4.3. FURTHER EXPOSURES AT THE FACILITY: THE SECOND EVENT

At 06:00 on Day 1 (Sunday 5 February), Worker D reported for duty on the day shift at the facility. He found the main door open, the facility shut down and the product boxes in disorder, with no sign of Worker A. Worker D straightened the boxes and started up the facility. When Worker A did not arrive for duty on the night shift at 18:00, Worker D remained and operated the facility for another shift. On Day 2 (Monday 6 February) at 06:00, he reported the matter to the maintenance manager.

The company was aware of the receipt of sick notes for the absent workers; however, these notes stated that the men were suffering from food poisoning. The company remained unaware that the accident on Sunday 5 February had caused any radiological injury to workers until contacted by medical staff of the Primero de Mayo Hospital on Day 4 (Wednesday 8 February). However, the significance of the injuries was then still not appreciated. For the rest of the week the facility was operated more or less normally; that is, with a typical number of shutdowns for repairs, usually requiring entry of the radiation room. A notable exception was on Day 4 (Wednesday 8 February) at 13:55, when the source rack became stuck but was released by the 'usual' overpressure technique.

Subsequent examination by representatives of the supplier showed a downward bending of the top and bottom horizontal bars of the lower source module and of the bottom bar of the upper module. This deformation had probably occurred in the accident on Day 1 (Sunday 5 February), and may have worsened when the source rack again became stuck on Day 4 (Wednesday 8 February). At some point, probably on Day 5 or 6 (Thursday 9 or Friday 10 February), some of the pencils fell from the upper source module into the pool.

The absence of some pencils was discovered on Day 6 (Friday 10 February) after quality assurance dosimetry had indicated that the doses to the irradiated products that had left the radiation room that morning were substantially lower than required. Upon learning this, the maintenance manager and the quality assurance specialist entered the radiation room at 12:00. They observed from the Cerenkov glow that some source pencils were missing from the upper source module and were lying on the bottom of the pool, and that two of the remaining pencils in the centre of the upper source module had become crossed. In all probability this meant that at least one of the pencils was protruding from the rack. However, it seems that at the time it was not appreciated that a projecting pencil might catch on one of the cross-pieces of the fixed rack positioner when the rack was raised. Since the ambient radiation level in the radiation room was normal, it was decided to continue operation but with longer exposures to compensate for the reduced source strength.

At 16:00 that afternoon (Day 6: Friday 10 February), operation of the irradiator was halted by an 'electromechanical' failure. The operator was unable to return the source rack to the storage position, and called on the head maintenance techni-

cian, Worker X, to help. They checked the radiation level with the portable radiation monitor (a 'beeper' type of monitor) outside the door and concluded, on the basis of an increase in the 'beep' rate, that the source rack must be stuck in the raised position. The two workers somehow managed to lower the source rack (probably by the overpressure method), as indicated by the source down light and a fall in the 'beep' rate of the portable monitor, again used *outside* the personnel access door. In the course of lowering the source rack, they heard a noise. This was probably when the remaining pencils were knocked out of the upper module of the source rack.

Workers X and Y opened the door with the key in the 'usual' way (see Section 3.5.2), under the impression that all the source pencils were safely in the pool since the 'beep' rate (as measured outside the door) was low. Worker X and two of his staff, Workers Y and Z, entered the radiation room without further checking the radiation level and, it seems, without a monitor. Not finding anything wrong, they requested the maintenance manager to make an inspection.

The maintenance manager observed that the source rack was indeed in the pool, but that the upper source module was empty of pencils. He left the radiation room to fetch the monitor and, on holding it in the maze entrance, he found that the dose rate was above normal. He closed the personnel access door and had the source rack raised and lowered to see whether this made any difference. It moved without difficulty. He again checked the level of radiation and found it still to be elevated.

TABLE I. RESULTS OF CYTOGENETIC ANALYSES MADE BY THE NATIONAL ATOMIC ENERGY COMMISSION OF ARGENTINA THROUGH THE WHO COLLABORATING CENTRE ON RADIATION EMERGENCIES: DOSES RECEIVED BY OTHER WORKERS ON DAY 6 IN THE SECOND EVENT

Worker	Dose estimate (Gy)	95% confidence interval (Gy)
Maintenance manager	0.22	0.0–0.38
Worker X	0.09	0.0–0.26
Worker Y	0.16	0.0–0.33
Worker Z	0.16	0.0–0.33

After repeating this process twice more with the same results, he concluded that something was amiss beyond their normal experience, and at 16:35 he ordered the facility to be closed and sent the staff to other parts of the plant. Four of the pencils from the top module, one active source pencil and three dummy pencils, were subsequently found to have fallen into the radiation room; the others had fallen into the pool.

The practice of using the dose rate monitor *outside* the closed personnel access door to the radiation room was a crucial factor in the exposure of at least four more workers: the maintenance manager and Workers X, Y and Z. The dose rate outside the door would have been at least 30 times lower than the dose rate just inside the entrance maze. Thus whereas a full, or even half full, source rack in the raised position was detectable with the monitor held outside the closed door, the single active source pencil was only detected when the monitor was held inside the entrance maze.

None of the workers had worn personal dosimeters. Their exposures were discovered only later after cytogenetic tests were made on all workers who might have been exposed as a result of the accident. These tests indicated that these four persons probably received doses beyond generally applied worker dose limits. (See Table I.)

Had the elevated radiation level in the radiation room due to the active source pencil remained undetected, operating personnel could have accumulated much higher, possibly even lethal, doses through continual uncontrolled exposure.

