The Radiological Accident in Istanbul

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FOREWORD

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

A serious radiological accident occurred in Istanbul, Turkey, in December 1998 and January 1999 when two packages used to transport ^{60}Co teletherapy sources were sold as scrap metal. The persons who purchased the two packages opened them and broke open the shielded containers, thereby unknowingly exposing themselves and several others to radiation from at least one unshielded ^{60}Co source. The persons who dismantled the containers suffered from acute radiation syndrome. The accident came to the attention of the relevant national authority when a doctor who had examined the victims reported that he suspected the possibility of radiation exposure. The national authorities identified other individuals who might have undergone acute radiation exposures, and a total of 18 persons (including seven children) were admitted to hospital. Of these, ten adults exhibited clinical signs and symptoms of acute radiation exposure.

Under the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, the Turkish authorities requested assistance from the IAEA in terms of advice on the medical treatment of persons and assistance in the emergency response to the accident and the subsequent investigation. The IAEA is grateful to the Turkish authorities for their assistance in the preparation of this report, and is also grateful for the assistance of the Çekmece Nuclear Research and Training Centre and the Radiation Health and Safety Department of the Turkish Atomic Energy Authority; the Turkish medical doctors from Haseki State Hospital; the Haematology Department, Cerrahpasa Medical Faculty of Istanbul University; Gülhane Military Medical Academy; Küçükçekmece Outpatient Department; and the specialists of the four laboratories involved in the biodosimetric analyses.

The IAEA wishes to thank the experts from the Curie Institute, France, and the National Radiological Protection Board, United Kingdom, who went to Istanbul to assist. The IAEA technical officers responsible for the preparation of this publication were I. Turai and J. Wheatley of the Division of Radiation and Waste Safety.

EDITORIAL NOTE

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CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

A common use of high activity ^{60}Co sources around the world is in the treatment of cancer patients (radiotherapy). In Turkey alone there are 46 radiotherapy centres. Intense beams of penetrating gamma radiation are needed to treat the cancer, hence high activity sources are used in specially designed machines to deliver the radiation dose in a controlled manner. The intensity of the radiation decreases over time, however, and the sources need to be replaced to avoid long treatment times. The services of specialist companies are normally used to exchange the sources and maintain the equipment.

One such specialist company, based in Ankara, Turkey, was licensed by the Turkish Atomic Energy Authority (TAEK) to import, transport and re-export radioactive sources. Specially designed shielded packages were used to transport the sources. In 1993, this company is recorded as having loaded three spent radiotherapy sources into individual Type B(U) transport packages in preparation for returning them to the original supplier in the United States of America. TAEK officials checked the packages, inspected the warning signs and transport labels, and issued the company with permission to transport and export the packages. The company did not send the packages to the original supplier, however, but stored them in Ankara from 1993 until 1998, without informing the TAEK.

In February 1998 the company transported two of the packages from Ankara to Istanbul and stored them in their general purpose warehouse on an industrial estate. After some time there was no room in this warehouse and the packages were moved to adjoining premises that were empty. After nine months or so, the adjoining premises were transferred to new ownership and the new owners, not realizing what was in the packages, sold both of them as scrap metal. The packages were labelled with trefoils, but the persons who purchased them were unaware of the radiation hazard. They opened them and broke open the shielded containers, and thereby unwittingly exposed themselves and several others to radiation from at least one unshielded ^{60}Co source. This occurred in the residential area of Ikitelli in the Küçükçekmece district of Istanbul on 10 December 1998.

On 13 December 1998, a total of ten persons who had spent time in proximity with the dismantled containers fell ill and six of them began to vomit. Although they sought medical assistance, the cause of the illness was not recognized until almost four weeks later (on 8 January 1999). Over a period of about two weeks, pieces of the dismantled containers and at least one unshielded source were left in a residential area before being taken to a local scrapyard, where they were left for a further two weeks.

When the injuries were eventually suspected as having been caused by radiation exposure, the doctor immediately alerted the national authorities. As a result, one

unshielded source was quickly discovered at the scrapyard and safely recovered, thus preventing further radiation exposure. Subsequent examination showed that the source capsule had not been damaged and there had been no leakage of radioactive material. The activity of the recovered source was estimated to be 3.3 TBq (88 Ci) of ^{60}Co.

As a result of advice from the Çekmece Nuclear Research and Training Centre (ÇNAEM) and media reports, a total of 404 persons applied for medical or haematological checks because of fears about possible radiation exposure. Of these, a total of 18 persons (including seven children) were admitted to hospitals. Ten adults exhibited clinical signs and symptoms of acute radiation syndrome. The five more severely affected persons were hospitalized for 45 days. In addition, one person had signs of radiation induced skin injury on two fingers of the right hand.

