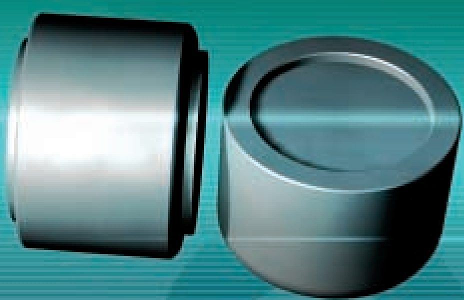
The Radiological Accident in Samut Prakarn



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FOREWORD

The use of radioactive materials offers a wide range of benefits throughout the world in medicine, research and industry. Precautions are, however, necessary to limit the exposure of people to the radiation that is emitted. Where the amount of radioactive material is substantial, as in the case of radiotherapy sources or industrial radiography sources, extreme care is needed to prevent accidents which may have severe consequences. Nevertheless, in spite of the precautions taken, accidents with radiation sources continue to occur, although infrequently. As part of its activities on the safety of radiation sources, the IAEA conducts follow-up reviews of such serious accidents to give an account of their circumstances and of the medical aspects, from which organizations with responsibilities for radiation protection and the safety of sources may learn.

A serious radiological accident occurred in Samut Prakarn, Thailand, in late January and early February 2000 when a disused ^{60}Co teletherapy head was partially dismantled, taken from an unsecured storage location and sold as scrap metal. Individuals who took the housing apart and later transported the device to a junkyard were exposed to radiation from the source. At the junkyard the device was further disassembled and the unrecognized source fell out, exposing workers there. The accident came to the attention of the relevant national authority when physicians who examined several individuals suspected the possibility of radiation exposure from an unsecured source and reported this suspicion. Altogether, ten people received high doses from the source. Three of those people, all workers at the junkyard, died within two months of the accident as a consequence of their exposure.

Under the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, the Thai authorities requested advice from the IAEA on the medical treatment of the exposed people. Subsequently, they invited the IAEA to assist in a review of the accident. The IAEA is grateful to the Thai authorities and the physicians of the Samut Prakarn Hospital in Samut Prakarn Province and the Rajavithi Hospital in Bangkok for their assistance in the preparation of this report.

The IAEA technical officers responsible for the preparation of this publication were J.G. Yusko, B. Dodd and I. Turai of the Division of Radiation and Waste Safety.

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CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

A common use of high activity ^{60}Co sources around the world is in the treatment of cancer patients (radiotherapy). In Thailand alone there are 20 radiotherapy centres, which have a total of 25 teletherapy units. Intense beams of penetrating gamma radiation are needed to treat cancer; hence, high energy and high activity sources are used in specially designed machines to deliver the radiation dose in a controlled manner. The intensity of the radiation decreases over time, however, and the sources need to be replaced to avoid long treatment times. The services of specialist companies are normally used to exchange the sources and maintain the equipment.

One company based in Bangkok, Thailand, possessed several teletherapy devices without an authorization from the Thailand Office of Atomic Energy for Peace (OAEP). In the autumn of 1999, the company relocated the teletherapy heads from a warehouse it had leased to an unsecured storage location, also without the authorization of the Thai authorities and without informing OAEP of this relocation.

In late January 2000, several individuals obtained access to the unsecured storage location and partially disassembled a teletherapy head. They took the unit to the residence of one of the individuals, where four people attempted to disassemble it further. The teletherapy head displayed a radiation trefoil and warning label. However, the individuals did not realize that this indicated radioactive material, and the warning label was not in a language they understood. On 1 February 2000, two of the individuals took the partially disassembled device to a junkyard in Samut Prakarn, Thailand, so that the component metals could be segregated and sold separately. While a worker at the junkyard was disassembling the device using an oxyacetylene torch, the source fell out of its housing, unobserved by either the junkyard workers or the individuals involved.

By the middle of February 2000, several of the individuals involved had begun to feel ill and sought medical assistance. Physicians at a local hospital recognized the signs and symptoms of several of the patients and suspected that an unsecured radiation source was the cause. They reported their suspicions to the regulatory authority (OAEP). Personnel from the regulatory authority, assisted by local public health personnel, searched for the source. When high radiation levels were found in the vicinity of the junkyard, they secured the area to prevent further access. An emergency response team was assembled, and by 20 February 2000 the source was recovered and transported to a secure storage area and the emergency terminated. Examination showed that the source capsule had not been breached and there was no contamination of the environment. The activity of the recovered source was estimated at 15.7 TBq (425 Ci) of ^{60}Co.

Under the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, the Thai authorities requested advice from the IAEA on the medical treatment of the exposed people. The IAEA is authorized to establish standards for radiation protection and for the safety of sources of radiation, and to assist in their application. The International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BSS) [1] establish the requirements for protection and safety. It is presumed that States have an adequate legal and regulatory infrastructure within which the requirements can be applied effectively. Requirements and guidance for the establishment of an appropriate infrastructure and other relevant matters are issued in the IAEA Safety Standards Series (see also Ref. [2]).

1.2. OBJECTIVE

For a number of years the IAEA has provided support and assistance under the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, and conducted follow-up investigations upon request, in the event of serious accidents involving radiation sources. Reports have been published on follow-up investigations of radiological accidents in San Salvador [3], Soreq [4], Hanoi [5], Tammiku [6], Goiânia [7, 8], Lilo [9], Yanango [10] and Istanbul [11]. The findings and conclusions of these reports have provided a basis for learning lessons on safety improvements [12–14].

The Thai authorities subsequently invited the IAEA to assist in a review of the accident. The objective of this report is to compile and disseminate information about the causes of the accident, the subsequent emergency response and the early medical aspects of the overexposures. With the dissemination of the lessons to be learned, Member States may be able to identify similar or precursor situations and take the necessary actions to prevent comparable accidents from occurring.

The information in this report is intended for the use of national authorities and regulatory bodies, emergency planners and a broad range of specialists, including physicists, technicians and medical specialists, and persons responsible for radiation protection. The report ends with findings, conclusions and lessons to be applied in order to help avoid such accidents in the future and to minimize the consequences of any that do occur.

1.3. SCOPE

This publication gives an account of the events reported to have occurred leading up to and following the accident, and the remedial measures reportedly taken thereafter. A number of uncertainties remain in relation to these events. There may also be further developments in terms of health consequences for those severely exposed.

The report also presents information relevant to licensees and operating organizations involved in the supply, storage and transport of high activity radioactive sources. The findings of this report and lessons to be learned from this accident will also be of interest to radiation protection staff and the medical community.

1.4. STRUCTURE

Background information about the radiation protection infrastructure in Thailand, the company involved in the accident and details about the source are provided in Section 2. An account of the reported events leading up to the accident, of the discovery of the accident, and of the emergency response to the accident, including the recovery of the source, the response by OAEP and the local public health authorities, as well as the IAEA's response in providing assistance, is provided in Section 3. The medical treatment of the severely exposed individuals is described in Section 4 and is targeted towards physicians and other medical personnel. Findings, conclusions and lessons to be learned are presented in Section 5.

2. BACKGROUND INFORMATION

2.1. RADIATION PROTECTION INFRASTRUCTURE

The Office of Atomic Energy for Peace (OAEP) is the body responsible to the Thai Atomic Energy Commission for Peace (AEC). The AEC is the regulatory authority for Thailand and was established by the Atomic Energy for Peace Act,[1] B.E. 2504 (1961) and B.E. 2508 (1965), and Ministerial Regulation No. 1 (1961), No. 2 (1961), No. 3 (1961), No. 4 (1968), No. 5 (1973) and No. 6 (1974). These acts and regulations involve several ministries, commissions and offices in the regulation of radiological safety, and the structure is such that it apparently resulted in gaps or overlapping roles for certain regulatory activities.

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[1] Atomic Energy for Peace Act (B.E. 2504 (1961) and B.E. 2508 (1965)) is the basic legislation for the regulation of nuclear and radioactive materials and industrial uses of X rays. Medical uses of X rays are regulated by the Ministry of Public Health, under Ministerial Regulation No. 4 (B.E. 2511) of the same Act.

The Thai AEC has eight subcommittees, one of which deals with the licensing of radioisotopes and nuclear materials. It also has responsibility for the development and promotion of atomic energy as well as for regulatory needs. All the responsibilities of the AEC are carried out by the OAEP.

The Ministry of Science, Technology and Environment is involved in administering the personnel, budget and facility management, as well as research and development activities conducted by the OAEP.

Reporting to the AEC is a Subcommittee for Licensing of Radioisotopes and Nuclear Materials. This is composed of OAEP members, and carries out its functions under the mandate of Ministerial Regulation No. 2 (B.E. 2504). The Health Physics Division within the OAEP conducts regulatory activities through its Licensing Section and its Radiation Protection Section.

The OAEP is responsible for about 650 licences for the possession and use of radioactive materials in Thailand. Licences generally are valid for one year. The licensing process involves the regulatory authority in determining the safety and adequacy of the facility where the radioactive materials are intended for use and checking that the qualifications of the users are satisfactory. The OAEP reports that in general inspections are intended to be carried out annually. The inspection priority is based on the level of risk the radioactive material presents, according to an unofficial classification[2] by the OAEP. It also depends on the availability of personnel resources to accomplish this task. Moreover, the OAEP issues licences for the import and export of radioactive materials. At the time of the accident, eight inspectors were responsible for checking all radiation source licensees, and the OAEP reported that, as a consequence of their workload, the annual performance inspections of licensees could not be performed effectively.

According to the Atomic Energy for Peace Act, no fees are imposed on licensees. If a licence is withdrawn and the licensee still possesses radioactive material, OAEP guidelines provide options for the licensee. The licensee may decide to keep a disused source at a storage location authorized by the OAEP, to transfer it to an authorized legal person, or to send it to be disposed of at the OAEP. For the last choice, a licensee from the private sector must pay the OAEP to recover and store the radioactive material. However, with the authorization of the OAEP, the licensee may transfer or otherwise dispose of the radioactive materials to an authorized legal person as a means of terminating use and the licence. According to OAEP regulations, one of the requirements of a licence is that licensed sources are not to be relocated without the OAEP's authorization.

[2] For example, priorities were based on source strength and use, and were ranked in the following (descending) order: radiography; teletherapy and brachytherapy; irradiation for sterilization and preservation.

The OAEP had begun a review of its regulations and of the requirements imposed on its licensees in the late 1980s. Starting in 1989, it began imposing conditions on the training requirements for personnel and for improved safety and security measures and storage conditions, as well as for the use of radiological instrumentation and for personal dosimetry services. The OAEP stated that it had used then extant IAEA guidelines as its basis for these changes.

2.2. THE LICENSED HOSPITAL

The device involved in the accident was installed originally at a hospital in Bangkok (RT hospital) in 1969. In 1981, after patient treatment times became impractical, a new source was installed. The new source had an initial activity of 196 TBq (5300 Ci) of ^{60}Co, and it was this new source that was ultimately involved in the accident.

Following replacement of the source in 1981, the hospital did not obtain any further service from Siemens, the manufacturer of the teletherapy unit and source. The local Siemens agent who had been contracted to do maintenance on the unit later declared bankruptcy. The teletherapy unit was reported to have been taken out of service in 1994, presumably when the patient treatment times again became too long to be practical.

2.3. THE NON-LICENSED SUPPLIER

When the unit was removed from service, Siemens was no longer manufacturing ^{60}Co teletherapy units. The hospital contacted Nordion, a manufacturer of teletherapy devices in Canada, through its agent in Thailand (KSE Company) to supply a new teletherapy unit. However, Nordion could not accept the return of the disused source to Canada since it was not the original manufacturer. This meant that the hospital would have been left with a disused source to manage and control, as required by the regulatory body. Since the hospital did not have sufficient storage space for the old teletherapy unit containing the disused source, it sold the device and source to the new supplier agent (KSE Company). The hospital reportedly did not inform the OAEP of the transfer of this radiation source and KSE did not inform the OAEP of its possession of the disused radiotherapy unit.

At this time KSE already possessed one therapy unit, imported from Canada in 1974 for a physician. The physician, however, had asked the company to store it until he found a suitable facility[3] in which to install it. The OAEP had issued a licence in 1988 for the company to store this teletherapy unit in a warehouse that they leased in the Bangkok area.

