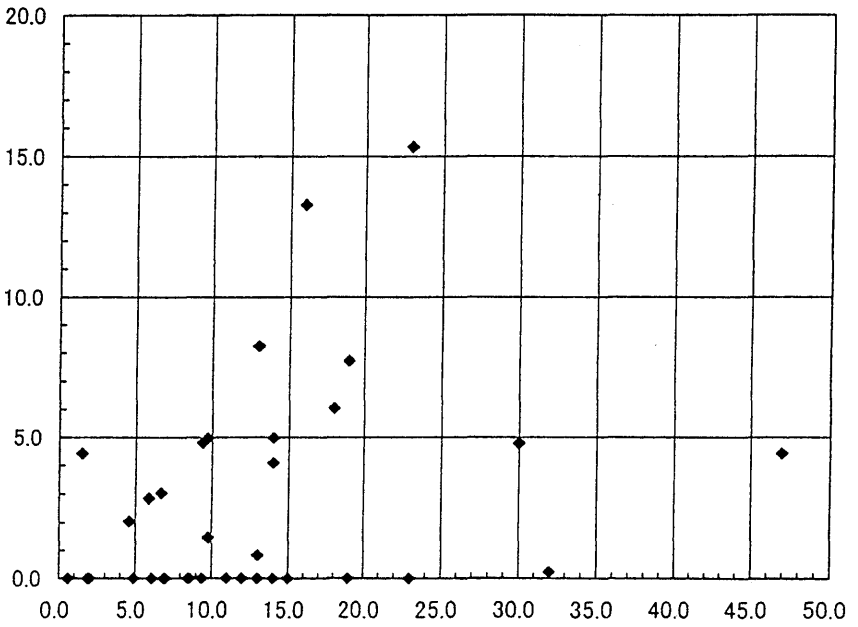


Figure 10–1 Comparison of dose estimated by chromosome analysis with that estimated from ^{24}Na measurements
X: Dose estimated from ^{24}Na measurements (mSv)
Y: Dose estimated by chromosome analysis (mSv)

11. International Response

The uranium processing plant's criticality accident was the first criticality accident in Japan. Japan had little experience in treating patients who had been exposed to high- level radiation. Offers of assistance and information were made in a variety of forms including by diplomatic routes and via email direct to the researchers involved. Due to the possibility of being tied up responding to the accident, visits immediately following the incident were refused, however offers of information in the form of papers and reports were gratefully received.

(1) Reception of the IAEA Investigation Committee

On Saturday October 16, three members of the IAEA Investigation Committee, Dr. Dominique Delattre, Dr. Malcolm Crick, and Dr. Yoshikazu Inoue (on temporary transfer from the NIRS to the IAEA) visited the NIRS. The goal of the Committee was to gather information concerning the accident, to offer advice if the Japanese authorities so desired, and to prepare a report for the chairman detailing the cause of the accident and its outcomes and effects. Therefore visits were made not only to the medical treatment facilities, but also to other locations including the accident site.

Also attending from the NIRS were Director General Sasaki, Dr. Murata, Director, Recearch Center of Charged Particle Therapy, Dr. Tsujii, Director of the Division of Radiation Health, Dr. Suzuki, Section Head at the Division of Radiation Health (at that time), Dr. Akashi, Section Head at the Division of Radiation Health, Dr. Shimo, Director of Division of Radiotoxicology and Protection and Mr. Hishiyama, Supervising Research Planner. Dr. Sasaki made an opening statement and explained the role of the NIRS, following which Dr. Suzuki detailed the emergency radiation exposure treatment system. Dr. Tsujii outlined the steps taken from the time the accident occurred to the time the patients were admitted, and Dr. Akashi elaborated on the diagnosis and treatment of the patients. Following this, the investigation committee visited the hospitals and emergency radiation exposure treatment facilities.

After departing the NIRS, the investigation committee visited the University of Tokyo Hospital and the Hospital of the Institute of Medical Science, The University of Tokyo where the other patients were undergoing treatment.

Upon its return to Vienna, the investigative committee complied a report. This report was published at the website of the IAEA.