The source that had supposedly been in the second container was never found, either at the scrapyard or anywhere else in Istanbul, or on any of the routes by which the containers were known to have been transported. This source is still unaccounted for at the time of publishing of this report. Records maintained by the company and the TAEK inventory give an estimated activity for this source, at 1 January 1999, of approximately 23.5 TBq (636 Ci) of ^{60}Co. However, the company's and the original supplier's records were reportedly unreliable, and it is still not clear whether the second container did actually contain a radioactive source. Investigations by the TAEK are continuing.

The IAEA is authorized to establish standards for radiation protection and the safety of sources of radiation, and to assist in their application. The International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BSS) [1] establish the requirements for protection and safety. It is presumed in the BSS that States have an adequate legal and regulatory infrastructure within which the requirements can effectively be applied. Requirements and guidance for the establishment of an appropriate infrastructure and on other relevant matters are issued in the IAEA Safety Standards Series; see also Ref. [2].

1.2. OBJECTIVE

For a number of years the IAEA has provided support and assistance, and conducted follow-up investigations upon request, in the event of serious accidents involving radiation sources. Reports have been published on follow-up investigations of radiological accidents in San Salvador [3], Soreq [4], Hanoi [5], Tammiku [6] and Goiânia [7, 8]. The findings and conclusions of these reports have provided a basis for drawing lessons on safety improvements [9–11].

The objective of this report is to compile information about the causes of the accident, the subsequent emergency response and the medical aspects of the overexposures. The information is intended for the use of national authorities and regulatory

organizations, emergency planners and a broad range of specialists, including physicists, technicians and medical specialists, and persons responsible for radiation protection. The report concludes with findings, conclusions and lessons to be applied to help avoid such accidents in the future and to minimize the consequences of any such accidents that do occur.

1.3. SCOPE

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

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

1.4. STRUCTURE

Background information about the radiation protection infrastructure in Turkey and the management of the company involved in the accident, and details of the sources, are provided in Section 2. An account of the events leading up to the accident and of the accident itself is given in Section 3. The emergency response to the accident, including the recovery of the source, the search for a second source and the response by the TAEK and the IAEA, is discussed in Section 4. Section 5 summarizes the medical aspects of the accident and Section 6 summarizes the dosimetric analyses. Findings and conclusions and lessons to be learned are presented in Section 7. The annexes provide more detailed information and data, including a chronology of the accident, medical data and information on biological dose estimation.

2. BACKGROUND INFORMATION

2.1. INFRASTRUCTURE FOR RADIATION PROTECTION IN TURKEY

The Preamble to the BSS [1] states that it is presumed in the Standards that Governments have an adequate national infrastructure in place in order to discharge

