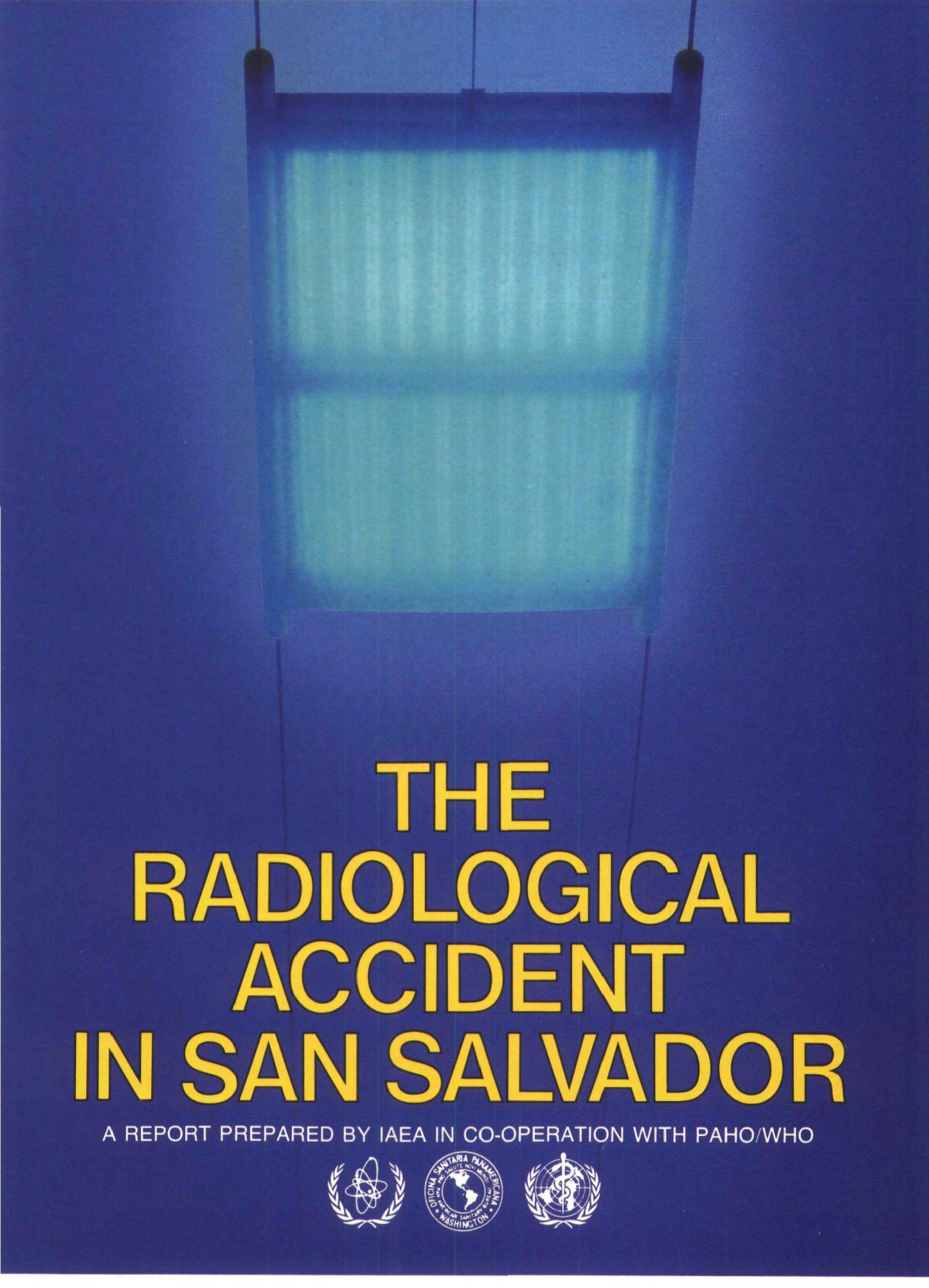


THE RADIOLOGICAL ACCIDENT IN SAN SALVADOR

A REPORT PREPARED BY IAEA IN CO-OPERATION WITH PAHO/WHO

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1990

The cover photograph shows a source rack similar to the one in the industrial irradiation facility in San Salvador at which a serious radiological accident occurred in February 1989. The rack holds intensely radioactive cobalt-60 gamma source elements. Photograph by courtesy of Nordion International Inc., Kanata, Ontario, Canada.

THE RADIOLOGICAL ACCIDENT IN SAN SALVADOR

THE RADIOLOGICAL ACCIDENT IN SAN SALVADOR

A REPORT PREPARED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
IN CO-OPERATION WITH THE
PAN AMERICAN HEALTH ORGANIZATION OF THE
WORLD HEALTH ORGANIZATION

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1990

THIS REPORT IS ALSO PUBLISHED IN
FRENCH, RUSSIAN AND SPANISH

THE RADIOLOGICAL ACCIDENT IN SAN SALVADOR
IAEA, VIENNA, 1990
STI/PUB/847
ISBN 92-0-129090-X

Printed by the IAEA in Austria
May 1990

FOREWORD

By the Director General

Technologies that make use of radiation continue to spread around the world: millions of people are employed in radiation related occupations and hundreds of millions of people benefit from these applications. The use of intense radiation sources for purposes such as the sterilization of medical products requires special care in the design and operation of equipment to prevent radiation injury to workers or to the public. Experience has shown that such technology is generally safely used, but controls have on occasion been circumvented and serious radiological accidents have ensued.

To the extent that reports on such accidents are incomplete or are unavailable to the scientific community, potentially valuable information is lost. Although the causes of accidents may be highly case specific, review of the circumstances in which they happen may yield generally applicable lessons that can be of help in preventing accidents in the future or in improving the response to those that do occur. Thus, the IAEA's review of the radiological accident in Goiânia, Brazil, in 1987, in which the misuse of an abandoned medical teletherapy source led to radiation injuries resulting in four deaths and to widespread contamination, has been found useful by the international radiation protection community in seeking to ensure the safety of major radiation sources.

The accident at an industrial irradiation facility in San Salvador was quite different from that in Goiânia, being limited to the external irradiation of workers. However, it did result in a fatality, as had similar accidents in Italy in 1975 and in Norway in 1982. There are more than 160 industrial irradiation facilities around the world that are as large as or larger than the one in San Salvador, and some of these are in countries that lack adequate infrastructures for radiation protection. An international review was undertaken to document the facts of the accident and to define generic lessons for the benefit of those having safety responsibilities for such facilities.

The report was prepared in co-operation with the Pan American Health Organization of the World Health Organization.

EDITORIAL NOTE

The use of particular designations of countries or territories does not imply any judgement by the publisher, the IAEA, of the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.

The mention of names of specific companies or products (whether or not indicated as registered) does not imply any intention to infringe proprietary rights, nor should it be construed as an endorsement or recommendation on the part of the IAEA.

The information presented in the appendices and annexes was provided by the medical teams at the Primero de Mayo Hospital in San Salvador and the Angeles del Pedregal Hospital in Mexico City. The IAEA cannot accept responsibility for its accuracy.

FIGURES

FIG. 13. Plan view of the positions in relation to the source rack of Workers A, B and C during the accident with dose rate contours in $Gy \cdot min^{-1}$. (Source: REAC/TS.)

FIG. 14. Dose rate contours for a standing figure: rates in $Gy \cdot min^{-1}$. (Source: REAC/TS.)

FIG. 15. Dose rate contours for a squatting figure: rates in $Gy \cdot min^{-1}$. (Source: REAC/TS.)

FIG. 16. Plan view of the positions in relation to the source rack of Workers A, B and C while attempting to free the source rack. (Source: REAC/TS.)

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

FIG. 18. Patient A: corporal distribution of effects of exposure. (Source: REAC/TS.)

FIG. 19. Patient B: corporal distribution of effects of exposure. (Source: REAC/TS.)

FIG. 20. Patient C: corporal distribution of effects of exposure. (Source: REAC/TS.)

TABLES

CONTENTS

1. INTRODUCTION

On 5 February 1989, a radiological accident occurred at an industrial irradiation facility near San Salvador, the capital of the Republic of El Salvador (see Fig. 1). Prepackaged medical products are sterilized at the facility by irradiation by means of an intensely radioactive cobalt-60 source in a movable source rack. The accident happened when this source rack became stuck in the irradiation position. The operator bypassed the irradiator's already degraded safety systems and entered the radiation room with two other workers to free the source rack manually.

The three workers were exposed to high radiation doses and developed the acute radiation syndrome. Their initial hospital treatment in San Salvador and subsequent more specialized treatment in Mexico City were effective in countering the acute effects. However, the legs and feet of two of the three men were so seriously injured that amputation was required. The worker who had been most exposed died six and a half months after the accident, his death being attributed to residual lung damage due to irradiation, exacerbated by injury sustained during treatment.

The report details the events leading up to the accident, the circumstances of the accident itself and the response to it. From the facts established, lessons are derived for operators and suppliers of irradiators, national authorities, medical staff and international organizations. Detailed information on dosimetric and medical aspects of the accident for the specialist reader is presented in the appendices and annexes.

2. THE BACKGROUND IN EL SALVADOR

El Salvador has been in a state of civil war since 1979. The national economy has been disrupted by armed attacks on transport links, military targets and economic targets such as factories and installations of the electricity generation and distribution system. The danger of being identified as an economic target has led to a tendency in managers of enterprises to divulge information relating to the security of commercial operations (including safety aspects) on a 'need to know' basis only, particularly for technical installations such as the irradiation facility at which the accident occurred. The commercial and economic isolation of the country because of the civil war was a factor in the accident.

The Ministry of Labour and Social Security in El Salvador is responsible for the administration of matters under the Labour Code. The Labour Code covers the responsibilities of managements and of workers in respect of hygiene and safety

FIG. 1. Central America, showing the locations of San Salvador and Mexico City.

measures in the workplace. However, neither the Code nor any of the sets of regulations derived from it makes any provisions for the use of ionizing radiations. Within the Ministry, under the General Directorate for Social Security, there is a Department of Occupational Hygiene and Safety; however, this Department has no expertise in radiological protection.

The Institute of Social Security (ISSS) of El Salvador is an autonomous institution affiliated to the Ministry of Labour and Social Security. One of its main functions is to collect social security payments from employers and employees, and from the proceeds to make social security provisions and to provide health care. In respect of health care, the ISSS runs its own hospitals. After the accident the three injured workers were treated at the Primero de Mayo Hospital of the ISSS in San Salvador. This has both an emergency department and radiotherapy facilities. The ISSS Department for Occupational Hazard Prevention is located on the same premises.

There is no regulatory control of nor any appropriate infrastructure for radiological protection in El Salvador. The country's only resources in this field are two persons in the Department of Nuclear Medicine of the Rosales Hospital, run by the

Ministry of Health. This 'team', which has no permanent staff and receives no funding, presently consists of a professor of physics at a local university who works unpaid at the Rosales Hospital and a non-technical member of the hospital staff who assists him. Donated equipment is used to provide a personnel monitoring service. However, it may take a long time to effect the repair or replacement of an item of equipment, and this monitoring service is intermittent.

In 1986 the IAEA funded the visit of an expert to El Salvador to help in the drafting of proposals for the regulatory control of sources of ionizing radiations. Owing to the civil war, the proposals were not given a high priority in the regulatory programme. Nevertheless, some enabling provisions were included in Decree 955 of 1988, Articles 191 and 192 of which gave the Ministry of Health the responsibility for controlling the use of radiation sources and the authority to promulgate regulations. At the time of the accident no regulations existed, but new proposals were being drafted.

3. THE IRRADIATION FACILITY

Note: *Observations on factors contributory to the accident are presented in italic script.*

3.1. HISTORY OF THE IRRADIATION FACILITY AND DESCRIPTION OF THE MODEL JS6300 GAMMA STERILIZER

The accident occurred at an industrial irradiation facility near San Salvador, El Salvador, that was built in 1974 and commissioned in 1975. The facility has a Model JS6300 Gamma Sterilizer designed, manufactured and installed by Atomic Energy of Canada Limited, which now trades as Nordion International Inc., hereinafter referred to as 'the supplier'. In irradiators of this design, the product packages to be sterilized are loaded into large product boxes and moved by pneumatic cylinders (pistons) around a centrally located, vertical rectangular source rack. The source rack contains cobalt-60 gamma source elements in the form of rods contained in 'source pencils'. The source is shielded when not in use by lowering it into a pool of water, making it a Category IV irradiator under the international classification[1].

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety Aspects of Gamma and Electron Irradiation Facilities, IAEA, Vienna (in preparation).

The Model JS6300 was designed for relatively small product throughputs, having a maximum source capacity of 9.25 to 18.5 PBq (250 to 500 kCi) using cobalt-60. However, the initial loading of the irradiator was only 4.0 PBq (108 kCi). The source was never replenished, and by the time of the accident its radioactivity had decayed to approximately 0.66 PBq (18 kCi).

The irradiation facility is owned by a company that manufactures intravenous solutions and blood dispersion sets. The sets are sterilized by irradiation or with autoclaves. At the time of commissioning of the facility in 1975 the company was owned by a Mexican–Salvadorian–Costa Rican consortium. Later that year it was sold to a consortium in the United States of America. It returned to Salvadorian ownership in December 1987.

During the facility's building and commissioning stages, the supplier trained three operators in operational and radiological protection aspects. However, these three trained operators left the company after it changed ownership in 1975. From this time onwards any training of operators was informal and oral only.

In 1975 an incident occurred in which the product boxes obstructed the movement of the source rack. The rack was deformed, allowing the pencils to fall out. However, the installed safety systems and the operators' training were sufficient to prevent any occupational exposure. The supplier was informed and sent staff to the plant to effect repairs.

The civil war in El Salvador has exacerbated the economic problems of the country, engendering a 'make do and mend' attitude at the plant, as elsewhere. One result of this was that the company did not seek to replenish the source material within the normal time period. Eventually, in 1981, the owner of the plant negotiated with the supplier for the replenishment of the source. A representative of the supplier travelled to San Salvador, only to turn back at the airport in consequence of the escalating civil war. In 1982 and 1984, the owner of the plant again communicated with the supplier about replenishing the source. However, because of the security situation, the supplier did not send a representative to El Salvador. The owner of the plant had kept up telephone contact with the supplier over the fourteen years since 1975. However, the facility had not had the benefit of the radiological safety audits that normally accompany any replenishment of the source by the supplier.

The key factors from the description here and in Section 2 are that over the fourteen year period from 1975:

(a) there was no regulatory control of radiological protection matters nor any readily available expertise in El Salvador;

(b) operators trained by the supplier of the irradiator had left at an early stage and subsequent training was only oral and informal;

(c) there was no direct access other than by telephone to the supplier and the supplier's radiological expertise.

One result of these shortcomings was a serious loss of understanding over the years of the functions of the installed safety systems and of what was important for radiological safety. The remainder of this section describes the facility and its operation at the time of commissioning and at the time of the accident. For clarity, the changes are shown in italic type. To supplement the description in the text of the design and layout of the facility, three detailed drawings have been included at the end of the report. (Figs 2–4: *see inside back cover.*)

3.2. THE RADIOACTIVE SOURCE

Radioactive cobalt-60 metal is the radiation source in the JS6300 Gamma Sterilizer. The cobalt-60 source elements are contained in doubly encapsulated stainless steel source pencils approximately 45 cm long, with solid stainless steel end caps approximately 1 cm in diameter (see Fig. 5). Each source pencil is identified by a

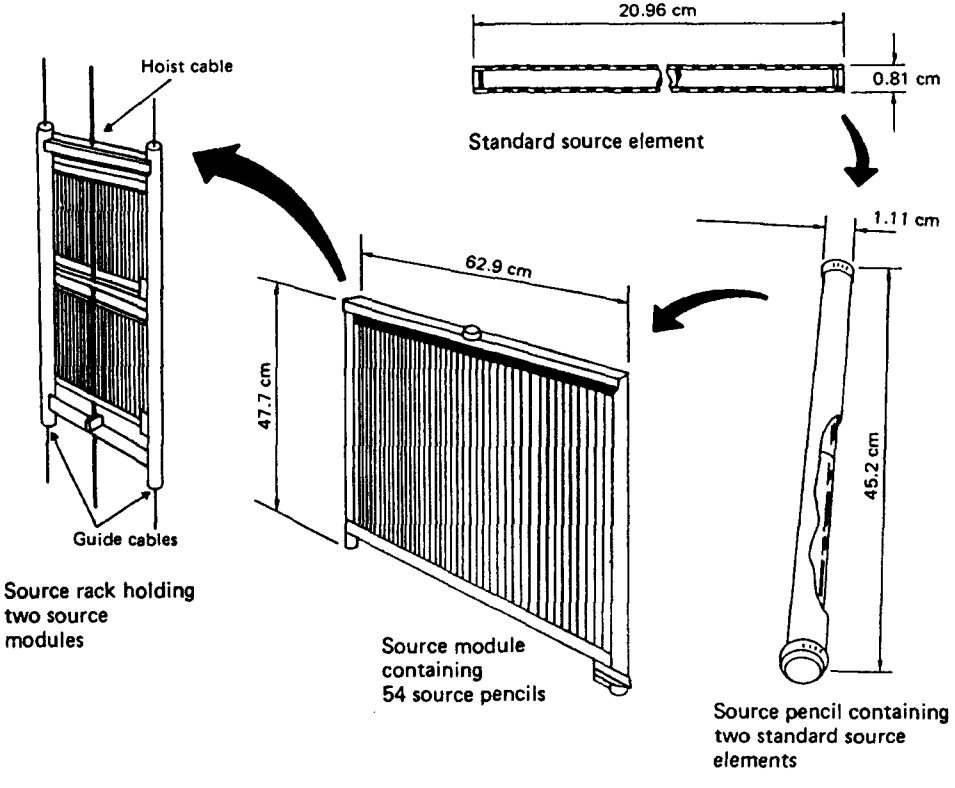


FIG. 5. The source rack with two source modules, each containing up to 54 source pencils with two standard source elements in each pencil. (By courtesy of Nordion International Inc.)

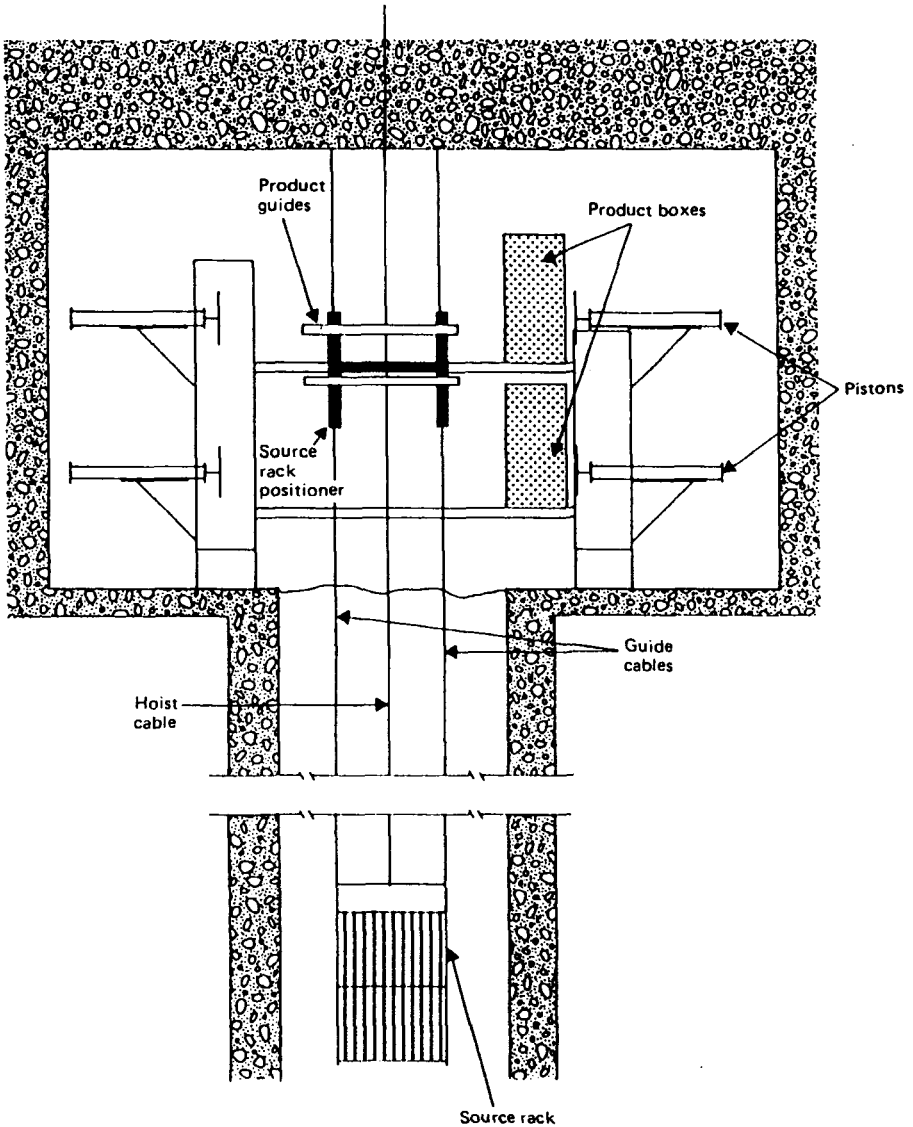


FIG. 6. Cross-sectional diagram of the source rack, hoist mechanism and transport mechanism. (By courtesy of Nordion International Inc.)

serial number engraved on an end cap. Fourteen active source pencils and 40 inactive dummy pencils (stainless steel spacer rods) were loaded into each of two source modules. The source pencils and dummy pencils are held in place in channels at the top and bottom of the source modules. The two source modules are placed one above the other in a flat, vertical source rack to give a uniform radioactivity over an area approximately 0.60 m by 0.90 m. When the source was installed in June 1975 the total radioactivity of the cobalt-60 gamma source was 4.0 PBq (108 kCi). By the time of the accident (5 February 1989) its radioactivity had declined to 0.66 PBq (18 kCi).

3.3. THE SOURCE HOIST MECHANISM

The source rack, when not in use, is stored near the bottom of a 5.5 m deep storage water pool and is raised to the irradiation position by a pneumatic hoist mounted on the roof of the facility above the radiation shield (see Figs 3 and 4). A stainless steel hoist cable attached to the source rack passes through the shield and the roof to two sets of sheaves in the hoist cylinder. When air pressure is applied to the hoist, the sheaves separate and the source rack is lifted. The movement of the source rack is guided by two taut guide cables, one at each end of the rack. In the raised position the source rack (see Fig. 6) actuates a microswitch to indicate that the source is up.

When air is exhausted from the source hoist, the source rack is returned under gravity to the safe storage position in the water pool. The weight of the source rack pulls the sheaves in the hoist cylinder back together, deactuating a microswitch mounted on the hoist cylinder to indicate that the source is down.