In 1993, KSE notified the OAEP of its need to expand its storage facility in Bangkok for more foreseeable disused (teletherapy) units. Before the OAEP responded to this request, KSE modified the notification by proposing to move the disused sources it had acquired to a new storage location in Petchaboon Province, approximately 400 km north of Bangkok. This new proposal described the intended facility as a storage building to be constructed on empty land. The regulatory authority felt that the location was not sufficiently secure, and advised the company to store the sources in or around Bangkok. The OAEP reportedly informed the company of its radiation protection guidelines and also advised the company either to obtain a licence for the sources or to transfer its sources to the OAEP for storage.

In 1996, KSE applied to the OAEP for a licence to export two ^{60}Co sources to Nordion. These two other sources were also spent teletherapy sources which had been in storage and were to be shipped back to Canada. An OAEP inspection, performed prior to the shipment of these sources, apparently disclosed that KSE had three other sources in addition to the licensed source which belonged to the physician.

KSE thus had four radiation therapy units in the warehouse. One belonged to the above mentioned physician and had been in storage since 1974. Two other units (one originally from Japan and the other from Germany) had been used in government medical institutions and were transferred to KSE when they were no longer of use. The fourth unit was that imported from Siemens in 1969 (but containing the replacement source dating from 1981).

Early in 1999, KSE was notified that its lease of the warehouse was to be terminated. The company was obliged to relocate the four sources that it possessed. The company returned the source belonging to the physician and notified the OAEP after the relocation. However, without reportedly obtaining authorization from the OAEP or notifying it, KSE moved the other three sources to a car parking lot that was owned by KSE's parent company. It was from this location that one of the sources was reportedly stolen. According to local residents, the sources were moved to the car parking lot in October 1999.

The car parking lot had been used by KSE's parent company to store new vehicles after their assembly in Thailand but was vacant at the time of the accident. A portion of the lot was roofed to protect vehicles. The source housings were stored under the roofed area. The car parking lot was fenced (with galvanized steel sheet); however it was not secure. Gaps had been made in the fences and residents of

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[3] The OAEP had denied a licence for a proposed facility citing inadequate and/or insufficient protection.

apartments across the street played football in the open space of the parking lot near the stored sources.

2.4. THE DEVICE AND ITS SOURCE

The device involved in the accident was a Gammatron-3 teletherapy unit, manufactured by Siemens of Germany. It was originally exported to Thailand in 1969 and had undergone at least one source change. The last change occurred in 1981, when a source of 196 TBq (5300 Ci) was installed. At the time of the accident, the activity was estimated to be 15.7 TBq (425 Ci).

The source holder (and shield) is of lead surrounded by stainless steel. It is cylindrical, 42 cm long by 20 cm diameter. The lead is 5 cm thick, with a weight of 97 kg, within a stainless steel casing that weighed an additional 30 kg. Figure 1 shows the teletherapy unit head and its source assembly.

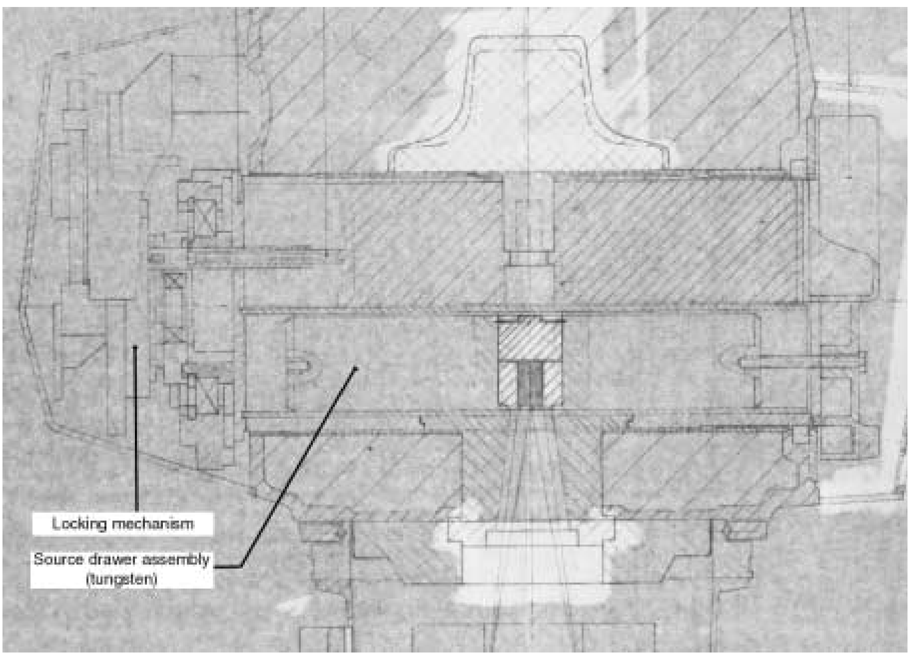

FIG. 1. The Siemens Gammatron-3 teletherapy head (cutaway side view). The lighter area in the centre is the source. Note the two cylindrically shaped objects around the source.

3. THE ACCIDENT

3.1. DESCRIPTION OF THE ACCIDENT

Patient 1 (P1)[4] (a 40 year old male[5]) and P2 (a 25 year old male), who were working as scrap collectors, claimed that on 24 January 2000 they bought some scrap metal (which included part of a teletherapy head) and took it home for dismantling for resale. P1 used a motor driven cart (known in Thailand as a tricycle) as the vehicle for carrying the materials. The batch of scrap metal was kept in an open space about 100 m from P1's residence until the end of January 2000 (Fig. 2).

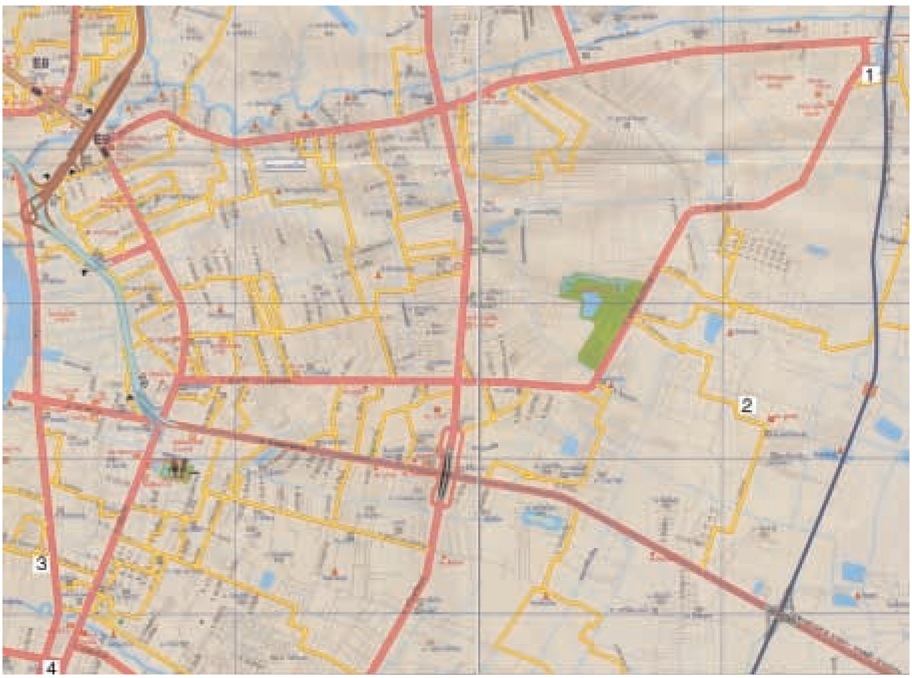

FIG. 2. Map of the sites (1: car parking lot; 2: P1 residence; 3: junkyard; 4: hospital).

[4] Pn = Patient identification number; see Table II for a brief description of the individuals involved.

[5] The names of the patients have been omitted to maintain confidentiality.

On 1 February 2000, P1, together with P2, P3 (a 19 year old male) and P4 (a 23 year old male and younger brother of P1's wife), reportedly tried to dismantle part[6] of the cylindrical metal piece of the teletherapy head, which was covered by stainless steel. This action took place at P1's residence. P2 and P4 worked for about an hour trying to separate the steel and the lead using a hammer and chisel. Most of this work was done by P2. They were able only to crack the weld seam, whereupon they noticed an oily liquid seep out. They could, however, see the lead inside the stainless steel box.

P1 then told them to stop and decided to take the metal to a junkyard for sale there. P1 and P3 brought the lead cylinder and other metal pieces to a junkyard located at Soi Wat Mahawong, Samut Prakarn Province. On the trip from P1's home, which took about 30 minutes, P3 was sitting in the cart with his (right) leg draped over the cylindrical metal piece (Figs 3 and 4).

FIG. 3. The teletherapy head with the missing source drawer assembly.

[6] This part was later discovered to be the source drawer of the teletherapy unit.

FIG. 4. Cylindrical pieces from the source assembly (the item at left is hollow; it previously surrounded the ^{60}Co source).

At the junkyard, P1 reportedly requested P5 (a 23 year old male), a junkyard employee, to cut open the cylinder with an oxyacetylene torch. Another junkyard employee, P6 (an 18 year old male), was working nearby, positioned behind P5. P5 successfully cut open the stainless steel box and the lead cylinder. He saw yellow smoke which “smelled bad” and saw two metal pieces from inside the cylinder fall to the ground. P5 picked up these pieces and weighed them in his hands. He later reported that his hands felt “itchy” from handling these pieces. These metal pieces from the cylinder were kept at the junkyard. P5 felt uneasy about the smoke and stopped cutting, but could not completely dismantle the stainless steel and lead materials. P7 (a 45 year old female and owner of the junkyard) watched the work and told P1 to take the cylinder back to his residence to continue the work there. P1 took the items back and left them in his vehicle overnight. On the way back to his residence on 1 February 2000, P1 started to experience severe headache and nausea. P3 also felt nauseous and felt an itching sensation on his legs. P5 and P6 started to feel dizzy, had bad headaches and not long afterwards started to vomit. P1 and P3 successfully separated the metal into 40 kg of stainless steel and 72 kg of lead and P1 reportedly brought these to the junkyard for sale on 2 February 2000.

P5 and P6 did not work on 3–4 February 2000 because of the Chinese New Year holiday. P6 went home during this holiday. His father subsequently said that his son had looked ill, had lost his appetite and lost weight, and had a sunburn type burn on his skin. Although P5 and P6 felt sick, they resumed work again on the next working day, 7 February 2000.

On 12 February 2000, P7 reportedly asked P1 to sell the lead at another place, presuming that the metal P1 had brought might be the cause of the illness of her employees. She also asked another scrap collector to throw away the two small cylindrical metal pieces. P1 had developed a burn on his hands, swollen fingers and an itchy palm, and went to see a doctor in a private clinic.

On 15 February 2000, P1 visited the outpatient clinic of the Samut Prakarn Hospital for an examination. A blood sample was taken and the doctor requested him to return the next day when the blood examination results would be ready. Upon his return, on 16 February 2000, P1 was admitted to the hospital. His burned hands were swollen and had become darkened. He had nausea, vomiting and some localized loss of hair.

Meanwhile, P5 and P6 had been suffering from diarrhoea, which was being controlled by medication.[7] P5 felt weak and had a fever. He had lost weight, his hair was falling out and he had burned hands. He too went to see a physician at the Samut Prakarn Hospital because of these symptoms. After a physical examination was made and a blood sample was taken, he was admitted to Samut Prakarn Hospital on 16 February 2000.

On 17 February 2000, P7, the junkyard owner, took P6 to Samut Prakarn Hospital because of his weakness, weight loss and hair loss and he was admitted. When P7 expressed her concern about her workers to the physician, he reportedly suggested that something unusual was occurring at the junkyard. Subsequently, P7 took P9 (a 33 year old female) to Samut Prakarn Hospital, where she was admitted for observation. P9 was a maid to both P7 and P8, as well as a part time worker at the junkyard.

Later, P7 and her husband P8 (a 44 year old male), who were both feeling weak, went to see a physician at Bangkok General Hospital. Blood samples taken from P7 and P8 both showed low white blood cell counts, and a bone marrow aspiration was performed on both patients. At this time, the physician decided not to have P7 admitted to the hospital, but P8, who had severe nose bleeding, was admitted. During this time, P7 also reportedly mentioned that a stray dog that had often been in the junkyard had died.