(2) Explanation at the IAEA

On October 18, 1999, at the request of the Science and Technology Agency, Dr. Fujimoto, Director of the Human Radiation Environment Division, Mr. Shimomura of the Nuclear Safety Bureau's Nuclear Safety Policy Division, and Dr. Kanamori, Manager of Administration Section, Environment and Safety Division, Japan Nuclear Cycle Development Institute visited the International Atomic Energy Agency (IAEA), located in Vienna, Austria, and explained the situation concerning the JCO criticality accident. The content of the explanation was a formal interpretation of the events based upon the information available at the time. The explanatory meeting convened at 10:00am in the boardroom of the IAEA, and was attended by approximately 400 people, well over the predicted 200 for whom briefing materials had been prepared. The three speakers were introduced by Mr. Gonzales, after which Mr. Shimomura explained the accident using OHPs and the prepared briefing materials. The explanation was followed by a lively open discussion. The main questions directed towards Dr. Fujimoto are outlined below. Dr. Benninson, a prominent member of the ICRP, expressed the following concern. "Argentina has experienced two criticality accidents, one in 1983 and one in 1993, in which two people died. Victims of the latest JCO accident received radiation doses in excess of the fatal dose of 18 GyEq, yet they are still alive. Is it not possible that an error was made in the evaluation of their doses?" Dr. Fujimoto answered as follows. "The doses of the three patients were tentatively 18, 10, and 2.5 GyEq respectively. However, the dose estimation has been carried out by four methods, and at this point, the doses has been judged as appropriate. That the patients are still alive can be attributed to the intensive medical treatment, use of a range of medications, and intestinal decontamination."

In response to the question concerning whether the use of Sievert (Sv) units or GyEq was more appropriate, the answer was as follows. "Sievert is the unit used in relation to radiation protection, thus is not appropriate for use in relation to this accident. GyEq unit was used since irradiation was occurred in the mixed field of gamma and neutron rays."

In addition, questions were raised by IAEA specialists concerning units used for radiation exposure dose, evaluation methods, nuclear fission yield, and amount of environmental release. The main questions and responses are as follows.

Q. What is the extent of the effect on the environment as a result of this accident?
A. The effect on the environment was not significant.
Q. Weren't the level of gamma rays equivalent to a 1 kW reactor?
A. Nuclear fission yield is believed to be in the range of 10 to the power of 17 to 18, however samples will need to be taken from the precipitation tank and analyzed to be certain.
Q. What was the scale of the criticality accident, and was it sufficient to blow the roof off the conversion test building?
A. The building and the tank remained sound, however a small amount of iodine and rare gases escaped through the ventilation system.
Q. What type of procedures and regulatory system does Japan have in place?
A. Fundamentally, recycling facilities and nuclear power plants come under the same regulatory system, and are inspected by the Science and Technology Agency and Safety Commission. However, uranium conversion facilities do not have a system of compulsory annual inspections.
Q. Iodine is thought to be generated to the amount of 1 Curie. If this were to be released, it would be equivalent to that produced in a year by a power plant. Isn't it likely to produce a greater effect on the environment?
A. The critical yield is currently under investigation. The exhaust system contains high efficient filters, and only small amounts of rare gases and iodine escaped into the atmosphere. The results of environmental soil analyses show that the concentrations are low.
Q. What concentration of uranium is permitted to be handled?
A. An application had been made for the handling of up to 20%. At that time, an evaluation of the operating manual was carried out. Following that, no application for change to the operating manual was made.
Q. Is the fuel of 18.8% concentration consistently handling in the facility?
A. Light water reactor fuel is less than 5%, and the 18.8% fuel in this instance was fast breeder reactor fuel.
Q. What was different from usual operation?
A. That is currently under investigation.
Q. Was the process in this case the disposal of weapons grade uranium?
A. I don't have information relevant to that subject.
Q. What was the exposure dose to the three victims?
A. 18, 10, and 2.5 GyEq respectively. These values were estimated by means of lymphcyte counts, measurement of the concentration of radioactive ^{24}Na in the blood, whole body counting (WBC) of ^{24}Na, and measurement of chromosomal aberration.
Q. Were critical safety measures taken for the solution tank?
A. Permitted critical management requests the operation with mass control of no more than 2.4 kg for 10% ~ 20% enrichment fuel.
In conclusion, Dr. Gonzales, head of the Radiation and Waste Safety Division spoke on behalf of all present to thank those who had come from Japan to explain the JCO accident, and expressed his hope for the completion of a detailed report.

In addition, an urgent request was made for our participation to an Advisory Group Meeting held in the following morning (October 19) discussing safety of nuclear power facilities in Asia and the Pacific, and an explanation of the JCO accident was given.

(3) Participation of Experts from the US, France, Germany, and Russia

At the Network Council for Radiation Emergency Medicine convened on October 29, the NIRS took the opportunity to invite the participation of overseas experts experienced in the treatment of radiation exposure and the estimation of radiation doses. Opinions concerning the treatment of victims of high dose radiation exposure were exchanged, and a visit was paid to the treatment facility. A total of 9 specialists

participated, with two being from the US, one from Germany, four from France, and two from Russia. These experts in the treatment of acute radiation exposure were from facilities with which the NIRS had experienced more contact in the form of such things as the exchange of information than in previous cases. On the morning of October 28 (Thursday), the specialists visited the NIRS, and following an explanation of the details of the accident, treatment, and radiation dose evaluation, opinions were exchanged. Following this, the doctors visited the University of Tokyo Hospital and the Hospital of the Institute of Medical Science of the University of Tokyo, while the radiation dose assessment specialists remained at NIRS and exchanged opinions with the NIRS specialists. The following day (October 29), the visitors took part in the Network Council for Radiation Emergency Medicine as observers, and participated in discussions with the Council members. Before departing Japan, the specialists completed report to be left behind (see reference 1 in the end of this text). The report outlined the extremely efficient role the NIRS and the Network Council for Radiation Emergency Medicine played, the high level of care given the patients, and the inclusion of the latest technology.