3.4. THE PRODUCT TRANSPORT MECHANISM

In the JS6300 irradiator, the products to be sterilized are loaded into fibreglass product boxes 0.40 m square and 0.90 m high. These boxes on stainless steel trays are irradiated in 29 positions, between which they are moved by pistons of the product transport mechanism (see Fig. 7). The boxes are moved backwards and forwards past the source rack along four rows, two on each side of the source rack, on each of two levels (shown schematically in Fig. 8), and are raised from the lower to the upper level by a pneumatic elevator. Steel product guides restrict the movement of the boxes to the path around the source and provide some protection to the source rack. Limit switches monitor the locations of the boxes and control the sequence of operation of the pistons.

The length of time for which a product box remains in each irradiation position (by 5 February 1989, the day of the accident, this had been increased to 140 min) is controlled by a master timer. When the time set on the master timer has elapsed,

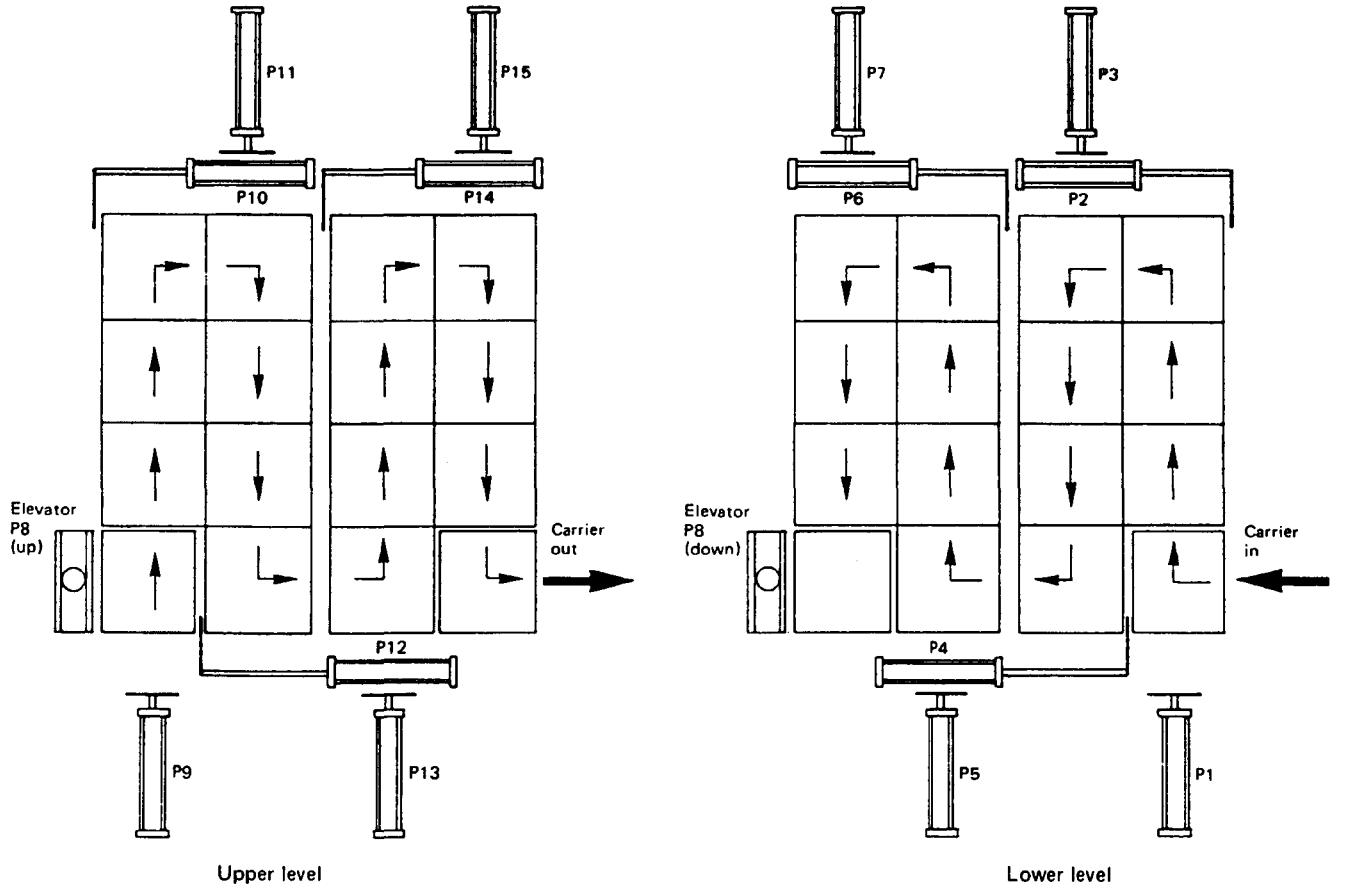


FIG. 7. Plan of the two levels of the transport mechanism of the JS6300 irradiator. (By courtesy of Nordion International Inc.)

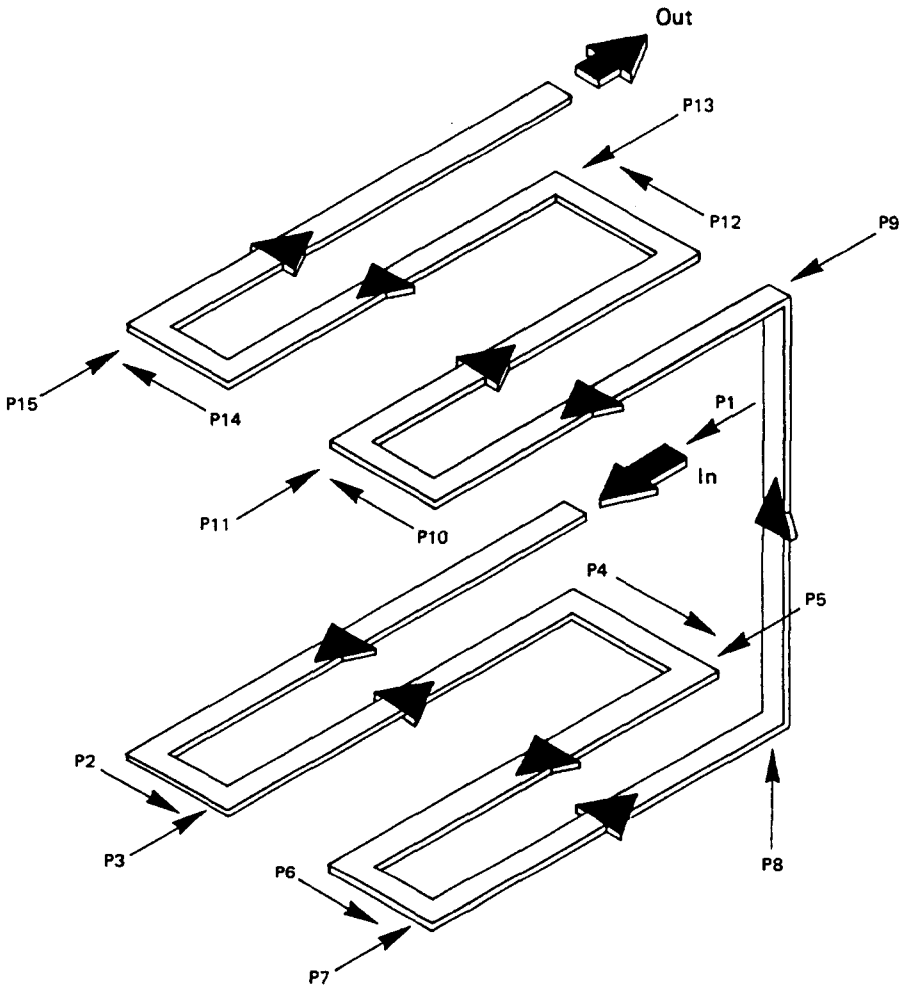


FIG. 8. Schematic diagram of the transport of product boxes in the irradiator. (By courtesy of Nordion International Inc.)

a sequential movement of the pistons is initiated. This advances each product box by one position and shifts one completely processed product box to the upper shelf of a product carrier which transports it from the irradiator.

Between 1975 and 1981, a number of incidents occurred at irradiators from the same supplier, in the USA and elsewhere (including the incident in San Salvador in 1975) in which damaged product boxes obstructed the source rack and caused it to jam. Consequently, in 1981, the supplier distributed *Warning Notice IND-81-1*,

in which it recommended that a steel source shroud be fitted around the irradiation position. It was also recommended that the condition of the boxes be routinely checked and that boxes in marginal condition be replaced.

The owner of the plant received this warning notice but never had its recommendations implemented owing to their cost and the increase in the exposure time that would be necessary to compensate for the shielding effect of the shroud. By the time of the accident in February 1989, the product boxes had been in use for a number of years. Many were in extremely poor condition and had been repaired with adhesive tape.

3.5. SAFETY INTERLOCKS AND ACCESS CONTROL

The following is a description of how the intact system as installed was intended to function.

3.5.1. The control panel

The wall mounted control panel (Fig. 9) has power and machine key switches and display lights for machine ready, machine on, source up and source down. A master timer, an overdose timer (which shuts down the irradiator in the event of a malfunction of the master timer) and a cycle counter are also mounted on the control panel.

Although Fig. 9 shows the panel as having illuminated legends, at the time of the accident the panel had no markings to indicate the significance of the controls or the warning lights. (However, the workers interviewed who were responsible for operating the controls were familiar with their functions.) In addition, a skylight above made it difficult to see whether the warning lights were on in the daytime.

3.5.2. Radiation monitoring

An L118 radiation monitor is interlocked with the personnel access door to prevent access to the radiation room if there are abnormal radiation levels inside when the source should be in the storage position. The L118 radiation monitor (see Fig. 10) is mounted on the wall in the radiation room and detects background radiation with a high sensitivity by means of an array of nine Geiger–Müller tubes. The monitor is designed to give an alarm condition for exposure rates in the range from the equivalent of about eight times that due to natural background radiation to greater than 10 000 $Sv \cdot h^{-1}$ (10^6 $rem \cdot h^{-1}$). Figure 11 is a schematic representation

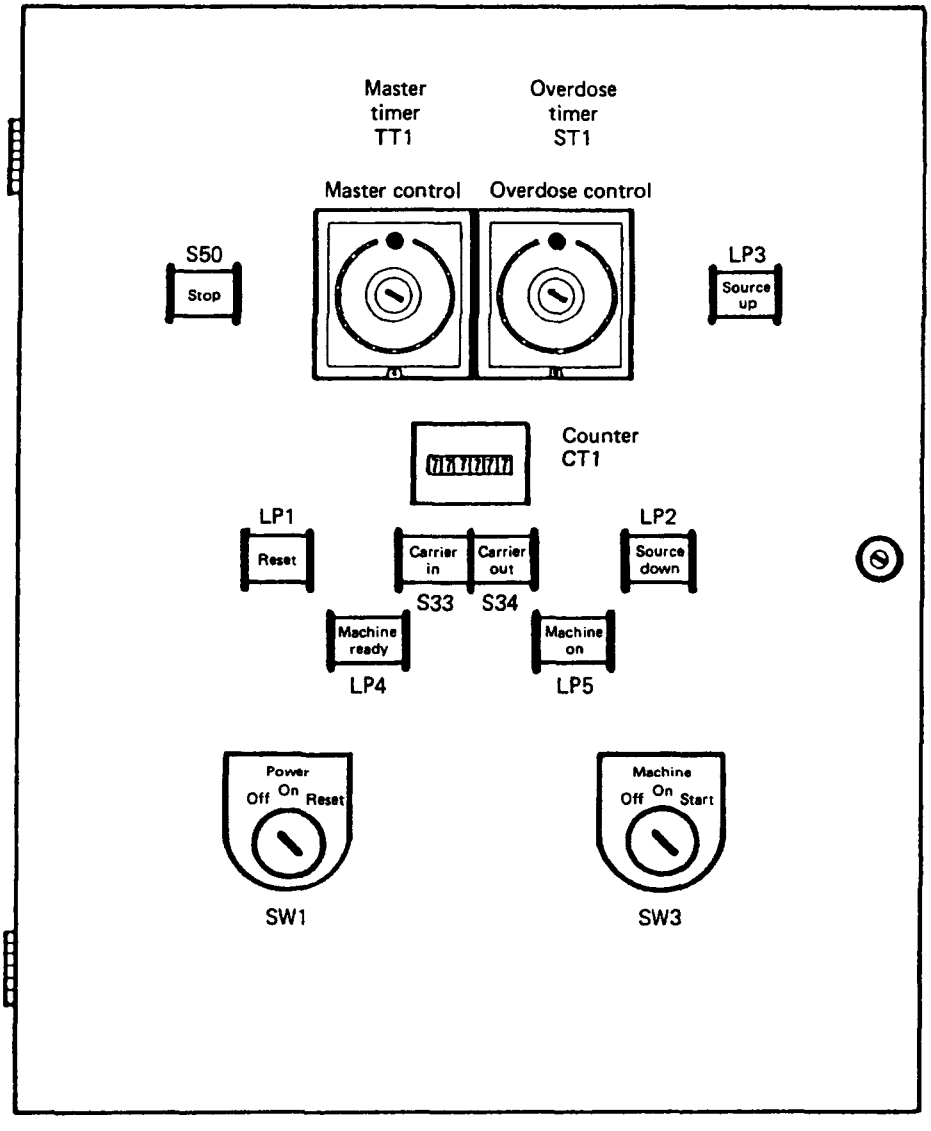


FIG. 9. The control panel of the JS6300 irradiator. (By courtesy of Nordion International Inc.)

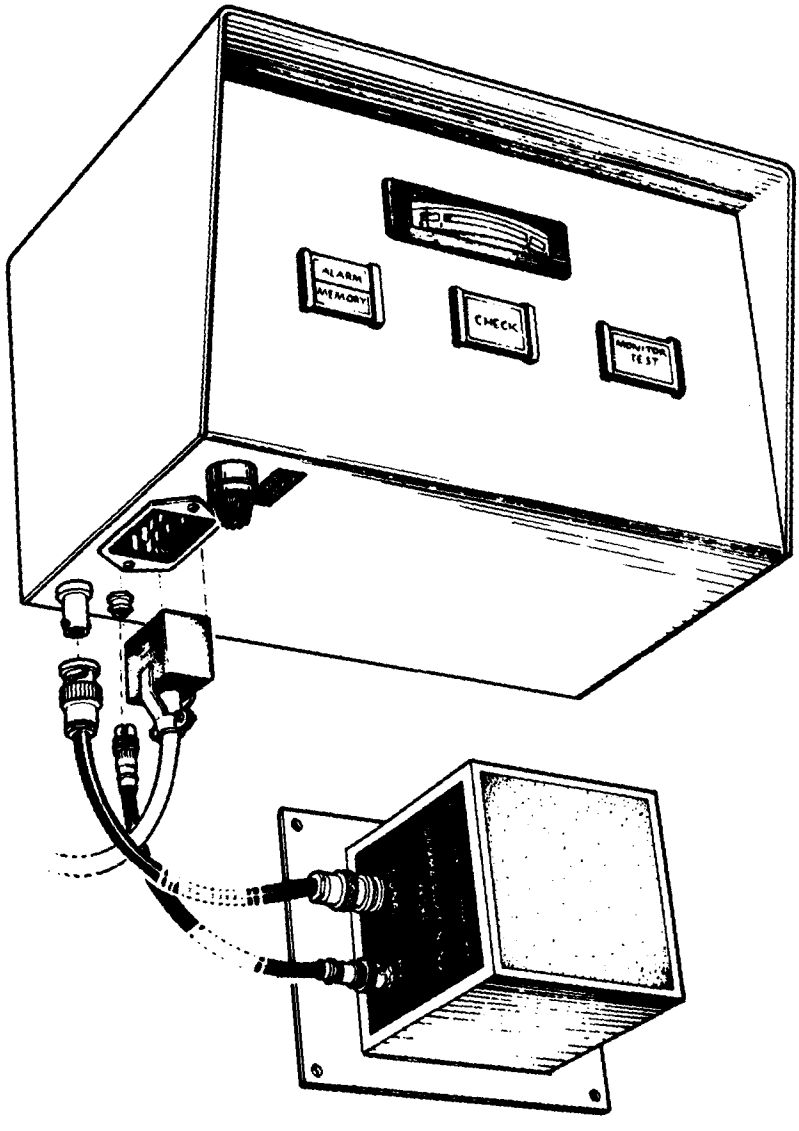


FIG. 10. The L118 wall mounted single probe monitor system. (By courtesy of Nordion International Inc.)

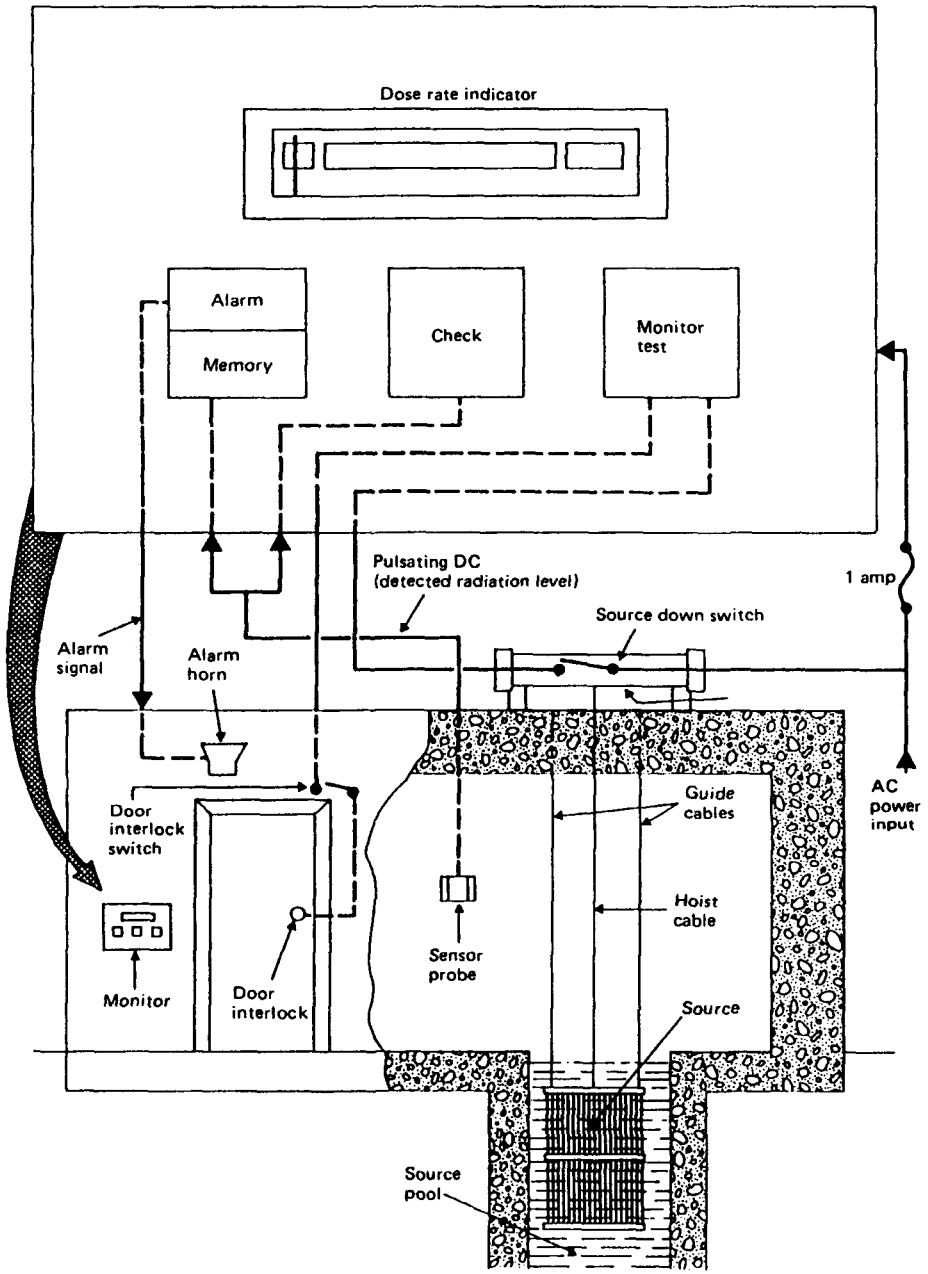


FIG. 11. Schematic diagram of the circuits for the monitor in the radiation room. (By courtesy of Nordion International Inc.)

of the monitor's main features and shows how they are integrated with other safety features.

In order to enter the radiation room, the operator must first press the monitor test button. The counting circuitry in the monitor then causes pulses from the monitor probe as it registers natural background radiation to give a test alarm indication. The test cannot be performed if the monitor is already showing the alarm condition. When the monitor test button is released, the monitor must again indicate normal background radiation before power can be supplied to the key switch that operates the door lock solenoid.

The radiation monitor is also interlocked with the source down microswitch. When the source rack is not fully down (in the storage position), power to the monitor is shut off. This also cuts off power to the key switch that operates the door lock solenoid, thus disabling the access control system and preventing access to the radiation room.

More than five years before the accident, the monitor probe had failed and the probe assembly had been removed. Its cabling remained. Removal of the monitor probe should have disabled the irradiator. However, it was discovered that access could be gained to the radiation room by depressing the monitor test switch and repeatedly cycling the buttons on the panel of the radiation monitor. This method of gaining access became the 'usual' procedure. The access door had not been maintained and had become badly fitting, with the result that it could also be opened by force or by using the blade of a knife to slip the catch (see Photographs 5 and 6). Thus one major safety feature of the design was bypassed.

3.5.3. Automatic safety features

The JS6300 Gamma Sterilizer has automatic safety features for the protection of personnel and the products for sterilization. Safety interlocks require the operator to enter the radiation room and actuate a switch and to close the door before raising the source rack.

The personnel access door can only be opened if the source rack is in the storage position and there are not high radiation fields in the radiation room. If the door is forced open when the source is up, a microswitch behind the door will shut down the irradiator and lower the source.

In the radiation room there is a key switch with a time delay operated by the machine key, to oblige the operator to enter the room before raising the source. The operator is then to make an inspection to ensure that there is no one in the room and that the transport mechanism is in order. When the delay timer is set, a buzzer sounds to warn personnel that the source rack is about to be raised. The operator then has

90 seconds to leave the radiation room, close the door and start the operation of the irradiator from the control panel.

The electricity generation and distribution system in El Salvador has been a common target of attack and power failures have been frequent. In order to reduce the startup time after power cuts and other stoppages, the time delay switch in the radiation room had been replaced with a switch at the control panel.

The radiation room door can be opened from the inside so that personnel cannot be locked in. In addition, an emergency pull cable mounted along the walls of the radiation room and the entrance maze actuates a stop switch that lowers the source or stops the startup operation.

Turning the machine key switch to the off position or pressing the stop button on the control panel will also stop the irradiator and lower the source.

If the irradiator malfunctions or a safety device is actuated, the irradiator is shut down, the source rack is lowered, the red stop light on the control panel lights up and the source transit alarm sounds until the source is in the fully down storage position. Possible causes of an irradiator shutdown include loss of air pressure to the source hoist cylinder, too high a temperature in the radiation room, failure of the source rack to reach the irradiation position in the allotted time, delay in completing the sequence of actions of the pistons, a power failure, or expiry to zero of the overdose time. (The overdose timer should be set to elapse about five minutes after the master timer.)