5. THE RESPONSE TO THE ACCIDENT

Section 5 presents a summary of the response to the accident. Sections 5.1 to 5.4 describe related events that are for convenience considered grouped as the initial medical treatment of the patients, the repairs made to the facility, the response of the authorities in El Salvador and the international participation in the response. Sections 5.5 to 5.7 give summaries of the dosimetric analyses made and of the medical treatment of the patients in the Angeles del Pedregal Hospital in Mexico City and after returning to San Salvador. For specialists, the appendices and annexes to this report describe in greater detail the dosimetric analyses and the medical management of the patients.

Workers A, B and C are from now on also referred to as Patients A, B and C.

5.1. THE MEDICAL RESPONSE IN SAN SALVADOR

On Day 1 (Sunday 5 February) at 03:55 Patients A and B arrived at the emergency room of the Primero de Mayo Hospital in San Salvador. Later, Patient C, who had initially returned to work, also arrived. All three were vomiting. The radiation source at the facility was mentioned; however, no further symptoms of radiation exposure were then manifest. The misdiagnosis was made of food poisoning, and the men were given three-day sick leave certificates and discharged at about 06:00 the same morning.

5.1.1. Patient A

On Day 3 (Tuesday 7 February) Patient A returned to the Primero de Mayo Hospital with nausea and vomiting and also strong general erythema and burns to his legs and feet. In consequence of his statements about the incident at the facility, he was hospitalized as having "radiation burns" from "acute exposure to cobalt". (Apparently, the medical staff then had in mind exposure to a cobalt medical teletherapy source. Their information on and experience of radiation effects derived from cancer radiotherapy.) They consulted by telephone the senior radiotherapist of ISSS, who concurred with their diagnosis and intended treatment.

Patient A was placed in improvised reverse isolation in an annex to the hospital to reduce the possibility of infection. This regime was apparently effective, since no symptoms of severe infection (such as sepsis or septicaemia) appeared. Blood tests and other appropriate tests were performed and symptomatic supportive treatment was begun, including transfusions of blood components (thrombocytes, erythrocytes and plasma) and administration of antibiotics.

The treatment initially appeared to combat the symptoms, but enteritis (inflammation of the gastrointestinal tract) set in on Day 9 (Monday 13 February) with recurrence of vomiting and diarrhoea and the onset of pain and fever. Although mouth lesions made it difficult for Patient A to eat, the medical team did not institute tube feeding. These factors, together with declining blood counts and worsening of the burns to the extremities, led to a deterioration in his general condition.

On Day 11 (Wednesday 15 February) the haematology staff decided that preparations should be made to transfer Patient A as soon as possible from San Salvador to better facilities elsewhere with staff experienced in bone marrow transplant surgery. (The medical staff also recommended that the senior staff of the Occupational Hazard Prevention Department of ISSS investigate the irradiation facility.)

5.1.2. Patient B

When Patient B returned to the facility on Day 4 (Wednesday 8 February), his supervisor released him from work until Day 9 (Monday 13 February) on grounds

of his ill health. On Days 5 and 6 (Thursday 9 and Friday 10 February) he played football with only some discomfort in his feet, but by Day 7 (Saturday 11 February) they were itching and painful. On Day 9 (Monday 13 February) he went back to work but, unable to carry a heavy load because of the pain in his feet, he returned to the Primero de Mayo Hospital and was admitted immediately.

5.1.3. Patient C

Patient C returned to the Primero de Mayo Hospital on Day 2 (Monday 6 February) when nausea and vomiting continued. He was admitted to the hospital, still with a diagnosis of food poisoning. Although radiation injury was diagnosed for Patient A on Day 3 (Tuesday 7 February), Patient C refused to remain in hospital and, since he was not so sick, he was discharged on Day 5 (Thursday 9 February). He returned again on Day 8 (Sunday 12 February) and was readmitted. Again, however, since he was markedly less ill than the other two patients and preferred not to remain in hospital, he was discharged three days later on Day 11 (Wednesday 15 February).

The account of the medical treatment of Patients A, B and C is resumed in Section 5.6.

5.2. SECURING THE FACILITY

Although the company had been informed of the admission of the workers to hospital (see Section 5.3), it seems that the significance of the information was not appreciated. On Day 6 (Friday 10 February) it was discovered at the facility that the pencils had spilled from the source rack in the irradiator. Once apprised of this, the plant manager immediately requested the supplier to send a representative to San Salvador to effect repairs to the facility. Two experts from the supplier duly arrived at the plant on Day 9 (Monday 13 February). They succeeded in determining, by means of a remote television camera and an ion chamber device sent into the radiation room attached to a product carrier, that there was an active source pencil on the upper level.

On the following day the two experts drilled a hole through the approximately 1.6 m thick concrete roof of the radiation room and were able to view remotely two pencils on the upper level. These two pencils were inadvertently moved out of reach in manipulating them with a remote source handling tool in an attempt to determine which was the active one. On Day 11 (Wednesday 15 February), after devising another remotely controlled tool, they succeeded in picking up one pencil and lowering it into the pool. At 19:30 the experts confirmed that the radiation in the radiation room was at the normal background level. They then entered the radiation room and found three inactive dummy pencils on the lower level.

The experts from the supplier were unaware of any overexposure of personnel and had been assured that the radiation monitor had always been used before entry into the radiation room. On Days 12 and 13 (Thursday 16 and Friday 17 February) they made follow-up examinations of the facility and in view of the poor state of the equipment, particularly of the safety systems, they disabled the irradiator to prevent further operation and discussed with plant staff its possible refitting. They carried out a radiation survey of the entire plant in an attempt to confirm that no active source pencil had fallen into a product box and remained on the premises.

As a result of the drilling of the concrete roof, there was too much dust in the water in the pool below for a definitive inventory of the pencils to be made visually. The experts told the plant staff how to obtain a portable pool filtration system for filtering the water to permit the inspection of the pool's contents. Instructions were also given for repairing the existing filtration system, for the upgrading of product boxes and for the manufacture of a source shroud. Since these actions would take some time, the two experts from the supplier returned home. It was not until Day 24 (Tuesday 28 February), on telephoning the plant for a progress report, that the supplier was informed of the accident on Sunday 5 February and the admission of Workers A, B and C to hospital.