These overseas specialists provided invaluable information from the time immediately following the incident. The participation of these specialists, unlike non-emergency times, allowed little time for preparation, and required immense efforts on the part of the Science Attache on the Ministry of Foreign Affairs' Overseas Establishments, and the Science and Technology Agency. The problem concerning the issuing of visas for visitors from Russia arose, but was dealt with in sufficient time to allow schedules to remain uninterrupted. The costs incurred by university researchers were absorbed in full or in part by the NIRS, and the costs incurred by public officers were handled by their respective countries. Many difficulties were experienced in the area of logistics (i.e. work concerning invitations, the development of schedules etc.), however these were all ultimately able to be resolved. In more hands-on aspects, the high praise received from top overseas specialists regarding the emergency medical treatment of radiation exposure victims may be considered evidence of success.

(4) The Need for an International Section at NIRS

Planning and coordination of the IAEA committee was carried out by the Division of Planning and Coordination. Formalities were completed satisfactorily by the staff of the Division of Planning and Coordination. However, as coordination over and above that required for everyday formalities was needed to deal with a range of national responses and work other than that related to the accident, it cannot be said that the Division of Planning and Coordination was able to competently deal with all contingencies. A strong argument can be made for the creation of an international post to be held by one with experience in international cooperation who is able to deal directly with overseas institutions, and who is able to undertake appropriate action as the need arises.

12. Press Release

Sometime after 1:00pm on September 30 (the day of the accident), contact was made by the head of the Division of Planning and Coordination that an accident had apparently occurred at the nuclear facility. Further information revealed that there may have been the need to transfer victims of the accident to the NIRS, and for this reason, a press release would be needed. Conference room 1 was set up for a press conference, and this instruction was carried out by the staff of the Division of Planning and Coordination.

From around 1:30pm the first press vehicles (television relay vehicles in particular) began to gather in the car park beside the main building of NIRS. Questions from the press concerning the accident particulars, the time of arrival of the victims, and the steps to be taken were fielded, however as no accurate information was available at that time, responding appropriately was difficult.

Regulations were established concerning the presence of the press outside the Medical Unit of Radiation Emergency in the event of the arrival of victims of the accident. Upon receiving notification was given that the patients would arrive at the NIRS at around 3:30pm, the press began to set up television relays. After the patients arrived and entered the Medical Unit of Radiation Emergency, questions from the press regarding the state of the patients, the time at which the press conference was to be held, and who was to be present at the conference were fielded.

NIRS held the press conference at 7:00 that evening, and the following day (October 1) saw a further press conference attended by Chairman Maekawa of the Network Council for Radiation Emergency Medicine.

Between October 2–4, press conferences were held concerning the decision to transfer the two patients exposed to the high levels of radiation to the University of Tokyo Hospital and the Hospital of the Institute of Medical Science, The University of Tokyo.

As the press questions concerning radiation were so varied, a series of lectures were held in order to deepen understanding about radiation. Those held on October 2 discussed the effects of radiation of biological effect and radiation dose evaluation. Those held on October 22 concerned the treatment of radiation injury.

October 28 saw the arrival of overseas experts and their attendance at the Network Council for Radiation Emergency Medicine, a portion of which was open to the press. Given the emergency nature of the event, press matters were handled with the utmost efficiency. In hindsight, following the press conference there were a number of quite specialized questions from the press concerning radiation which the press secretary was unable to answer, and which had to be fielded by specialists who were busy in their own duty with treatment and radiation dose assessment. In the future, the specialists themselves must be involved to the press secretary.

13. Uranium Processing Plant Criticality Accident Investigation Committee, and the Health Management Committee organized by the Nuclear Safety Commission

(1) Uranium Processing Plant Criticality Accident Investigation Committee organized by the Nuclear Safety Commission

The Uranium Processing Plant Criticality Accident Investigation Committee was established based upon an October 4 directive to investigate the cause of the accident by the Government Affairs Administration headed by the Prime Minister. The day the directive was received, the Nuclear Safety Commission sought the participation of those knowledgeable in relevant fields to thoroughly identify the cause of the accident from a third party perspective, and to establish a strategy to prevent the recurrence of such an accident. Aside from members of the Nuclear Safety Commission, members consisted of Mr. Yoshikawa, President of the Science Council of Japan, as chairman, 24 others with relevant expert knowledge, and the NIRS's Director Sasaki as the only medical treatment expert. The Committee has convened eleven times since its inaugural meeting on October 8, 1999, and has conducted on-site surveys. On November 5, taking heed of the extent of the social consequences of the accident, from the perspective of the necessity for the establishment of timely, precise countermeasures, and founded upon the results of the five meetings thus far held, the Committee presented its "Urgent Recommendation and Interim Report" to the government.