3.5.4. Administrative controls

In addition to the automatic safety features, there should be administrative controls to ensure that the facility is operated only by trained, authorized operators in accordance with the procedures given in the instruction manual.

In operating the facility, a single machine key is used for resetting faults, operating the irradiator, opening the door and actuating the time delay in the radiation room. A portable radiation monitor should always be attached to this key to ensure that the operator never enters the radiation room without a monitor. This radiation monitor should be checked before each entry of the room with a small test source mounted in the door key switch.

There was no portable radiation monitor attached to the key of the facility and no one knew where the test source was. As is discussed later, there are doubts whether the portable radiation monitor was always used and whether it was used correctly.

3.6. MAINTENANCE

A regular preventive maintenance programme is prescribed in the instruction manual for the irradiator. The number of irradiator shutdowns can be kept to a minimum by following this preventive maintenance programme. A monthly test of all emergency shutdown devices is included in the maintenance programme.

This preventive maintenance programme had not been implemented.

A warning is given in the instruction manual for the JS6300 Gamma Sterilizer that any attempt to modify the installed mechanical, pneumatic or electrical systems of the facility may prove hazardous to personnel and cause extensive damage to the machinery, and that any such modifications must have the written approval of the supplier.

No approval had ever been sought from or given by the supplier for any modifications to the facility.

3.7. OPERATION

The facility should be operated only by trained, authorized personnel in accordance with the operating rules and procedures and emergency procedures given in the instruction manual.

The English language instruction manual provided by the supplier had been translated at the plant; however, the Spanish version was inaccurate and incomplete.

To restart the irradiator after a shutdown, the operator first turns the machine key switch on the control panel to the off position and removes the machine key. Lights on the control panel will indicate the status of the irradiator and whether a fault has occurred. The following procedure should then be followed:

(a) The operator presses the monitor test button on the L118 radiation monitor panel next to the personnel access door and holds it until the monitor alarm sounds. When the monitor test button is released, the alarm stops and the monitor test light remains on, indicating that radiation levels in the radiation room are normal and that the door can be opened with the machine key.

(b) The operator checks the operation of the portable radiation monitor attached to the machine key with the small test source mounted in the door key switch. He (or she) then opens the door with the machine key, enters with the portable radiation monitor, carries out an inspection of the entrance maze and radiation room and corrects any fault that may have caused the shutdown.

(c) To start the irradiator, the operator actuates the 90 second delay timer in the radiation room with the machine key, ensures that no one is in the room and leaves through the entrance maze. The door must be closed and the machine key inserted into the machine key switch and turned to the on position. This raises the source and starts the irradiator.

Each of these operating procedures given in the instruction manual had been circumvented or adapted at the facility, as described in the foregoing sections.

To shut down the irradiator and lower the source, the machine key switch is turned with the machine key to the off position. The machine key can be removed from the machine key switch only when the key switch is in the off position.

3.8. SUPERVISION AND RADIOLOGICAL TRAINING

Initial training in radiation safety, operation of the irradiator, preventive maintenance and maintenance 'troubleshooting' was provided by the supplier at the time of installation of the irradiator. The supplier's normal practice is to train operators during the time taken to install the irradiator in order to familiarize them with its construction, operation and maintenance. Three operators were initially trained to operate the irradiator.

The in-facility course on irradiator operations included instruction in the following:

(a) the purpose of industrial irradiation;
(b) familiarization with the facility (with a tour);
(c) the monitoring system;
(d) the control panel;
(e) auxiliary equipment;
(f) operating procedures;
(g) administrative procedures;
(h) emergency and safety procedures;
(i) maintenance procedures;
(j) contamination detection procedures.

No one at the plant had been given responsibility for radiological protection matters. After the departure, within a year of the facility's commissioning, of the operators who had been trained by the supplier, relevant training was given only orally and informally as part of the instruction of operators in how to operate the facility. There were no effective written local rules. Over the years, awareness of the nature and effects of radiation seems to have dwindled to the point that no one working at the plant appreciated the potential hazards or their scale.

This was the situation in February 1988 when Worker A joined the staff as a maintenance technician. He also became a shift operator of the irradiation facility in September 1988 and received oral training in its operation. He was regarded as showing initiative and resourcefulness in solving the frequent maintenance problems at the facility.

The safety systems at the facility had thus become degraded in several vital respects and the employees did not appreciate the dangers. This state of affairs might be characterized as amounting to 'an accident waiting to happen'. On 5 February 1989, the potential for an accident was fulfilled.

4. THE ACCIDENT

4.1. OVERVIEW

The accident comprised two distinct but associated events. In the first event, on Sunday 5 February (Day 1), three persons were exposed to radiation from the cobalt-60 source elements while manipulating the source rack, receiving potentially lethal doses. Throughout the following week, the management of the plant remained unaware of the seriousness of the accident and the facility continued to be operated normally.

It is believed that the source rack was damaged in this first event, which led to the second event at some time later in the week, in the course of which all the pencils were knocked out of the upper source module. One active source pencil was later found to have remained in the radiation room; the others all fell into the water pool. Although the consequences of this second event were not as great as those of the first, they could potentially have been much more serious, and there are lessons to be learned from both events.

The elevated radiation level in the radiation room (due to the active source pencil) was detected on Day 6 (Friday 10 February). In response to the company's consequent request for help, the supplier sent two of its personnel, who were eventually able to locate the active source pencil and remove it to the pool. It was initially believed that this second event had not resulted in the exposure of any personnel. However, cytogenetic tests made in the course of the investigation of the accident indicated that four workers had received doses in excess of generally applied worker dose limits. The second event is described in Section 4.3.

The investigation of the accident included interviews with the workers and other people involved. As might be expected, there were some minor inconsistencies between the various accounts. The description in the following sections seems to be the most plausible and consistent account of what happened.

4.2.1. The initiating events

At 18:15 on Saturday 4 February 1989, Worker A began a night shift as operator of the facility. That evening, as usual, he had to deal with a number of power failures and problems with the pistons, but he managed to restart the operation each time. At about 02:00 on Sunday 5 February (Day 1), while he was taking a coffee break, a fault condition occurred which caused the source rack to be lowered automatically from the irradiation position. On returning from his coffee break, he heard the source transit alarm ringing, indicating that the source was neither fully up nor fully down.

He went to the control panel and followed the reset procedure. When this failed to stop the alarm and release the door, he left the control point, walked around through two gates to the other side of the facility and climbed the ladder to the roof where the source hoist is mounted. There, he followed the 'usual' procedure (not that recommended by the supplier) adopted at the facility in such circumstances to return the source to the fully down storage position. He detached the normal regulated pressurized air supply and applied an overpressure to force the source into the fully raised position, in the hope that this would free the source rack and permit its descent to the storage position.

This attempt was also unsuccessful. Since the source transit alarm continued to sound and the hoist cable was still not under tension, he forcibly pulled the slack cable fully out of the hoist mechanism by hand and then fed it back down through the shield. This had the same effect on the microswitch of the hoist cable as though the source rack were in the fully down storage position and finally stopped the alarm.

Worker A descended and returned to the control panel. He found that the (red) general failure light and the source up light were on. He went back to the roof and managed to manipulate the source down microswitch so that when he returned to the control panel he found the (green) source down light on.

In its original design, the facility had a fixed radiation monitor in the radiation room which would have detected radiation from the (still raised) source rack and prevented unlocking of the personnel access door. However, this monitor probe had been removed more than five years before and had not been replaced. To unlock the door, Worker A followed another 'usual' procedure at the facility (not recommended by the supplier) of rapidly cycling the buttons on the L118 radiation monitor panel (which simulated the detection by the fixed monitor of normal background radiation in the radiation room) while turning the key in the door switch (see Fig. 10). At about 02:30 he succeeded in opening the door. Established practice then required waiting for some minutes for ozone to be ventilated from the radiation room. He did so and then switched off the power supply to the facility.

Worker A seems to have been aware that he had not solved the problem of the stuck source rack but not to have appreciated the nature or magnitude of the danger of entering the room. His statements indicated that his impression was that radiation, like ozone, would dissipate and that, as with unpowered X ray equipment, there would be no continuing radiation.

4.2.2. The first entry

Having switched off the power supply, Worker A entered the radiation room with a torch. He did not check the radiation level with the portable radiation monitor. He examined the pistons around the lower of the two levels of the product transport mechanism, noticing nothing out of order. He then removed two fibreglass product boxes from normal positions on the product entry side of the lower level. In the second row, adjacent to the source rack, he found five boxes jammed into the space for four; that is, a nominal total length of boxes of 2.00 m in a floor length of 1.90 m.

Earlier in the shift, when repairing one of the pistons for this second row, he had found that two boxes had cracks, but since they could still hold the products he had not removed them. These deformed boxes may subsequently have disrupted the system for detecting the positions of the boxes, causing the five boxes to be squeezed into the space for four. The deformation of these boxes probably buckled the metal product guides on the conveyor (see Fig. 6), preventing the source rack from being lowered.

Working by torchlight, Worker A removed two of the five boxes, one of which was wedged against the lower of the two source modules in the source rack (see Fig. 5). This took several minutes. The left side of the source rack then became visible. He noticed that the slack cable that he had paid through from the roof was draped over the fixed product guide just above the upper floor level and was obstructing the descent of the source rack.

Unable to free the rack by himself, Worker A left the radiation room about five minutes after his initial entry. He switched the electrical power back on. The failure light (red) was on and the source down light (green) was intermittent. There was no alarm sounding. He then went to seek help.

4.2.3. The second entry

Shortly afterwards, at about 03:00, Worker A returned with Workers B and C, from another department, who had no experience of the irradiation facility. On being asked about any hazard, Worker A assured the others that there was no danger since the machine was switched off. The three men entered the radiation room and proceeded to remove product boxes from the third row on the upper level (adjacent to the source) so that the source rack could be freed from above (see Figs 12 and 13).

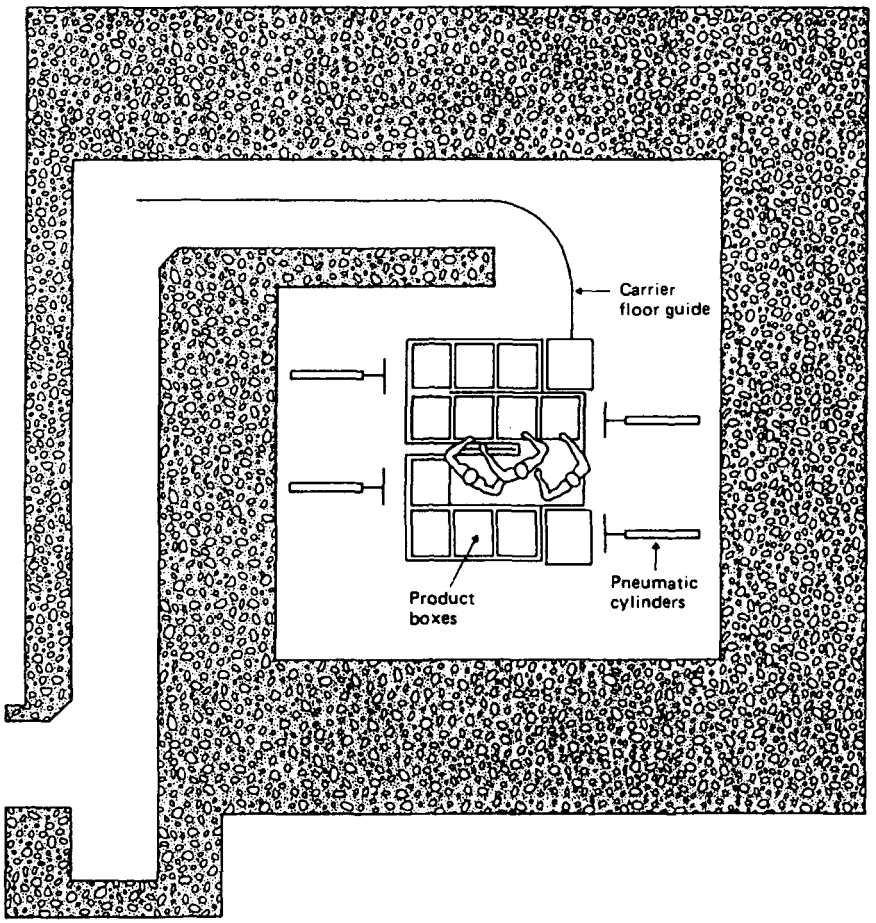


FIG. 12. Plan view of the positions of Workers A, B and C in the radiation room during the accident. (Source: REAC/TS.)

The next phase of the accident was probably when the three workers sustained the largest share of their doses. They would have been moving, but the positions and dose rate contours shown in Figs 13–15 can be taken as indicative of the patterns of exposure. In order to free the source rack they first had to raise it (a mass of about 60 kg) by all three pulling on the hoist cable. Eventually the three men were standing broadly in line on the upper level (Fig. 16). Worker A was in a crouching position with his legs slightly apart and his right leg forward directly in front of the rack. To his right, Worker B had his left leg nearer the source. (The leading leg of each man

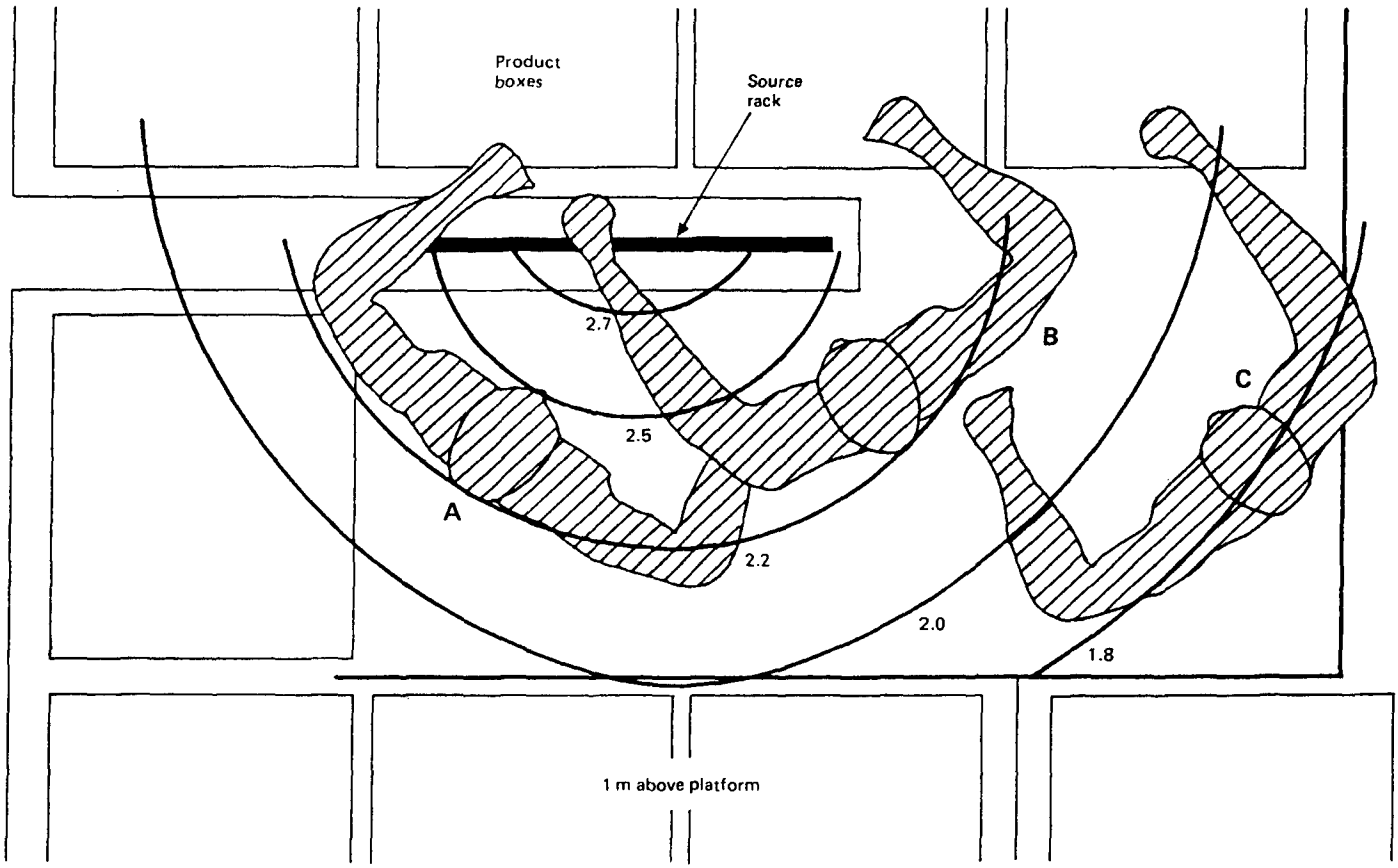


FIG. 13. Plan view of the positions in relation to the source rack of Workers A, B and C during the accident with dose rate contours in Gy·min^{-1}. (Source: REAC/TS.)

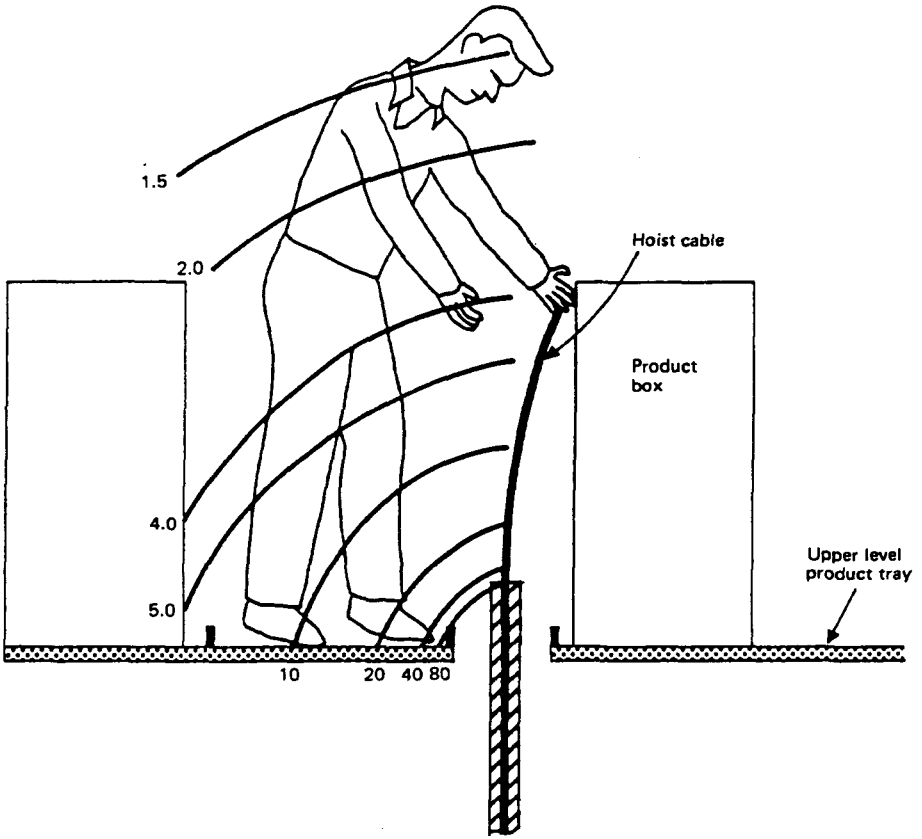


FIG. 14. Dose rate contours for a standing figure: rates in Gy·min^{-1}. (Source: REAC/TS.)

was subsequently amputated first.) Worker C was standing with his left foot on the upper product level and his right foot on a piston. He pulled the hoist cable free while Workers A and B raised the rack.

The three men then paid out the cable over the top of the source rack framework to lower the source rack into the pool. After about two metres of cable had been paid out, the source rack reached the surface of the water, and the men saw the blue glow due to Cerenkov radiation. Worker A was surprised at this and, on fully lowering the source rack, he told his helpers to withdraw quickly. At this point, apparently, he began to suspect that there was some kind of hazard, but not how lethal it was. On leaving the radiation room, Worker B noticed the portable radiation monitor some distance away from the irradiator and asked what its purpose was.

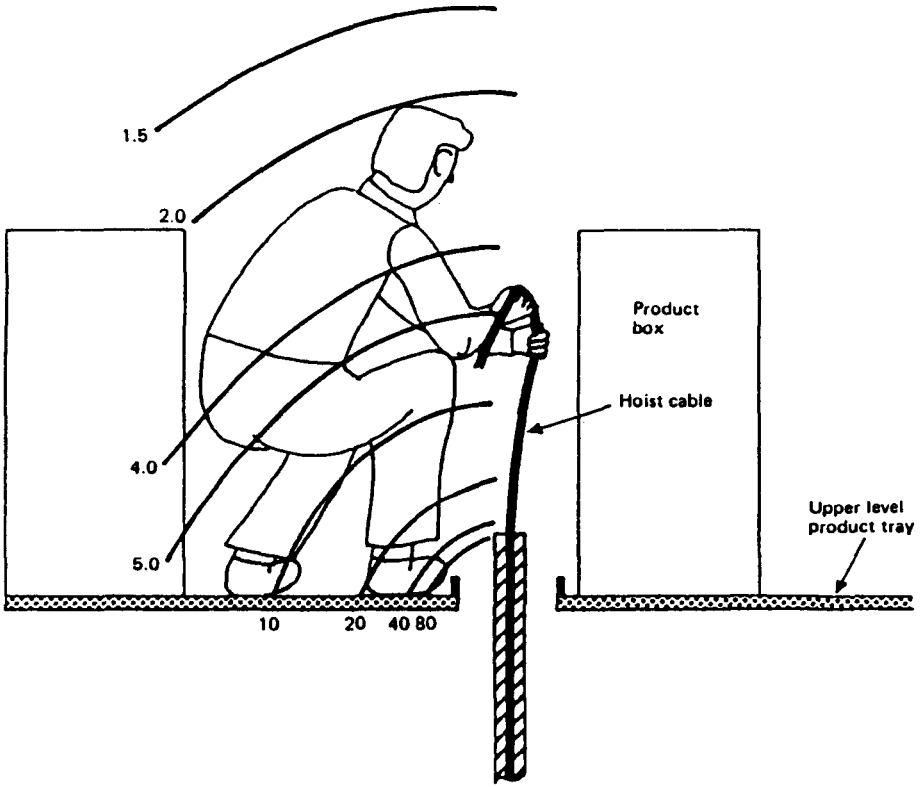


FIG. 15. Dose rate contours for a squatting figure: rates in Gy·min^{-1}. (Source: REAC/TS.)

Worker A replied that it was used for measuring radiation, but that this had not been necessary.

Worker A began vomiting within minutes of leaving the radiation room with the others, having been initially exposed about an hour earlier and being the most exposed of the three. They went outside the building and sat down. He felt increasingly ill. At about 03:30 he began to vomit blood and they went to seek medical help. Since the guard at the gate to the facility was not permitted to leave his post, Worker B helped Worker A about 100 metres to the main road, where they took a taxi to the emergency unit of the Primero de Mayo Hospital. Worker B then began vomiting. Worker C also began to vomit after returning to his work area, and he too went to the Primero de Mayo Hospital. Details of the subsequent medical treatment of Workers A, B and C are given in Section 5.