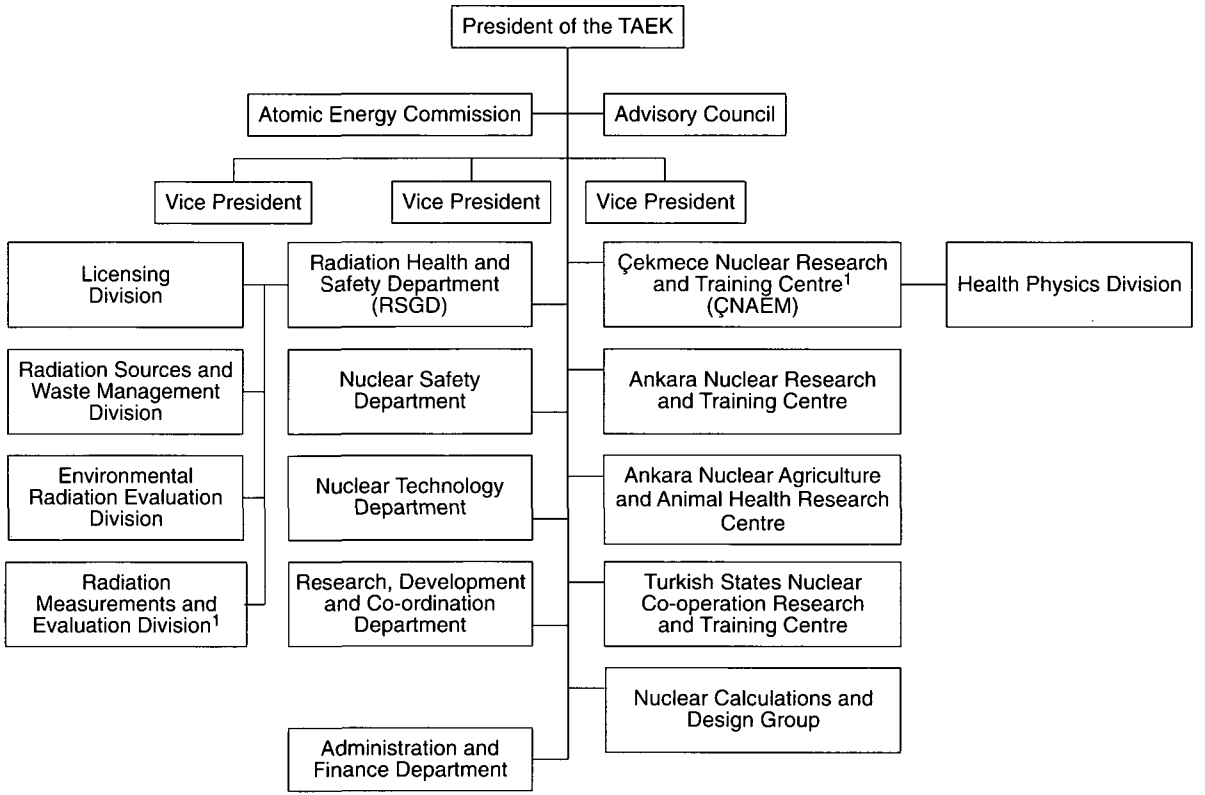


FIG. 1. Structure of the TAEK. [1]Control of radiation for centres in five prefectures of Turkey is carried out by the Radiation Health and Safety Department (RSGD), and for centres in the other two prefectures by the Health Physics Division of ÇNAEM, with the measurement results of the control being sent to the RSGD for evaluation.

their responsibilities for radiation protection and safety. In Turkey, the relevant national authority for regulating activities involving radioactive sources is the TAEK. The structure and responsibilities of the TAEK are shown in Fig. 1. Regulation is achieved by means of the regulatory structure illustrated in Fig. 2.

A full discussion of the requirements of the legislation referred to in Fig. 2 is beyond the scope of this report. However, the regulatory requirements most relevant to the accident are summarized below.

(a) It is prohibited to use, produce, import or export, purchase or sell, store or transport radiation sources without a licence from the Radiation Health and Safety Department (RSGD) of the TAEK. Before a licence is issued, the TAEK carries out inspections to ensure that the facilities, equipment, working procedures and arrangements for record keeping are satisfactory. The licence specifies the responsible qualified person(s), the technical specifications of the radiation sources and the address at which they are held, and is valid for five years.

(b) The officials of the TAEK are entitled to enter sites at any time to carry out inspections and audits, and to demand to examine any documents and/or certificates which they consider necessary.

(c) Additional permission is needed from the TAEK every time a source is imported to or exported from Turkey, and whenever a source is to be transported within Turkey. In order to obtain permission to transport sources, the consignor must comply with the Turkish Regulations for the Safe Transport of Radioactive Materials. Permission is granted when the TAEK has been provided with the appropriate paperwork, including details of the transport route and emergency plans. According to Article 59 of the previous Radiation Safety Regulations, the TAEK is required to make dose rate measurements around the transport packages. Imported sources are also subject to customs control by TAEK officials.

(d) Operators of radiotherapy facilities must notify the TAEK each time a source is to be changed. The TAEK is then required to make dose rate measurements to ensure that the shielding of the installation and treatment head is satisfactory for the new source. Additionally, the output values of ^{60}Co teletherapy sources are checked annually using TLDs by the method of dose comparison in the Secondary Standard Dosimetry Laboratory of the TAEK.

2.2. DESCRIPTION OF THE COMPANY

The company responsible for the cobalt sources is owned by a single person who employs approximately 20 persons. The company's headquarters are in Ankara,