In order to conduct detailed analysis, the Committee constructed three task groups dealing with "Technology and Evaluation", "Companies and the Industry", and "Society and Safety". After consideration of the facts and causes, and structural and ethical problems behind the facts, the Committee completed its "Uranium Processing Plant Criticality Accident Investigation Committee Report" on December 24. The section concerned with the NIRS discussed the treatment policies in place in the event of a nuclear disaster, namely, the state of policies for the emergency treatment of radiation exposure, the action taken for victims of high level radiation exposure, the realities of medical treatment, assessment of radiation exposure doses and identification of types of radiation exposure, actions taken concerning nearby residents, and future necessary measures.

The subjects of scrutiny included all aspects of the accident, however as only one member of the Committee was a treatment expert, from the perspective of a medical specialist, one is left with the impression that debate over health and treatment issues was somewhat lacking. The effects of radiation on health is being discussed in detail by the Health Management Committee, which is comprised of treatment and radiation protection experts.

(2) The Nuclear Safety Commission Health Care Study Committee[2)]

The Health Care Study Committee was established under the Nuclear Safety Commission in order to consider the management of future health issues which may arise as a result of the Uranium Processing Plant Criticality Accident. Its members consisted of the director of the Radiation Effects Research Foundation, Shigenobu Nagataki, as the chairman, eleven others with specialist knowledge in relevant fields, and Makoto Akashi, Section Head of Radiation Injury Control at the NIRS's Division of Radiation Health. The role of the Health Care Study Committee was to consider health management issues based upon radiation dose assessments, and its aim was to present the Administration with a policy for health management. From November 8, 1999, a total of 12 conferences was convened to discuss, first, the importance of health management based upon radiation dose assessment, and second, to consider the actual formulation of a policy based on the results of that discussion. Discussion was entered into with enthusiasm, and the exchange of ideas continued via email.

On January 25, 2000, the interim report was presented outlining a basic policy for the health management of local residents. Public opinion was sought regarding the policy, following which further discussion took place, and on March 27, the Report by the Health Care Study Committee was completed. This report looked at the fundamentals of radiation and the effects it has on the human body, and detailed the influence of radiation on human health. In addition to general considerations of health management in the event of radiation exposure, the

report proposed a concrete health management policy including an outline of the need in this case for health examinations to ease residents' concerns, and health consultations including psychological aspects. In order to facilitate comprehension of the report, easy to understand explanations of a range of questions concerning radiation were included as references.

Based on this report, health examinations were conducted in the manner previously described.

1) The Uranium Processing Plant Criticality Accident Investigation Committee Report, Atomic Energy Commission (December 24, 1999). (In Japanese)
2) The Report by the Health Care Study Committee, Nuclear Safety Commision (March 27, 2000). (In Japanese)

14. Handling of Information

(1) Informed Consent Regarding the Radiation Dose Measurement

The treatment data from the patients who were the victims of high-level radiation exposure is invaluable. If in the future an incident should occur from which a similar patient emerges, the data will be useful in determining what type of treatment regime should be undertaken, and should also be utilized by those involved in treatment and related fields for the advancement of treatment and learning. Considerations concerning the kind of treatment system for radiation exposure to be constructed are being undertaken by various authorities and the Nuclear Safety Commission, however without knowledge of the actual treatment performed, treatment systems will not move part the drawing board stage. On the other hand, as two of the three victims of high level radiation exposure have died, the possibility of treatment information being easily identified with the individual patients is high. Therefore, the fundamental contradiction inherent in the right to privacy versus the publication of information for the purpose of advancing treatment and academic fields must be reconciled, and due consideration to this end should be given soon by those involved.

In the field of medical treatment, the importance of informed consent is widely recognized. The idea of informed consent goes back to the Declaration of Helsinki adopted at the 18th World Medical Association General Assembly, held in Helsinki in June, 1964. Implicit in informed consent is that the content of tests have been explained to the testee, that the testee is satisfied with the test content, agreement has been reached, and that the test may be performed for the first time on a human.

Based on the Declaration of Helsinki, the NIRS had each of the three victims of high-level radiation exposure or their families sign a "Consent for Tissue Sampling for the Purpose of Radiation Dose Measurement". That is, the NIRS explained the importance of the estimation of radiation dose through the testing of the patient's blood, stools, hair, body hair, and teeth in the determination of treatment protocols and prognosis. In addition, permission was acquired for the NIRS to publish results in specialist medical journals, present papers at conferences, and report to public commissions for the purpose of the advancement of medical knowledge, science, and public safety policies with the precondition that the patient's right to privacy be respected.