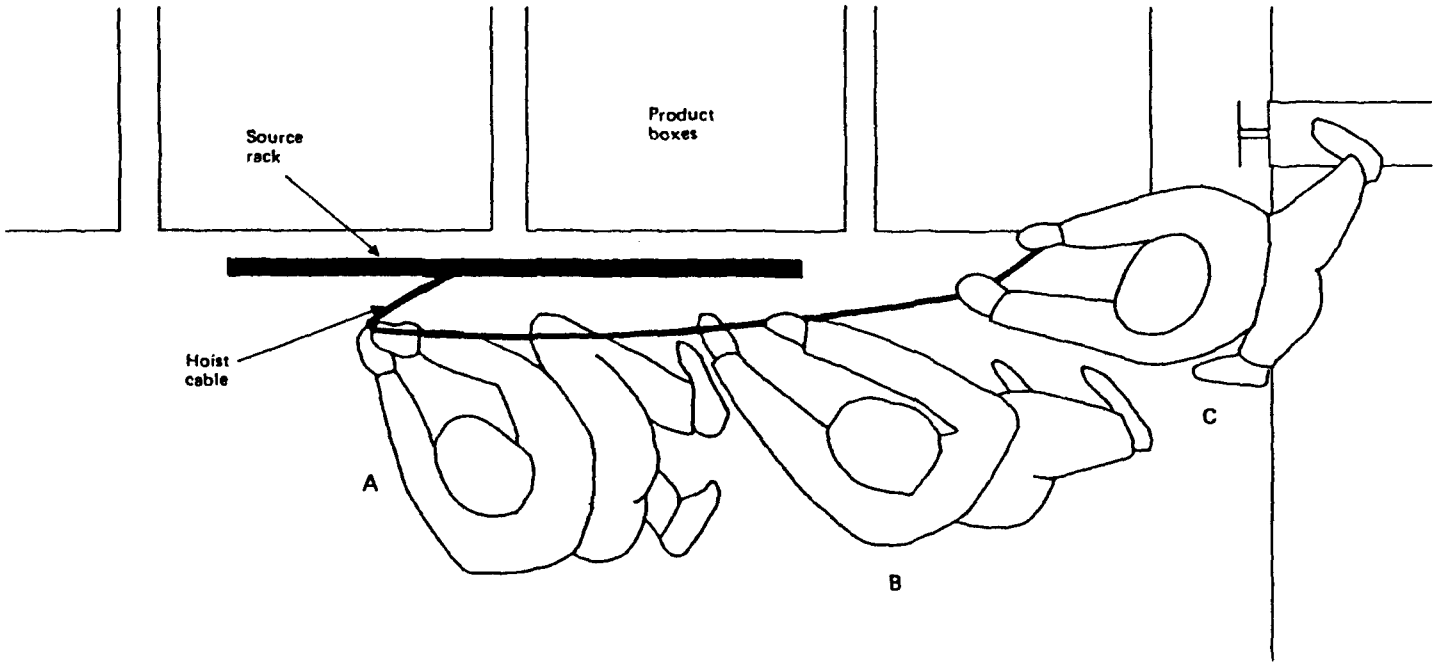


FIG. 16. Plan view of the positions in relation to the source rack of Workers A, B and C while attempting to free the source rack. (Source: REAC/TS.)

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.

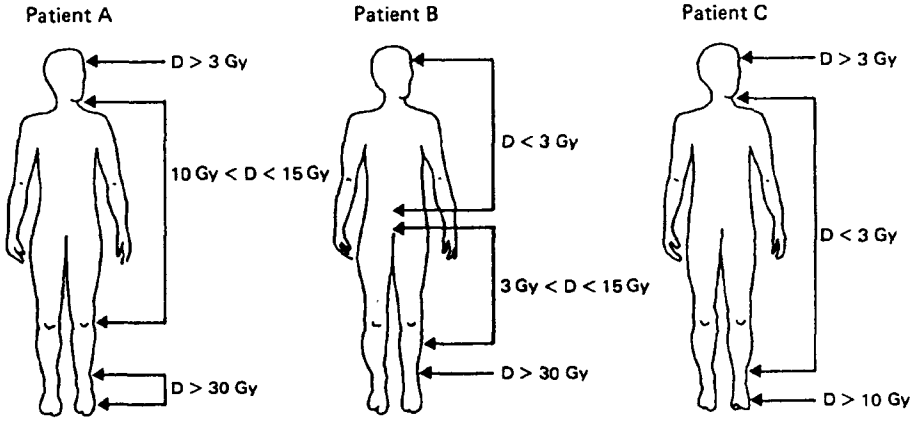


FIG. 17. Patients A, B and C: doses D incurred by different parts of the body. (Source: REAC/TS.)

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.

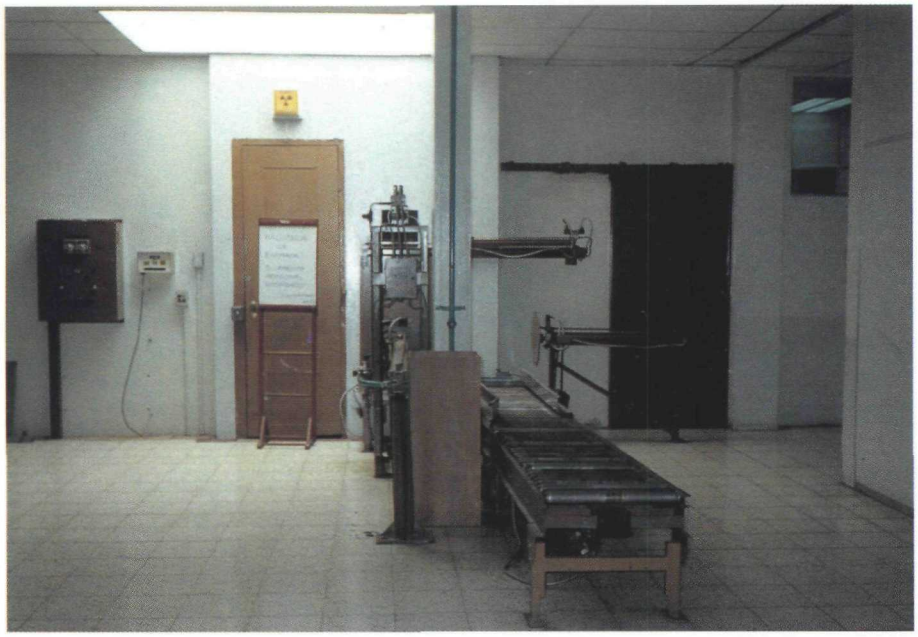
20. Patient B, Day 26 (Thursday 2 March). Oropharynges, white spots and red areas.

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.

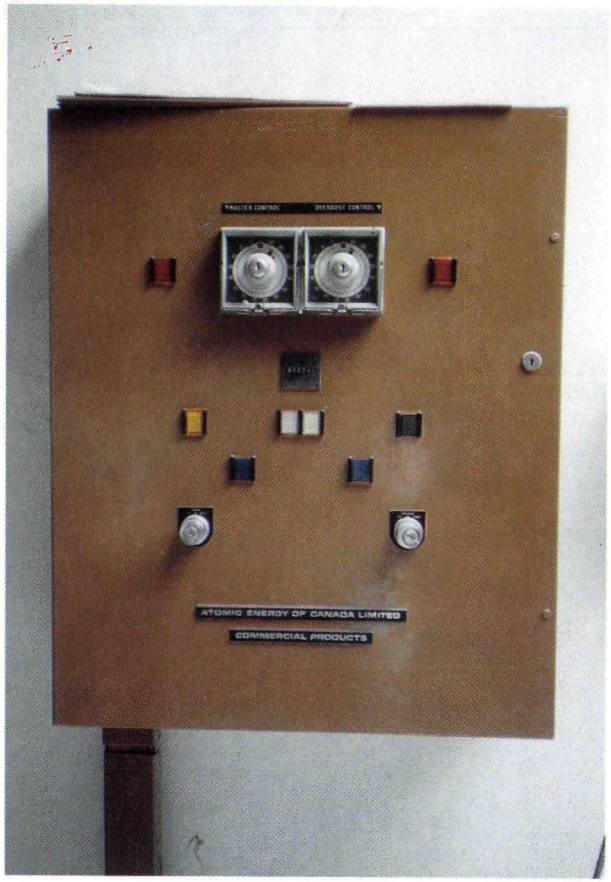
23. Patient C, Day 33 (Thursday 9 March). Posterior plantar region with healing from second degree burns in first and second toe.

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



1. General view of the front of the irradiator.

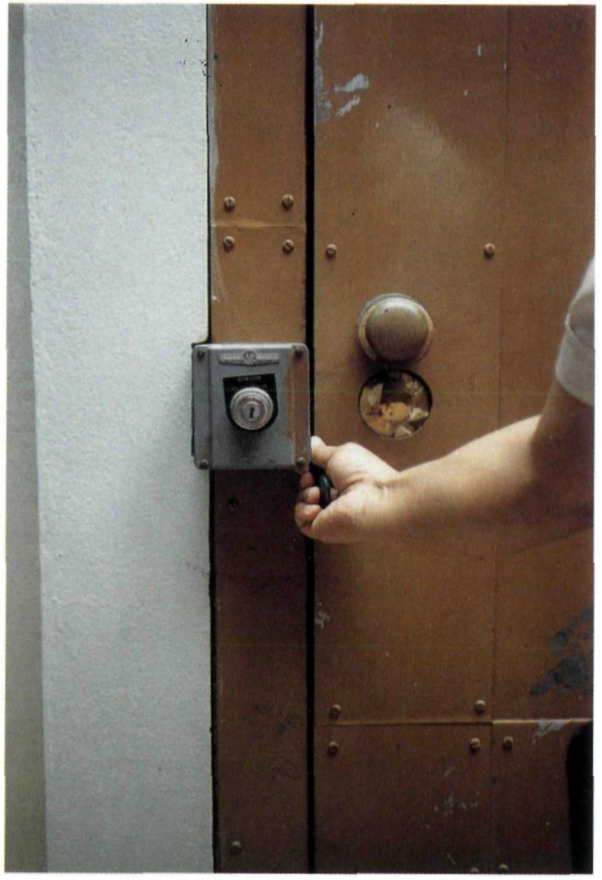
2. The front of the irradiation facility.



3. The unlabelled control panel.

4. The water treatment plant at the facility.

5. *The degraded main door could be opened easily.*

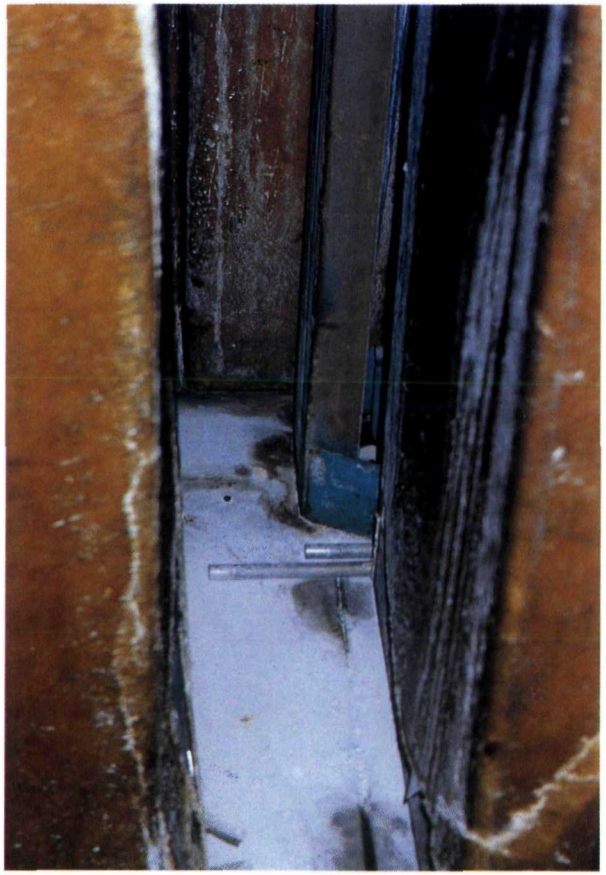


6. *Opening the main door with a knife blade.*

7. The radiation room.

8. The radiation room.

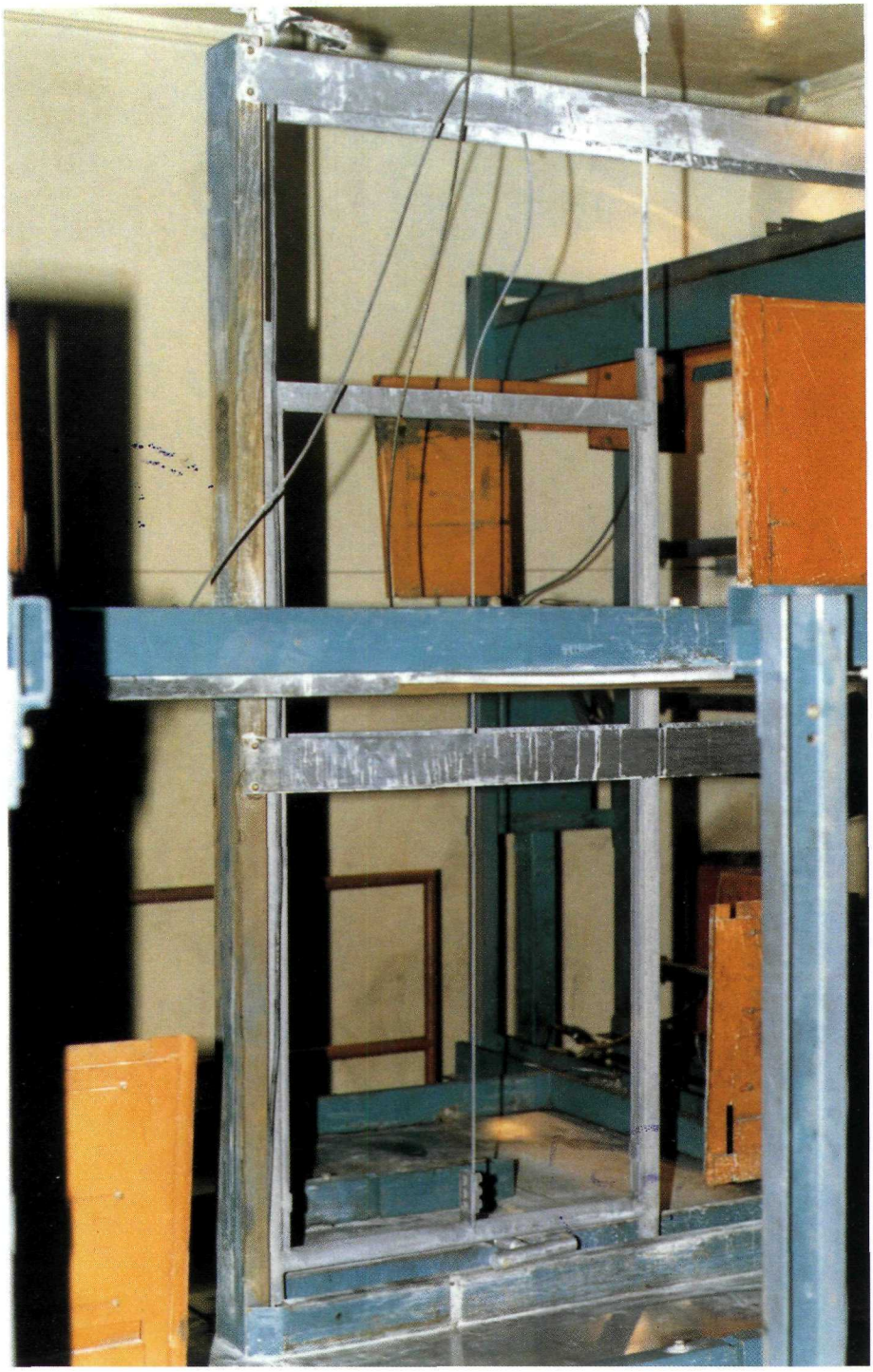
9. Fibreglass product box in poor condition.



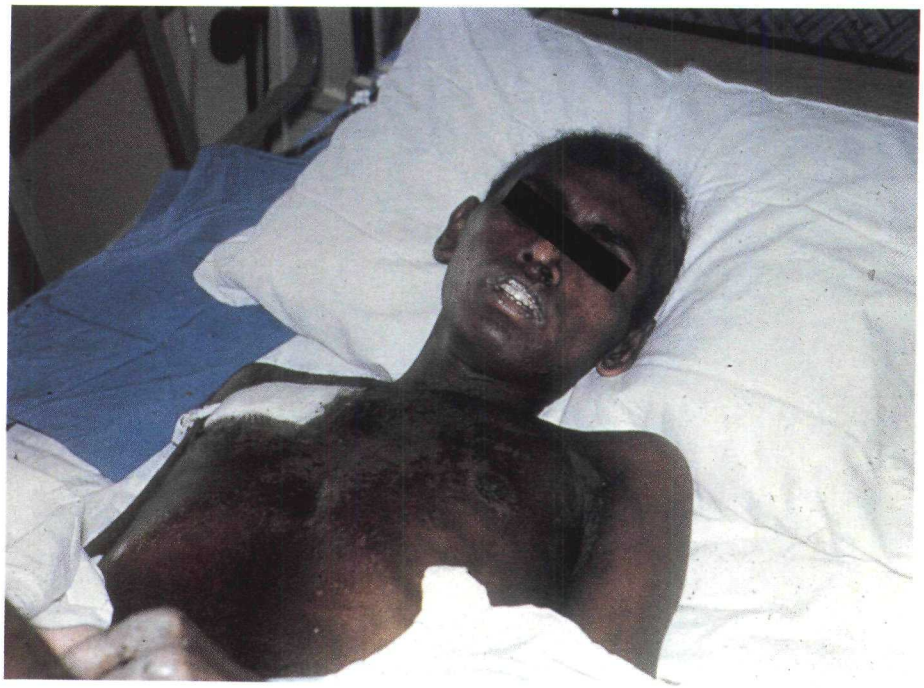
10. Inactive dummy pencils found between product boxes.

11. A product box could obstruct the source rack.

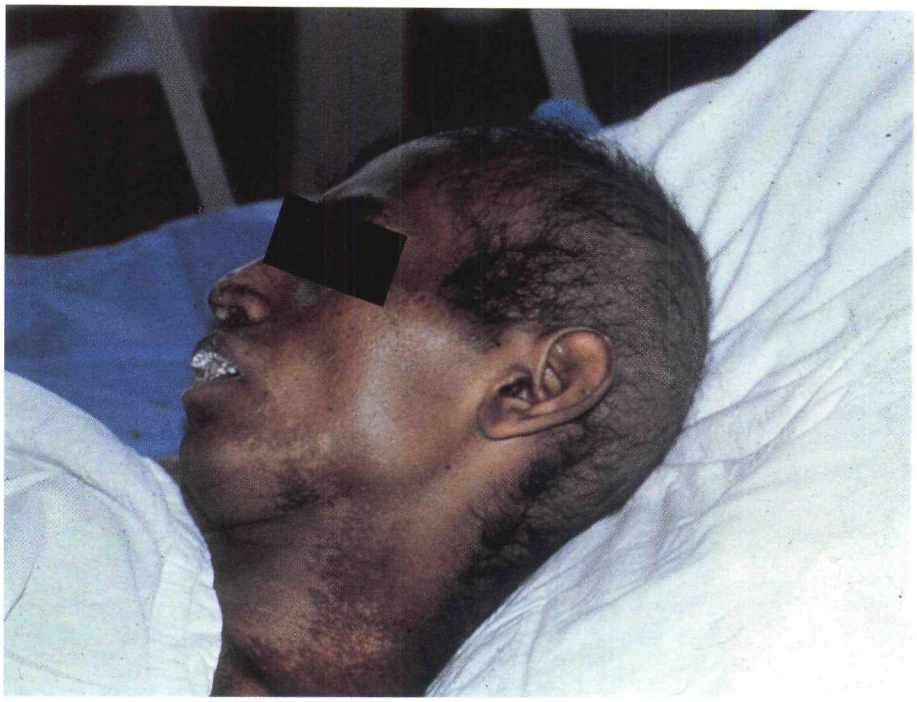
12. The radiation room roof during securing of the sources.



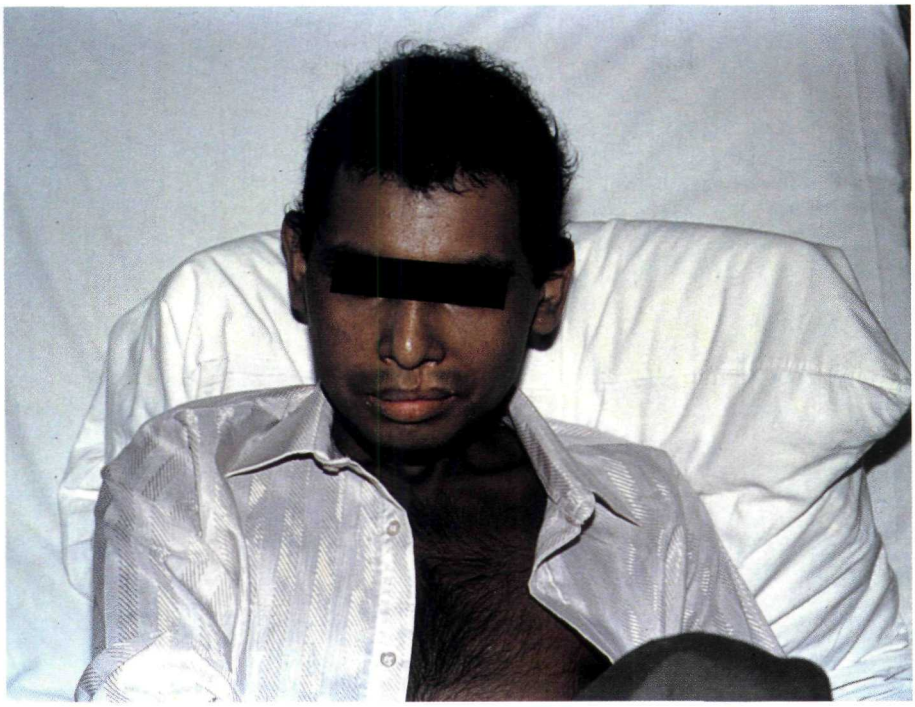
13. The empty source rack and the entangled source hoist cable.