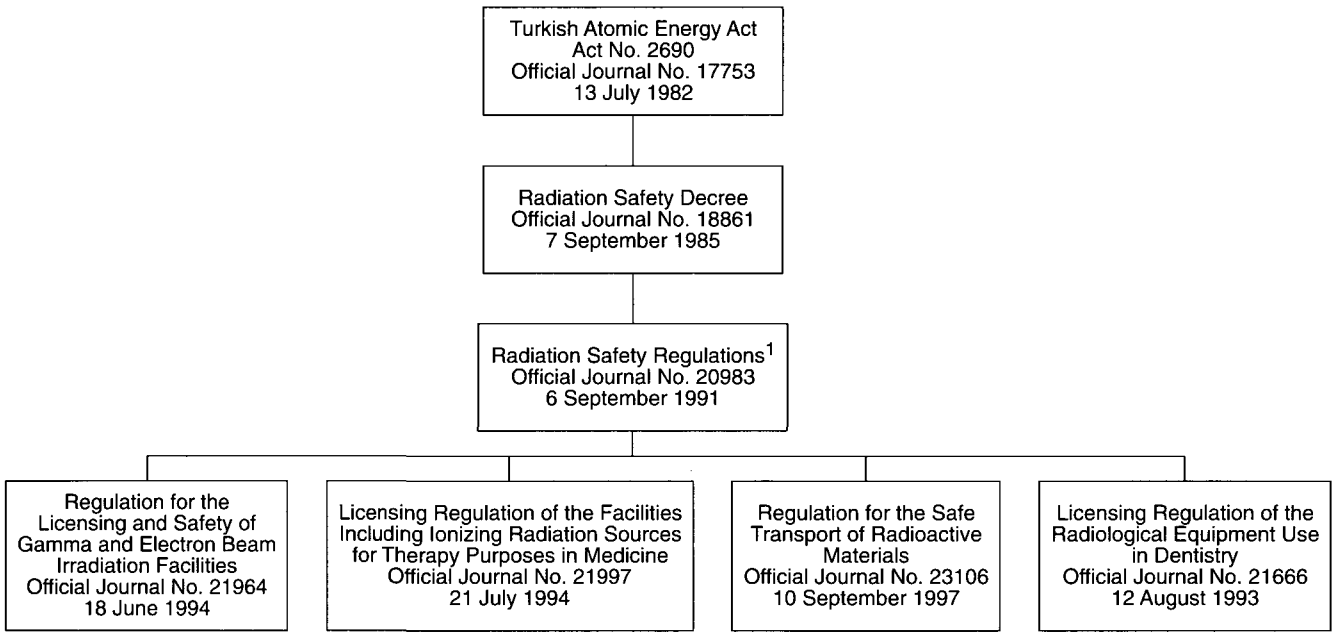


FIG. 2. Turkish legislation relating to the Atomic Energy Authority and to radiological protection and safety. [1]The revised version of the Radiation Safety Regulations, based on the BSS [1] and 96/29/Euratom EC Directive [12], was issued in March 2000 (Official Journal No. 23999).

where most of the employees are based. The company's main business is the supply and maintenance of diagnostic and radiotherapy equipment to medical establishments throughout Turkey.

The company was licensed by the TAEK (on 10 September 1987, with renewal on 16 April 1992) to import, re-export and transport ^{60}Co sources and to supply them to hospitals. The sources and associated equipment involved in this accident were purchased from the United States of America. The company usually transported the sources directly from customs to the radiotherapy facilities declared in the application for permission to import. In special cases the company was allowed to store spent sources temporarily in company premises in Ankara if it notified the TAEK. The import and export of equipment were via the seaports and airport of Istanbul and the airport of Ankara. The company owns a small warehouse on an industrial estate in Istanbul and this was used for general purpose storage. It was not continuously occupied and had no dedicated facilities for the storage of radioactive sources. The TAEK had not been notified that radiation sources would be held at this warehouse.

The routine installation, exchange and packaging (for transport) of ^{60}Co sources were undertaken by two engineers who were trained in the USA by the source suppliers. A technician was also trained to install and exchange sources under the supervision of an engineer. Satisfactory proof of the training of these employees was supplied to the TAEK as part of the company's licence application.

The company followed the TAEK licensing procedures, and had sought permission to import, transport and re-export sources. It also maintained records of the quality, activity and location of sources, the serial numbers of containers and information about the supplier. The company records were not, however, comprehensive (for example, source serial numbers were absent) and the company had no procedures for auditing these records or for verifying the location of radioactive sources at regular intervals. Because of this, it was difficult to establish which of the radioactive sources were involved in the accident described in this report.

2.3. THE RADIOACTIVE SOURCES AND PACKAGES

The company supplies ^{60}Co sources with a typical activity (when new) of 185 TBq (5000 Ci). The radioactive material is in the form of ^{60}Co grains contained within an international standard capsule. Traditionally the sources were delivered inside a source exchange container as shown in Fig. 3. This container is designed to connect to a ^{60}Co teletherapy head. The top of the exchange container contains a shielded cylinder which is removable to allow source loading. The side of the container is fitted with a retractable drawer mechanism that allows two sources to be