(2) Network Council for Radiation Emergency Medicine Code of Ethics

Debate concerning the handling of the three patients' treatment data began at the Network Council for Radiation Emergency Medicine on January 6, 2000, and accord was reached on March 25. It was agreed that the data should be handled as carefully as possible due to the small number of patients resulting in easy intrusion on their privacy, the important nature of the treatment data and specimens, and the fact that a number of facilities were involved. For this reason, all those who had presented papers, academic reports, or lectures were required to submit the relevant particulars to allow all concerned to come to terms with the presentations as a whole. In addition, the use of the patients' specimens and samples was to be determined the person in charge in the University of Tokyo Hospital, the Hospital of the Institute of Medical Science of the The University of Tokyo, and the NIRS respectively. It was also agreed that individual patients not be identified in presentations, and the right to privacy of the patients and their families be awarded the utmost consideration. In the case of presentations, informed consent was to be obtained as the need arose.

(3) Publication of Patient Photographs in Weekly Magazines

In a manner which had not been predicted by those concerned, patients' photographs appeared in a certain weekly magazine. On May 15, 2000, a weekly magazine printed photographs of the patients which had been presented at The Third Annual Meeting of Japanese Society for Emergency Medicine. The acknowledgement of the family or the person who had given the presentation was not sought, and no attempt was made to disguise the patients' identities. In response, a letter of protest was sent to the magazine in the name of the group of doctors involved in the patients' treatment, and the letter

was also circulated to newspapers and television stations. The letter was reported in a number of newspapers, and appeared a number of issues later in the magazine concerned.

On Sunday May 28, the doctors in charge met with the families of the patients to apologize for the magazine's publication of the patients' photographs and the subsequent trouble incurred and to explain the steps that had been taken following the release of the magazine. They also elaborated upon steps which had been taken to prevent a recurrence of the incident.

In order to prevent a recurrence, the Chairman of the Network Council for Radiation Emergency Medicine introduced the following policies.

①All treatment records, examination data, pathology specimens, macroscopic photographs, specimens and samples are to be managed with the utmost control.

②Before using patient data in academic presentations, the presentation of papers, or lectures must be contacted to the appropriate section in charge at the University of Tokyo Hospital, and the Hospital of the Institute of Medical Science of the University of Tokyo and NIRS.

③Public access to information or photographs which may cause emotional distress to the families of patients or infringe upon the dignity of a patient should not be permitted for a considerable period of time.

④If the use in presentations of slide photographs of patients' faces or bodies is important for the purpose of information sharing at an academic level (for example, if it is necessary to communicate the tragedy of radiation exposure treatment, or to explain the reality of radiation burns to a specialist in the field of burn treatment), the patient's identity must be disguised, and permission must be sought through the relevant institution from the family of the patient after explaining the actual content of the presentation. Additionally, conference sponsors must be made aware of the complete ban on press photography, members of the audience must also be advised of the ban on photography, and ultimate responsibility for any events following the presentation must rest with the presenter.

Through observance of such procedures it is hoped that the privacy of the patients can be maintained while advances in treatment are realized. If, on the other hand, since the photographs are published in weekly magazines, necessary information may not be communicated between those involved in treatment and research.

This accident was the first of its kind, and it is beyond dispute that aspects of its handling including the management of data and the media response were conducted on a trial and error basis. The fact that an academic presentation appeared in a weekly magazine for the general public should be uppermost in the thoughts of all involved.

15. Radiation Emergency Medical Preparedness at the NIRS: Future Issues and Prospects

The Tokai-mura criticality accident, the worst nuclear accident in Japan's history, and the deaths of two employees, has caused interest in radiation emergency medical preparedness to reach a level thus far unsurpassed. While many aspects of safety have been dramatically improved, so long as nuclear power continues to be used, the possibility of another nuclear disaster or accidental radiation exposure incident cannot be denied. This accident has once again drawn attention to the importance of complete preparedness. The radiation emergency medical preparedness has placed the NIRS in a position of authority and responsibility. However this accident has again emphasized the importance of disaster countermeasures and the minimization of the impact on public health by means of those measures. This incident has also taught us a great deal concerning the questions of the manner in which the NIRS should confront radiation emergency medical preparedness, and the role the NIRS should play in a unified national system.