In summary, P1, P2, P3 and P4 were the individuals who had reportedly obtained the teletherapy head on or about 24 January 2000. P5, P6, P7, P8 and P9 were workers at the junkyard, including the owner, P7, and her husband, P8. P9 was the maid as well as a part time worker at the junkyard who lives with P7 and P8. Their residence is situated across the street from the junkyard. Finally, P10 is the 75 year

[7] Since the diarrhoea was being controlled by medication, the radiation dose received by these individuals was probably less than 10 Gy, although it will have exceeded 6 Gy.

old mother of the owner, who also lived with her daughter (P7) and son in law (P8). P10 was attending to the workers at the junkyard regularly.

By 17 February 2000, P1, P5 and P6 had been admitted to Samut Prakarn Hospital and P8 had been admitted to Bangkok General Hospital.

3.2. DISCOVERY AND NOTIFICATION

P1 and P5 had been seen at the surgical ward of Samut Prakarn Hospital. Both had swollen fingers and were nauseous and vomiting. P5 also had a low white blood cell count. P6 was seen at the medical ward, also showing nausea and vomiting, and he also had a low white blood cell count. The physicians reviewed the cases of these three individuals who were demonstrating very similar symptoms. This led them to the realization that these patients may have been exposed to ionizing radiation. On coming to this conclusion, at around 11:10 local time on 18 February 2000, one of the physicians called the OAEP about the three patients and expressed his concern about a possible unsecured radiation source in the environment.

The OAEP reported that, upon receipt of the call, they immediately dispatched two officers (health physicists) who arrived at the Samut Prakarn Hospital at 12:30 on 18 February 2000 to investigate the cases further. The OAEP officers met with the treating physicians and with patients P5 and P6. The physicians provided the officers with a description of their patients' symptoms and repeated their suspicion that an unsecured radiation source was present in the local environment. P7 was later called to the hospital for questioning.

From the information provided by P7, the OAEP officers, jointly with local public health officers, initiated a search to find the two small metal pieces that had been given to the other scrap collector. This was done in the belief that one of these small metal pieces was the source. The officers met the scrap collector and together they went to search a public U-shaped concrete drainage point identified by the scrap collector as the place where he had dumped the small pieces. They found the small metal pieces, but a radiation survey showed that they were not radioactive.

Since these two pieces of metal were not the radiation source, the officers went to check the junkyard. During their journey towards the junkyard the officers had their radiation detectors switched on. Around 19:00 on 18 February 2000, while driving through one of the streets of Samut Prakarn district in the direction of the junkyard, they noted a significant increase in radiation levels (about 20 times normal). They continued moving through two small back streets for about another 150 m or so until they reached the junkyard. There, a radiation level of about 1 mSv/h was measured at the side entrance of the yard, confirming the presence of an intense gamma source. At this point they recognized that this was a serious radiological accident and called for assistance (Figs 5–7).

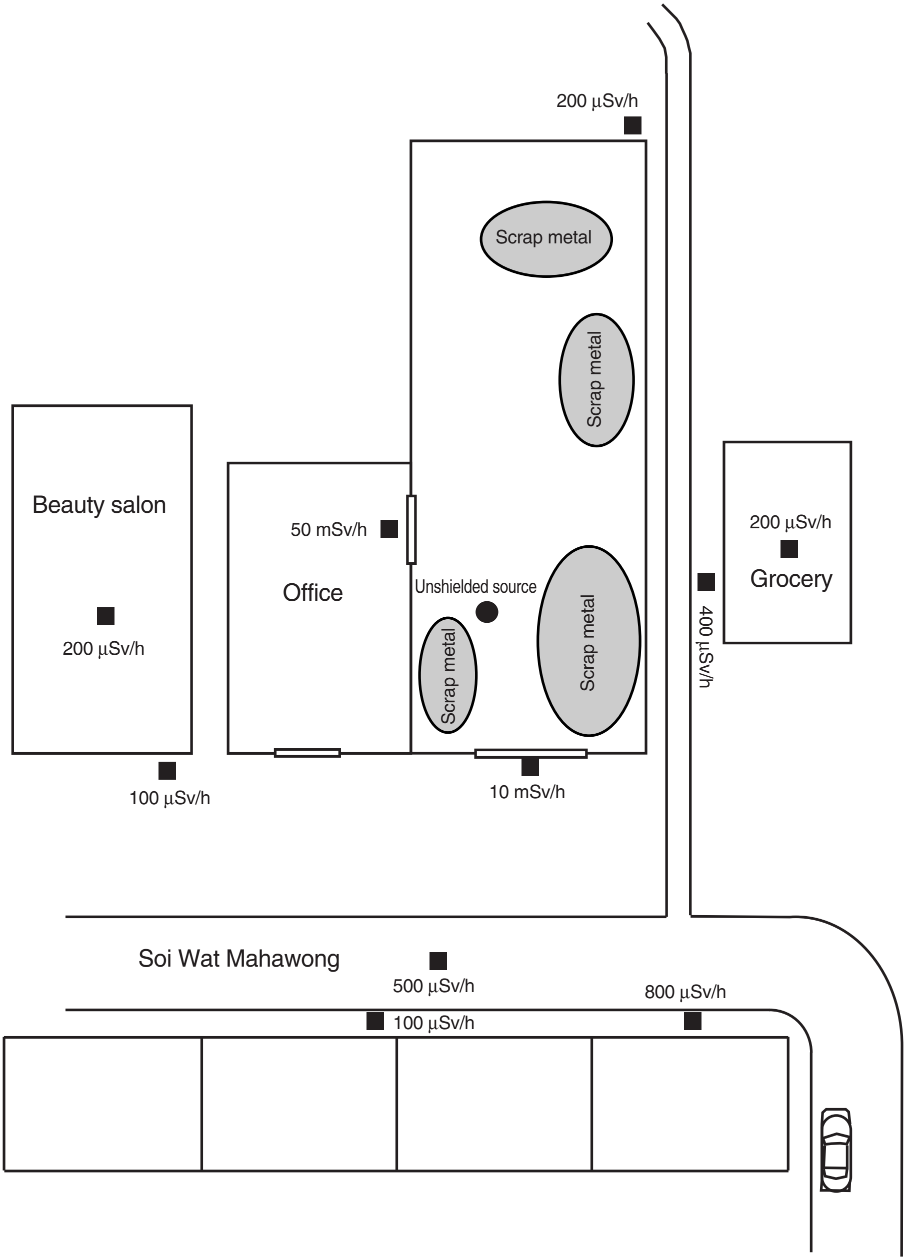

FIG. 5. Radiation levels encountered at the junkyard.

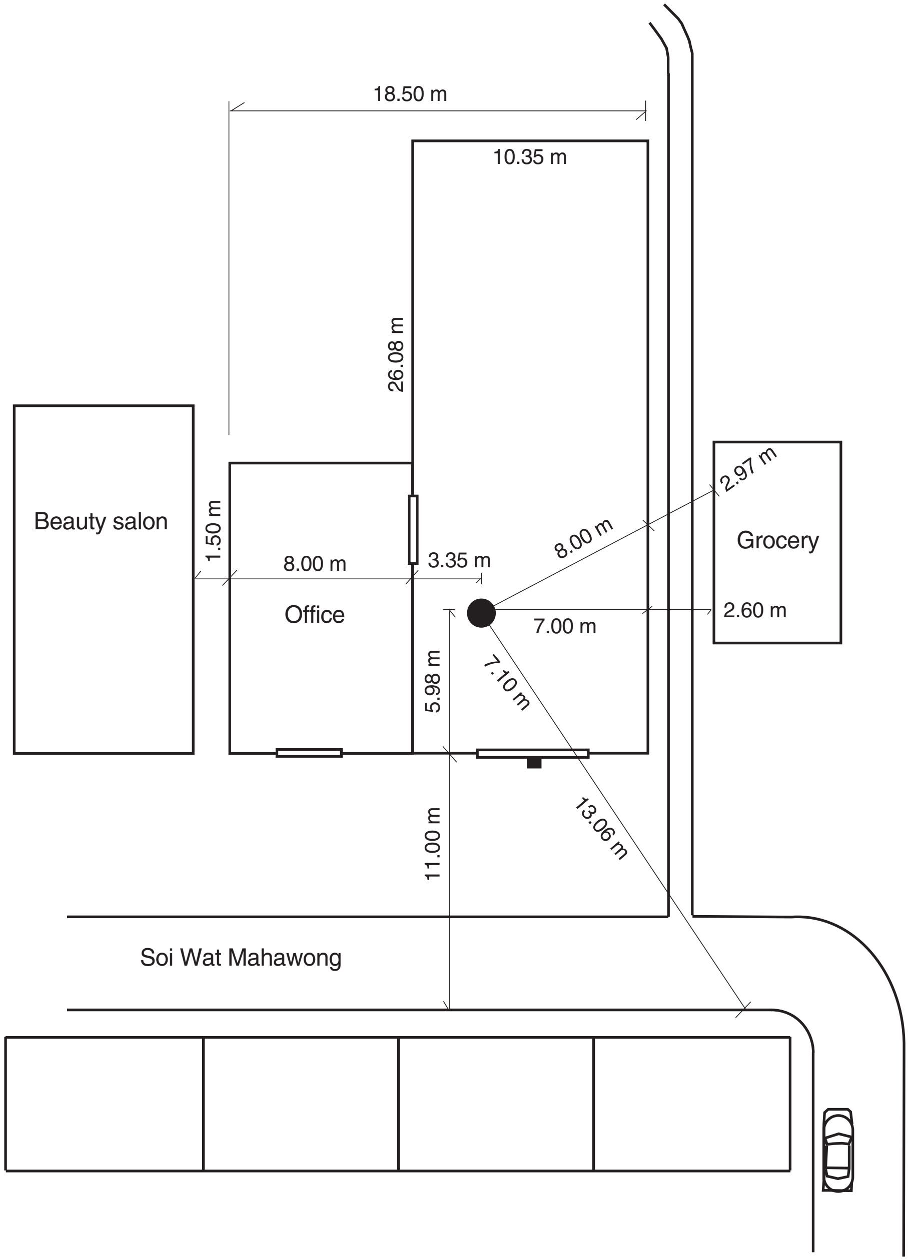

FIG. 6. Plan of the junkyard and its vicinity.

FIG. 7. Elevated view of the junkyard. Scrap piles are on the left; the building in the centre is the junkyard office, the building across the street is the residence of P7 and P8 (junkyard owner and husband) in which P9 (maid and part time junkyard worker) and P10 (mother of P7) also resided.

3.3. RESPONSE AND RECOVERY

Recognizing the seriousness of the radiological situation, the OAEP officers called upon an emergency response team. A command and co-ordination post was then established in the vicinity of the junkyard. In addition to a radiation level survey, contamination surveys were also carried out. No contamination was found. From this survey, the emergency response team concluded that the accident involved a sealed radioactive source of unknown size, either from an industrial radiography device or from a medical treatment machine. The radiation level survey found a dose rate of up to 10 Sv/h in the junkyard around the pile of scrap where the source was located.

Reportedly, the evacuation of residents was considered by both the OAEP and the public health authorities. They reviewed the radiation survey data and concluded that evacuation was not necessary as the radiation was isolated and confined only to the junkyard, and, in their judgement, evacuation would cause confusion or panic among those affected. Therefore, swift action to abate the problem was the preferred course. Accordingly, the local area was cordoned off at a radiation level of 300 μSv/h, which occurred about 10 m from the junkyard. Access to the junkyard was restricted and the street outside was closed to traffic. The very high radiation level prevented the emergency response team from getting close enough to pinpoint the exact location or determine the physical shape of the source among the scrap material.

Further field operations to locate the source continued throughout the night until 04:00 on the morning of 19 February 2000. The operation was recorded with a video camera. It was then decided to suspend operations until later that morning and the police secured the entire area (Fig. 8).

Later on the morning of 19 February 2000, the local public health authorities resumed recovery operations at the junkyard. At approximately 150 m from the junkyard, a dose rate of 1.7 μSv/h was measured. This level increased to 200 μSv/h on the sidewalk across from the junkyard at a distance of approximately 20 m from the source.

Meanwhile, the emergency response team recovery operation resumed its activities at the OAEP. Personnel watched the videotapes taken the previous night and planned the retrieval operations, and gathered the necessary tools and equipment for the source recovery. The team then returned to the junkyard around 14:00. After discussions with the local public health authorities and with the provincial civil defence group, a retrieval plan was agreed upon. Actual source retrieval operations commenced around 16:00. The planning included rehearsals using a dummy object in order to familiarize emergency response team members with the tools and techniques for retrieving the unknown source when it was finally located.