The existing pool filtration system was not repaired; however, in a few weeks the water had cleared sufficiently for a visual inspection to be made in an attempt to count the active source pencils by means of their Cerenkov radiation. Although this preliminary check indicated that the full complement of source pencils was present in the pool, their disarray left an element of doubt.

A definitive count of the source pencils was made photographically in November 1989 at the request of the owner of the plant. The results showed that all fourteen active source pencils dislodged from the upper module of the source rack in the second event, clearly distinguishable by their Cerenkov radiation, were on the floor of the storage pool. The photograph also showed that the lower source module containing a further fourteen source pencils was intact. Copies of the photograph were sent to the supplier and forwarded to the IAEA (see photograph).

This confirmed evidence gained previously from an inspection made with a remote television camera by the two experts from the supplier, and also during the IAEA mission, when the lower module was removed from the source rack to the floor of the storage pool. Thus all the source pencils were satisfactorily accounted for in the pool and no further exposure could ensue.

5.3. THE RESPONSE OF THE AUTHORITIES IN EL SALVADOR

On Day 4 (Wednesday 8 February), ISSS staff for internal medicine asked the plant management about the radiation illness of the three workers. They were told that everything at the plant was operating normally.

Because of the worsening condition of the patients, two specialists in occupational medicine from the ISSS went to the plant to investigate on Day 12 (Thursday 16 February). The plant manager had left on a business trip after the experts from the supplier had secured the source pencils, and the medical staff were met by the maintenance and personnel managers. The managers indicated that the company was aware of some kind of accident to three workers in which safety systems had been overridden and that the facility, although temporarily out of operation, was then secure. The ISSS staff did not inspect the facility. They reported the interview to the deputy director of the ISSS.

On the basis of reports by staff of the ISSS and consultants, the deputy director of ISSS initiated a series of actions. On Day 17 (Tuesday 21 February) arrangements were made (including obtaining visas for the patients and for family members who could serve as bone marrow donors) to transfer the patients to a hospital in Mexico City with better facilities and more experienced staff. On Day 18 (Wednesday 22 February) the Ministers of Health and of Labour were briefed and on Day 19 (Thursday 23 February) officials from the ministries of Health and of Labour and representatives of the ISSS met to discuss further steps.

On Day 20 (Friday 24 February) this group met again, and a Salvadorian physicist from the Ministry of Health also attended. After a briefing by the ISSS on the conditions of the three patients, the attendees went to visit the plant immediately. At the plant, the plant manager and staff briefed them and the physicist surveyed radiation levels. They then viewed the intact source rack and the sources in the pool and concluded that the situation was under control. Thermoluminescent detectors were placed in various positions around the facility. When they were read on Day 26 (Thursday 2 March), radiation levels were found to be acceptably low.

Later on Day 20 (Friday 24 February) the Salvadorian physicist contacted Worker C at his home to arrange for his admission to hospital. Worker C was by this time evidencing some hair loss as a result of the radiation exposure, and agreed to be admitted to hospital for the third time. He remained there from Day 23 (Monday 27 February) until his transfer to Mexico City on Day 33 (Thursday 9 March).

The first news that the public had of the accident was a report on late evening television in El Salvador on Day 27 (Friday 3 March). Since the weekend editions of the newspapers had by then already gone to press, the first press accounts appeared on the morning of Day 30 (Monday 6 March). The television news on the Monday evening included an interview with the Salvadorian physicist. On Day 31 (Tuesday 7 March) government officials met and then gave a press conference, after which officials and journalists visited the plant. At this point the public had been informed of the events as they were then understood.

5.4. INTERNATIONAL PARTICIPATION

International participation began after Day 20 (Friday 24 February) at about 15:00 (23:00 Central European time (CET) in Vienna), when the deputy director of the ISSS telexed the IAEA to report a case of "radioactive contamination", requesting experts and equipment and help to determine the effects. The telex message, which was in Spanish and lacked the appropriate codeword for an emergency and whose significance was thus not appreciated by the duty officers on their rounds, did not reach staff of the IAEA's twenty-four hour emergency response system (ERS) until Day 23 (Monday 27 February) at 16:45.

Upon receiving the message, the staff of the emergency response unit informed the responsible IAEA staff and sought, through the office of the United Nations Development Programme (UNDP) in San Salvador, more details from the authorities in El Salvador of the type of help needed. The UNDP became a major communication link between the authorities in El Salvador and the IAEA, since El Salvador is not a signatory of the Convention on Early Notification of a Nuclear Accident (the Notification Convention) or the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (the Assistance Convention) and has no designated point of contact in San Salvador or representative in Vienna.

On Day 24 (Tuesday 28 February) at 16:00 CET the Salvadorian physicist responded to the IAEA's enquiry, informing the Agency that medical assistance was needed for three persons in serious condition owing to overexposure to radiation in an accident at an industrial irradiator three weeks previously. He estimated that the doses received were between 4 and 6 Gy, and added that there had been no contamination. On the basis of the information available, the ERS staff contacted the Radiation Emergency Assistance Center/Training Site (REAC/TS) of the United States Department of Energy at Oak Ridge to ascertain whether a team could participate in a mission to San Salvador to assist in the medical treatment of the exposed workers. REAC/TS later suggested that a representative of the Pan American Health Organization (PAHO) of the World Health Organization (WHO), based in Washington, D.C., also participate. This request was endorsed by the IAEA, and the Mission of the USA in Vienna was informed of the IAEA's intentions.