15-1. Radiation Emergency Medical Preparedness at the NIRS

(1) Construction and Maintenance of System

According to the Nuclear Safety Commission's "Disaster Prevention Measures in Nuclear Facilities" and the Central Disaster Prevention Council's "Basic Disaster Prevention Plan", the responsibility of the NIRS is to dispatch the On-site Emergency Radiation Medical-Team to the On-site Radiation Emergency Center, to admit victims of radiation exposure requiring specialist diagnosis or treatment and to form a network with other specialist treatment facilities, to exchange information, to cooperate in research matters, and to exchange personnel in order to enable the smooth transition from day-to-day to emergency situations. The damage caused by whole body exposure to radiation is not restricted to a single organ, but is compound in nature, and requires treatment by specialists in a wide range of fields. This necessitates that appropriate action be taken in consultation with other top specialist facilities. As treatment does not merely involve intensive care, but also such things as bone marrow transplants and skin grafts which, although not specific to the treatment of injuries caused by exposure to radiation are nevertheless specialist treatments, the development of cooperative networks with other specialist facilities is desirable. For over ten years, the NIRS has held "Discussion Group Concerning the Radiation Emergency Medical Preparedness" and "Working Group for Countermeasures in Radiation Emergency Medical Preparedness" meetings and has included the opinions of those knowledgeable in their fields in the consideration of radiation emergency medical preparedness strategies. In 1997, the "The Role of the National Institute of Radiological Sciences in the Radiation Emergency Medical Preparedness in Japan" was published. In addition to clarifying the role of the NIRS, the document clearly outlined the conceptualized structure of a treatment network. The concept was reflected in the revised "Basic Disaster Prevention Plan", and in 1999 was replaced by the Network Council for Radiation Emergency Medicine, a network of researchers and doctors from university and specialist hospitals, and research facilities. The effectiveness and efficiency of the Network Council for Radiation Emergency Medicine received praise in relation to the Tokai-mura criticality accident.

In addition to constructing the Network Council for Radiation Emergency Medicine, the NIRS also maintained a medical care unit for radiation emergency through which triage, decontamination, first aid, measurement, and temporary hospital admission was possible. Reverse isolating rooms were established in the Hospital for Charged Particle Therapy, and particular attention was paid to the maintenance of contaminant testing, and the measurement vehicles and instruments used for the assessment of radiation doses. The NIRS also examined and stored internal decontamination drugs which are difficult to obtain in Japan, organized transportation of patients and established a system which enabled a rapid response in emergency situations. In addition to maintaining the facilities and equipment necessary in the treatment of radiation exposure, the NIRS emphasized the

education of necessary staff. Staff were sent to a training course for radiation emergency medical preparedness sponsored by the US Department of Energy (DOE) and run by Radiation Emergency Assistant Center/Training Site (REAC/TS), participated in a range of overseas conferences and study groups on radiation exposure, exchanged information with radiation facilities in the US, Russia, Germany, China, and Korea among others, cooperated with the World Health Organization (WHO) emergency radiation exposure medicine database, and accepted radiation exposure patients from other countries. In this manner, the NIRS, Japan's only radiation exposure specialist hospital, maintained its high level of efficiency. In the past, accident involving radiation sources have caused local injuries, however that a nuclear accident, specifically a criticality accident of such magnitude as to cause the death of two people should occur caused the reconsideration of the phrase "Accidents are unexpected". On the other hand, the transfer of patients to other hospital facilities despite the fact that the NIRS specializes in treatment in the case of radiation exposure attracted both internal and external criticism. That the treatment of victims of severe radiation exposure requires a high level of specialist technology has already been discussed. That more effort was not made in explaining the difficulty of treating several such patients at the one facility, and the limits of the NIRS in terms of personnel and facilities leading to the network construction is to be regretted. It has been pointed out that policies concerning residents and the response team were somewhat clumsy, and although the reality that an accident of this magnitude had never before been experienced in Japan is insufficient excuse, of saving grace is the fact that the victims received the best of care.

(2) Hospital Functions

The Japanese fishing boat "Lucky Dragon No. 5" was exposed to a thermonuclear bomb test explosion at Bikini Atoll in 1954 and 23 fishermen were suffered from acute radiation injuries. It was realized at that time that the facilities of researches and medical preparedness for acute and prolonged radiation injuries have to be instituted. In order to investigate the effects of radiation on the human body, and to advance the use of radiation in medical science while suppressing its harmful aspects, thus, National Institute of Radiological Sciences (NIRS) was established in 1957 under the auspices of the Science and Technology Agency with its many researchers in the fields of medicine, physics, and biology.

Subsequently, the NIRS became the only subsidiary of the Science and Technology Agency to possess a hospital facility. The hospital began medical examinations in 1961, and the current Division of Radiation Health was established four years later in 1965. Experience in the treatment of radiation exposure victims at the NIRS, while perhaps insufficient, has a history of over 30 years, beginning with the medical check-ups of the Bikini Atoll victims and the follow-up study on patients with deposition with thorotrast, contrast medium for blood vessels, in World War II, radiation dose assessment and treatment of the victims of the 1972 iridium radiation accident at Ichihara city in Chiba prefecture and the victims of the 2000 radiation accident in Yoka-ichiba-city, Chiba prefecture.