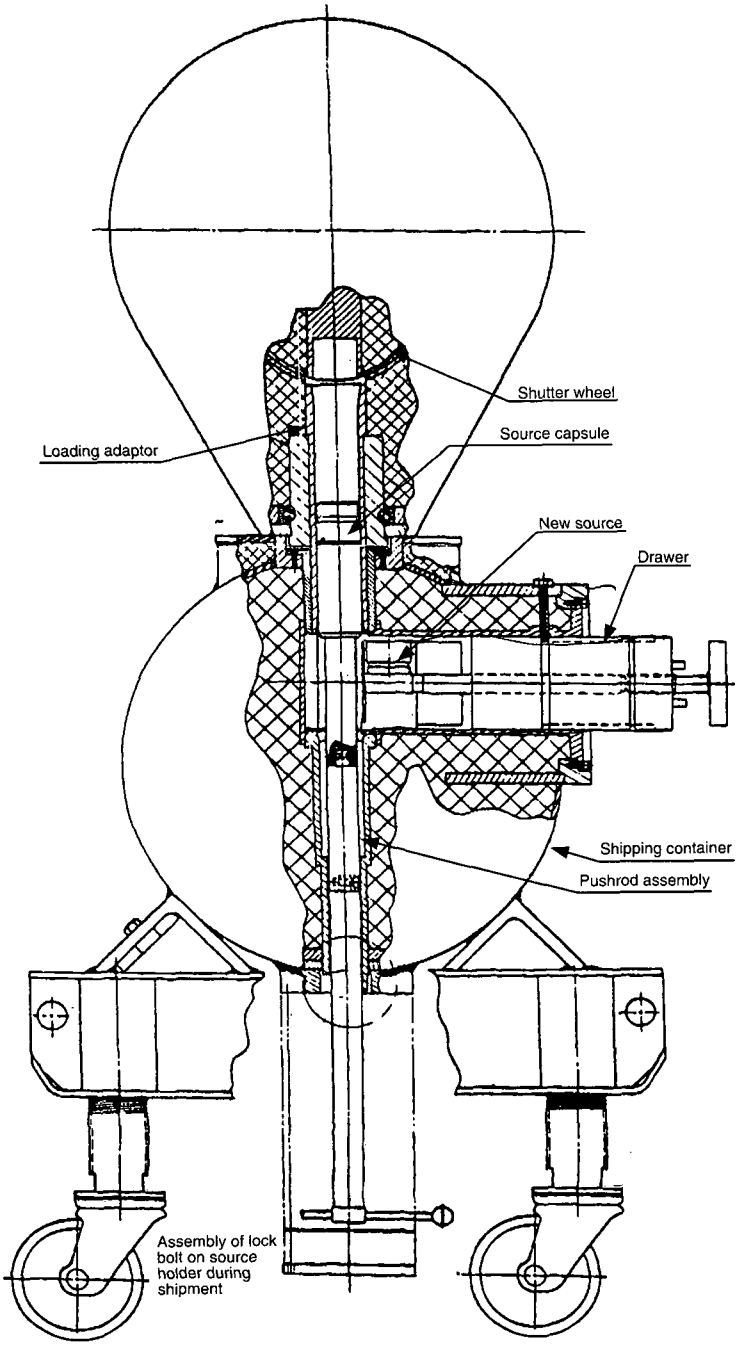
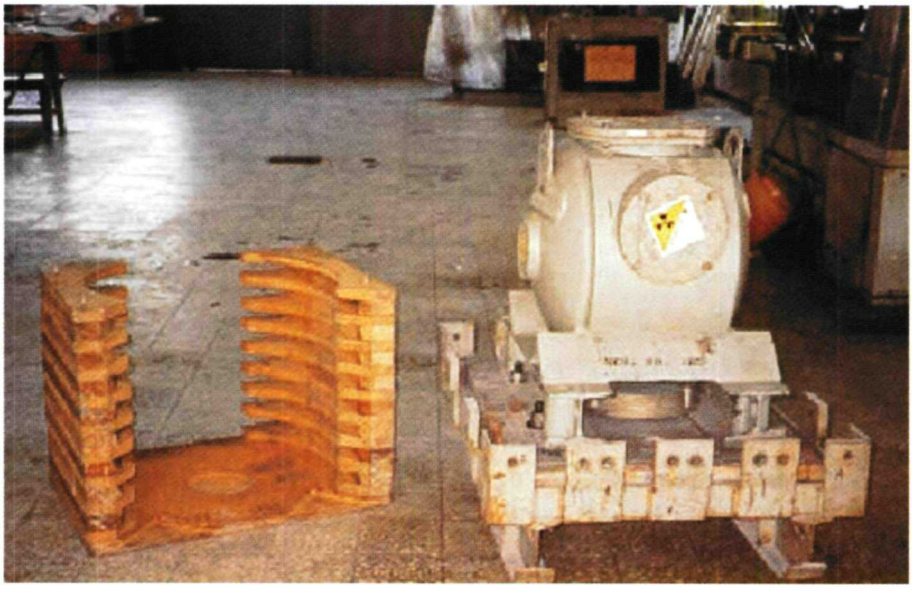


FIG. 3. Source exchange container.

temporarily held during the exchange procedure. This side assembly may also be fully withdrawn from the container if the appropriate screws are loosened.

After the sources have been exchanged, the cylinder and the drawer assembly are secured and steel cover plates are bolted in place (it is not possible to do this if two sources are still inside the container). For transport, the cover plates are fitted with wire seals and the whole exchange container is packed inside a transport package which consists of an inner wooden crate and an outer metal case. The various components described above are shown in Photographs 1–5.

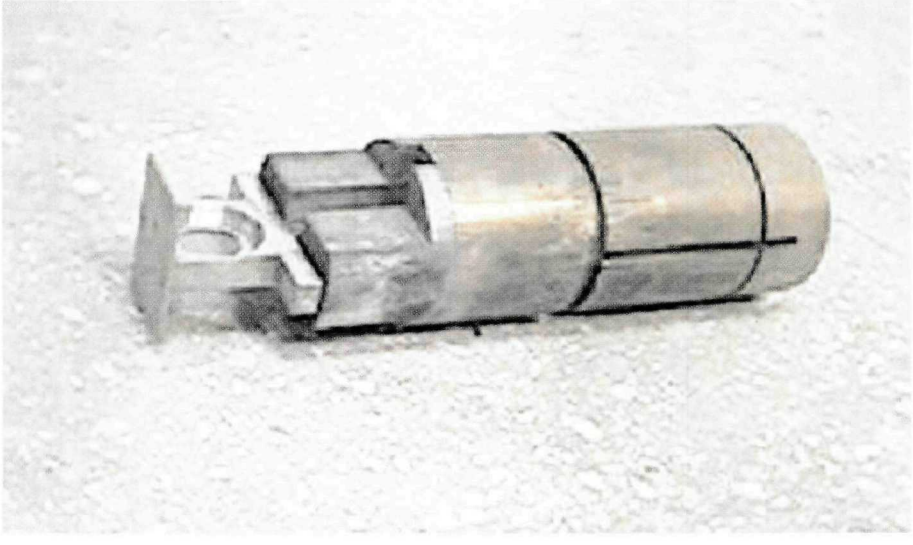
Photograph 1. Type B (U) transport package.