In view of the serious exposures, the IAEA emergency decision making group approved on Day 25 (Wednesday 1 March) the dispatch of two persons (one each from REAC/TS and PAHO) to render medical assistance for two weeks. Subsequently, REAC/TS volunteered a third person and then a fourth. The support of authorities in the USA was obtained through the Mission of the USA in Vienna and the authorities in El Salvador were notified. However, the mission was delayed while the patients were transferred to Mexico City, and the REAC/TS medical assistance team did not arrive in Mexico City until Day 32 (Wednesday 8 March). The group included a health physicist from the Oak Ridge Institute of Nuclear Studies who was

to make more accurate theoretical dose estimates after interviewing the three patients.

On Day 36 (Sunday 12 March) the expert team returned to the USA, and on Day 37 (Monday 13 March) the Mexican medical team sent word through the Mission of Mexico in Vienna that all three patients were expected to survive.

In the mean time, from Day 31 to Day 38 (Tuesday 7 to Tuesday 14 March), the physicist from PAHO and the Salvadorian physicist visited the plant in San Salvador and interviewed staff about the accident. From Day 39 to Day 43 (Wednesday 15 to Sunday 19 March), the PAHO physicist interviewed the three patients in Mexico City. These interviews formed a major element in the subsequent reconstruction of events. The PAHO physicist requested that blood samples be taken of all those staff who might have been exposed and sent through the WHO Collaborating Centre on Radiation Emergencies in Argentina to the National Atomic Energy Commission of Argentina for cytogenetic dose assessment. As stated in Section 4.3, the results indicated that at least four more workers had been exposed significantly over the dose limit for occupational exposure, probably as a result of the incident with the active source pencil on Day 6 (Friday 10 February).

On Day 196 (Saturday 19 August) the IAEA received an urgent request for medical help from the authorities in El Salvador, in response to which an IAEA staff member who had directed the treatment of patients with radiation injuries after the accident at Chernobyl went to San Salvador to render further assistance.

5.5. DOSIMETRIC ANALYSES

From Day 32 to Day 36 (Wednesday 8 to Saturday 12 March) the medical team at the Angeles del Pedregal Hospital in Mexico City worked together with the IAEA expert team from REAC/TS to assist in both medical and dosimetric aspects. Assessments of the patients' dose distributions were made on the bases of the onset and extent of epilation and dry and wet desquamation and early signs of necrotic lesions. These assessments, which did not substantially change afterwards, are presented in Fig. 17.

Blood samples for cytogenetic analysis were collected from the patients upon their admission to the Angeles del Pedregal Hospital: from Patient A on Day 24 (Tuesday 28 February), from Patient B on Day 26 (Thursday 2 March) and from Patient C on Day 33 (Thursday 9 March). Further samples were collected on Day 32 (Wednesday 8 March) for independent analysis by the specialist centres at REAC/TS and the Angeles del Pedregal Hospital. The results of the cytogenetic analyses at the two centres, presented in detail in Appendix I, were in very good agreement. The estimates of mean doses from these results were as follows:

Patient A: 8.1 Gy
Patient B: 3.7 Gy
Patient C: 2.9 Gy.

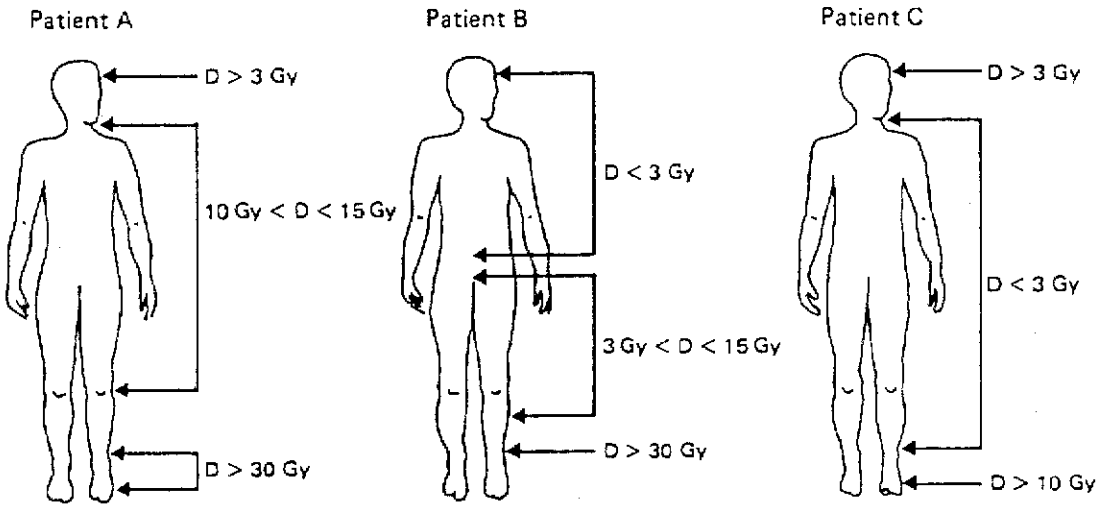

FIG. 17. Patients A, B and C: doses D incurred by different parts of the body. (Source: REAC/TS.)

5.6. FURTHER MEDICAL TREATMENT IN MEXICO CITY

5.6.1. Patient A

When admitted to the Angeles del Pedregal Hospital in Mexico City on Day 24 (Tuesday 28 February), Patient A was severely ill with gastrointestinal and haematopoietic radiation syndromes. He had general radiodermatitis, extensive burns to his legs and feet, and oedema in his hands. He continued to suffer nausea, vomiting and diarrhoea and was severely malnourished, having lost 20% of his (normally light) body weight. His blood and bone marrow were in extremely poor condition, but some effective bone marrow that could support recovery may have remained owing to the non-uniformity of his exposure.