The Samut Prakarn Provincial Civil Defence Unit assisted in making available the necessary machines and equipment (a mechanical excavator, a back hoe and large spotlights). The support of the local fire brigade was also obtained.

FIG. 8. Back hoe/front loader moving a lead barrier for use in recovery operations (taken from a video image).

To clear a path to the location of the source within the junkyard, a heavy iron fenced entry gate and some scrap were removed with the help of a mechanical excavator. This excavator was also used to place a lead wall 5 cm thick by 1 m wide by 2 m high near the source to provide some shielding to individuals trying to find and recover the source. The dose rate behind this shield was reduced more than twenty-fold. Spotlights and two closed circuit television (CCTV) cameras and monitors were installed to facilitate the operation (Fig. 9).

As some of the participants in the recovery operation insisted on wearing lead aprons for protection against the radiation emitted from the source, lead aprons suitable for diagnostic radiological procedures were obtained and worn by some of the team members. Note, however, that the protection afforded by these lead aprons is not adequate against the highly penetrating photons from the ^{60}Co source. They may even slow down an individual's movements, which may result in increased exposure. Moreover, the aprons may provide a false sense of security. Reportedly, the OAEP did not agree with the use of the lead aprons, but acquiesced in order to ease workers' fears.

To gain access to the suspected location of the source, large pieces of scrap near the source location were removed with a long grasping tool. In the process, each piece was surveyed using a teledetector to ensure that there were not unexpectedly high radiation levels. Smaller pieces of metal on the ground that were in the likely vicinity

FIG. 9. View of the junkyard rigged for night time operations (taken from a video image).

of the source also needed to be screened as part of the sorting process. For this purpose, an ad hoc scrap screening system was improvised.

Pieces of scrap would be removed from the pile using an electromagnet at the end of a 5 m bamboo pole and brought to a large washtub in which the high range radiation dose rate probe was placed. The detector output was led into its survey meter by means of a 30 m long cable, and the operator would watch the meter readout to determine whether he had picked up the actual source. The emergency response team calibrated this improvised system in their planning exercises. Located near the washtub was a lead shielded container (of thickness 8.5 cm) into which the source, if found, could be placed. After six operations of removing scrap metal, much of the overburden metal was removed. The exact location of the source could still not be determined, however, owing to pieces of metal nearby.

Finally, in an effort to locate the source accurately, a fluorescent screen was used. The fluorescent screen was of a size suitable for image intensification for diagnostic X ray films. However, even with the floodlights turned off, the moonlight was so bright that the source could not easily be located with the fluorescent screen. Personnel had to wait until the moonlight had diminished for suitable darkness in which to use the screen accurately. At around 21:00 on 19 February 2000, the position of the source within the remaining pile of scrap was accurately determined. However, many pieces of scrap metal still surrounded the source (Fig. 10).

FIG. 10. A luminescent screen was used to determine the location of the source accurately (taken from a video image).

Having now located the source, OAEP emergency response team personnel innovated a means of retrieving it by attaching an electromagnet to a length of bamboo. Other grasping tools were not long enough to afford adequate personnel protection, and spending time trying to grapple the source with tongs would have resulted in personnel receiving radiation doses from the intense radiation field.

On 20 February 2000 at 00:20, the source, which had been estimated to be about 4 cm long and 2.5 cm in diameter, was retrieved. Tongs 2 m in length were used to pick up the source and place it into a lead shielded container (Fig. 11). The radiation levels in the scrap pile and the yard were surveyed again after removal of the source and container. Only background radiation levels were found, confirming that the source had been successfully removed. In situ gamma spectrometry was performed and the source was identified to be ^{60}Co. The source activity was estimated at roughly 15.7 TBq (425 Ci).

The source was transported to safe storage at the OAEP on 20 February 2000. The lead container containing the source was placed under 4.5 m of water in what was formerly a spent fuel storage pool (Fig. 12).

Individual thermoluminescent dosimeters (TLDs) were employed for dose control purposes during the source recovery operations, and the results of the dosimetry are summarized in Table I. The maximum individual dose recorded for the emergency workers was reported as 32 mSv.

FIG. 11. Transfer of the retrieved source to a shielded transport container (taken from a video image).

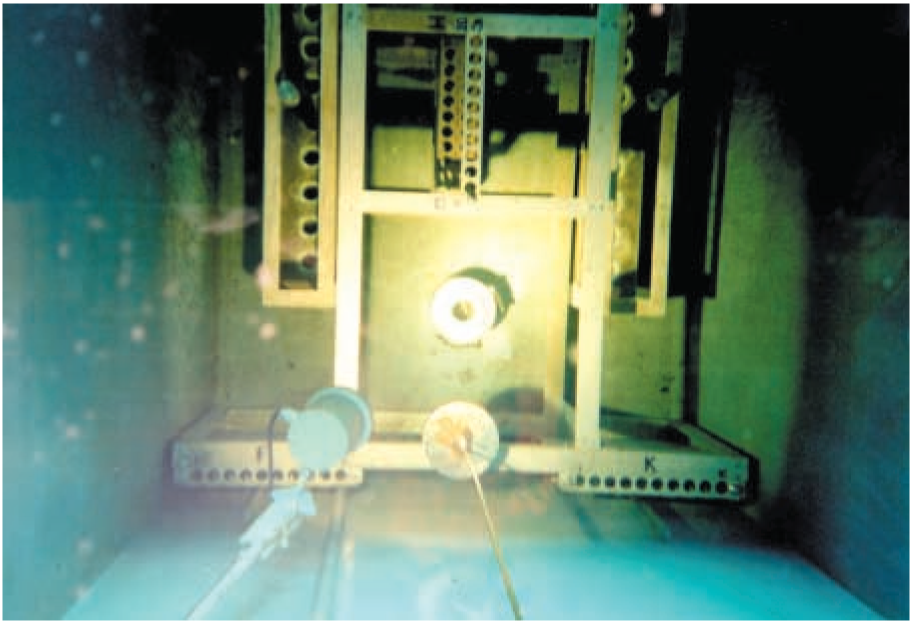

FIG. 12. Storage location of the retrieved source.

During the operation to retrieve the source, the emergency response team was informed that three radiation machines had been found in a parking lot in a suburban area of Bangkok. They dispatched officers to this site to assess the situation. After visual and radiological inspection, the OAEP officers concluded that these machines were ^{60}Co teletherapy units and that the lead cylinder that would have contained the source was missing from one of the units. It was later confirmed that this was the lead

TABLE I. DOSES RECEIVED DURING RECOVERY OF THE SOURCE

Dose range (mSv)	Number of individuals in group
<1	11
1–5	18
5–10	11
10–20	6
20–32	6
>32	0

cylinder involved in the accident. On 21 February 2000, all three machines (two of which contained sources) were removed to be kept at the OAEP for temporary storage (Fig. 13).

During this whole operation, the OAEP emergency response team was given full support by the Samut Prakarn Provincial Civil Defence Unit and by the Samut Prakarn Provincial Public Health Care Unit.

3.4. INVOLVEMENT OF THE IAEA

On 21 February 2000, the OAEP contacted the IAEA and, under the terms of the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, described the accident and the successful recovery of the source. This was followed by additional reports to the IAEA on 31 March and 26 April 2000 which provided information on the total number of previously unsecured disused radiotherapy sources and the total number of victims of the accident and their medical status. The second report also informed the IAEA of three subsequent fatalities and

FIG. 13. The three teletherapy heads at the car parking lot. The unit in the foreground was the device from which the source drawer assembly (containing the source) was removed.

the results of the screening of the population in the vicinity of the accident site that was conducted by the Ministry of Public Health.

On 24 February 2000, the Permanent Mission of Thailand in Vienna, on behalf of the Thai Government, requested that the IAEA dispatch a team of experts in medicine and radiation protection to share its expertise with the Thai authorities in Bangkok. The IAEA acknowledged receipt of the request under the terms of the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency and assembled a team, which arrived on 26 February 2000 and stayed for a week. The team consisted of two IAEA staff members trained in radiation protection and emergency response management and three medical doctors from Japan who specialize in the treatment of radiation victims. The team discussed the situation with the OAEP and others involved and provided feedback and advice as appropriate, particularly with further regard to the care and treatment of the injured.

In addition, the IAEA prepared this report with the assistance of representatives from the OAEP and the attending physicians from Rajavithi Hospital.

4. RADIOPATHOLOGICAL CONSIDERATIONS

4.1. GENERAL

This section provides details of the radiopathology for the people who were exposed, and is intended to be of interest primarily to medical staff.

From the description of the accident provided (see Section 3), it can be seen that, although part of the teletherapy unit was reportedly removed on 24 January 2000 and taken to a location near the residence of P1, the source remained in a shielded condition. Only on 1 February 2000 did P1 and his friends try to separate the device into smaller components. Therefore, the sequence of severe radiation exposures began on 1 February 2000. Section 3.1 provides a description of the signs and symptoms displayed by the accident victims in the early stages of the accident.

Owing to the accident's occurrence in a populated area, and also owing to the length of time until the radiation source was discovered and recovered, there were several groups of people exposed. Those who obtained the source (P1–P4: Group 1) and the junkyard workers and relatives (P5–P10: Group 2) received the largest radiation doses. Some of the scrap collectors received severe localized radiation injuries (as evidenced by the radiation burns presented); however, their whole body doses were around 2 Gy. The individuals at the junkyard received greater total body radiation doses due to their prolonged exposure to the ^{60}Co source. Four of these individuals (P5–P8) received doses of more than 6 Gy.[8] Three of these four persons died within two months of the accident as a consequence of their severe radiation injuries.

Many of the victims in Groups 1 and 2 visited an outpatient clinic of Samut Prakarn Hospital with symptoms of weakness, epilation and radiation burns, and histories of nausea, vomiting or diarrhoea (see Table II).

The third group consists of other individuals who lived in the vicinity of the junkyard and whose radiation doses, as estimated later, were not as significant as for those who worked on or near the source. The fourth group includes personnel of the OAEP and others who worked in the response and recovery unit. Their whole body radiation doses, as described in Section 3.3, did not exceed 32 mSv for the duration of the accident response.

TABLE II. IDENTIFICATION CODES, AGE, GENDER AND EARLY CLINICAL DATA OF THE ACCIDENT VICTIMS

ID	Age (years)	Sex	Involvement	Clinical symptoms and signs
P1	40	M	Scrap collector	Burns, nausea, vomiting, epilation, amputation
P2	25	M	Associate of P1	Burns, nausea, vomiting, epilation
P3	19	M	Associate of P1	Burns, nausea, vomiting, epilation
P4	23	M	Younger brother of P1's wife	Burns, nausea, mild vomiting
P5	20	M	Junkyard employee	Burns, nausea, vomiting, epilation, diarrhoea, epistaxis, fever; death on 18 March 2000
P6	18	M	Junkyard employee	Nausea, vomiting, epilation, diarrhoea, fever; death on 9 March 2000
P7	45	F	Junkyard owner	Nausea, vomiting, epilation, diarrhoea
P8	44	M	Husband of P7	Nausea, vomiting, epilation, epistaxis; death on 24 March 2000
P9	33	F	Maid of P7; junkyard worker	Nausea, vomiting, headache, epilation
P10	75	F	Mother of P7	Nausea, vomiting

8 Doses estimated from clinical findings.

For Group 1, on the basis of an evaluation of the prodromal signs and symptoms, significant non-homogeneous whole body irradiation occurred. Estimates of the doses received are: P1: 2 Gy; P2: 2 Gy; P3: 2 Gy; and P4: 1 Gy.

Both P1 and P3, however, showed severe localized radiation burns. P1's burns were confined primarily to his hands, while P3 presented burns to his hands and also a larger radiation burn on the posterior-lateral side of his right leg, near the knee[9]. Patient P1 suffered the most severe radiation burns on both his hands, affecting all fingers and half of the palmar surfaces. The other three (P2–P4) also had serious radiation burns: to the hands and fingers (P2), to two fingers and the right knee region (P3), and to the fingers only (P4).