Photograph 2. Wooden crate and exchange container.

Photograph 3. Exchange container.

Photograph 4. Plug and drawer assembly.



Photograph 5. Drawer assembly.

3. THE ACCIDENT

A detailed chronology of events is given in Annex I and a summary is given in Table I. The sequence of events has been reconstructed mainly from personal recollections. Inevitably, the facts cannot be precisely determined. Furthermore, there were some conflicting testimonies and disagreements about events. Attempts have been made to highlight such problems where these might affect the findings of this report.

3.1. INITIATING EVENTS

(1) In December 1993 the licensed company is recorded as having packaged three spent ^{60}Co sources (see Section 2.3) for transport back to the USA. The activity of these sources is thought to have been as shown in Table II.

(2) The sources were located in exchange containers which in turn were packaged in wooden crates inside metal shipping packages (Photographs 1–5). The company stated that the exchange and shipping containers were sealed and labelled in accordance with the 1985 Edition of the IAEA Regulations for the Safe Transport of Radioactive Material [13].

(3) On 27 December 1993, the company applied to the TAEK for permission to export three spent ^{60}Co sources in shielded transport packages and it provided the detailed information on 28 December 1993. The radiation levels around the packages were measured by the TAEK staff on 6 May 1994 and permission was then granted. Istanbul Harbour's Customs Directorate was informed on 12 May 1994 that export permission had been granted.

(4) The packaged sources were not re-exported but were stored by the company in Ankara, without permission from the TAEK.

(5) In February 1998, the company decided to transport two of the packages (A and B) from Ankara to Istanbul. The third package (C) remained in Ankara and, after the accident, it was taken into custody (fully intact, sealed and labelled) by the TAEK and transferred to the Waste Treatment Section of ÇNAEM.

(6) Two packages were received by the Istanbul branch of the company, which arranged for them to be stored in their general purpose warehouse in the Ikitelli area. After some time there was no room in this warehouse and the packages were moved to empty premises adjoining the warehouse in an industrial area in the Küçükçekmece district of Istanbul (Marmara Estate, see maps in Figs 4 and 5). The frontage of the premises consisted of large windowed metal doors into which the glass had at that time not yet been mounted (Photograph 6). These doors were not locked. The packages were located

TABLE I. SUMMARIZED CHRONOLOGY OF EVENTS LEADING UP TO THE ACCIDENT AND THE SUBSEQUENT RECOVERY OF THE SOURCE

Date	Event	Location and persons exposed
1993		
November and December	Company collects sources from hospitals.	Izmir, Ankara
27 Dec.	Company applies to the TAEK to obtain transport and export permission to re-export the used sources to the USA.	Ankara
1994		
12 May	Approval certificate issued by the TAEK for re-export and transport.	Ankara
1998		
February	Two transport packages transported to Istanbul and put in empty premises adjacent to company's warehouse.	Marmara Estate
8 Nov.	Sale of premises where the packages are stored.	IB
9 Dec.	Packages sold by new owners of premises to two scrap collectors; packages loaded onto the truck and left next to the family home.	Mehmet Akif — 1 MI, 2 NI
10 Dec.	Packages driven to house of father-in-law, where they are unloaded and dismantled by three members of the family. The outer casing is removed to reach the source exchange containers, then the shielding plug is removed from one container. Operation is watched by several casual observers. Containers (and parts) are put back on the truck and taken to the family house. Dismantling suspended owing to bad weather. Containers and other parts taken back to the family house by truck.	Bayramtepe — 1 MI, 2 NI, 4 KI
13 Dec.	Shielding plug removed from second container. Dismantling continues (including use of oxyacetylene torch and mechanical excavator). At 16:30 (approximately) persons dismantling container begin to feel ill, followed shortly afterwards by observers who had been nearby.	Mehmet Akif — 1 MI, 2 NI, 3 HI, 4 KI, 5 II, 6 HG, 7 AI, 8 HS, 9 AS, 10 ED

TABLE I. (cont.)