Experienced medical and dosimetric teams were assembled and a complete range of tests were made (see Appendices I and II). The treatment regime for Patient A included strict protective isolation, blood transfusions and, to supplement his meagre oral nutritional intake, total parenteral feeding. In addition, on his arrival Patient A commenced a twenty day course of treatment with the experimental agent granulocyte macrophage colony stimulating factor (GMCSF), which may promote bone marrow recovery. (A supply of GMCSF was donated by a Swiss company through its Mexican subsidiary.) This treatment was preferred to bone marrow transplant surgery, which in this case was not considered appropriate. Although the drug was first given at a time (about 30 days after irradiation) when spontaneous bone marrow recovery might in any case have been expected, it nevertheless seemed to the Mexican medical staff for a number of reasons to have expedited recovery. The

use of GMCSF seemed not to be harmful, although it did cause side effects of tremors and weakness.

This regime led to a steady improvement. Patient A was removed from isolation on Day 47 (Thursday 23 March) but otherwise the regime was maintained. Although special attention was given to treating his leg burns, which were hindering his general recovery, gangrene appeared three months later. Consequently, on Day 132 (Friday 16 June) his right leg was amputated above the knee.

His prognosis was then guardedly for continued recovery; however, the danger of recurrent infections would persist; further blood transfusions would be necessary to combat anaemia; amputation of his left leg could become necessary; the probability of his subsequently developing cataracts was not insignificant; and there was a greater than normal possibility of his contracting acute leukemia. Nevertheless, by Day 173 (Thursday 27 July) his condition was considered to have improved sufficiently for him to be returned to the Medico-Surgical Hospital of the ISSS in San Salvador, where his nutritional, orthopaedic, physiotherapeutic and haematological condition was kept under close observation and where the more familiar surroundings were a positive psychological factor.

5.6.2. Patient B

Patient B was transferred to the Angeles del Pedregal Hospital in Mexico City on Day 26 (Thursday 2 March) with gastrointestinal and haematopoietic symptoms of acute exposure and severe burns to the legs and feet. He also was malnourished and had a severely depressed blood picture. As with Patient A, the non-uniformity of Patient B's exposure was a factor in his favour in that not all his bone marrow was severely irradiated.

Although the effects of Patient B's overexposure developed somewhat more slowly and to a lesser extent than for Patient A, who had received a much higher dose, the treatment regimes were similar. Patient B's treatment included the use of GMCSF, a ten day course of which was begun on his arrival and completed without notable side effects. After 11 days his blood picture had improved sufficiently to permit his removal from isolation. Again, the Mexican medical team considered that GMCSF was effective in promoting recovery. Psychological support was also an important element of the treatment.

The burns to Patient B's extremities were severe, and progressive necrosis of a toe eventually necessitated the amputation of his left leg above the knee on Day 161 (Saturday 15 July). After this, he also made sufficient general progress to be returned to San Salvador on Day 173 (Thursday 27 July), where he was kept under close medical supervision, particularly for the condition of his other (right) foot.

5.6.3. Patient C

Patient C was admitted to the Angeles del Pedregal Hospital on Day 33 (Thursday 9 March) with less severe haematopoietic symptoms and burns to his left foot. He required less intensive treatment. The medical staff followed a course of treatment similar to those for Patients A and B but to a lesser extent, including a nine day course of GMCSF begun on Day 34 (Friday 10 March) and tolerated without notable side effects. Since Patient C showed no other complications (with his extremities, for example), he was released from the Angeles del Pedregal Hospital on Day 55 (Friday 31 March) and transferred for continued medical supervision in San Salvador.

5.7. MEDICAL FOLLOW-UP IN SAN SALVADOR

5.7.1. Patient A

Patient A was returned to San Salvador on Day 173 (Thursday 27 July) and placed in a separate specially prepared room in the Medico-Surgical Hospital of the ISSS. Although he continued to make progress, his other (left) leg was not healing and a second amputation was likely to become necessary. On Day 187 (Thursday 10 August) his condition began to deteriorate. He had contracted pneumonia by Day 191 (Monday 14 August) and his condition was critical. At some time during this period, a lung was perforated when a catheter was placed in his neck (the condition of his limbs being too poor to permit the insertion of a catheter).

After a week in critical condition in intensive care, Patient A died at 07:00 on Day 197 (Sunday 20 August), six and a half months after the accident. His family did not permit a post-mortem examination. The cause of death cannot be stated with certainty, but it was attributed to residual radiation damage to the lungs complicated by traumatic perforation.

In response to an urgent request received from the authorities in El Salvador on Day 196 (Saturday 19 August), an IAEA staff expert who had directed the treatment of patients after the Chernobyl accident went to San Salvador. However, Patient A died shortly before the expert arrived in San Salvador the following day. The expert assisted in planning further treatment and follow-up for Patients B and C.

5.7.2. Patient B

Patient B was discharged from the Angeles del Pedregal Hospital and returned to San Salvador on Day 173 (Thursday 27 July). He also was admitted to the Medico-Surgical Hospital and placed in a separate room, and his condition continued to improve. However, progress was slow owing to the worsening condition of his other

(right) leg. After the right leg also had been amputated on Day 202 (Friday 25 August), his general recovery was more rapid. His need for psychological support then became the most important factor in his further progress. He was transferred on Day 221 (Thursday 14 September) to the Hospital for Rehabilitation. His prognosis is good except for the possibility of late effects such as cataracts.

5.7.3. Patient C

Patient C was returned to San Salvador on Day 55 (Friday 31 March), and had his next medical examination on Day 58 (Monday 3 April). He remained on sick leave from work until Day 199 (Tuesday 22 August). On Day 220 (Tuesday 12 September) further rehabilitation therapy was commenced to relieve residual chronic effects, particularly in his more exposed (left) foot, which was painful and caused him to limp. The prognosis is promising for his full recovery; however, the possibility of late radiation injury to the eyes remains.