Group 3 consisted of 1872 individuals who live within 100 m of the junkyard. Various services were provided to these individuals, including checkups (862 individuals, ~46%), blood examinations (782 individuals, ~42%), information and advice (907 individuals, ~48.5%). Of this group, 258 individuals lived within 50 m of the location of the source and are being followed up by the Ministry of Public Health for any latent effects. Within this distance of 50 m, there were five pregnant women, one of whom decided to have an abortion. This woman had received counsel from the Royal College of Radiologists in Thailand that the risk of having an abnormal baby was low.

The patients from Group 1 were first admitted and treated at Samut Prakarn Hospital, where there was medical care available for both the haematological treatment and the necessary restorative plastic surgery for their severe, yet localized, radiation injuries. The patients in Group 2 had suffered severe whole body exposure and, although some were admitted either to Samut Prakarn Hospital or to Bangkok General Hospital, they were subsequently transferred to Rajavithi Hospital, where better facilities for their treatment were available. Rajavithi Hospital is the designated treatment hospital for radiological accidents in Thailand.

4.2. TREATMENT AND CLINICAL PROGRESSION OF PATIENTS IN GROUP 1 (P1–P4)

Patient 1

P1 was admitted to Samut Prakarn Hospital with burns on his hands on 16 February 2000. Figure 14 shows hard blisters on his swollen hands with macerated and infected skin, on 23 February 2000, day 23 after exposure.

[9] Recall that P3 had been in the tricycle cart with his right leg draped over the metal cylinder which contained the source.

FIG. 14. Hard blisters on the swollen hands and fingers of P1 on day 23, 23 February 2000. Note the sharp demarcation lines on both the palmar and dorsal sides.

His general clinical symptoms and complete blood count were normal. His burned hands were treated with antibiotic intravenously (Cloxacillin, 4 g/d), Trental (400 mg) and dressings. He occasionally had a low grade fever. His white blood cell count and platelet count progressively decreased, then administration of granulocyte colony stimulating factor (G-CSF) was started (500 μg/d, which was 10 μg/kg per day) on 29 February 2000. On 2 March 2000, he was transferred to Rajavithi Hospital with fever, skin peeling from both hands, and low white blood cell count and platelet count.

At Rajavithi Hospital, he was treated with a combination of G-CSF (1000 μg/d, which was 20 μg/kg per day on 3 and 4 March, and 500 μg/d, which was 10 μg/kg per day, on 5 March 2000) and granulocyte macrophage colony stimulating factor (GM-CSF) at 300 μg/d, and other treatments he received were as at Samut Prakarn Hospital. His white blood cell count and platelet count increased, and he was taken off G-CSF and GM-CSF on 6 March 2000 (see Fig. 15).

The antibiotic was changed from Cloxacillin to Cefazolin 3 g/d because he still had fever. After this, his fever abated.

The radiation burns experienced by P1 caused him severe pain. Dressing and debridement of the wound areas continued. On 2 March 2000, wet desquamation was found on the first to fourth fingers of both hands, and a dry eschar had developed over the distal parts of the thumbs and index fingers of both hands, the more severe eschar being on the left index finger. After dressing with silver sulphadiazine and administration of Cephalosporin, skin grafting was performed on his left hand on 15 March 2000, using skin from his left thigh. The skin graft was mainly successful, except for his left index finger, where the graft sloughed and the flexor tendon was exposed. He requested to be discharged from the hospital on 24 March 2000, and this was done, reportedly against medical advice.

He was readmitted to Rajavithi Hospital on 27 March 2000 owing to continued pain in the area of the graft. The graft on the second and third fingers of his left hand had failed, and surgeons noted that the second finger was deeply necrotic. Figure 16 shows his left hand after debridement on 28 March 2000 with the exposed flexor tendon in the middle phalanx of the second finger.

Dry desquamation was noted on the wound on his right hand. An abdominal flap on his left hand was attempted on 30 March 2000. The flap was detached on 20 April 2000. An angiogram of the right forearm and hand showed normal vasculature and staining, so this was treated with physical therapy.

Patient 2

The radiation burns to P2 were less severe. He was admitted to Samut Prakarn Hospital on 20 February 2000 with a low platelet count (from a study initiated on 19 February 2000). He also had evidence of burns at the distal phalanges and palmar

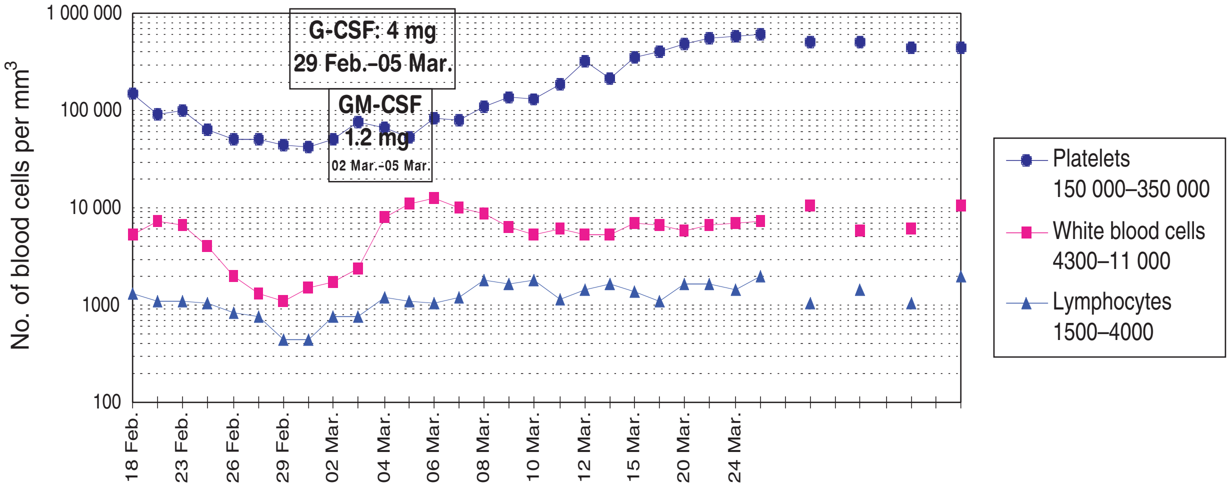

FIG. 15. Haematological chart for P1 while in hospital.

FIG. 16. Condition of the left hand of P1 eight weeks after exposure. Note the exposed flexor tendon in the middle phalanx of the second finger and adjacent soft tissue necrosis.

surfaces of both hands and a huge hard blister on the right hypothenar (Fig. 17), epilation and low fever.

P2 was treated with Cloxacillin antibiotic (2 g/d orally), Trental and, on 29 February 2000, G-CSF (500 μg/d) when his white blood count decreased. He was also treated with platelet concentrate (ten units) as his platelet count was lower than 20 000/mm^3.

P2 was transferred to Rajavithi Hospital on 2 March 2000 with wounds on both hands, a wound to the hypothenar eminence of his right hand with a ruptured blister (diameter 4 cm) and a red, peeling thenar eminence on his left hand. His white blood cell count remained low (1800), so administration of GM-CSF (300 μg/d) was begun on this date. On 3 March 2000, there were many blisters on both palms, with the largest (approximately 5 cm × 6 cm) on the right hypothenar area.

Both G-CSF and GM-CSF were discontinued when his white blood cell count increased. By 9 March 2000, most blisters had healed spontaneously, except for the largest one which appeared to be a chronic wound (Fig. 18).

FIG. 17. Appearance of the hands of P2 three weeks after exposure. Note the dry desquamation of swollen fingers and both palms, with a large hard blister on the right hypothenar.

FIG. 18. Wet desquamation (rupture of huge blister) on the right hypothenar of P2 seven weeks after exposure.

P2 was discharged from the hospital on 11 March 2000, with biweekly appointments made for follow-up. By 7 April 2000, the wound on the right hand was decreasing in size and extent (diameter about 1 cm), but on 19 April 2000 at a follow-up check swelling in both hands was noted.

Patient 3

P3 was admitted to Samut Prakarn Hospital on 20 February because of a low platelet count from a study initiated the previous day. He also demonstrated burns at the distal phalanges of the second and third fingers of his right hand and a 30 cm long burn near his right knee. On 23 February 2000, an extended necrosis of the epidermis was observed on the lateral side of his right thigh just above the knee, while below knee level a 5 cm × 8 cm area demonstrated wet desquamation (Fig. 19).

P3's wounds were treated with Cloxacillin antibiotic (2 g/d orally), Trental and G-CSF. He was also given a platelet transfusion (ten units) when his platelet count fell below 20 000/mm^3.

On 3 March 2000, P3 was admitted to Rajavithi Hospital. Second degree burns were seen on the index and middle fingers of his right hand, as well as a 30 cm long wet desquamation in the popliteal area of his right knee (Fig. 20).

FIG. 19. Extended necrosis and wet desquamation on the lateral side of the right leg of P3 23 days after exposure.

FIG. 20. Wet desquamation 30 cm long in the popliteal area of the right knee of P3 five weeks after severe local exposure.

P3 was treated with a combination of G-CSF (250 μg/d) and GM-CSF (300 μg/d). These were discontinued when his white blood cell and platelet counts increased.

P3 was discharged on 12 March 2000, with biweekly appointments made for follow-up. On 17 March (seven weeks after exposure), his extended wound had become infected below the knee (Fig. 21).

On 24 March 2000, he was readmitted to the hospital. His finger wound had already healed but the (now) 28 cm × 30 cm radiation wound to his right popliteal fossa had deepened so much that it had to be debrided. A skin graft was performed on 27 March 2000 using skin from the left thigh. Although for a few days the graft appeared to have been successful, on 2 April 2000 it had to be opened. P3 was discharged three days later, reportedly at his own request. He returned after two weeks when he was experiencing severe pain in his leg. The areas showed signs of massive infection and incipient necrosis (Fig. 22). Debridement was performed again.

Patient 4

P4 also demonstrated burns on his right second finger and left fourth finger upon admission to Samut Prakarn Hospital. He was treated there and was transferred to Rajavithi Hospital on 3 March 2000 together with P3. Treatment at Rajavithi Hospital consisted of 2 g/d of Cloxacillin antibiotic, Trental and wound dressing. He

FIG. 21. Appearance of the popliteal area for P3 seven weeks after severe local radiation exposure.

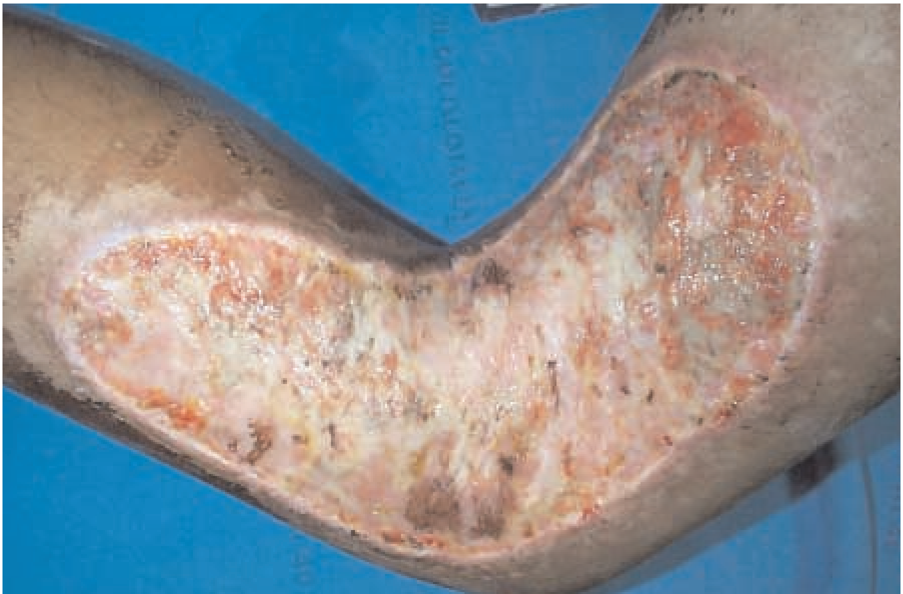

FIG. 22. Massive infection and beginning of necrosis of the extended wound on the right leg of P3 on 19 April 2000, 11 weeks after exposure.

was discharged on 7 March 2000 and scheduled for biweekly follow-up visits. On follow-up visits on 31 March and 3 May 2000, his wounds were healed. However, the nails of the second and fourth fingers of his right hand had sloughed off owing to the radiation burns to the fingers. Hypopigmentation and the absence of fingernails were noted in a checkup on 3 May 2000.