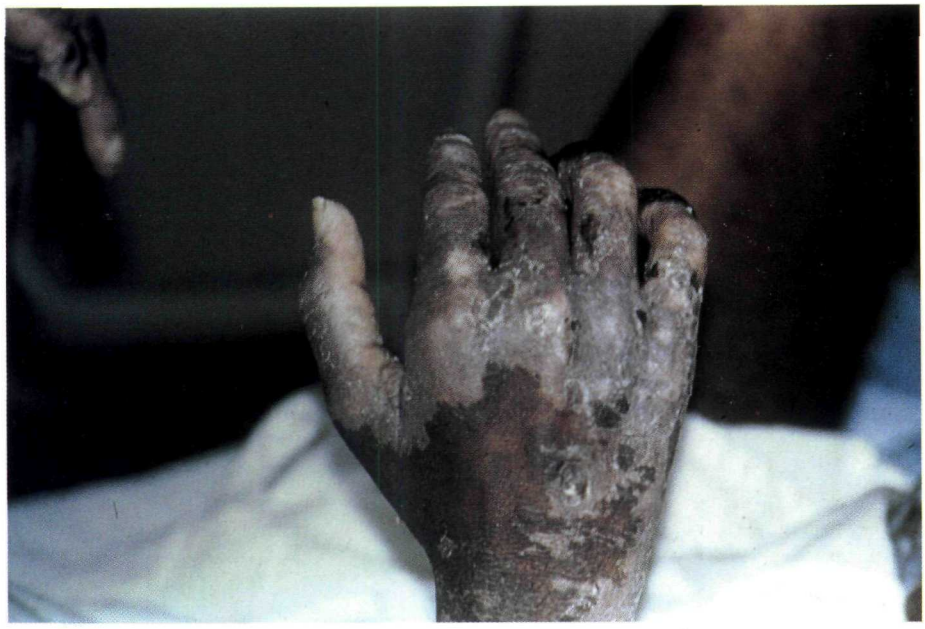
14. Patient A on admission to hospital in Mexico City (Day 26).



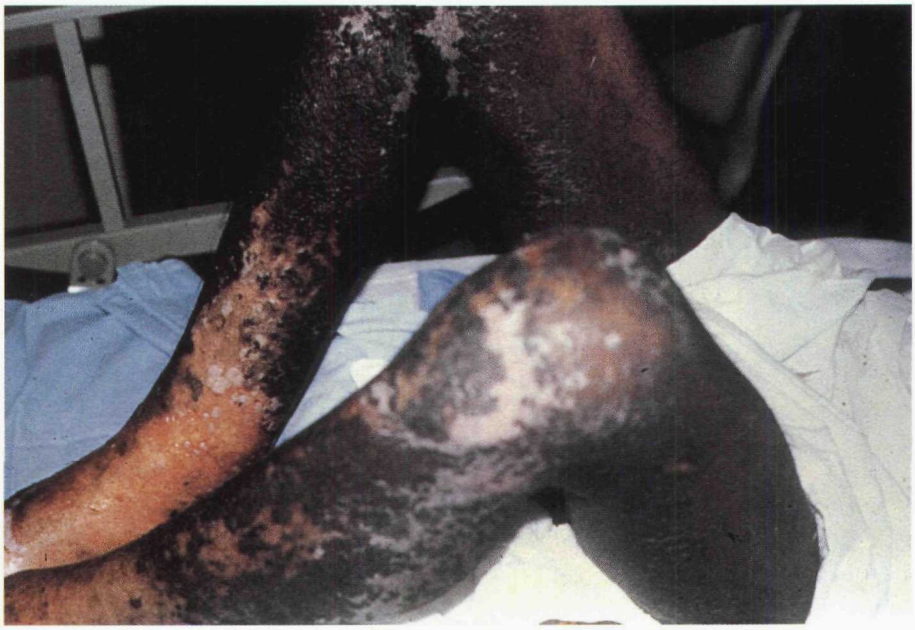
15. Patient A (Day 26).



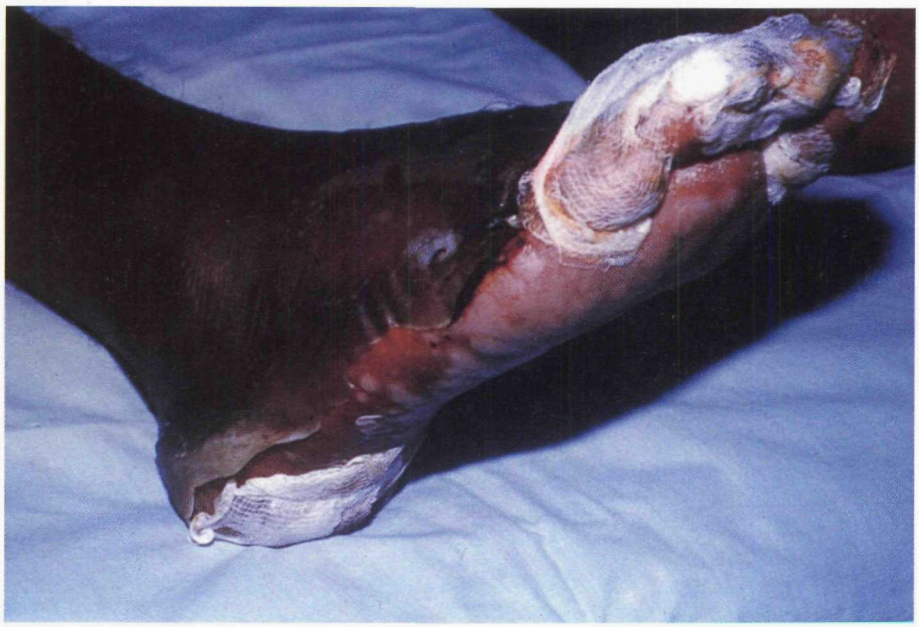
16. Patient A on discharge from hospital in Mexico City (Day 173).



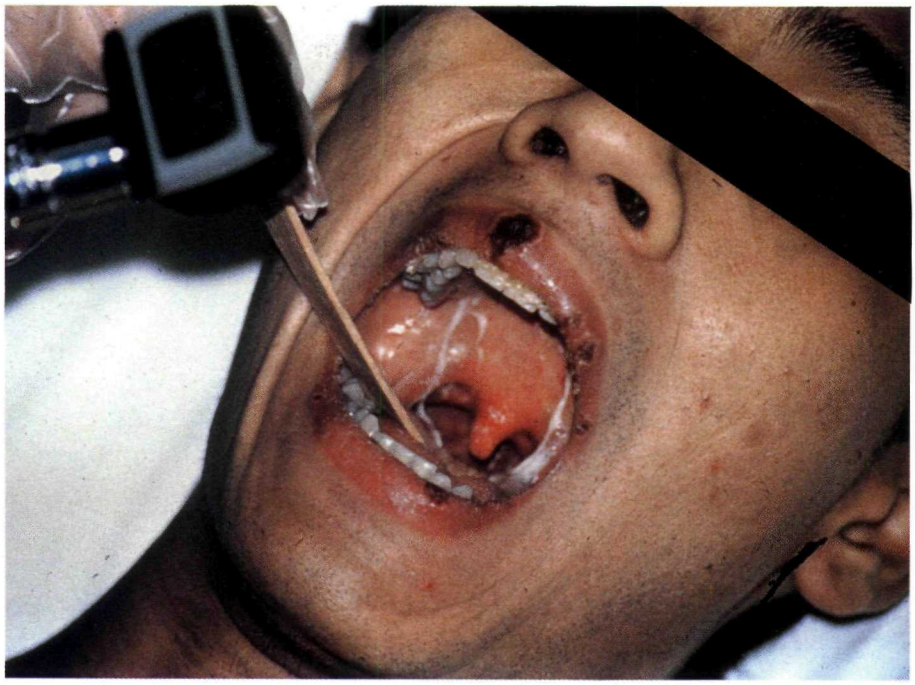
17. Patient A (Day 26): burns to the hand.



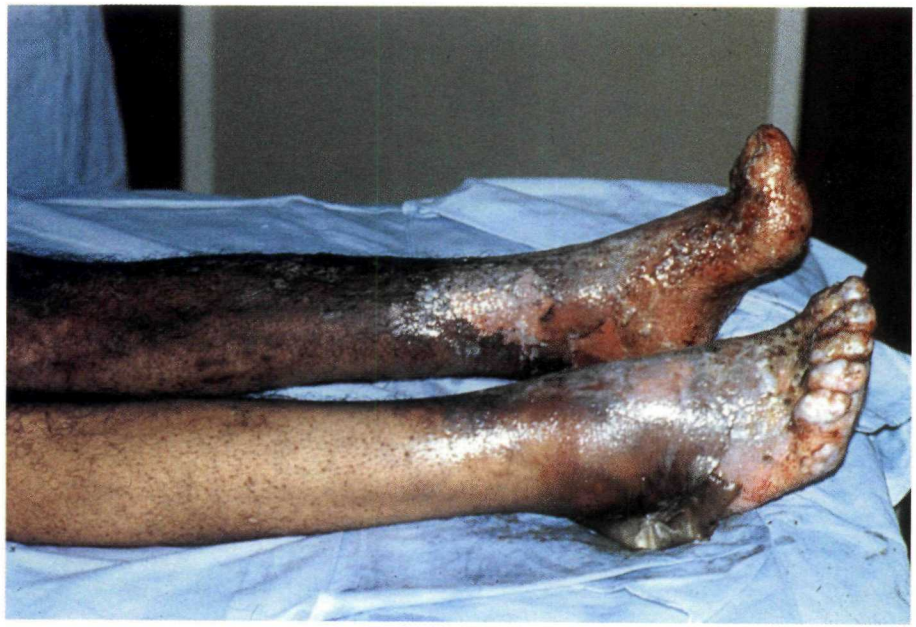
18. Patient A (Day 26): burns to the legs and feet.



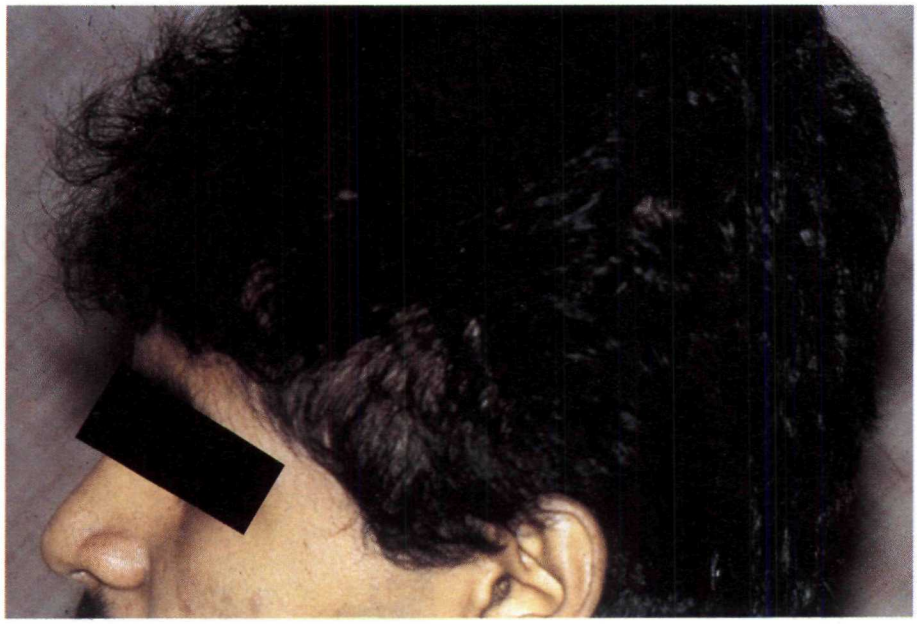
19. Patient A (Day 26): the more exposed foot.



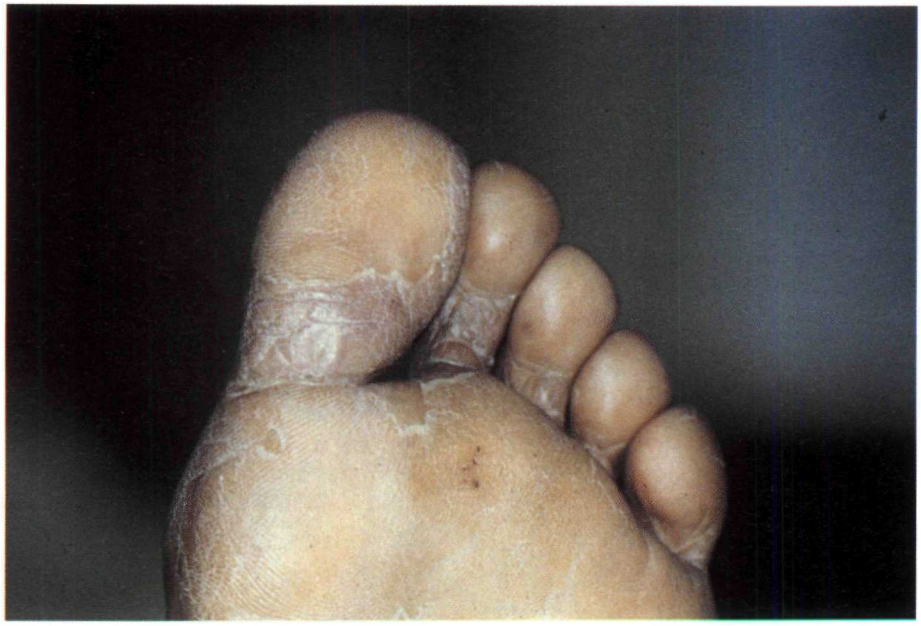
20. Patient B (Day 26): mouth sores; Patient A had similar sores.



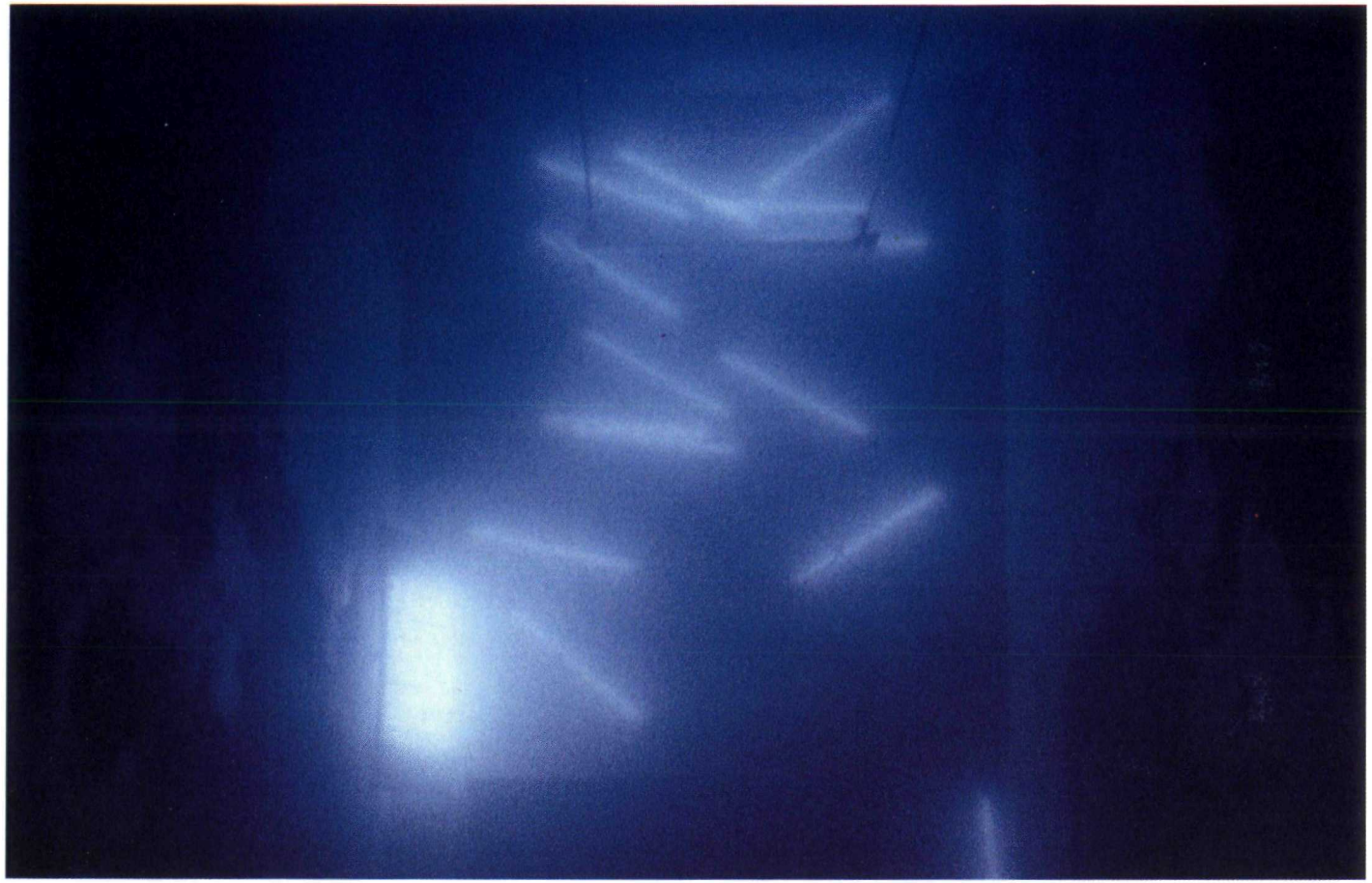
21. Patient B (Day 26): burns to the legs and feet.



22. *Patient C (Day 33): radiation induced temporary hair loss.*



23. *Patient C (Day 33): healing of burns to toes.*



24. The Cerenkov radiation shows all fourteen source pencils.

Appendix I

DOSIMETRIC ANALYSIS

Post-accident dosimetry has two main objectives:

(1) to provide input to the clinical prognosis, especially in anticipating difficulties in medical management associated with bone marrow depression; and
(2) to provide data to help improve the understanding of the effects in man of acute exposure to high doses of radiation.

In this accident only crude physical dose estimates were available in the critical period for clinical decisions concerning bone marrow depression and the expression of localized injury to the skin and underlying tissues. Thus, most of the dosimetric analysis performed was directed towards the second objective. Under the IAEA's assistance programme, dosimetry was principally carried out by REAC/TS. A summary of the dosimetric procedures, based on the interviewing of patients, data relating to the source, and radiobiological and cytogenetic considerations, is presented here. The sequence of presentation reflects the refinement of the dose estimates over time.

AI.1. INITIAL ESTIMATES

When the accident in San Salvador was first reported to the IAEA and assistance was requested, the range of whole body doses sustained by the three irradiated workers was estimated in San Salvador to be from 4 to 6 Gy. The workers had not been wearing personnel dosimeters, and this crude estimate was based largely upon the signs and symptoms of acute radiation injury expressed by the patients. Attempts were made to estimate the doses received on the simplified basis of a point source and the exposure times and positions estimated by the workers. However, the whole body doses so estimated were so high (of the order of 40 Gy) as to be manifestly unrealistic.

In view of the deteriorating medical condition of the patients, it was decided in mid-February to transfer them to the Angeles del Pedregal Hospital in Mexico City. There was already a mutual assistance agreement between El Salvador and the Angeles del Pedregal Hospital. By Day 33 (Thursday 9 March), all three patients had been transferred to this hospital, where the medical team made preliminary dose estimates for each patient on the basis of haematological analysis and the extent and severity of local radiation injury. At this stage it was evident that the irradiation had been very non-uniform. The orders of magnitude of doses to the lower limbs and the equivalent whole body doses that were estimated on Day 32 (Wednesday 8 March) upon admission to the Angeles del Pedregal Hospital are presented in Table II.

TABLE II. ESTIMATES OF DOSES TO THE LOWER LIMBS AND EQUIVALENT WHOLE BODY DOSES MADE ON DAY 32 (WEDNESDAY 8 MARCH) BY REAC/TS, OAK RIDGE, USA, FOR PATIENTS A, B AND C

Patient	Dose to lower limbs (Gy)	Whole body dose (Gy)
Patient A	100	6–8
Patient B	100	6–8
Patient C	10	2–4

AI.2. DOSE PROFILES FROM BIOLOGICAL EFFECTS

From Day 32 to Day 36 (Wednesday 8 to Sunday 12 March), the medical team at the Angeles del Pedregal Hospital worked together with an IAEA expert group from REAC/TS which assisted in both medical and dosimetric aspects. Refined assessments of the 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.

AI.3. CYTOGENETIC ANALYSIS

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) and were independently analysed by the specialist centres at REAC/TS in Oak Ridge and the Angeles del Pedregal Hospital. The results of the cytogenetic analyses at the two centres, summarized in Table III, were in very good agreement. Further information on cytogenetic analyses by REAC/TS is presented in Tables IV and V.

REAC/TS staff also estimated from the cytogenetic data what proportions of the patients' bodies received radiation doses (for a detailed description of the methods used, see IAEA Technical Reports Series No. 260[3]). In brief, homo-

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Biological Dosimetry: Chromosomal Aberration Analysis for Dose Assessment, IAEA Technical Reports Series No. 260, IAEA, Vienna (1986).

TABLE III. RESULTS OF CYTOGENETIC ANALYSES MADE BY THE ANGELES DEL PEDREGAL HOSPITAL, MEXICO CITY, AND REAC/TS FOR PATIENTS A, B AND C

Patient	Angeles del Pedregal Hospital		REAC/TS	
	Dose estimate (Gy)	95% confidence interval Gy)	Dose estimate (Gy)	95% confidence interval (Gy)
Patient A	8.19	7.62–8.59	7.97	7.29–8.65
Patient B	3.58	3.40–3.72	3.77	3.52–3.96
Patient C	2.96	2.73–3.17	2.92	2.74–3.10

TABLE IV. CYTOGENETIC DOSE ESTIMATES MADE BY REAC/TS FOR PATIENTS A, B AND C

	Patient A	Patient B	Patient C
Number of metaphases scored	35	350	500
Number of dicentrics observed	131	306	266
Dicentrics·cell^{-1}	3.74	0.87	0.53
Equivalent whole body dose estimate (Gy)	7.97	3.77	2.92
95% confidence interval (Gy)	7.29–8.65	3.52–3.96	2.74–3.10
Dose to exposed fraction (Gy)	8.27	4.41	3.24
95% confidence interval (Gy)	7.56–8.99	4.15–4.67	3.04–3.45
Percentage of lymphocytes exposed	99%	91%	92%

Source: Cytogenetic Dosimetry Laboratory, Oak Ridge Associated Universities, Radiation Emergency Assistance Center/Training Site (REAC/TS).

TABLE V. DISTRIBUTION OF DICENTRICS IN FIRST DIVISION METAPHASES OF LYMPHOCYTE CULTURES INITIATED ON DAY 35 (SATURDAY 11 MARCH) FOR PATIENTS A, B AND C

		Patient A	Patient B	Patient C
Number of metaphases scored		35	350	500
Number of dicentrics observed		131	306	266
Number of cells with n dicentrics				
n = 0	Observed	3	170	304
	Expected	0.8	147	294
n = 1	Observed	4	104	143
	Expected	3	128	156
n = 2	Observed	2	44	39
	Expected	6	55	41
n = 3	Observed	6	19	11
	Expected	7	16	7
n = 4	Observed	7	10	3
	Expected	7	3.5	1
n = 5	Observed	4	2	—
	Expected	5	<1	—
n = 6	Observed	7	—	—
	Expected	3	—	—
n = 7	Observed	1	1	—
	Expected	1.6	<1	—
n = 8	Observed	<1	—	—
	Expected	<1	—	—
Index of dispersion		1.18	1.44	1.14
Unit normal deviation		0.74	5.90	2.28

Source: Cytogenetic Dosimetry Laboratory, Oak Ridge Associated Universities, Radiation Emergency Assistance Center/Training Site (REAC/TS).

geneous whole body irradiation results in a Poisson distribution of dicentric aberrations among the blood cells. Non-uniform exposure produces an overdispersed distribution, which may be approximated by a Poisson distribution of aberrations distorted by a fraction of undamaged cells. By this analysis, the fractions of cells scored that had been damaged by irradiation and the doses to these fractions were estimated.