6. FACTORS CONTRIBUTORY TO THE ACCIDENT

Section 6 presents a brief recapitulation of some significant factors that contributed to the accident.

The accident occurred after damaged fibreglass product boxes caused the irradiator's transport mechanism to jam, forcing five boxes into the space for four. The boxes were forced against a thin steel bar in the frame inside which the source rack is raised and lowered. The bowing of this bar was sufficient to cause the source rack to become stuck in a raised position. If this had occurred soon after the commissioning of the facility in 1975, any one of the multiple in-built safety systems together with the training of the operators should have sufficed to prevent access to the radiation room while radiation levels were potentially lethal. The problem in February 1989 might well have been solved had help been sought from the supplier, whether advice by telephone or direct assistance. Indeed, a similar event in 1975 was successfully dealt with. However, in the intervening fourteen years a combination of circumstances led to degradation in the safety features installed and in the level of staff training.

El Salvador's economy has been severely disrupted since 1979, fostering a make do and mend approach at the plant, as elsewhere, rather than a positive approach to maintaining and improving safety. This is exemplified by the following:

(1) The company continued to use significantly depleted source elements, even when it could have funded their replenishment. When the company could afford to invest in such replenishment in 1981, the supplier would not send personnel to El Salvador for personal security considerations.

(2) The company did not implement measures detailed in notices from the supplier designed to upgrade the safety of the facility.

One result of the financial difficulties and the security aspects of the civil war was that the only contact between the company and the supplier between 1977 and 1989 was by telephone. The supplier would normally expect to visit most facilities it had constructed once every two to three years to replenish the source, on which occasions it would be possible to detect any serious safety deficiencies and to instigate corrective actions.

The civil war also brought about a high level of security consciousness in El Salvador. The company regarded the irradiation facility as a high technology installation and a potential target for attack. The significance of this lay in the fact that the existence of the facility was therefore not publicized; moreover, there was a reluctance to commit any information on its operations to writing, even safety measures and operating procedures. Training in these matters was passed on orally from one operator to another.

Although proposals for the regulatory control of ionizing radiations were made in 1986 and enabling legislation was drafted, there have never been any regulations in El Salvador governing the use of ionizing radiations, nor has any organization acted as an official point of reference on the subject. The lack of regulatory control and the loss of contact with experts in radiation matters caused an information void that, coupled with the effects of the civil war, led to a fall in the standards of radiation protection.

This decline began with the departure from the company, within a year of the commissioning of the facility, of the three operators trained by the supplier. Their experience was passed on orally to their successors and from them to subsequent replacements, with a concomitant potential for corruption of information. The result was that at the time of the accident no one in the plant seemed to have a full appreciation of the potential hazards of the facility.

In the accident, Worker A, unaware of the extreme danger, entered the radiation room on his own initiative, as he had in the past, in an attempt to keep the facility operating. The installed safety systems, which would normally have prevented human error from leading to an accident, had degenerated or been bypassed over the years.

As in accidents elsewhere, the victims were initially diagnosed as having food poisoning and sent home. However, within a few days they had returned to hospital with more extensive and severe symptoms. A correct diagnosis was then made and appropriate treatment regimes were instituted.

After it had been confirmed that the three workers were suffering from the effects of overexposure to radiation, there was a significant delay before the source of the exposure was recognized and effective actions were instigated to verify that no further uncontrolled exposure was occurring. That there was a significant potential for further exposure was demonstrated by the subsequent spill of pencils from the upper source module in the second event, which gave rise to doses in excess of generally accepted worker dose limits to four other persons. The elevated radiation level in the radiation room due to a spilled active source pencil was detected before more serious doses were incurred (see Section 4.3).

When the management of the plant realized that dealing with this second event was beyond its competence, it contacted the supplier for help. The following week, two experts from the supplier located an active source pencil in the radiation room and succeeded in removing it to the pool. They also disabled the source hoist mechanism in view of the degraded condition of the safety systems at the facility. It was only then, almost two weeks after the first event, that the facility could be considered to have been 'made safe'.

7. GENERIC LESSONS LEARNED

The information that was made available to the IAEA, as presented in this report, is a basis for reaching conclusions about the causes of the accident and how it was dealt with. These conclusions lead to generally applicable recommendations to those responsible for the safe operation of irradiation facilities on actions designed to prevent accidents in the future or to make the response to those that do occur more effective.

Many of the recommendations cover procedures and practices already widely considered to be essential to safe operation. Action on others, particularly those relating to international aspects, would enhance and reinforce present safety practices. The lessons necessarily concern irradiation facilities; however, many of the recommendations apply to radiation safety in other areas.

Conclusions and (in italic type) recommendations which follow from them are presented for the major groups concerned with the safety of such facilities: operating organizations, national authorities, source suppliers, the medical community and international organizations.

A. OPERATING ORGANIZATIONS

(1) The physical integrity of the irradiation facility, particularly its safety features, was allowed over a long period to degrade significantly and the supplier's recommendations for upgrading safety were not heeded.

The operating organization should, as a minimum, ensure:

(a) that safety systems conform to the supplier's current recommendations;
(b) that preventive maintenance is part of the operating plan;
(c) that recommendations by the supplier for upgrading safety are promptly considered, and that the reasons for any non-implementation are fully documented and the supplier and national authorities are informed of them.

(2) Safety procedures at the facility and training in their observance had deteriorated to the point of inadequacy. Not only did this contribute to the accident, it also meant that the initial exposures went unrecognized, as did the damage to the source rack, which led to further overexposures.