4.3. TREATMENT AND CLINICAL PROGRESSION OF PATIENTS IN GROUP 2 (P5–P10)

Patient 5

P5 was admitted to Samut Prakarn Hospital on 16 February 2000 with burned and swollen hands. On 17–18 February, his white blood cell count was 100 mm^{-3}, his platelet count was in the range 40 000–50 000 and he had a high fever (Fig. 23).

The antibiotic Cefpirome was administered (2 g/d). When he was transferred to Rajavithi Hospital on 19 February, he had already suffered alopecia, fatigue and high fever. Radiation burns "like a sunshine burn" had appeared on both hands, face and anterior chest. Antibiotic treatment and G-CSF (500 μg/d: 10 μg/kg per day) and dressing of the burn areas were continued. Fever was controlled but he had epistaxis that needed nasal packing. His lips and tongue were severely swollen (Fig. 24).

P5's white blood cell count could not be increased and approached zero, so the dosage of G-CSF was increased to 1000 μg/d (20 μg/kg per day). A bone marrow aspiration performed on 23 February 2000 showed severe aplasia, but a chromosomal study could not be completed because no metaphases were apparent. Fever returned on 24 February 2000, when apthous ulcers were noted at the tip of his tongue. His white blood cell count was still very low, so the antibiotic was changed to 3 g/d Ceftazidime plus 300 mg/d Netilmicin, together with GM-CSF (300 μg/d). Prophylactic antifungal drugs were also administered.

His burned hands were swollen on 25 February 2000 and the skin started peeling off by 28 February. Diarrhoea returned on 2 March and by 6 March 2000 he could not take food orally. He still had fever and a haemoculture test was positive *(Enterococci)*, so nutrients were provided through a nasogastric tube. Antibiotics were changed according to the results of a sensitivity test. He continued to have low white blood cell and platelet counts (Fig. 23) and needed single donor platelets daily. On 15 March 2000, tachypnea was noted and lung crepitation was detected, so breathing was assisted by a respirator. By 17 March 2000, he had lost consciousness and his blood pressure was dropping. P5 died on 18 March 2000, 47 days after exposure, owing to septic shock. His heart blood culture tested positive for *Enterococci*.

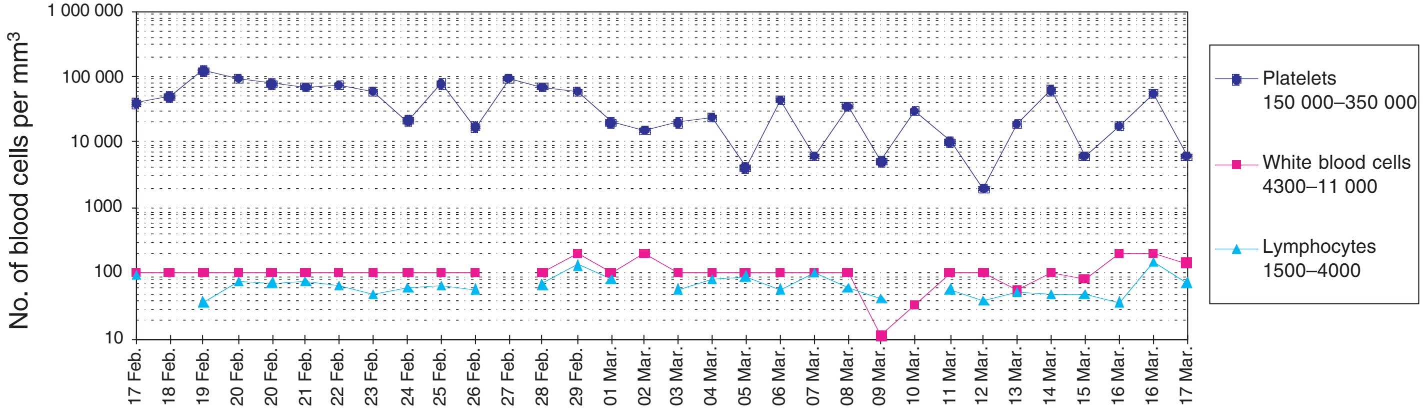

FIG. 23. Haematological chart for P5 while in hospital.

FIG. 24. Swollen lips and tongue of P5 on 22 February 2000, three weeks after severe whole body exposure.

Patient 6

P6 exhibited alopecia, mucositis and swelling on both palms when admitted to Samut Prakarn Hospital on 17 February 2000. His white blood cell count was 100/mm^3, so the antibiotic Cefpirome (2 g/d) was given. He was transferred to Rajavithi Hospital on 19 February. He was weak and skin burn was noted on his face and chest areas. Steroid cream was applied to the burned skin. Treatment there continued with the same antibiotic, together with 500 μg/d G-CSF. His fever was controlled but hair loss continued. A bone marrow aspiration was performed on 22 February 2000, which showed severe aplasia. A chromosomal study could not be completed because there was no metaphasic activity. On 25 February he was still weak and a low grade fever returned. Alopecia and an ulcer developed by this date above his ear (Fig. 25) and an ulcer in his mouth was also noted.

P6's fever continued and the antibiotics had to be changed. An antifungal drug, an antiviral drug and GM-CSF were added to his regimen. On 6 March 2000, he could not eat, so nutrients were administered through a nasogastric tube. On 7 March, he was having difficulty breathing. A chest X ray showed right lobar pneumonia and a blood gas test showed metabolic acidosis, so a respirator was installed to help breathing. His blood pressure was dropping and bleeding was observed, emanating

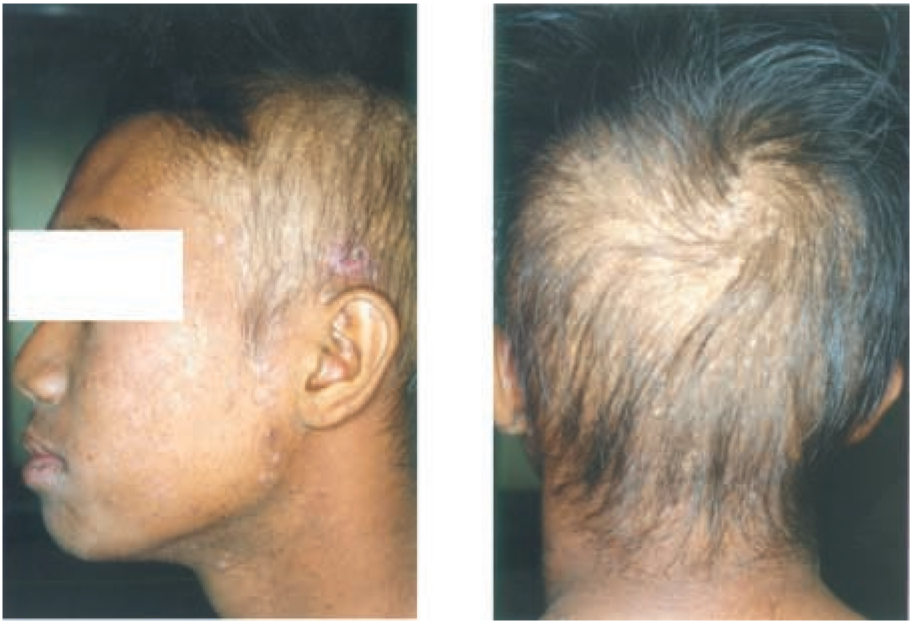

FIG. 25. Severe alopecia and ulceration above the left ear of P6 on 22 February 2000.

from the upper gastrointestinal tract. Although he had been given Dopamine to raise his blood pressure, supraventricular tachycardia of the type that needs cardioconversion and acute renal failure were noted on 8 March 2000. On the following day, 9 March 2000, a generalized clonic seizure was noted at 13:20, after which his pupils were fixed dilated. Cardiopulmonary resuscitation was performed twice on account of brachycardia but failed. P6 died at 19:38 that evening, on day 38 after exposure, owing to septic shock. A heart blood culture test was positive for *Enterococci*.

Patient 7

P7, the owner of the junkyard, demonstrated feelings of weakness, alopecia, anorexia and low white blood cell count when she presented herself at the outpatient clinic of Bangkok General Hospital on 17 February 2000. A bone marrow aspiration showed pancytopenia and a biopsy showed slightly hypocellular marrow. She was transferred to Rajavithi Hospital on 20 February 2000. Her white blood cell count was low and her platelet count was less than 20 000, so she was treated with 500 μg/d G-CSF. Owing to excessive menstruation, she was provided with blood and platelet transfusions and hormonal therapy. Her white blood cell count fell to 100/mm^3, so the dosage of G-CSF was increased to 1000 μg/d and prophylactic antibiotics

(Ciprofloxacin, 1 g/d orally) were administered. Her white blood cell count was still low, so GM-CSF (300 μg/d) was also given. A chromosomal study from peripheral blood was performed on 29 February 2000 but showed no metaphases. Also on this date she had fever with chills and looked pale. A physical examination found suspicions of haematoma at the rectal wall, so a septic evaluation was performed. Packed red cell, single donor platelets and broad spectrum antibiotics (Ceftazidime plus Netilmicin plus Metronidazole) were administered, and the dosage of GM-CSF was increased to 600 μg/d (the upper limit), while the dosage of G-CSF was reduced to 750 μg/d. Her white blood cell and platelets slowly started recovering. Between 11 and 14 March 2000, administration of G-CSF and GM-CSF was tapered off. Antibiotics continued to be given for more than two weeks, owing to positive haemoculture and pneumonia at the lingular segment of the left upper lung. She was discharged from the hospital on 28 March 2000 and biweekly appointments were made for follow-up.

Patient 8

When P8 was admitted on 17 February 2000 to Bangkok General Hospital, he was bleeding from his nose and had abdominal pain, diarrhoea, buccal mucositis and cheilitis. Severe aplasia was noted upon completion of a bone marrow aspiration and biopsy that same day. His white blood cell and platelet counts were very low, so G-CSF (300 μg/d) was administered, starting on admission to hospital. On 20 February 2000, antibiotics (Ceftazidime plus Amikacin) were started after a septic evaluation was performed.

P8 was transferred to Rajavithi Hospital on 20 February demonstrating fever, weakness, alopecia and skin burn on his face and chest. The dose of G-CSF was increased to 1000 μg/d and the antibiotics were continued. On 25 February 2000, a papulovesicular eruption diagnosed as *Herpes zoster* was spreading over his back and a fungal infection also appeared in his subaxillary region (Fig. 26).

Antiviral drugs (Zovirax, 200 mg six times per day for three days, then reduced to 400 mg twice per day until 17 March 2000) and antifungal drugs (Sporal, 100 mg twice per day for three days, then Ambisome 100 mg per day intravenously for two days) were administered. The antifungal drug was administered as a prophylaxis. Low grade fever continued and worsened to high fever (~40°C), which continued in mid-March.

His white blood cell count could not be improved, despite the continued administration of the G-CSF to which GM-CSF (600 μg/d) was added (intravenously). Rusty looking sputum was noted by 18 March 2000, and chest pain developed on 19 March. Ventilation was assisted on 21 March, when tachypnea was observed.