Additional calculations were made to correct for the effects of interphase death and mitotic delay, both of which reduce the number of irradiated cells observed. It was estimated (see Table IV) that the proportion of the body irradiated exceeded 90% for each patient. In each case the estimated dose to the exposed fraction of the body was only a few per cent higher than the 'estimated equivalent whole body dose'.

AI.4. RECONSTRUCTION OF THE ACCIDENT

Attempts were made to reconstruct the accident on the basis of interviews with the patients and others in order to estimate the doses received. The main factors of which knowledge is required in order to make such estimates are:

(a) the distribution of radioactivity in the source module;
(b) the position of the source module at the time of the accident;
(c) the positions of the exposed persons relative to the source and to any shielding;
(d) the durations of exposure for each configuration.

Good data were available for (a), but the other details, particularly those for (c) and (d), were not precise enough to permit reliable estimation of doses from the reconstruction alone. However, as described in the following, consideration of these details in conjunction with the biological effects of the doses helped in forming and validating an understanding of what happened in the accident. (See Figs 2–6.)

The physical size of the source module and the distribution of radioactivity within it were well known for the undamaged source module. For the normal operating position of the source rack, the dose rates at various points in the radiation room could be calculated and corrections could be made for gamma attenuation by the product boxes and for room scatter.

However, it soon became known that the source had not been in the normal operating position at the time of the accident. The irradiator operator, Worker A, said that the source module had been intact but had become stuck while being lowered from the operating to the storage position. The exact position of the source rack during the accident could not be determined since it was freed by the workers and lowered into the pool.

Since the dose rate decreases rapidly with distance from the source, knowledge of the relative positions of the source and of the workers is especially important if the workers were close to the source, which they were. The calculation of the radiation doses received also requires knowledge of the length of time for which each person was exposed in each different position relative to the source. Further information would help to refine the calculations; however, such refinements are only useful if the basic details are accurately known. In the present case, the exposure times and the configurations of the source and of the three workers could not be exactly determined.

Each of the three men was interviewed on several occasions in an attempt to determine his probable positions and that of the source. As might be expected, their recollections differed and varied somewhat with each telling. On the basis of these statements, adjudged in conjunction with the resultant biological injury and the physical dimensions of the facility, it seems that the source became stuck with the top of the upper source module about 10 cm above the upper platform. The normal operating position of the source rack is with its top about 30 cm above the upper platform. In the accident, the source was raised briefly by 10 cm before being lowered into the pool.

Dose rates in the radiation room were calculated for a 10 cm x 10 cm x 10 cm matrix, on the assumption that the source was in the position just described. Figure 13 shows resulting horizontal isodose lines at one metre above the upper platform and Figs 14 and 15 show vertical isodose lines half-way along the length of the source rack. The actual isodose lines would have been asymmetrical owing to the uneven loading of the source module.

The next requirement was to determine the positions of the individuals during their exposure. Worker A reported that he initially entered the radiation room to examine the pistons. He estimated that he was in the room for five minutes. The dose he received in this period was enough to induce nausea but was probably only a fraction of the dose he later sustained when he was working close to the source, and has therefore not been considered in detail. He then left the room to seek help and returned later with Workers B and C.

All three men then entered the radiation room. They removed some of the product boxes and freed the source rack, lowering it to the storage position in the pool. From the interviews with the three men it seems that while so doing their positions on the upper level were as shown in Figs 13 and 16 for most of the period of exposure. They did not remain in fixed positions, of course, but such an approximation serves as a reasonably good model. Worker C may also have been on the lower level for some time; however, the present dose estimates are based on all three workers having received the principal share of their doses while on the upper level.

The greatest uncertainties in the dose calculations were in the lengths of time for which each man was exposed. Each mentioned different time intervals, ranging from a few minutes to ten minutes. The exposure intervals were also estimated on the bases of the probable dose rates for the positions in which the exposures occurred and the specific biological effects of exposure on the men (see Figs 18–20), which indicated the doses received. By this iterative process, the best estimate of their exposure time was about three minutes. Knowledge of the distribution of biological injury also helped in determining the positions in which the men were exposed.

Patient A described his position as shown in Figs 13, 15 and 16. His pattern of desquamation (see Fig. 18) was assessed on the basis that a dose of at least 15 Gy is necessary to cause dry desquamation and a dose of 30 Gy or more for wet desquamation. The results suggest an exposure period of about three minutes. Patient A's

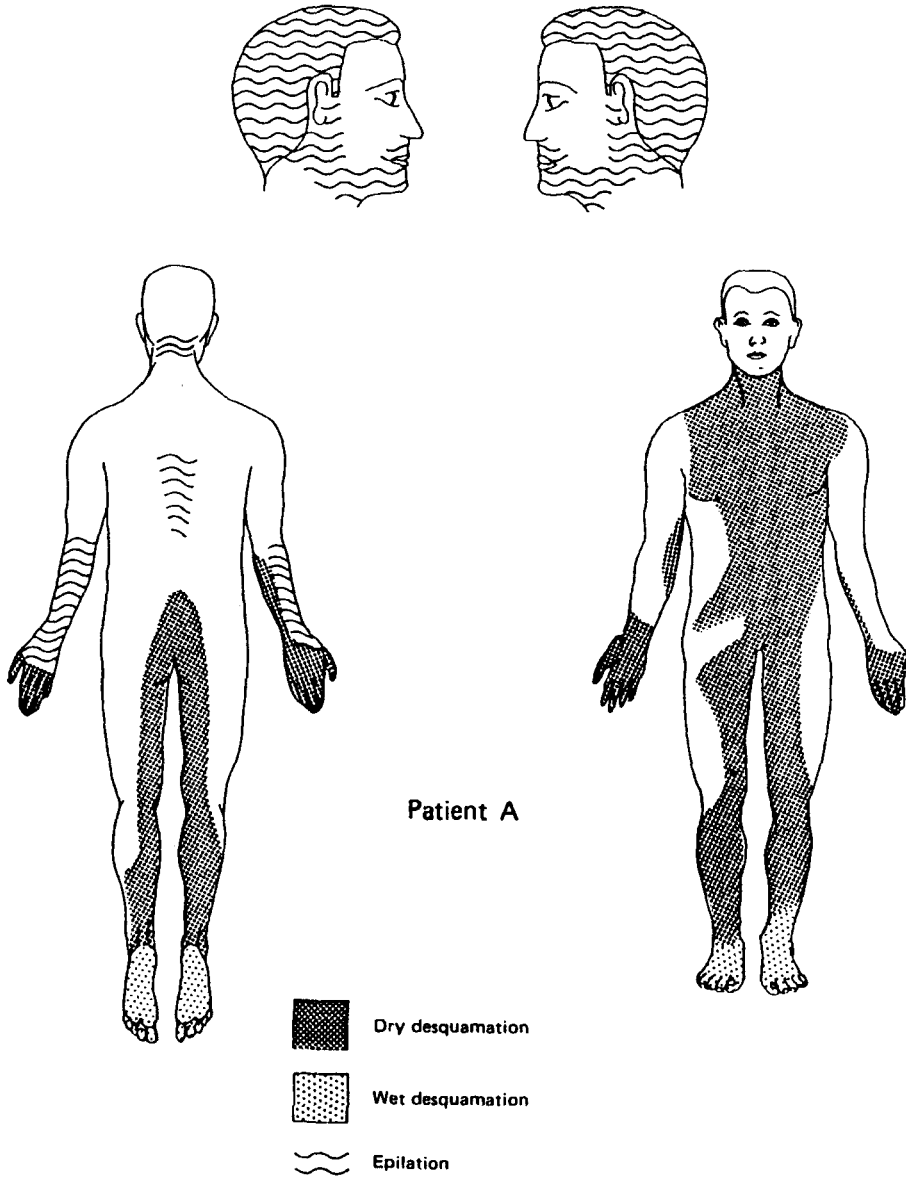


FIG. 18. Patient A: corporal distribution of effects of exposure. (Source: REAC/TS.)

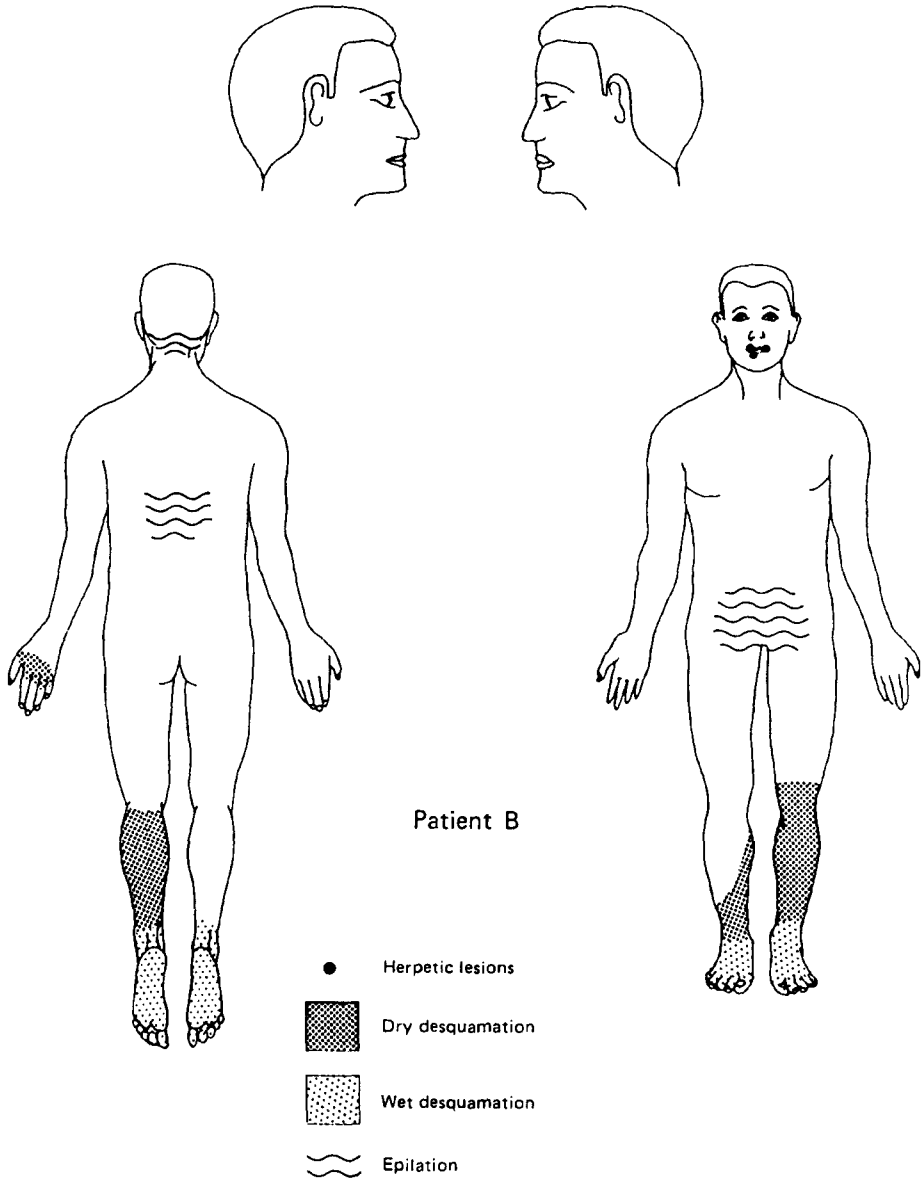


FIG. 19. Patient B: corporal distribution of effects of exposure. (Source: REAC/TS.)

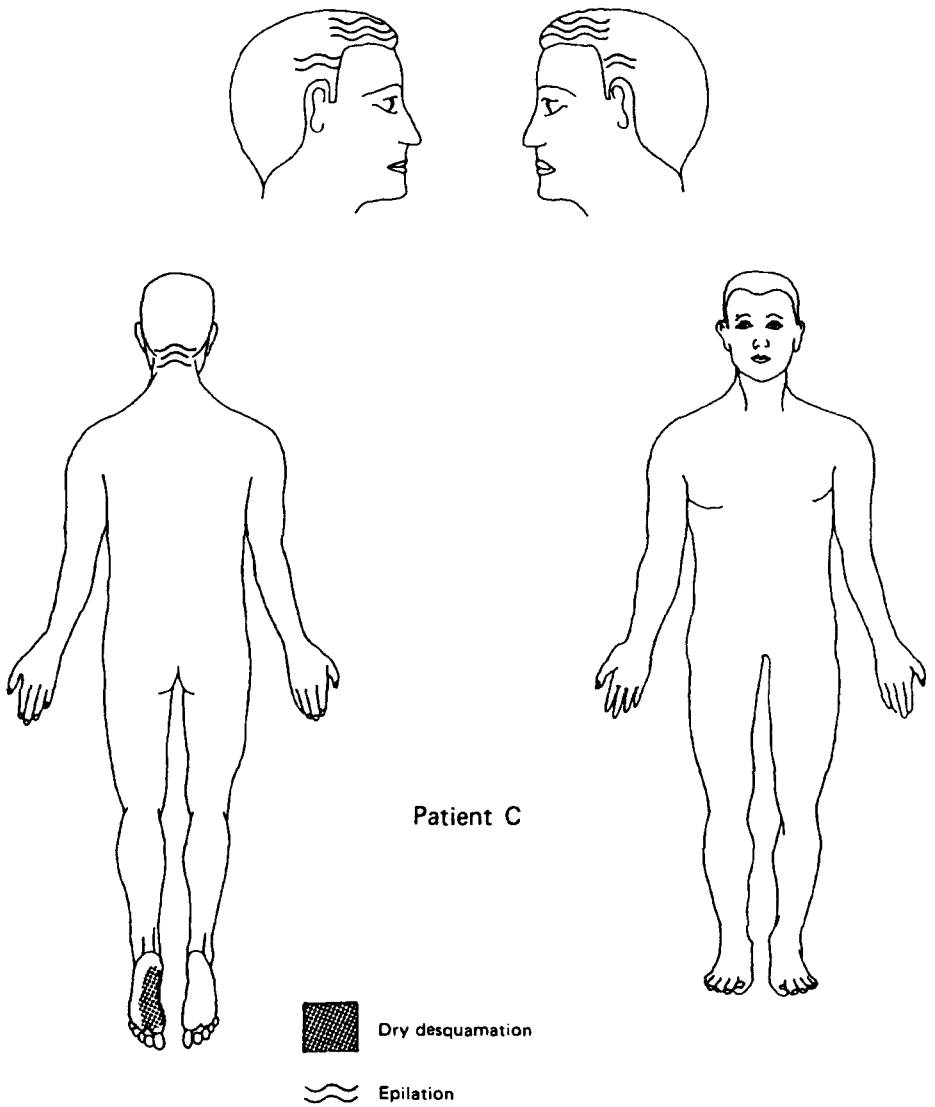


FIG. 20. Patient C: corporal distribution of effects of exposure. (Source: REAC/TS.)

exposure pattern differed from that of Patient B in that the medial surfaces of his legs were more seriously exposed. This suggests that he squatted with his legs apart while freeing the source rack. Adopting such a position rather than standing would have increased the dose to his upper body. His pattern of epilation and skin bronzing bears out such an exposure position. The pattern of wet and dry desquamation also suggests that the source was below the level of his knees. The difference in biological response between the medial and lateral surfaces of his legs also corresponds quite well with the expected results of attenuation by tissue. Worker A probably not only squatted but also bent over the source module.

Analysis of the information on Worker A's position and other factors yields the following dose estimates. The dose to his feet probably exceeded 200 Gy. His average mid-line air dose was about 10 Gy during his second period in the radiation room. The total mid-line air dose due to this period and to his earlier presence there could have been as high as 15 Gy. The average whole body dose, which depends upon the orientation of the individual and the quality and attenuation of the radiation, was determined to be about 80% of the average mid-line air dose. For Worker A, the average whole body dose would therefore have been up to about 12 Gy, rather uniformly distributed.

In view of the limited space in the radiation room, Worker B's position was probably as shown in Figs 13 and 16. In his case, epilation was from approximately the umbilicus down (see Fig. 19). Wet desquamation of the feet extended above the ankles to midway between the ankle and the knee of the right leg and somewhat higher on the left leg, above which dry desquamation occurred. On the basis that a dose of at least 15 Gy is necessary to cause dry desquamation and a dose of 30 Gy or more for wet desquamation, the dose rate must have been higher by a factor of about two at the ankle than at the knee. This factor of two for the decrease in the dose rate corresponds quite well to the position of the source as previously described. The biological response observed in Patient B also suggested an exposure time of about three minutes.

Given that the isodose lines and the biological effects correspond to a three minute exposure, the dose to the feet can be estimated to have been about 200 Gy. Owing to the rapid decrease in the dose rate with distance from the source, this can only be considered an order of magnitude estimate; however, it does seem to correspond to the biological response. The dose to the upper part of the body for Worker B would not have exceeded about 3 Gy. The uneven dose to the body corresponds to an estimated average mid-line air dose of between 4 and 5 Gy. This dose would also need to be multiplied by about 0.8 to yield an average whole body dose.

Patient C exhibited minor epilation and had a small area of dry desquamation on the big toe of the left foot (see Fig. 20). A reasonable estimate of the period of his exposure while on the upper platform is also about three minutes. His position was as shown in Figs 13 and 16. The exposure would thus have been more or less uniform to the whole body, primarily to the anterior surface. This exposure would

have resulted in an estimated average mid-line air dose of between 2 and 4 Gy, and the average whole body dose would have been about 80% of this. This assessment is consistent with the cytogenetic dose estimates. However, it is difficult to conceive of a way consistent with Patient C's recollection of events in which he could have received a dose to the toe sufficient to cause dry desquamation. It would seem that at some stage he must have stepped close to the source rack for a short time.

All three men were required to bend while they were on the upper platform since the clearance to the ceiling is only 1.5 m. Workers B and C presumably lowered their heads.

None of the three received high enough doses to the hands to cause wet desquamation.

Further calculations have since been made but they do not significantly increase the accuracy of the dose estimates. The doses were probably incurred mainly during the few minutes for which the three workers were close to the source. In view of the biological damage the three men suffered, medical staff asked whether secondary electrons liberated in the interaction of gamma radiation with the stainless steel platform and surrounding materials may have contributed to the surface doses received. Irradiation by secondary electrons would cause greater surface biological damage in a shorter time than gamma irradiation alone, which would mean that the figures for the deep doses estimated on the basis of the surface damage were too high. However, a calculation of the possible electron dose and its distribution does not seem to support such a hypothesis.

In this case, cytogenetic dosimetry currently provides the best estimate of the doses received by the three men since it integrates exposure rates and exposure intervals. However, as discussed in Section AI.5, other techniques may provide further input to the dose estimates.

AI.5. OTHER DOSE ESTIMATION TECHNIQUES

After the irradiator accident in Norway in 1982, the main inputs to the dose estimation came from:

(1) thermoluminescence analysis of jewels in a wristwatch worn by the victim; and
(2) analysis by electron spin resonance of tablets that were in the victim's pocket.

In the accident in San Salvador, none of the three workers had items on their person that would readily have permitted the use of these techniques. However, the amputation of legs of Patients A and B permitted histopathological examination and analysis of sections of bone by electron spin resonance to derive further dose estimates for the lower limbs. The clothes that Patient A was wearing at the time of the accident were analysed by electron spin resonance dosimetry and lyoluminescence dosimetry to gain additional information on the dose sustained. The results of these investigations, performed in the USA and at the Institute of Biophysics of the Ministry of Health in the USSR, were not available when this report went to press.

Appendix II

MEDICAL TREATMENT

Appendix II presents a general summary of the medical treatment of the three patients. Annexes I and II provide nutritional reports specific to the treatment of the patients in Mexico City. The information presented in this appendix and in Annexes I and II was provided by the medical teams at the Primero de Mayo Hospital in San Salvador and the Angeles del Pedregal Hospital in Mexico City. It is recognized that in some respects the data are incomplete. Nevertheless, it is considered important to present those that are available. This has been done with a minimum of editorial changes to the English translation of the text provided by the medical teams.

AII.1. INITIAL DIAGNOSIS AND TREATMENT AT THE PRIMERO DE MAYO HOSPITAL IN SAN SALVADOR

The first medical examination of Patient A took place in the Primero de Mayo Hospital in San Salvador at 03:55 on Day 1 (Sunday 5 February), when prodromal symptoms such as intense nausea, vomiting, total erythema, weakness and headache had developed. The patient was misdiagnosed as having food poisoning and nausea and discharged at about 06:00 the same day.

The first laboratory analyses of samples were carried out on Day 3 (Tuesday 7 February) and a severe lymphopenia was registered: the cell count was about 500 μL^{-1} (compared with about 2500 μL^{-1} normally).

In the first two to three days, Patient A's main complaints were weakness, nausea, headache, anorexia and pain in the feet. Total erythema showed up slightly. Dark hyperaemia of the skin on the legs and feet was strongly developed with oedema. A diagnosis of severe radiation lesions was consequently made. In this period the patient received appropriate symptomatical therapy.

It should be noted that prodromal symptoms in combination with deep lymphopenia could be an indication for acute radiation syndrome (ARS) in addition to radiation burns.

The prodromal phase of ARS is usually followed by a latency period. In the case of Patient A, however, the severe radiation damage to the mucosa of the mouth and oesophagus appeared on Day 4 (Wednesday 8 February) and developed with the occurrence of some ulcers. It was not possible for him to eat normally. The mouth pain was intense and almost continuous for two weeks.

Another symptom of acute radiation syndrome, radiation enteritis, began on Day 8 (Sunday 12 February). It was manifested by diarrhoea, vomiting and pain. Fever began at the same time.

The main syndromes of ARS cytopenia became evident at the same time: the number of leucocytes in the blood was 2900 μL^{-1} on Day 6 (Friday 10 February) and only 900 μL^{-1} on Day 10 (Tuesday 14 February). A typical abortive rise in the number of granulocytes was observed on Day 19 (Thursday 23 February), but this was not significant (maximum 1900 μL^{-1} leucocytes). The decreasing concentration of thrombocytes was evident after Day 10 (Tuesday 14 February) and a minimum level of about 20 000 μL^{-1} was observed after 20–25 days. There was no significant decrease in the concentration of erythrocytes, but a drop in that of haemoglobin was evident, to 86 $g \cdot L^{-1}$ (normally 160 $\pm$ 2 $g \cdot L^{-1}$).

After a latency period (from Day 4 to Day 14: Wednesday 8 to Saturday 18 February), the skin lesions began to cause difficulties and severe pain, and oedema of feet and skin followed by the development of ulcers was observed.