The operating organization should ensure:

(a) that operators have initial and continuing training in radiological safety that is separate and distinct from training for production operations;
(b) that training is based on the up to date and official written operating, maintenance and emergency procedures and on practical exercises;
(c) that the operating manual, operating rules and procedures and emergency procedures are available at the control panel in an accurate local language version;
(d) that staff are trained to recognize situations that call for implementing such arrangements;
(e) that written emergency procedures detail effective arrangements for notifying the authorities of radiological accidents and for initiating actions to limit residual hazards;
(f) that operators and maintenance staff wear personal dosimeters and dosimetric records are kept.

(3) The management of the facility failed to maintain a corporate awareness of the acute danger inherent in the unauthorized or improper operation of such an irradiation facility.

The management of such facilities should manifest continuing recognition of the primary responsibility of the operating organization for safety by at a minimum:

(a) *participating fully in radiological protection matters, especially in providing continuity regardless of changes in ownership, management or staffing;*
(b) *emphasizing to personnel the primary importance of safety for themselves and, ultimately, for continued productivity;*
(c) *appointing two radiation safety officers with full authority in such matters, of whom one should be available at all times;*
(d) *seeking periodic independent safety review by recognized experts.*

(4) Production concerns overrode any safety concerns that the sole operator on duty may have had.

The radiation room of an irradiation facility must on no account be entered unless someone assigned sole responsibility for radiation protection is on call.

(5) The immediate cause of the accident (the jamming and deforming of product boxes which in turn obstructed the descent of the source rack) would have been prevented had earlier recommendations by the supplier been heeded.

A metal shroud should be installed in such irradiators to protect the source rack from obstruction; product boxes should be inspected regularly and marginal boxes replaced.

B. NATIONAL AUTHORITIES

(6) The lack of a national infrastructure for overseeing radiological safety, despite earlier proposals, was a major factor in the failure to identify and remedy deficiencies in radiological protection at the facility and to respond more expeditiously and effectively to the accident.

There should be in place in all countries with irradiation facilities as a minimum infrastructure for overseeing radiological safety:

(a) *enabling legislation, a central regulatory authority and simple, specific implementing regulations;*
(b) *an organization with adequate resources and expertise to ensure that essential safety services such as personnel monitoring and training are provided;*
(c) *a comprehensive national inventory of all man-made sources of ionizing radiation;*
(d) *a system for the registration and inspection of sources;*

(e) a widely disseminated emergency response plan to ensure the prompt notification of any accident to the authorities, the transmission of adequate information to the public and follow-up to determine causes and to take corrective action.

(7) Although the need for more experienced medical staff and better facilities than those available in El Salvador was recognized, there was a significant delay in effecting the transfer of the patients to a suitable hospital elsewhere.

In countries where applications of radiation are widespread, the national emergency plan should identify at least one central medical unit capable of treating victims of a radiological accident. There should be plans for transferring any seriously overexposed patients for more specialized treatment, possibly in another country. Plans should also be in place for the speedy fulfilment of administrative requirements such as obtaining passports and visas.

(8) Once the accident had come to attention and caused concern, prompt steps were taken fully to inform representatives of the media and, through them, the public.

National emergency plans should expressly recognize the need to provide timely, factual information to the public on the nature, extent and significance of a radiological emergency.

(9) The reporting of the accident to the IAEA and hence the provision of assistance would have been facilitated had the government of El Salvador been party to the Notification and Assistance Conventions.

The governments of all countries in which major radiation sources are in use should consider subscribing to the Convention on Early Notification of a Nuclear Accident or the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency[2] *and setting in place the necessary infrastructure for the implementation of their provisions.*

---

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Convention on Early Notification of a Nuclear Accident and Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, Legal Series No. 14, IAEA, Vienna (1987).

C. IRRADIATOR SUPPLIERS

(10) The English language instruction manual provided by the supplier was not available in a local language version. The manual had been translated at the plant; however, the Spanish version was inaccurate and incomplete. Safety aspects were covered in the instruction manual only under production aspects and not separately.

It should be ensured that the instruction manual, including operating rules and procedures and emergency procedures, is available at all facilities in an accurate local language version. To help managers and operating and maintenance staff to appreciate the safety significance of their actions, operating manuals should cover radiation safety separately from production aspects.

(11) The supplier did not send representatives to the plant for personal security reasons, and was thus unable to detect the serious safety deficiencies and instigate corrective actions.

In the absence of regular, full communication with the operating organization, suppliers of irradiators should use all possible channels, formal and informal, to alert national authorities or appropriate international organizations in a timely manner to identified or suspected safety deficiencies at irradiation facilities. (See also Recommendation (17).)

(12) Confirmation of the preliminary visual inventory of source pencils in the pool to demonstrate that no further exposures beyond those already sustained were possible was significantly delayed.

The emergency procedures of the supplier should emphasize the need to make a prompt inventory to demonstrate (normally to the national competent authority) that all source pencils have been accounted for.

(13) Although assessment of the facility was made difficult by the long history of practices in circumvention of the systems of protection, no fundamental design flaws were identified.

Design, operation and emergency procedures for irradiation facilities should be reviewed after an emergency response so that practical lessons can be identified, documented and acted on, as in this case. Probabilistic safety assessment might be of use in such a review.

D. THE MEDICAL COMMUNITY

(14) Once acute radiation exposure had been diagnosed after two days, the medical staff in San Salvador carried out a generally effective treatment strategy despite their lack of experience in treating radiation injuries.

Further efforts should be made to acquaint medical practitioners with the symptoms and treatment of acute radiation syndrome (such as by including synopses of typical accidents in initial and continuing training) in order to facilitate prompt recognition and initial treatment.

(15) The post-initial treatment by the medical team in Mexico City was especially effective; for example, in the use of parenteral nutrition, in forgoing bone marrow transplantation, in scheduling amputation, in providing physiotherapeutic and psychotherapeutic support, and, above all, in haematological analysis.

The post-initial treatment of seriously exposed persons should be undertaken at specialized facilities by experienced medical staff, assisted as necessary by specialists from elsewhere.