By 22 March 2000, greater tachypnea was noticed and pink frothy sputum seen, which his physicians attributed to pulmonary oedema. He was moved to the intensive

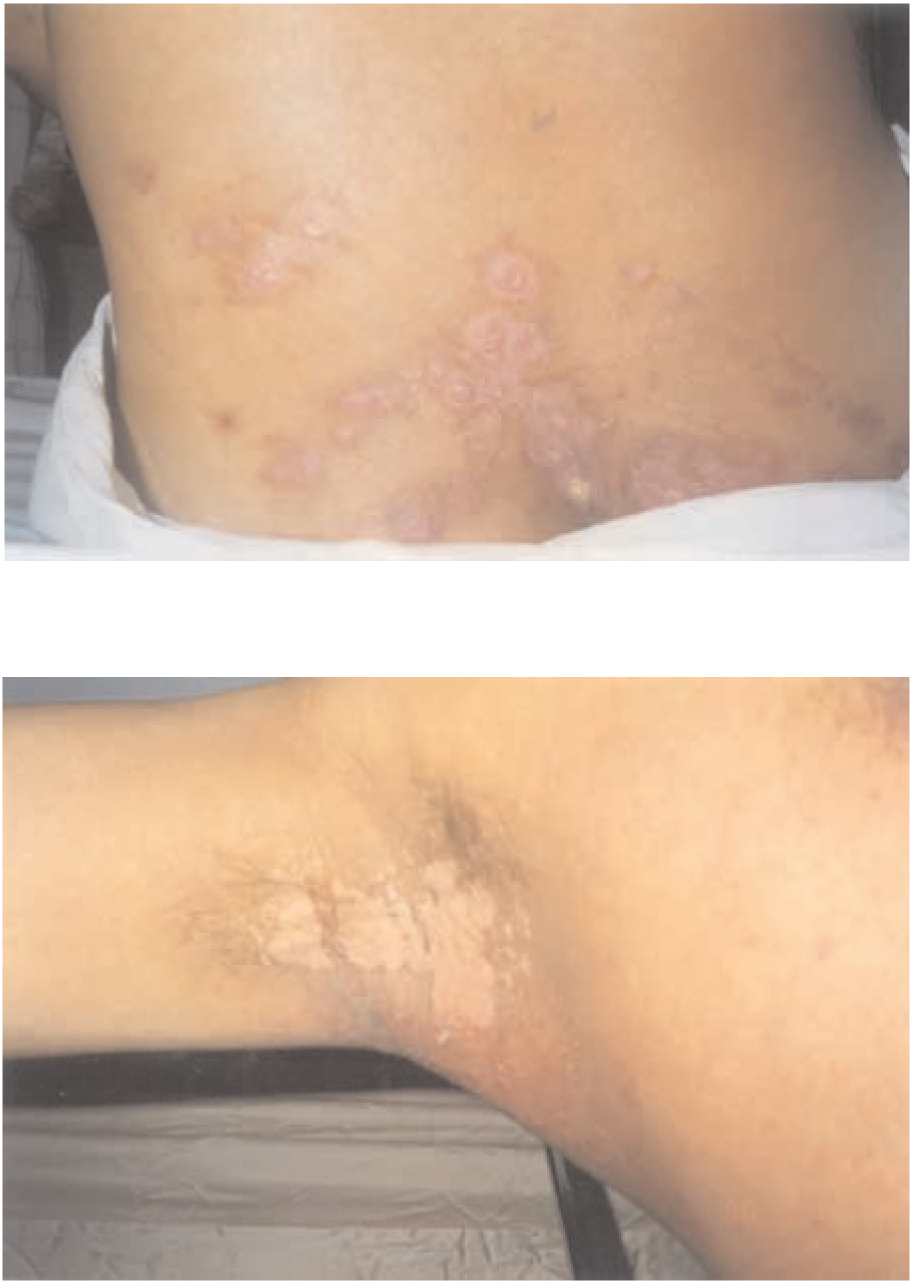

*FIG. 26. Viral infection (*Herpes zoster*) in the lower back (top) and fungal infection in the subaxillary region (bottom) of P8 on day 25 after exposure.*

care unit and placed on a ventilator. On 23 March 2000, additional oxygen-assisted breathing was maintained, but he became stuporous and did not react to verbal commands. His blood pressure dropped and both the heart rate and respiratory rate increased. At 10:30 on 24 March 2000, P8 suffered cardiac arrest. He was pronounced dead at 10:50 (on day 52 post-exposure). His heart blood culture was positive for *Morganella morganii*, and a necropsy culture of his left lung was positive for *Stenotrophomonas maltophilia*.

Patient 9

P9, who worked at the junkyard and also as a maid for P7 and P8, was seen on 19 February 2000 at Samut Prakarn Hospital after complaining of nausea, vomiting, decreased appetite and headache. She was transferred that day to Rajavithi Hospital, where alopecia and a slight fever were noted upon admission. A bone marrow aspiration and biopsy were performed on 22 February, in which severe aplasia was noted. Complete blood examinations to note the progression of her white blood cell count were performed daily. The dosages of G-CSF and GM-CSF were adjusted to increase her white blood cell count as quickly as possible. On admission, G-CSF was administered, starting at 250 μg/d from 19 to 23 February, boosted to 500 μg/d on 24 February, and then to 1000 μg/d from 25 February to 17 March 2000, when administration of this drug was terminated. She was also given 300 μg/d of GM-CSF from 26 February to 5 March; this was increased to 600 μg/d from 6 to 15 March and was terminated on 16 March. No metaphasic activity was noted in a chromosomal study performed on 29 February. Additionally, she was given 500 mg of Ciprofloxacin twice a day from 24 February to 16 March 2000 as a prophylactic antibiotic for neutropenic patients. Transient low grade fever due to an upper respiratory tract infection was also noted during her stay in hospital. She was discharged from the hospital on 25 March 2000 with biweekly follow-up appointments made. Also, owing to menstruation, she was given several units of platelets and hormonal therapy during her hospital stay.

Patient 10

P10, the mother of P7, was admitted to Samut Prakarn Hospital on 22 February 2000, having previously complained of nausea, vomiting and weakness. She also had a low white blood cell count. A slight fever was noted but the physical examination performed on this date was unremarkable. She was transferred to Rajavithi Hospital on 25 February with no specific symptoms; she had been in the junkyard, however. A chromosomal study from peripheral blood performed on 29 February 2000 showed a complex chromosomal abnormality, with ring chromosomes in some cells. Mild hypocellular marrow was noted on 1 March 2000 during a bone marrow aspiration, with lymphocytic series cells predominant. Megakaryocytes and erythroid and myeloid series cells were slightly diminished. The doses of G-CSF and GM-CSF were adjusted according to P10's white blood cell count each day. She was given G-CSF at 250 μg/d from 25 February, 500 μg/d on 2 and 3 March, 1000 μg/d on 4 and 5 March, 500 μg/d on 6 and 7 March, back to 1000 μg/d for 8–18 March, reduced to 500 μg/d on 19 and 20 March, and then the dose was further reduced to 250 μg/d for 21–23 March until it was terminated on 24 March. She was also administered GM-CSF at 300 μg/d from 26 February through 5 March, 600 μg/d from 6 through 10 March, 500 μg/d from 11 through 18 March, 300 μg/d on 19 and 20 March, with the termination of this treatment on 21 March. She was discharged from the hospital on 28 March 2000 with biweekly appointments made for follow-up.

4.4. CHROMOSOMAL STUDY

A chromosomal study from bone marrow taken together with a bone marrow smear on 22 February 2000 from P5 and P6 showed no metaphases. A bone marrow sample taken the same day from P9 showed a normal female chromosome (46, XX) with only three metaphases.

Samples of peripheral blood were drawn on 29 February 2000 from P5–P10. The analysis showed no metaphases in the white blood cells of P5–P9. It was thus concluded that the radiation doses these individuals had received had been sufficient to ablate leukopoiesis. On 1 March 2000, the bone marrow of P10 displayed a complex chromosomal abnormality, presenting seven different patterns, including ring and dicentric chromosomes (Fig. 27).

Peripheral blood samples from P2–P4 were taken on 14 March. P3 and P4 presented normal (46, XY) karyotypes, while P2 displayed eight different abnormal patterns, including triple rings (Fig. 28). Some cells showed an unremarkable karyotype. The varieties of the abnormalities shown in the peripheral blood, together with the normal karyotypes, suggests a variation attributable to severe but localized radiation exposure.

Despite the absence of metaphases in cultured lymphocytes from most of the blood or marrow samples, severe chromosomal aberrations could have been detected (multiple rings, dicentrics). This could have allowed biological estimation of doses if the laboratory had had its own in vitro calibration curve (see, for example, Refs [15, 16]).

5. FINDINGS, CONCLUSIONS AND LESSONS TO BE LEARNED

The primary objectives of the IAEA's investigation of the accident in Samut Prakarn were to: (a) ascertain the causes of the accident; (b) review the effectiveness

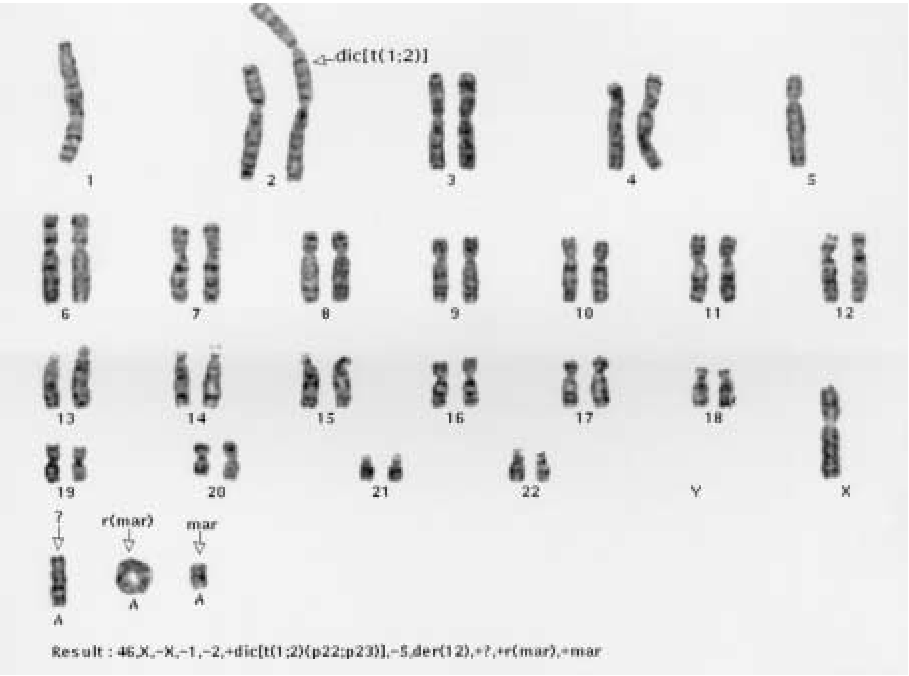

FIG. 27. Dicentric and centric ring chromosomes in the karyotype of P10 four weeks after exposure.

of the response; (c) draw conclusions on the basis of the findings; and (d) consider the lessons to be learned. A number of lessons are not unique to this accident but are worth reiterating in this report. The specific findings and conclusions from this accident are presented, together with the general lessons to be learned (in italics).

The contributory factors to the accident were as follows:

— There were difficulties in the disposition of disused radiation sources:
  - there was no clear or effective end-of-life provision for the source involved;
  - the original manufacturer (in another country) no longer provided that type of equipment or support for it, nor reportedly was willing to take back the source;
  - the local supplier was facing financial difficulties;
  - the vendor of replacement equipment was reportedly unwilling or unable to accept the disused source.

— The national authority's workload reportedly limited its oversight of licensees.

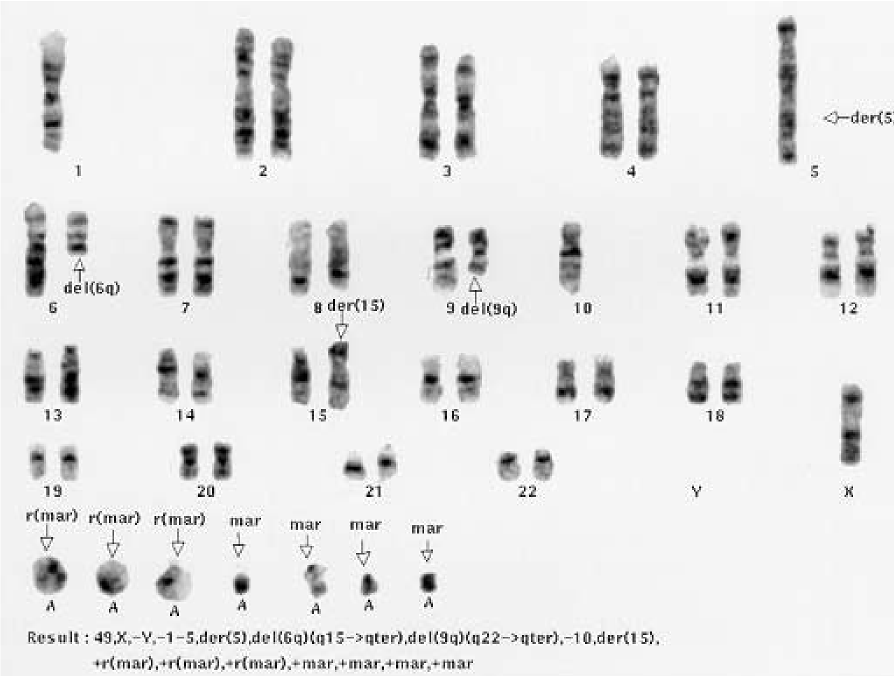

FIG. 28. Triple ring chromosomes in the karyotype of P2 six weeks after exposure.