Date	Event	Location and persons exposed
14 Dec.	Medical advice sought. Persons released after a few hours when their nausea and vomiting had ceased (no reports of radiation sources or suspicion of radiation effects).	Basak clinic — 1 MI, 2 NI, 3 HI, 4 KI, 5 II, 6 HG
	Unshielded source(s) remain(s) in yard adjacent to the family house.	Mehmet Akif — 5 II's family and neighbours exposed
15 Dec.	Lead shielding containers carried back to father-in-law's house and buried. Source(s) remained at the junkyard adjacent to the family house, probably under a pile of scrap.	Bayramtepe — 5 II and CA
27–28 Dec.	Scrap metal, including source(s), loaded onto truck by hand and shovel and taken to large scrap metal dealer in the same area.	Mehmet Akif to Ziya Gökalp — 5 II, KA, AA
1999		
3 Jan.	Steel outer casings thought to have been smelted at a factory outside Istanbul.	Izmit
8 Jan.	Morning: Two persons involved in dismantling the containers seek medical assistance from private hospital. Doctor suspects symptoms are radiation induced.	Günes Hospital
11:30	Doctor informs ÇNAEM of his suspicions.	
	Early afternoon: ÇNAEM team interviews patients.	Ziya Gökalp
15:00	ÇNAEM team detects high dose rates at entrance to scrapyard. Area is evacuated and is fully cordoned off by 16:30.	
9 Jan.	Recovery operation proves to be difficult, so operations suspended until next day.	
10 Jan.	Source recovered. No sign of contamination.	

towards the front of the premises and would have been clearly visible from outside. The packages remained in this location for over nine months with no effective supervision or security. Photograph 6 shows the condition of the warehouse after the accident.

TABLE II. ACTIVITY OF THREE SPENT COBALT-60 SOURCES PACKAGED IN DECEMBER 1993

Source	Activity when new	Activity of used sources	
		On 1 December 1993	On 1 January 1999
A	89.5 TBq (2418 Ci) on 1 December 1973	6.4 TBq (172 Ci)	3.3 TBq (88 Ci)
B	248 TBq (6700 Ci) on 1 March 1981	46 TBq (1245 Ci)	23.5 TBq (636 Ci)
C	99.6 TBq (2691 Ci) on 5 May 1987	41.8 TBq (1129 Ci)	21.3 TBq (577 Ci)

(7) On 9 November 1998, the premises were sold and the new owners set about removing all unwanted articles from the premises. On 8 December 1998, the packages were sold by the new owners of the warehouse (for approximately US $30) as scrap metal to two brothers who lived in the same district.

(8) The two brothers took the two packages away on the back of a truck to the family house in the same area, Mehmet Akif (see Fig. 5).

(9) On 10 December 1998 the packages were taken to another location in the same area (Bayramtepe) to a house owned by the father-in-law of one of the brothers. The packages were unloaded onto a small area of open ground across the road from the house and the outer metal case and wooden crates were then removed (Photographs 1 and 2). The top and side flanges (lids) were unscrewed, the shielding plug and the drawer assembly were removed from one of the exchange containers (Photographs 4 and 5). This operation was undertaken by three members of the family. One of them (1 MI) inserted his hand into the centre of the container in an attempt to determine what was inside (Photograph 7). Another person (2 NI) claimed that he saw the source in its housing (Photograph 8). The operation was watched by several casual observers (an explanation of the codes used to identify the exposed persons is given in Annex I).

(10) Before any further dismantling took place, the containers and the parts that had already been removed were put back onto the truck. It is understood that the opened container remained upright and the source is thought to have remained inside.

(11) All parts of the two packages were returned to the family house and were rolled off the back of the truck directly into a small adjacent yard used to accumulate scrap metal and paper. This yard adjoined neighbouring houses and was open at the front, allowing access to the road (see Fig. 6). None of the persons involved can recall seeing the bare source capsule at any time, although in view of its small size and the amount of other scrap material present, this was not surprising. Further dismantling of the source containers was suspended for a few days owing to bad weather.

FIG. 4. Map of the Istanbul region.