(16) The medical team in Mexico City considered that granulocyte macrophage colony stimulating factor (GMCSF) was effective in expediting bone marrow recovery, although the evidence was not unambiguous (it was administered at a time when spontaneous recovery might in any case have been expected).

The timely use of GMCSF in treating the victims of radiological accidents should be considered.

E. INTERNATIONAL ORGANIZATIONS

(17) Although it was not the case for this facility, major radiation sources have been provided with the financial assistance of other countries or international organizations to countries in which the supervision of radiological safety by national authorities is inadequate.

Governments or international organizations that have facilitated the provision of major radiation sources should investigate with suppliers and national authorities possible means of continuing co-operation to ensure that there is adequate radiation protection. (See also Recommendation (11).)

(18) The co-operation between several governments and intergovernmental organizations in the rendering of expert assistance to El Salvador in medical treatment, physical dosimetry and investigation of the accident was hindered because normal administrative procedures were followed rather than special procedures appropriate to an emergency.

The tasks and responsibilities of participants in the emergency response to a radiological accident should be well defined to facilitate the response of governmental and intergovernmental organizations in extraordinary circumstances.

(19) The UNDP office in San Salvador was a key communication link that facilitated the provision of assistance and the follow-up.

Official points of contact should be identified in all countries, even those whose adherence to the Notification Convention or the Assistance Convention has not yet been effected.

ADDENDUM

In February 1990, the IAEA was informed of plans to refit the irradiator in San Salvador to extant irradiator safety standards and to recommission it for operation. New cobalt-60 source elements and new parts will be shipped and installed and the original source elements will be returned to the supplier. Requirements for the import of radioactive source elements into El Salvador and for the use of the irradiator are set out in a licence issued by the ministry now designated as responsible for the control and use of radiation sources and by the newly appointed competent authority.

- *Instruction manual.* The manual will be revised for the refitted unit and will include a section on radiation safety and the danger to health of misuse of the equipment. The revised manual will be sent to the company for translation into Spanish and personnel from the supplier will verify the translation by rehearsing the operating and maintenance procedures with it.
- *Training of personnel.* The training of operation and maintenance personnel by the supplier will be fully certified, their competence must be demonstrated and the competent authority must be so informed. The danger of neglecting maintenance and of circumventing interlocks and other safety features will be emphasized.
- *Safety systems.* The safety systems will be demonstrated to the competent authority by plant personnel, overseen by the supplier, by means of a 'cold' check before installation of the new cobalt-60 sources.
- *Radiation survey.* The supplier will make a radiation survey of the shielding and send the results to the company and the competent authority.
- *Periodic safety audits.* The results of periodic safety audits by the supplier and any deficiencies found will be reported to the company. The competent authority will be informed if action is not taken to remedy any deficiencies.
- *Safety checklist.* The competent authority will be given the supplier's safety checklist and will be informed how to perform a safety audit and to assess the competence of authorized operators in case personnel from the supplier are unable to inspect the plant.

When the facility has been refitted and company personnel have been trained, the safety systems will be demonstrated to the competent authority and the facility will be recommissioned.

PHOTOGRAPHS

1. General view of the front of the irradiator (July 1989). From left to right: the control panel, the monitor probe, personnel access door to the radiation room, product entrance and main door to the sterilized product area.

2. General view of the front of the irradiator (July 1989).

3. The control panel. The skylight makes it difficult in the daytime to distinguish whether indicator lights are on or off. Note the absence of labelling on the control panel.

4. The water treatment plant at the facility (February 1989).

5. The personnel access door to the irradiator had so deteriorated that it could be opened with a knife blade.

6. The personnel access door to the irradiator had so deteriorated that it could be opened with a knife blade.

7. The radiation room. The guide cables and source hoist can be seen in the centre, between the product containers.

8. The radiation room. Top centre: the hole drilled by the experts from the supplier and the remote tool used to transfer the active source pencil to the pool.

9. Fibreglass product boxes used in the facility. Note the damage to the boxes and the use of adhesive tape to repair them.

10. Inactive dummy pencils between product containers after the spillage of pencils from the source rack in the second event.

11. A product container inside the radiation room. The edges can interfere with the movement of the source rack.

12. Work on the ceiling to return the active source pencil to the pool was done with the help of television cameras and remotely manipulated tools.

13. The radiation room free of product containers, showing the source positioner, the empty source rack and the tangled source hoist cable.

14. Patient A, Day 26 (Thursday 2 March). Use of a Wickman catheter; bleeding in left nostril.

15. Patient A, Day 26 (Thursday 2 March). General aspect on admission: general alopecia; first degree burns; hyperpigmentation; acute malnutrition; atrophying of the masseter muscles; xerostomia; acute mucositis.

16. Patient A, Day 173 (Thursday 27 July). General aspect on discharge from hospital in Mexico City to San Salvador.

17. Patient A, Day 26 (Thursday 2 March). Back of right hand.

18. Patient A, Day 26 (Thursday 2 March). Legs with first, second and third degree burns from the front inner thigh and abundant necrotic tissue.

19. Patient A, Day 26 (Thursday 2 March). Posterior plantar region and toes of one foot.

20. Patient B, Day 26 (Thursday 2 March). Oropharynges, white spots and red areas.

21. Patient B, Day 26 (Thursday 2 March). Lower legs: first and second degree burns, upper and middle anterior tibial region: third degree burns and tissue loss in anterior and posterior surfaces of the feet.

22. Patient C, Day 33 (Thursday 9 March). Partial alopecia in left parietal.

23. Patient C, Day 33 (Thursday 9 March). Posterior plantar region with healing from second degree burns in first and second toe.

24. The source storage pool showing the Cerenkov radiation which confirms the presence of all fourteen spilled active source pencils.