- — The licensee sold a disused source without notifying the regulatory authority of the transfer.
- — The recipient was not authorized to receive the source (or to possess the other sources that it had).
- — The recipient had relocated its radiation sources to an unsecured location.
- — There were no warning signs in the local language on the source container.
- — The unsecured device was disassembled and taken for sale as scrap metal.

5.1. OPERATING ORGANIZATIONS

(1) The original licensee (a hospital) was replacing its teletherapy unit and had no suitable space available to store the disused device. There were no provisions for returning the disused source to the manufacturer. The hospital contracted with a local supplier of similar equipment to handle the disused device (including the disused source) and sold it without notifying the regulatory authority.

(2) The local supplier company acquired and possessed radiation sources without a valid authorization.

(3) The local supplier company possessed radiation sources in long term storage and did not have satisfactory arrangements for prompt disposition of the disused sources.
(4) The local supplier company relocated its radiation sources to unsecured storage.
(5) Insufficient security over the storage location allowed unauthorized access to the radiation sources.

The BSS (Ref. [1], paras 2.34, IV.1, IV.15–IV.17) establish requirements for ensuring that all radioactive sources are kept secure and require that this function be the prime responsibility of the registrant or licensee as a legal person. The BSS also require that registrants and licensees as legal persons make a safety assessment of the protection and safety of radiation sources for which they are responsible (Ref. [1], paras IV.3–IV.7).

5.2. NATIONAL AUTHORITIES

(1) The current national regulations in Thailand, although they had not been revised or updated significantly since their promulgation, should have been sufficient to control and regulate authorized legal persons, if fully implemented.
(2) There was a lack of clear language in the regulations and licence requirements establishing the duties and obligations of authorized legal persons.

Regulatory authorities need to consider methods to ensure the continuity of control throughout the lifetime of a source. This may include establishing licensing requirements for the future that take account of the disposal of the source at the end of its useful life.

(3) Reportedly, no clear instructions, including instructions relating to long term storage or disposition, had been provided to the authorized legal persons, nor had there been any communication on such instructions with them.

National authorities need to review their legislative and regulatory systems and, where necessary, make modifications to these systems in order to achieve compliance with the BSS. National authorities are encouraged to make use of IAEA-TECDOC-1067 [2] in considering the implementation of the provisions of the BSS. Such authorities may also find it useful to consider whether the regulatory system in their States is adequate to prevent a sequence of events such as that described in this report and in other IAEA reports on radiological accidents (see also Refs [3–11, 17, 18]).

(4) At the time of the accident, the national inventory of radiation sources appeared to be incomplete.

Legal persons need to maintain accurate and current inventory records of radiation sources, and the national authority needs to maintain records of authorized radiation sources under its authority [27]. While it is not at present a requirement for a national inventory to be kept, the IAEA's Categorization of Radiation Sources [19] provides guidance on the priorities for sources to be considered if such a task is undertaken.

(5) The staffing of the national authority appears to have been insufficient to enable it to perform the necessary routine annual inspections or to follow up appropriately on the information that had come to its attention.

Routine inspections by the national authority have the potential for detecting non-compliance with regard to the transfer and storage of radioactive sources and thereby preventing the precursor events to an accident [27].

(6) The presence of a radioactive source was not detected at the junkyard, and the actions that were taken by the junkyard workers could have breached the integrity of the source or otherwise transferred the source to metal processing facilities.

National authorities need to develop strategies for detecting and dealing with 'orphan' radioactive sources. Workers such as dealers, processors and exporters of scrap metal, customs officers and border police who may be occupationally or accidentally exposed to radioactive sources need to be provided with suitable information and guidance (see, for example, Ref. [20]).

(7) The sequence of events leading to this accident was similar to those described or identified in other IAEA reports on radiological accidents. In particular, there are significant parallels with the accident that occurred in Istanbul, Turkey, in December 1998–January 1999 [11]. The similarities are a cause for concern because the accident in Samut Prakarn could have been prevented by applying the lessons of the accident in Istanbul.

National authorities are encouraged to disseminate information on radiation accidents widely to help prevent accidents of a similar nature in the future.

(8) The Thai authorities appear to have an effective national emergency plan for dealing with radiation emergencies which involves local emergency services such as the police and fire brigade.

The BSS (Ref. [1], para. V.1) presume that States will have determined in advance the assignment of responsibilities for the management of interventions in emergency exposure situations between the regulatory authority, national and local intervening organizations, and registrants and licensees. National authorities are encouraged to make use of IAEA-TECDOC-953 on Method for the Development of Emergency Response Preparedness for Nuclear or Radiological Accidents [21] or IAEA-TECDOC-1162 on Generic Procedures for Assessment and Response During a Radiological Emergency [22].

(9) Co-ordination by the Thai emergency response team in the source recovery operation included:
- — Co-ordination with the local authority to bring the situation under control upon recognizing the serious radiological threat to the public;
- — Co-operation and co-ordination among the regulatory authorities, the local public health office, local fire brigades and the provincial civil defence unit, resulting in the prompt availability of the requisite personnel, tools and equipment for immediate action.

A successful operation for recovery from an accident needs co-ordination with and co-operation among local authorities in the vicinity, resulting in a well prepared and equipped rescue and recovery team.

(10) The Thai emergency response team's preparations to recover the source included:
- — Experienced personnel with expertise in dealing with high radiation fields and control of known contamination;
- — The use of videotaping to assist in the review of the situation, training and rehearsal for responding personnel, and planning of recovery strategies.

Emergency responders need to include personnel with diverse experience and qualifications. Modern communications media proved to be valuable and vital to the successful recovery of the source.

(11) The Thai emergency response team used innovative means to achieve rapid recovery of the source, which was in a difficult location. These included:
- — Using fluorescent screens to pinpoint the location of the source;
- — Using a light bamboo rod instead of a much heavier metal pole for quick moving and screening of scrap items;
- — Utilizing a thick lead shield to reduce exposure of personnel during the response and recovery.

Challenges need to be anticipated and prepared for in the management of interventions in emergency exposure situations. Preparedness and training are crucial to the prompt abatement of a serious radiological threat, yet emergency responders need to maintain some flexibility and allow for innovation in responding to challenging situations, including adapting equipment as necessary.

(12) Public concerns and misinterpretations [23–26] of the accident included the following:
- — The Thai emergency response team was perceived as 'not taking the matter seriously' [23] with regard to the radiation hazard;
- — The Thai emergency response team was perceived as being unprofessional and lacking the necessary training;
- — The bodies of the irradiated accident victims were perceived as being 'radioactive'.

Information needs to be given clearly and effectively for it to be understood by the public. Adequate and effective communication with the news media can be improved by, for example, having regular press briefings and updating the media on the progress of events.

Lack of routine and effective public information about radiation and radioactive materials can lead to misconception and distrust on the part of the public, which can lead to a situation where good scientific practice is not recognized.

(13) Representatives of the news media reportedly hampered or interfered with the conduct of the recovery operations.

The designation of a single contact point for the news media during an emergency and recovery operations is suggested for all regulatory authorities, to allow responders to perform their functions and to prevent misunderstanding and confusion when information is obtained from several sources.

5.3. INTERNATIONAL CO-OPERATION

(1) Thailand informed the IAEA of the accident and requested assistance as a signatory party to the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, and the initial notification was followed by other reports.

(2) As with this accident, the IAEA can provide assistance, upon request, to Member States in response to radiation emergencies, within the framework of

the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency. It helps in preparing for the provision of assistance for the IAEA to be informed of accidents as soon as possible.

The governments of all countries in which major radiation sources are used are encouraged to adopt the Convention on Early Notification of a Nuclear Accident as well as the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.

(3) Preparation of this report has assisted in the recording of a comprehensive account of the radiological and medical management of this radiation accident by the national authorities.

National authorities are encouraged to share information on radiological accidents with the IAEA and with other States in order to help prevent or mitigate the consequences of such accidents in the future.

(4) The trefoil symbol on the source containers failed to convey the potential radiation hazard. The signs and warning labels that were present were not understood by the individuals who gained access to these containers.

There is a need for an international review of the usefulness of the trefoil symbol and the possible need for a more intuitively understandable warning sign for Category 1 or 2 sources. If words are used in addition to symbols, they need to be in a language which is understandable to the local public and workers.

5.4. EQUIPMENT SUPPLIERS

(1) Information about the type, size and shape of the radiation source or device was not readily available. The problem was compounded by the fact that a small source was lost in a large volume of scrap metal.

Information about the source, such as its type, activity and dimensions, would have enabled response personnel to identify the source more readily for prompt retrieval and recovery. Note that the IAEA, with the assistance of Member States, manufacturers and suppliers, is preparing a compendium of types of radiation sources, intended to provide information concerning manufacturers, physical sizes of sources, radioactive material(s) used and activity ranges, year of manufacture and information about their distribution.

(2) It was possible to dismantle the teletherapy source housing readily with relatively simple tools, which allowed individuals to be exposed to the high radiation field from the source.

Defence in depth and engineering controls designed into the construction of shipping containers for teletherapy source housings could help to prevent the unauthorized removal of shielding and extraction of the source or exposure to it.

(3) There was no provision for the return of the disused source to a different device manufacturer.

National authorities, working in co-operation with source or device manufacturers, need to pursue options for the safe return of spent or disused sources to the manufacturer or to a different source or device manufacturer.

5.5. THE MEDICAL COMMUNITY

(1) The individuals exposed in the accident in Samut Prakarn reported to hospitals and outpatient clinics, but their original symptoms (diarrhoea, nausea and vomiting) were not initially diagnosed as being caused by radiation exposure.

Physicians need information on and training in the basic symptoms and signs of acute radiation exposure, both whole body and localized exposure, and the types of radiation sources that might cause such effects.

The IAEA, in co-operation with the World Health Organization, has prepared and distributed a poster and a leaflet on 'How to Recognize and Initially Respond to an Accidental Radiation Injury'. These are intended to inform physicians on how to recognize a possible radiation injury from patients' signs and symptoms.

(2) There was apparently no adequate biological dosimetry to assess the probable range of the radiation doses received by the individuals involved.

A cytogenetic laboratory needs to be designated as the (national) biodosimetry laboratory in a State in which radiation sources capable of causing severe radiation accidents are widely used. This laboratory needs to develop its own calibration curves for the most common types of acute radiation overexposure, for example due to ^{60}Co, ^{192}Ir *and* ^{137}Cs.

(3) By means of adequate support and care, platelet transfusions and leukocyte lineage stimulation (by G-CSF and GM-CSF), safe levels of blood cell counts were achieved for many of the accident victims.

The clinical evolution following this accident confirms that, even with rather severe haematopoietic syndrome due to whole body irradiation with a dose of several grays, it was not necessary to perform bone marrow transplantation.

(4) Three individuals died of infectious complications within two months, despite the efforts made by the specialized hospital in providing all available treatment modalities.

Immediate reverse isolation, coupled with the administration of antiviral, antibacterial and antifungal agents, needs to be considered if severe whole body exposure is suspected.

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CONTRIBUTORS TO DRAFTING AND REVIEW

Aramratana, M.	Office of Atomic Energy for Peace, Thailand
Boonnak, S.	Office of Atomic Energy for Peace, Thailand
Boonpadhanapong, T.	Rajavithi Hospital, Thailand
Chinudomsub, K.	Office of Atomic Energy for Peace, Thailand
Dodd, B.	International Atomic Energy Agency
Gerdvichai, W.	Samut Prakarn Hospital, Thailand
Jinaratana, V.	Rajavithi Hospital, Thailand
Nogueira de Oliveira, C.	International Atomic Energy Agency
Ohtani, M.	Hiroshima University School of Medicine, Japan
Pongpat, P.	Office of Atomic Energy for Peace, Thailand
Rerkamnuaychoke, B.	Ramathibodi Hospital, Thailand
Somchat, C.	Samut Prakarn Hospital, Thailand
Suzuki, G.	Radiation Effects Research Foundation, Japan
Tanosaki, S.	National Institute of Radiological Sciences, Japan
Turai, I.	International Atomic Energy Agency
Waniksumsombut, W.	Office of Atomic Energy for Peace, Thailand
Wrixon, A.	International Atomic Energy Agency
Yusko, J.	International Atomic Energy Agency

Consultants meeting

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