Upon transfer to the NIRS, a patient undergoes assessment of the type and dose of radiation exposure, and is checked for the existence of contamination with radionuclides and wounds. If necessary, decontamination is undertaken and wounds are tended. If it is determined that treatment is necessary, the patient is admitted. If a considerable amount of contamination is present, the patient is admitted to the medical care units for radiation emergency, otherwise to the Hospital for Charged Particle Therapy that contains reverse isolating rooms. Where the treatment of patients in radiation accidents varies from that in other types of accidents is that radiation protection and management specialists are needed in addition to regular medical staff in order to conduct the necessary diagnosis and treatment of radiation exposure injury, the identification of radionuclides, contamination assessment and decontamination. The significance of the existence of the NIRS lies in these points, and that the patient is dealt with by both the medical treatment team and the radiation dose measurement and evaluation team in cooperation. For this reason the NIRS is the only one of its kind in Japan, and would be exceptionally difficult to duplicate all over the country.

From June 1994, the NIRS has been using a charged particle cancer treatment device, the Heavy Ion Medical Accelerator in Chiba (HIMAC), in clinical trials on cancer. Reverse

isolating rooms were established in a new ward (the Hospital of Charged Particle Therapy) in 1997, and the Medical Care Unit for Radiation Emergency was completely renovated in the old ward. This is the only radiation-oncology college hospital in Japan, providing not only charged particle therapy but also ordinary radiation treatment, brachytherapy and imaging diagnosis. The facility comprises a total of 100 beds, of which six are devoted to radiation emergency medicine. Of the six beds, four are in the Medical Care Unit for Radiation Emergency for the use of contaminated patients, and two are in the new ward's reverse isolating rooms. The remaining 94 beds are located in the new ward and are used for the non-emergency treatment, however if necessary, they can also be used to accommodate patients not contaminated with radioactive nuclides. While the Medical Care Unit for Radiation Emergency contains four beds for contaminated patients, there is room to accommodate a maximum of ten patients.

As has already been discussed, the primary role of the NIRS in the treatment of radiation exposure victims is the special care required for those who have been exposed to radiation. The other important role is the medical coordination of radiation emergency including the assessment of radiation dose, the measurement of internal and external contamination, decontamination (difficult to carry out in other levels of facilities), patient prognosis, and contaminated patient management. The purpose of establishing the network was to enable the transfer without delay of patients who require such highly specialized treatments as emergency intensive care, bone marrow transplants, and skin grafts to facilities at which they can be performed. The decision was made to transfer the two patients exposed to high level radiation as a result of the Tokai-mura criticality accident to the University of Tokyo Hospital and the Hospital of the Institute of Medical Science, The University of Tokyo. As a result, the two patients, initially given life expectancies of one week and one month, lived three months and seven months respectively due to the medical care they received.

15-2. Prospects for the Future: Expectation of the NIRS

Radiation is tasteless, odorless, and colorless, and radiation injuries do not manifest immediately. It can even be difficult to determine if a nuclear disaster is actually occurring. These facts serve to reinforce unease. Nuclear disasters are fundamentally man-made in origin, and responsibility for treatment among other things lies largely with bureaucracy. This incident leaves lessons to be learned in all of these aspects. The treatment of patients and assessment of radiation doses were of course undertaken, in addition to explanations for residents regarding radiation exposure, and the presentation of information and predictions based on scientific principles by the police and investigators in order to determine legal responsibility. Yet efforts were made to protect the privacy and dignity of individuals. Additionally, explanations concerning health issues were made to ease the fears of others involved such as regional authorities, police, fire-department, and members of the media, and every opportunity was made to provide the media with accurate information concerning exposure to radiation. To enable those engaged in providing treatment at the other network facilities involved to do so without concern, radiation protection guidelines including the collection of excreta were offered. Following the accident, the number of telephone questions concerning the effects of radiation increased dramatically, and the number of questions fielded from municipalities which own nuclear facilities was also overwhelming. The NIRS is considered a facility for radiation emergency medicine, however even excluding the areas of measurement and dose assessment, the radiation emergency medicine facilities themselves are unique, and the lessons learned from this accident must be reflected in future NIRS policy.

The Tokai-mura accident was the first nuclear power disaster in Japan's history, and as has been discussed already, manifested many aspects which were not included in the NIRS's scenario of radiation emergency medical preparedness. One such aspect was the assessment of the impact on residents' health and the explanations required to calm their fears, and the activity required at the site. The NIRS is expected to dispatch its treatment team to provide guidance and medical treatment under the direction of the disaster countermeasures command office. However what was required in this case was not decontamination or aid activities, but conversing with residents. There were also difficulties in terms of human resources in simultaneously dispatching the treatment team and

admitting patients, and the reality is that steps were taken only following the receipt of requests from those on site. The role that the team should play, the steps which should be taken in dispatching it, the timing of the dispatch, and the activities the team should undertake were all reinforced. As a result of this accident, municipalities which own nuclear facilities have revised their manuals, and the expectations made of the NIRS have increased. In addition, due to the Ministries of Health and Welfare, and Labor, and Education, Science and Culture stepping in to maintain medical treatment facilities around the site, still further demands will be made on the NIRS in terms of on-site activity in the event of another such accident. Based on the above mentioned points, issues concerning the dispatch treatment team should be considered, and thorough examination should be made to allow the application of health measures for residents based on accurate information. An issue which should be considered is the preparation of system by NIRS doctors and researchers in which the effects of radiation can be explained simply during explanatory meeting for residents and individual consultations. Likewise, in areas where nuclear power facilities are established, contact between residents and community nurses is important (in Tokai-mura, community nurses actually offered assistance to residents), and their participation in NIRS or regional authority sponsored training and lectures should be considered.