By Day 11 (Wednesday 15 February) the medical staff of the Primero de Mayo Hospital in San Salvador considered that the patient might require bone marrow transplantation. On Day 24 (Tuesday 28 February), Patient A was transferred to the Angeles del Pedregal Hospital in Mexico City. Similar documented clinical information in respect of Patients B and C was not available.

AII.2. TREATMENT IN THE ANGELES DEL PEDREGAL HOSPITAL IN MEXICO CITY

Upon arrival at the Angeles del Pedregal Hospital, the three patients were carefully examined and their medical histories were recorded. The patients were found to be exhibiting signs and symptoms of whole body irradiation (see Tables VI and VII) with acute injury to the legs and feet (Figs 18–20). The diagnosis was made of ARS in the latent period characterized mainly by severe pancytopenia, which occurs about 20 days after whole body irradiation.

Immediately after the patients' admission to the Angeles del Pedregal Hospital, it was decided to conduct the following studies:

(1) routine laboratory and X ray screening;
(2) bone marrow aspiration and bone biopsy;
(3) making of ABO blood group cultures and human leucocyte antigen (HLA) aspiration biopsy cytology (ABC) cultures, degeneration reaction (DR) cultures, complotype cultures and mixed lymphocyte cultures for Patients A and B and their brothers;
(4) calorimetric and nitrogen balance analyses;
(5) serology studies for Herpes I and II, cytomegalovirus, human immunodeficiency virus (HIV) and viral hepatitis profile;
(6) electrocardiogram, echocardiogram and cardiological evaluations;
(7) analysis of cultures of the feet obtained serially;

TABLE VI. SIGNS AND SYMPTOMS FOR PATIENTS A, B AND C UPON ADMISSION TO THE ANGELES DEL PEDREGAL HOSPITAL

Signs and symptoms	Patient A (On Day 24)	Patient B (On Day 26)	Patient C (On Day 33)
Nausea	Moderate	Mild	None
Vomiting	Moderate	Mild	None
Diarrhoea	Severe	None	None
Weight loss	10 kg	4-5 kg	None
Meatal obstruction[a]	Severe	None	None
Foot pain	Severe	Severe	None

[a] Secondary to mucous plug.

TABLE VII. RESULTS OF PHYSICAL EXAMINATIONS FOR PATIENTS A, B AND C UPON ADMISSION TO THE ANGELES DEL PEDREGAL HOSPITAL

	Patient A (Day 24)	Patient B (Day 26)	Patient C (Day 33)
Karnovsky score	30%	30%	80%
Pallor	Severe	Moderate	Moderate
Bleeding	Gingival and epistaxis	No	No
Petechia and echymosis	In venipuncture sites	In venipuncture sites	No
Mucositis	Severe	Moderate	No
Body temperature	39.5°C	39.0°C	Normal
Xerostomy	Present	Present	Absent
Alopecia	Total	Partial	Minimal, biparietal

TABLE VIII. VITAL HAEMATOLOGICAL VALUES FOR PATIENTS A, B AND C UPON ADMISSION TO THE ANGELES DEL PEDREGAL HOSPITAL

Patient	Haemoglobin ($g \cdot L^{-1}$)	White blood cells (μL^{-1})	Total neutrophil count[a]	Platelets (μL^{-1})
Patient A (Day 24)	60	200	0	20 000
Patient B (Day 26)	86	700	56	54 000
Patient C (Day 33)	84	2300	437	35 000

[a] Total neutrophil count is calculated as count per unit blood volume multiplied by estimated blood volume.

(8) computerized tomography of legs and magnetic nuclear resonance as well as Doppler studies of the legs;
(9) cytogenetic dosimetric studies of blood samples obtained.

For Patients A and B the positive results of laboratory studies were as follows:

(1) severe pancytopenia with life threatening neutropenia (see Table VIII);
(2) bone marrow aplasia in aspiration and bone biopsies;
(3) cultures of the feet were positive for *Staphylococcus saprophyticus* (coagulase negative) and *Staphylococcus aureus*;
(4) ABO blood groups and HLA:
Patient A: O positive. A3, A28, B35, B7, Bw6, Cw4 and MLC negative and identical HLA, ABC, DR and complement with four identical brothers.
Patient B: A positive. A1, A28, B35, BX, Bw6, Cw4 and MLC negative and identical HLA, ABC, DR and complement with one identical brother.

Treatment strategy

(1) *A multidisciplinary medical team.* A medical team and a paramedical team were established for a multidisciplinary approach, including specialists in: haematology; bone marrow transplantation; infectology and hospital infection control; clinical laboratory analysis; cytogenetics; cardiology; clinical nutrition; plastic and vascular surgery as well as general surgery; nuclear medicine; pathology; psychiatry; anaesthesiology; pain clinic; dermatology; and physiotherapy. Nurses with

extensive experience in the management of neutropenic patients were assigned to each patient. Consultations were established with advisers and experts from the Mexican National Commission for Nuclear Safety and Safeguards and from REAC/TS at Oak Ridge, USA.

(2) *Intensive supportive care.* The patients were put in reverse isolation in single rooms. All medical and nursing staff and relatives as well as visitors in contact with the patients wore caps, gowns, sterile surgical gloves, face masks and sterile boots, and washed their hands with iodine solution before visits. Food was sterilized in microwave ovens. Strict precautions were taken in puncturing the skin and intramuscular injections were restricted. Vascular access for Patients A and B was with Hickman double lumen catheters for intravenous fluids, drug administration, total parenteral nutrition, and blood and component therapy transfusions, as well as for taking laboratory blood samples.

(3) *Transfusion.* Administration of packed red blood cells was indicated to maintain the haemoglobin level higher than 100 $g \cdot L^{-1}$. HLA compatible platelet concentrates donated by matched brothers were obtained by standard haematological techniques with an intermittent cell separator machine (Haemonetics 30S, Braintree, Massachusetts, USA). Transfusions were administered when the platelet count was below 20 000 μL^{-1} or when there were signs of bleeding with a platelet count of below 50 000 μL^{-1}. All blood cell products administered were first irradiated to 20 Gy in order to prevent acute graft versus host disease after the transfusion.

(4) *Clinical nutrition.* Nutritional conditions were carefully evaluated. Patient A was put on parenteral nutrition and Patients A and B on enteral nutrition. Supervision was on a daily basis; nitrogen balance and calorimetric estimates were made and potassium, calcium and albumin counts were performed, and diets were adjusted accordingly in an attempt to overcome the patients' calorie and protein malnutrition on admission. (A detailed description is given in Annexes I and II.)

(5) *Intestinal sterilization.* Oral and intestinal sterilization with nystatin and trimethoprim–sulphamethoxasole was indicated for Patient A; likewise for Patients B and C but in the neutropenic period only.

(6) *Treatment of infectious complications.* Systemic administration of amikacin, vancomycin and cephtazidime IV was used successfully to treat staphylococcal infections in Patients A and B, with fever remission after three days of therapy. Only Patient A received amphotericin B for oral, oesophagal and urinary infection by *Candida albicans*, demonstrated by signs and symptoms as well as by direct identification and cultures.

(7) *Treatment of haematological disturbances.* The three patients met the established criteria for bone marrow depression of differing severities. They were referred to the medical staff in the Angeles del Pedregal Hospital for inclusion in the

bone marrow transplantation programme. However, bone marrow transplantation was considered not to be indicated in view of the poor clinical condition of Patients A and B and well known complications of the treatment (high risk of infection due to long term immunosuppression, graft versus host disease, drug toxicity) and uncertainties about the follow-up and treatment in San Salvador.

Treating the bone marrow depression

Since the precise indications for bone marrow transplantation in patients who have received high radiation doses due to whole body irradiation in accidents remain uncertain, it was decided to use recombinant human GMCSF (rHuGMCSF; supplied by Scheramex Laboratories, Mexico City) on the basis of its ability to reduce the interval of life threatening neutropenia associated with chemotherapy, as demonstrated in various clinical trials.

For all three patients, the administration of rHuGMCSF was commenced at a daily dose of 240 $\mu g \cdot m^{-2}$ body surface area by intravenous infusion for two hours until the total neutrophil count (TNC) had increased to at least 1500 μL^{-1}. The numbers of days required for TNC and for haematological recovery are indicated in Table IX. The medical team at the Angeles del Pedregal Hospital considered that the

TABLE IX. HAEMATOLOGICAL RECOVERY FOR PATIENTS A, B AND C

Patient	Number of days for recovery[a] of total neutrophil count (TNC)		Number of days for recovery of platelets		Number of days for recovery of haemoglobin	
	Since accident	Since first intake of GMCSF[b]	Since accident	Since first intake of GMCSF[b]	Since accident	Since first intake of GMCSF[b]
Patient A	44	20	132	108	—	—
Patient B	36	10	42	16	80	56
Patient C	43	9	41	7	48	14

[a] The criterion for recovery of the total neutrophil count is defined as an increase in the count of 1500 μm^{-1} over the lowest value recorded.

[b] rHuGMCSF was first administered to Patients A, B and C on Day 24 (Tuesday 28 February), Day 26 (Thursday 2 March) and Day 33 (Thursday 9 March) respectively. The figures given are the number of days for which rHuGMCSF was administered.

increase in TNC was due to the administration of rHuGMCSF in view of the following observations:

(a) The nadir of cytopenia after whole body irradiation was evident in the three patients upon admission to the Angeles del Pedregal Hospital, with spontaneous recovery expected only after at least three weeks.
(b) The number of days required for the TNC to increase to 1500 was 20 for Patient A, ten for Patient B and nine for Patient C from commencement of the course of rHuGMCSF. The haemoglobin and platelet values were 80 $g \cdot L^{-1}$ and 11 000 μL^{-1} for Patient A; 90 $g \cdot L^{-1}$ and 76 000 μL^{-1} for Patient B; and 78 $g \cdot L^{-1}$ and 133 000 μL^{-1} for Patient C. The patients were dependent on transfusions at this time.
(c) The spontaneous recovery of haemoglobin and platelet counts was greater than that of TNC, which bears out the fact that rHuGMCSF stimulates granulocyte precursors only.
(d) Bone marrow aspiration when TNC reached 1500 μL^{-1} showed increased granulocyte mass and decreased red blood and megakaryocyte precursors.
(e) The increase in eosinophils in Patients A and B also suggested indirect effects of rHuGMCSF.

In early June the bone marrow aspiration showed dishaematopoietic morphological changes despite normal serum levels of iron, folic acid and vitamin B12 and this was the reason for the persistence of anaemia 172 days after admission.

Acute local radiation injury

Severe radiation injuries to the skin and underlying tissues of the lower extremities of Patients A and B were manifested by swelling, erythema, hyperpigmentation, epilation, and dry and wet desquamation. Radiodermatitis was observed in the anterior abdominal wall and chest in Patient A, and swelling of the lower legs after three days. Significant oedema and erythema were seen after a week in Patient A. Epilation with dry and wet desquamation was evident by a week after the accident (see Figs 18–20). The patterns of epilation and desquamation as well as the degree and extent of local skin injury reflect each person's position in relation to the source at the time of the exposure.

Treatment of acute local radiation injury consisted of daily surgical debridement with the use of antiseptic and analgesic solutions and topical antibiotics. Areas of dry desquamation were observed and were allowed to evolve through an expected clinical course of sloughing and epithelialization. By early June the extensive dry desquamation experienced by Patient A had evolved its clinical course and, with the exception of the hands, the skin appeared normal. His hands were partially depigmented and covered with thin, fragile epithelium. They were fully functional and not painful.

By early June only partial healing was evident of the parts of the body that had sustained high doses, namely the feet and lower legs. The patients were unable to stand and were experiencing severe pain from which almost no analgesic drugs or narcotics gave any relief. A mild response was found only with meperidine IV. Amniotic membranes were used to cover the plantar surfaces of the patients' feet. The blood flow to the lower extremities was evaluated by blood pool imaging, Doppler tests and magnetic resonance imaging. No significant circulatory embarrassment or deep tissue necrosis was revealed.

Nevertheless, a progressive dry gangrene occurred in the right foot of Patient A which ultimately necessitated amputation above the knee on Day 132 (Friday 16 June). A similar but delayed process was evident in Patient B, leading to amputation of the left leg on Day 161 (Saturday 15 July). Platelet recovery occurred; however, pain increased and there was progressive necrosis in the feet with no response to the antiaggregating agents used. After amputation, the general condition of Patients A and B improved and their requirements for drugs to reduce pain were less.

On Day 173 (Thursday 27 July), Patients A and B left the Angeles del Pedregal Hospital and were returned to the Medico-Surgical Hospital of the ISSS in San Salvador. Patient C, who experienced no severe localized radiation injury, returned to San Salvador on Day 55 (Friday 31 March), having recovered from his haematological depression.

Psychiatric treatment

Depression and anxiety were the main psychological disturbances suffered by the patients, and pain in the feet contributed to their emotional upset, especially for Patient A. Psychological and emotional support given by medical staff, nurses and family members were essential to the care of all three patients. Psychiatric consultations were made when necessary, and therapy was given to counter depression and anxiety arising as a result of prolonged confinement, incapacitating pain, fear of amputation, fear of dying, and separation from family and friends. Antidepressant medication was given when necessary.

AII.3. FURTHER TREATMENT IN SAN SALVADOR

Patient A

After returning to San Salvador on Day 173 (Thursday 27 July), Patient A remained at home until Day 177 (Monday 31 July) and was then transferred to a special room prepared for him in the Medico-Surgical Hospital. The follow-up treatment could not be fully carried out, mainly owing to the unavailability of prescribed

medicaments. On Day 187 (Thursday 10 August), a few days after his readmission to hospital in San Salvador, Patient A's condition began to deteriorate. By Day 191 (Monday 14 August) his condition had become critical, with high fever, rapid breathing, pneumonia, infection of his other (left) leg, poor circulation and low blood pressure, and he was moved to the intensive care unit. On Day 192 (Tuesday 15 August) he sustained a pneumothorax as a consequence of the perforation of the lung membrane by a catheter. His haemoglobin count fell from 100 to 50 $g \cdot L^{-1}$, and the concentration of thrombocytes dropped to 20 000 μL^{-1}. The treatment plan prescribed was for blood transfusion, administration of antibiotics and albuminum infusion. Nevertheless, it was considered that he might still recover from this condition after the planned amputation of his other (left) leg.

Patient A died at 07:00 on Sunday 20 August, 197 days after the accident. Since his family did not give the permission necessary for a post-mortem examination to be performed, no definite cause of death can be stated. Radiation induced pneumonitis complicated by traumatic perforation of the lung membrane may be considered to be the main cause of death.

Patient B

After returning to San Salvador on Day 173 (Thursday 27 July), Patient B also remained at home until a special room was set up for him in the Medico-Surgical Hospital. His general condition continued to improve, but the condition of his other (right) leg worsened, with poor circulation, infection and extreme pain. Wide antibiotic coverage was prescribed before amputation was performed on Day 202 (Friday 25 August). Subsequently, Patient B was recovering and was in good physical and mental condition. However, his risk of developing cataracts is high.

Patient C

Patient C returned home to San Salvador on Day 55 (Friday 31 March) and from Day 58 (Monday 3 April) he was under observation as an outpatient by the ISSS. Except for residual but less evident effects in his left foot, the prognosis for his full recovery is good. On Day 199 (Tuesday 22 August) he returned to work at the plant and on Day 220 (Tuesday 12 September) he commenced physiotherapy for his left foot.

Annex I

PATIENT A: A NUTRITIONAL REPORT BY THE ANGELES DEL PEDREGAL HOSPITAL IN MEXICO CITY

Patient A entered the Angeles del Pedregal Hospital with a diagnosis of exposure to ionizing radiation resulting in secondary dermatomucositis and medullary hypoplasia. In the first evaluation of his condition, on Day 25 (Wednesday 1 March), a body weight of 50 kg was noted, representing 82% of the theoretically appropriate weight for his height (1.65 m) and average build. Patient A had lost 10 kg in the previous month. The tricipital cutaneous fold measured 6 mm (50% of the theoretical value), 23 mm being the sum of the four standard folds and 220 mm the mesobrachial circumference. The laboratory reported serum albumin of 34 $g \cdot L^{-1}$, which became 23 $g \cdot L^{-1}$ once the patient had undergone hydration; serum globulins were 24 $g \cdot L^{-1}$. Indirect calorimetry indicated an energy consumption of 1800 kcal (7530 kJ) with oxidation of 130 g in lipids, 95 g in carbohydrates and 60 g in proteins, a pattern suggesting the presence of sepsis. This evidence indicated the following body composition: brachial muscular area about 22 cm^2; muscular mass 14 kg; fat mass 4 kg; lean mass 46 kg; total body water 34 kg; this pointed to a weight deficit of 10 kg in muscular mass and a diagnosis of second grade protein denutrition.

A diet was worked out containing 3000 kcal (12 550 kJ), with 100 g of protein, 410 g carbohydrates, 105 g lipids, 120 milliequivalent (mEq) sodium [one milliequivalent is the number of grams of solute contained in one millilitre of Normal solution], 140 mEq potassium, and 45 mMol phosphates and calcium. It was hoped that this diet would lead to a weight increase of 220 g per day.

To deal with anorexia and poor absorption, parenteral feeding was adopted from the time of Patient A's admission to the hospital on Day 25 (Wednesday 1 March) until Day 67 (Wednesday 12 April). His admittedly scant oral ingestion was continued at the same time in order to maintain trophic stimulus to the intestinal mucosa. During this period, twenty-four hour losses of uric nitrogen in urine were 20–37 g (daily average) with creatinine excretion of 0.97–1.00 $g \cdot d^{-1}$, indicating a serious catabolic state. During this period, the net nitrogen loss was between 3 $g \cdot d^{-1}$ and 6 $g \cdot d^{-1}$, equivalent to a loss of muscular mass of 180 $g \cdot d^{-1}$.

When parenteral feeding was started, the patient's energy consumption rose to 2440 kcal (10 210 kJ) with oxidation of 104 g of lipids, 207 g of carbohydrate and 138 g of protein. No mechanical, metabolic or septic complications that could have been attributed to the parenteral feeding were detected during the whole period (certain extreme laboratory results were explained by the fact that samples had been taken by catheter during the parenteral feeding).

When the cycle of parenteral feeding was finished, we noted a weight increase to 55 kg and an increase in the tricipital cutaneous fold to 7 mm, with the mesobrachial circumference remaining at 220 mm. Twenty-four hour urinary creatinine dropped to 0.71 g and serum albumin rose to 30 $g \cdot L^{-1}$. The ending of the parenteral feeding cycle, decided on since the malabsorption problem seemed to have been solved, coincided with the suspension of the administration of the medullary stimulation factor and a reduction in urinary excretion of nitrogen. This exceptionally important reduction led us to think of the medullary stimulation

factor as a catabolic agent for extramedullary tissue (as is reported in connection with other similar substances).

During the period from Day 68 (Thursday 13 April) to Day 87 (Tuesday 2 May), the patient's oral ingestion was carefully monitored; we noted, however, that there was no adequate acceptance of the diet owing to anorexia with a consequent loss of 6 kg in weight. During this period ingestion did not rise above 1200 kcal (5020 kJ) and 45 g of protein, whereas the measured energy consumption was about 1500 kcal (6280 kJ). A nasogastric probe was therefore inserted in order to cover the patient's nutritional requirements. At the outset there was a certain intolerance of the enteral feeding which manifested itself in nausea and steatorrheic stools, as a result of which high doses of pancreatic enzymes had to be administered together with loperamide up to 30 $mg \cdot d^{-1}$. In this way it was possible to restore adequate digestion and absorption, according to the clinical indicators, and the patient's weight increased by 2 kg within 40 days.

Following supracondylar amputation of the right leg, the patient weighed 43 kg, and it was possible to maintain a daily weight increase of 40 g. On Day 157 (Tuesday 11 July) serum albumin was 27 $g \cdot L^{-1}$; anthropometry indicated a weight of 44 kg with a tricipital cutaneous fold of 3.5 mm, a mesobrachial circumference of 205 mm and the sum of the four folds 16 mm, indicating recovery of the brachial muscular area to 22 cm^2. Energy consumption was evaluated by calorimetry to be 1500 kcal (6280 kJ), whereas it was not possible for oral ingestion to rise above 1300 kcal (5440 kJ) and 65 g of protein. The possibility of malabsorption was evaluated by determining the fat content of the faeces once the administration of pancreatic enzymes and loperamide had been suspended, and the possibility of pancreatic insufficiency or other damage was investigated by tomography of the pancreas. These possibilities were thereby eliminated.

The nutritional diagnosis remained second degree denutrition with serious muscle wastage through disuse without malabsorption. During the patient's hospitalization it was impossible to carry out an intensive physiotherapy programme owing to his state of severe psychic depression. The nutritional plan for the following days required an energy input of 2500 kcal (10 460 kJ) with 120 g of protein, 300 g of carbohydrate and 90 g of lipids, in a fractionated oral diet including five meals (breakfast at 07:30, a mid-morning snack at 11:00, lunch at 13:00, tea at 17:00 and dinner at 21:00). Enteral feeding was to be resorted to if the anorexia persisted, with a nasogastric probe and infusions of 400 mL every three to four hours. This diet would need to be supplemented by calcium ($2 g \cdot d^{-1}$), orally administered multivitamins and zinc sulphate ($25 mg \cdot d^{-1}$). Among the factors responsible for the persistent denutrition in Patient A's case must be listed firstly anorexia and secondly the disuse of muscular function, both being secondary to the severely depressed state of the patient. There seemed to be no objective organic conditions that would have justified the anorexia.

It should be noted that throughout his hospitalization Patient A remained bedridden with very little activity, a situation which favours not only muscular but also bone catabolism, and it was not possible to reverse the latter even by administering high doses of calcium ($1.5–3.0 g \cdot d^{-1}$). Without supplementary calcium, a substantial rise in alkaline phosphatase was observed, which did not drop off completely even when the calcium supplement was resumed. For practical purposes, it might have been useful to try calcitonin, but not in the areas affected by radiation and osteomalacia. In the event that bone decalcification persisted, when active mobilization was recommenced it would have been important to test the response to calcitonin in vivo before administering this compound on a therapeutic basis.

The following points remained to be clarified:

(1) The question of whether a forced, intensive physiotherapy programme applied from the beginning would have modified the evolution of muscular wastage and improved the trophism of the affected muscle and skin.

(2) The question of whether the use of medullary stimulation factor played a decisive role in inducing the catabolic state observed in Patient A.

Annex II

PATIENT B: A NUTRITIONAL REPORT BY THE ANGELES DEL PEDREGAL HOSPITAL IN MEXICO CITY

Patient B was referred to Clinical Nutrition on Day 26 (Thursday 2 March) with a diagnosis of exposure to ionizing radiation and secondary dermatomucositis.

Physical examination revealed the following alterations: thin skin, conjunctival pallor, fissured lips, bleeding gums, hot tongue, xerosis of the skin, altered pigmentation and muscular hypotonia.