The unresolved issues concerning the medical treatment system are considerable. Despite the best care Japan could offer, two of those exposed to radiation subsequently died. Treatment for radiation exposure does not require immediate treatment such as for wound or burns, but rather intensive treatment of the internal organs which are damaged when exposed to high level radiation. For this reason, the NIRS established a system, namely the Network Council for Radiation Emergency Medicine, to enable the smooth and rapid performance of such things as intensive care, skin grafts, and stem cell transplantations. As Tokai-mura is located approximately 100 km from the NIRS, the transportation of patients by helicopter was not problematic. However, if the accident site had been Kyushu or Hokkaido, in addition to the limits of transportation by helicopter, the negative aspects from the patient's point of view of transportation to a distant location are significant. For this reason, the NIRS drew existing facilities in distinct areas into the Network Council for Radiation Emergency Medicine. The essential elements of the Network Council for Radiation Emergency Medicine are the measurement and assessment of radiation dose, and specialist treatment facilities, however to construct a facility which has all of these elements is difficult. A specialist treatment facility must of course posses the requisite equipment, including such things as whole body counters, however for maintenance and management, as well as measurement and assessment, a specialist is required. The same applies for the problems of the identification of radionuclides and the assessment of internal contamination. The maintenance through contracts and training of medical treatment facilities through which the cooperation of radiation management and protection specialists can be rapidly obtained in times of need is the essence of a regional network. To enable the smooth management of such a system, the education of local personnel is essential. It is a very important role of NIRS to train specialists to become lecturers for regional education sessions. Furthermore, the involvement in drills or exercises for nuclear disaster in local areas with established nuclear power facilities is significant; thus requests for the NIRS to send personnel for nuclear power disaster training and education seminars are numerous, however to respond to these requests is an issue in itself.

The final remaining issue is that of research. The research required in the area of radiation emergency medical preparedness can be broadly differentiated into the diagnosis and treatment of high dose radiation exposure, the field of internal decontamination, the reduction of latent manifestations of radiation injuries, and the development of fast, accurate measurement methods. If these were ranked according to the order in which they should be conducted by the NIRS as a national facility for radiation emergency medical preparedness, then that which is not attempted by private facilities or that research which is too difficult for private facilities to conduct should be placed at the top of the list. Following the conversion of status to that of an independent corporation in 2001, research projects to be conducted internally include the basic patho-physiology of exposure to high dose, the development of internal radionuclide decontaminants, the radio-protectors, and research to increase measurement speed.

Projects which the NIRS is unable to carry out will be performed in conjunction with other research facilities, or will be commissioned. In relation to research, the NIRS hopes to become a research facility which offers leadership to other national and overseas facilities. Another important issue is to enhance the compatibility of such research with the training and seminars requested by regional authorities. As the need for radiation exposure data collection and a reference center for emergency number 119 calls concerning radiation exposure increases, so too, predictably, will the role of the NIRS.

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Approximately 40% of Japan's energy needs are met by nuclear power plants, which have become an indispensable part of the landscape. In order to permit the safe use of nuclear powered energy in the future, habitual safety maintenance is the most important condition to be met. On the other hand, the insurance of thoroughly radiation emergency medical preparedness is important. Nothing could be better than to not need insurance, however in reality, the occurrence of an accident like the Tokai-mura criticality accident, in which such insurance was essential, only serves to reinforce its importance. For as long as no insurance exists to guarantee that such an accident will not reoccur, we have learned that the maintenance of a system for treatment of victims in radiation accidents is important.

Japan is fortunate in that radiation accidents in which medical treatment is required rarely occur. However, questions have been asked by those who attend the training courses or seminars for radiation emergency held by the NIRS concerning who, if contacted in the case of a radiation accident, will conduct measurements as part of their response. In 2000, although involving only localized radiation exposure, a high dose radiation exposure accident involving x-rays occurred in Chiba prefecture, and monazite was discovered in Nagano, Saitama, and Chiba prefectures. Thailand and Egypt have also experienced fatal radiation exposure accidents. The enhancing of a system for radiation emergency medical preparedness in Japan is not simply for our own sake. Rather, a radiation emergency medical preparedness system which can make a contribution on an international scale is highly desirable.