Patient B's weight on admission on Day 26 (Thursday 2 March) was 60 kg (84% of the theoretically appropriate value): his normal weight was 65 kg (91% of the theoretically appropriate value) and he had lost 5 kg over the previous month. His height was 1.77 m, the tricipital cutaneous fold was 8 mm (80% of the theoretical value), and the sum of the four principal folds was 26 mm. The patient was slight of build and showed poor physical autonomy. The laboratory reported serum albumin of 34 $g \cdot L^{-1}$, lymphocytes 500 μm^{-3} and twenty-four hour urinary creatinine 1.4 g.

These data enabled us to calculate the following body composition: brachial muscular area 36 cm^2; fatty mass 6 kg; lean mass 53 kg; muscular mass 23 kg; total body water 39 kg. This added up to a weight deficit of 4 kg, including 3 kg muscular mass.

Indirect calorimetry indicated an oxygen consumption of 325 $mL \cdot min^{-1}$ and carbon dioxide production of 277 $mL \cdot min^{-1}$, with a respiratory quotient of 0.85, corresponding to a consumption of 2300 kcal (9620 kJ), with oxidation of 204 g glucose, 89 g lipids and 130 g protein.

The nutritional diagnosis was first grade protein denutrition. The nutritional recommendations were as follows: energy input 3300 kcal (13 810 kJ); protein 130 g; carbohydrates 530 g; lipids 98 g; sodium 70 mEq; potassium 130 mEq; calcium and phosphorus 49 mMol. With this prescription it was hoped to bring about a daily increase of 200 g in body weight. The feeding path initially recommended was oral, but in view of the patient's poor oral ingestion of the recommended diet and his rejection of an enteral probe, it was decided to supplement the diet by parenteral feeding since a central catheter was available. The parenteral feeding was started on Day 27 (Friday 3 March) and continued until Day 49 (Saturday 25 March), providing 85 g amino acids, 200 g glucose, 100 g lipids and 2100 kcal (8790 kJ) in total by this path. In conjunction with oral ingestion, the parenteral feeding succeeded in arresting the patient's intense catabolic decline and in improving the nitrogen balance from $-20\ g \cdot d^{-1}$ to $-1\ g \cdot d^{-1}$, which reduced muscle loss to approximately 30 $g \cdot d^{-1}$. At the end of the parenteral feeding period (22 days) the serum albumin level had risen slightly to 36 $g \cdot dL^{-1}$; the anthropometric values remained constant. There were no mechanical, metabolic or infectious complications in the administration of parenteral feeding.

When the parenteral support was suspended, oral ingestion remained within acceptable limits during the first two weeks, then dropped successively to values of 1500 kcal (6280 kJ) and 1200 kcal (5020 kJ) and 40 g protein, which meant a progressive weight loss of 100–150 $g \cdot dL^{-1}$. The reason for the reduced oral ingestion in the following three months was anorexia due to depression and poor acceptance of the standard meals provided by the hospital.

On Day 169 (Sunday 23 July) a new evaluation was made, revealing twenty-four hour creatinine excretion in the urine of 1.05 g; weight 49 kg (68% of theoretical); tricipital cutaneous fold 8 mm (80% of theoretical); sum of the four folds 28 mm; a mesobrachial circumference of 243 mm (90% of theoretical); brachial muscular area 28 cm^2; fat body mass 5 kg; lean mass 43 kg; muscular mass 19 kg; total water 31 kg; and a deficit of 10 kg of muscular mass. The albumin value was 41 $g \cdot L^{-1}$ and the oncotic pressure was 32 mmHg.

In view of the albumin value and the absence of sepsis or a critical state, a diagnosis of second degree protein-muscle malnutrition of the marasmic type was then made. On many occasions it was planned to try the enteral path to supplement the patient's scant oral ingestion, using a nasogastric probe, but in consequence of the patient's rejection of this probe it was finally decided to use strictly supervised oral feeding, which had variably satisfactory results.

From Day 150 (Tuesday 4 July) onwards it was possible to maintain oral ingestion above 2000 kcal (8370 kJ), as compared with a measured energy output of 1600 kcal (6690 kJ), with oxidation of 177 g carbohydrates and 45 g protein. This permitted a daily weight increase of approximately 100 g, and the patient's weight rose to 50.5 kg by Day 159 (Thursday 13 July). Following amputation, in order to alleviate the intense trauma induced catabolism, peripheral parenteral feeding was applied for two days with an input of 1900 kcal (7950 kJ), 100 g lipids, 85 g amino acids and 180 g glucose. Once oral ingestion had been completely restored, this parenteral support was suspended. The nutritional recommendations as of Day 166 (Thursday 20 July) were 2700 kcal (11 300 kJ), 420 g glucides, 67 g lipids and 100 g protein, with 100 mEq potassium, 40 mMol calcium and orally administered vitamin supplements, the diet being without restriction and divided into four meals per day.

LIST OF PARTICIPANTS

REVIEW MEETING
ON THE ACCIDENT IN SAN SALVADOR

San Salvador
24–28 July 1989

Croft, J. R. *(Chairman)*	National Radiological Protection Board, United Kingdom
Borrás, C.	Pan American Health Organization of the World Health Organization
Chu, R.	Nordion International Inc., Canada
Defalco, G.	Nordion International Inc., Canada
Granados, Taufik Esmahan	Pan American Health Organization of the World Health Organization
Kenneke, A.	International Atomic Energy Agency
Lemus, R.	Delmed Ltd, El Salvador
Melara, N.E.	University of San Salvador, and Rosales Hospital, Ministry of Health, El Salvador
Millian, L.	Ministry of Labour and Social Security, El Salvador
Monje, Hugo Prado *(part-time)*	Pan American Health Organization of the World Health Organization
Toruño, H.R.	Institute of Social Security, El Salvador
Zúñiga-Bello, P.	International Atomic Energy Agency

LIST OF CONTRIBUTORS

Drafting of the report by the IAEA

Croft, J.R.	National Radiological Protection Board, United Kingdom
Kenneke, A.	International Atomic Energy Agency
Zúñiga-Bello, P.	International Atomic Energy Agency
Delves, D. (Editor)	International Atomic Energy Agency

Review of the draft report

Asculai, E.	International Atomic Energy Agency
Barabanova, A.	International Atomic Energy Agency
Borrás, C.	Pan American Health Organization of the World Health Organization
Burger, M.	Radiation Emergency Assistance Center/ Training Site (REAC/TS) of the US Department of Energy, United States of America
Chu, R.	Nordion International Inc., Canada
Cloutier, R.	Oak Ridge Institute of Nuclear Studies, Inc., United States of America
Defalco, G.	Nordion International Inc., Canada
Echegoyen de Hernández, A.	Primero de Mayo Hospital, Institute of Social Security, El Salvador
Hurtado Monrroy, R.	Angeles del Pedregal Hospital, Mexico City, Mexico
Lemus, R.	Delmed Ltd, El Salvador
Littlefield, G.	REAC/TS, US Department of Energy, United States of America

Lushbaugh, C.	REAC/TS, US Department of Energy, United States of America
Melara, N.	University of San Salvador, and Rosales Hospital, Ministry of Health, El Salvador
Millian, L.	Ministry of Labour and Social Security, El Salvador
Ricks, R.	REAC/TS, US Department of Energy, United States of America

Medical team, Angeles del Pedregal Hospital, Mexico City

Ahumada, M.
Alanís, A.
Alvarez Tostado, Raul
Alvarez Tostado, Roberto
Armendáriz, C.
Borbolla, J.
Carrillo, S.
Florez Córdoba, N.
Frankel, D.
García Velazco, J.
Guadalajara Boo, J.
Gutierrez Carreño, R.
Hurtado Monrroy, R.
Ibarrola, J.L.
Lascurain, E.
León Rodriguez, E.
López Karpovitch, J.
Madrazo, M.
Maisterrena, J.
Masse, S.
Molinar, L.
Mutchinic, O.
Ortega Cerda, J.
Pasquel, C.
Pasqueti, A.
Portela, J.M.
San Martín, J.
Secin, R.
Sierra, A.M.
Simón, J.
Sosa Sánchez, R.
Valenzuela, J.

HOW TO ORDER IAEA PUBLICATIONS

An exclusive sales agent for IAEA publications, to whom all orders and inquiries should be addressed, has been appointed in the following country:

UNITED STATES OF AMERICA — UNIPUB, 4611-F Assembly Drive, Lanham, MD 20706-4391

In the following countries IAEA publications may be purchased from the sales agents or booksellers listed or through major local booksellers. Payment can be made in local currency or with UNESCO coupons.

ARGENTINA	Comisión Nacional de Energía Atómica, Avenida del Libertador 8250, RA-1429 Buenos Aires
AUSTRALIA	Hunter Publications, 58 A Gipps Street, Collingwood, Victoria 3066
BELGIUM	Service Courrier UNESCO, 202, Avenue du Roi, B-1060 Brussels
CHILE	Comisión Chilena de Energía Nuclear, Venta de Publicaciones, Amunategui 95, Casilla 188-D, Santiago
CHINA	IAEA Publications in Chinese: China Nuclear Energy Industry Corporation, Translation Section, P.O. Box 2103, Beijing IAEA Publications other than in Chinese: China National Publications Import & Export Corporation, Deutsche Abteilung, P.O. Box 88, Beijing
CZECHOSLOVAKIA	S.N.T.L., Mikulandska 4, CS-116 86 Prague 1 *Alfa, Publishers, Hurbanovo námestie 3*, CS-815 89 Bratislava
FRANCE	Office International de Documentation et Librairie, 48, rue Gay-Lussac, F-75240 Paris Cedex 05
HUNGARY	Kultura, Hungarian Foreign Trading Company, P.O. Box 149, H-1389 Budapest 62
INDIA	Oxford Book and Stationery Co., 17, Park Street, Calcutta-700 016 *Oxford Book and Stationery Co., Scindia House, New Delhi-110 001*
ISRAEL	Heiliger & Co. Ltd. 23 Keren Hayesod Street, Jerusalem 94188
ITALY	Libreria Scientifica, Dott. Lucio de Biasio "aeiou", Via Meravigli 16, I-20123 Milan
JAPAN	Maruzen Company, Ltd, P.O. Box 5050, 100-31 Tokyo International
PAKISTAN	Mirza Book Agency, 65, Shahrah Quaid-e-Azam, P.O. Box 729, Lahore 3
POLAND	Ars Polona-Ruch, Centrala Handlu Zagranicznego, Krakowskie Przedmiescie 7, PL-00-068 Warsaw
ROMANIA	Ilexim, P O. Box 136-137, Bucharest
SOUTH AFRICA	Van Schaik Bookstore (Pty) Ltd, P.O. Box 724, Pretoria 0001
SPAIN	Díaz de Santos, Lagasca 95, E-28006 Madrid Díaz de Santos, Balmes 417, E-08022 Barcelona
SWEDEN	AB Fritzes Kungl. Hovbokhandel, Fredsgatan 2, P.O. Box 16356, S-103 27 Stockholm
UNITED KINGDOM	Her Majesty's Stationery Office, Publications Centre, Agency Section, 51 Nine Elms Lane, London SW8 5DR
USSR	Mezhdunarodnaya Kniga, Smolenskaya-Sennaya 32-34, Moscow G-200
YUGOSLAVIA	Jugoslovenska Knjiga, Terazije 27, P.O. Box 36, YU-11001 Belgrade

---

Orders from countries where sales agents have not yet been appointed and requests for information should be addressed directly to:

Division of Publications
International Atomic Energy Agency
Wagramerstrasse 5, P.O. Box 100, A-1400 Vienna, Austria

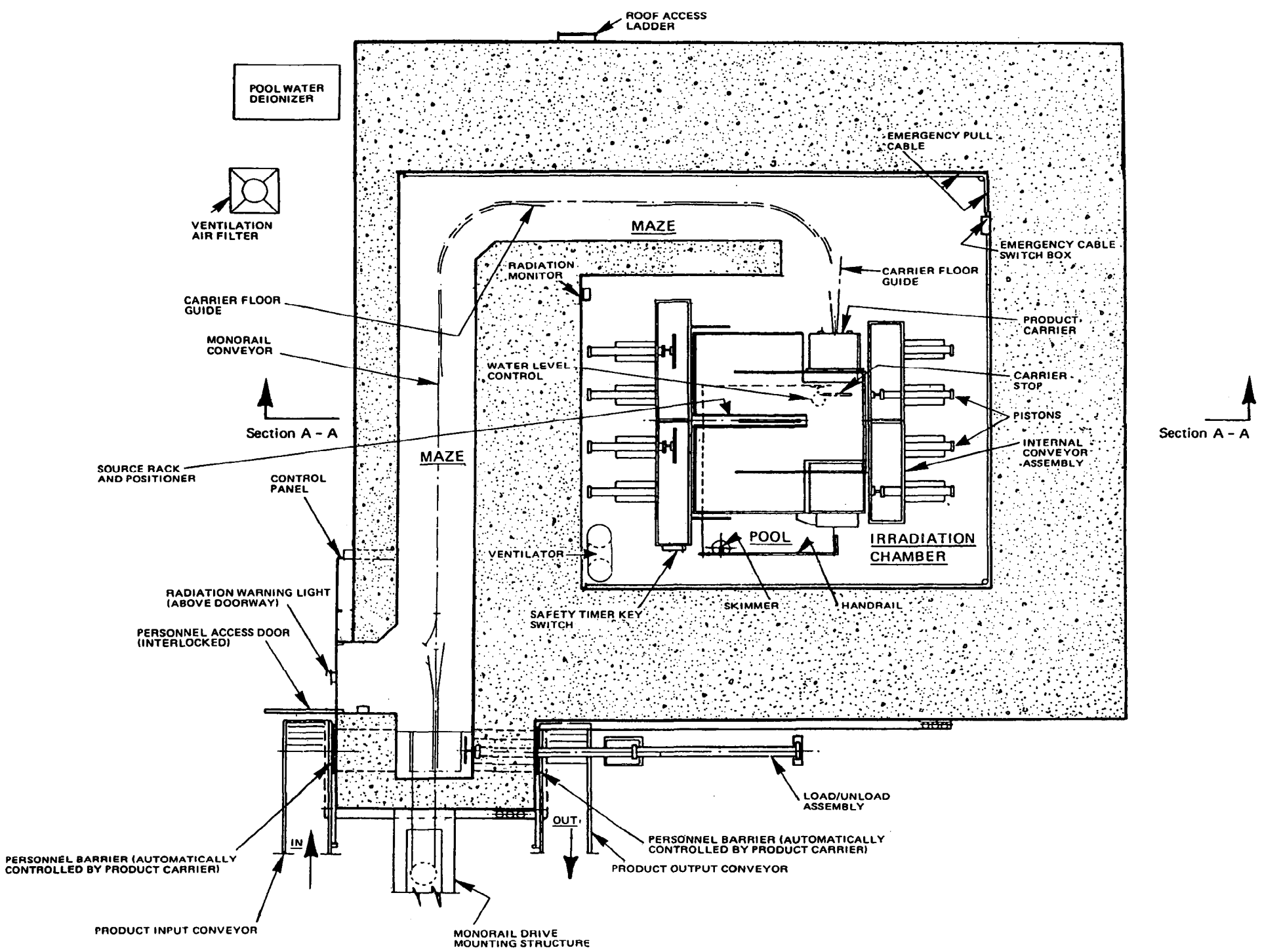


FIG. 2. A floor plan of the irradiation facility and JS6300 irradiator. (By courtesy of Nordion International Inc.)

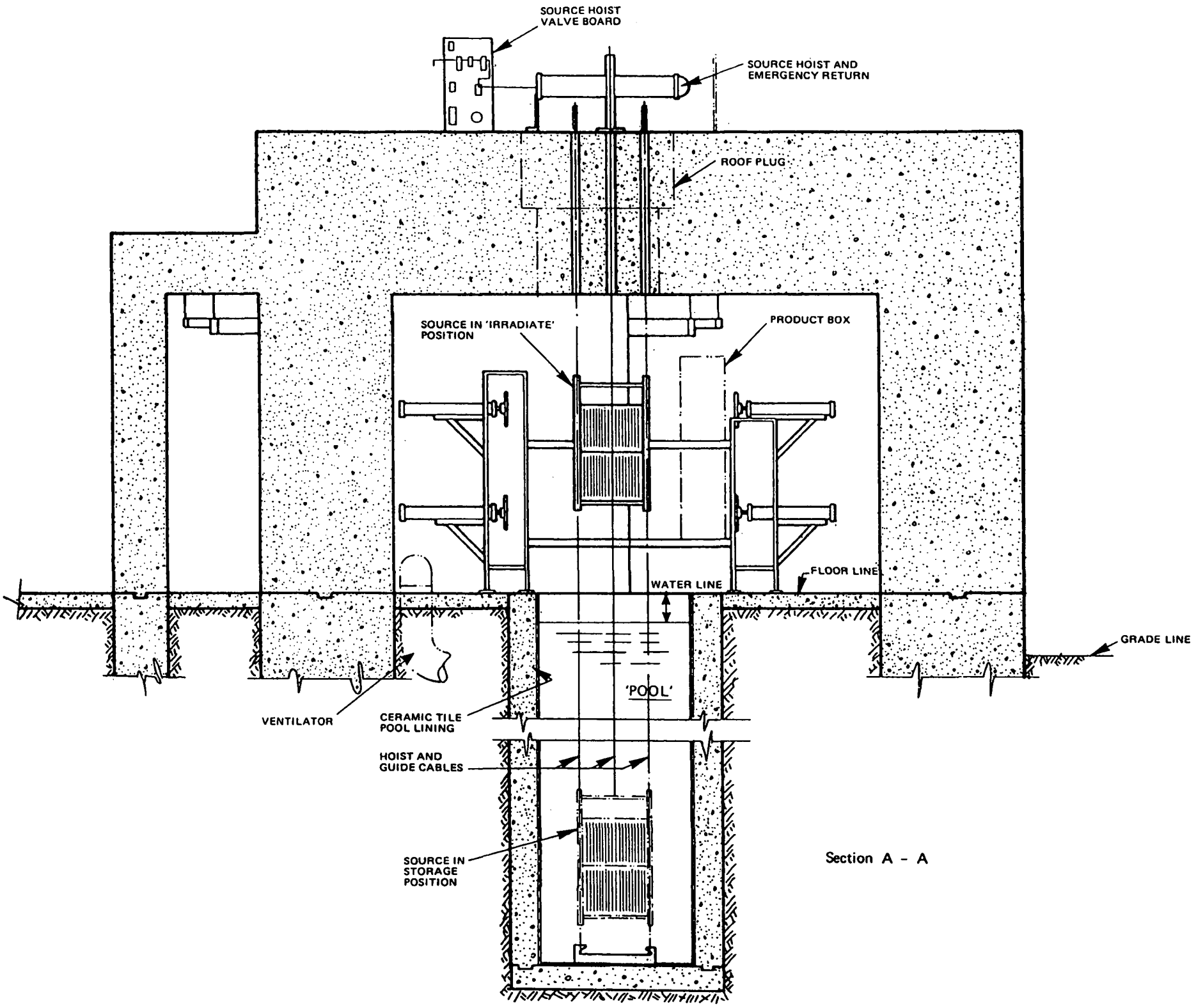


FIG. 3. A cross-sectional elevation of the irradiation facility through Section A–A (see Fig. 1). (By courtesy of Nordion International Inc.)

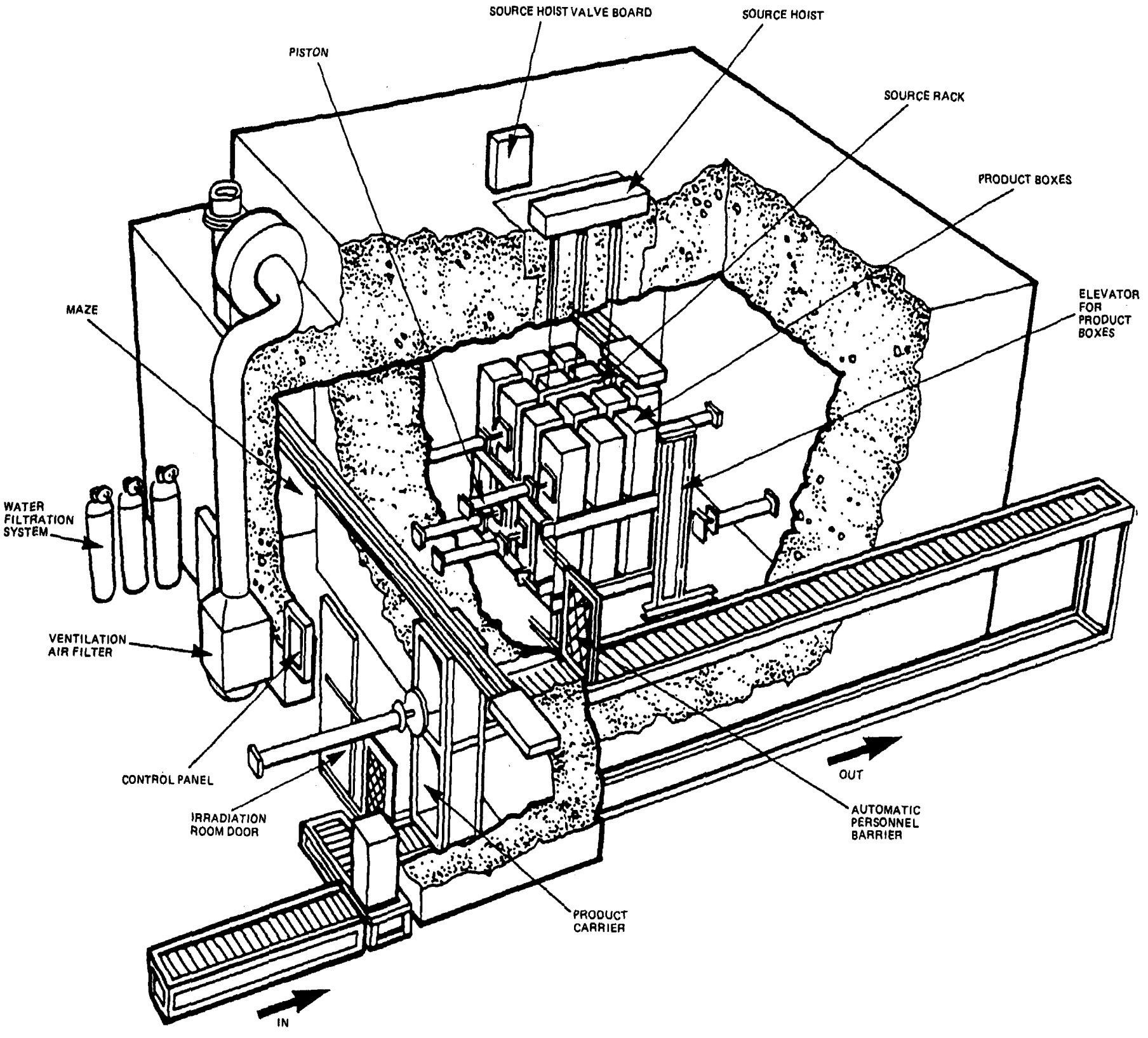


FIG. 4. A cutaway three dimensional diagram of the J6300 irradiator and the irradiation facility. (By courtesy of Nordion International Inc.)

INTERNATIONAL
ATOMIC ENERGY AGENCY
VIENNA, 1990