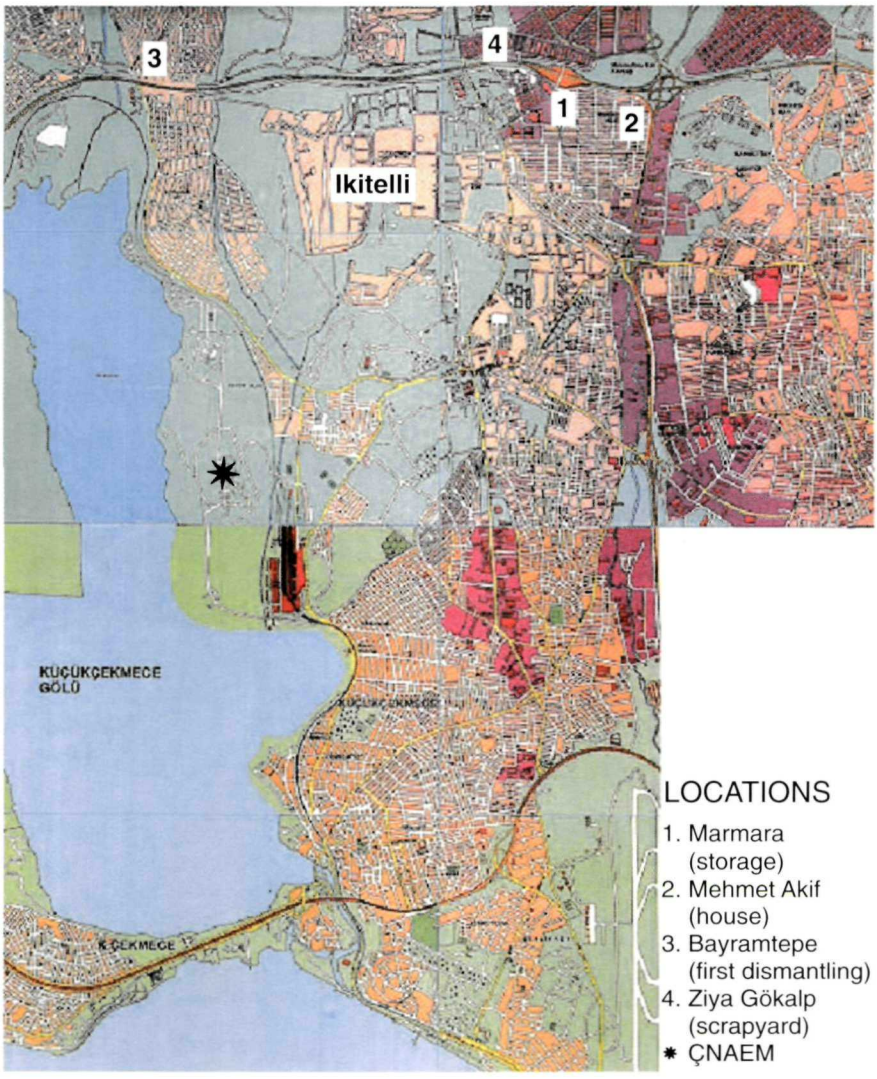
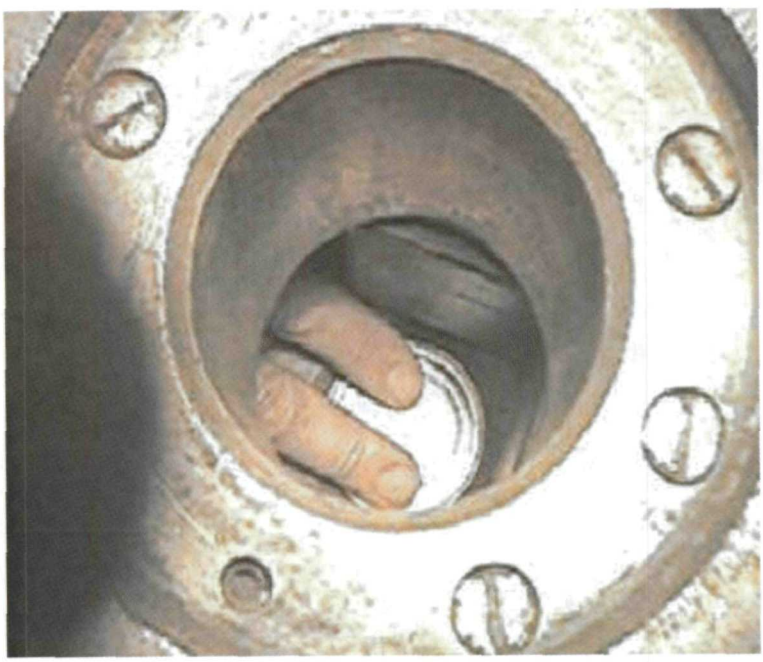


FIG. 5. Map of the Küçükçekmece district.

(12) At about 09:00 on 13 December 1998, dismantling of the containers was resumed. First, the lids were unscrewed and the shielding plug and drawer assembly were removed from the second container. Unsuccessful attempts were then made to remove the screws holding the brass collars around the open ports (Photograph 9). The steel shells of both containers were then peeled away (using an oxyacetylene torch and then a mechanical excavator) to reveal the

Photograph 6. Frontage of the premises in the Küçükçekmece district (Marmara Estate).



Photograph 7. Fingers of patient 1 MI (reconstruction).

lead inside. The containers were rolled over during this operation and it might be considered likely that the source in the second container, if present, would have fallen onto the ground at this time. The operation continued until about 16:30 and several casual observers, mostly other family members, were present throughout.

3.2. SUBSEQUENT EVENTS

(13) At about 16:30 on 13 December, the persons dismantling the containers began to feel unwell, with nausea that rapidly progressed to vomiting. Within a short period of time, other persons who had either assisted or watched the operation also started to suffer from similar symptoms. The affected persons went to a local medical clinic, where they were diagnosed as having food poisoning or lead poisoning and were treated with an intravenous saline infusion. Within a few hours the nausea and vomiting had subsided and the patients were discharged. Some reddening appeared on the tips of two fingers of 1 MI on 17 December 1998.

Photograph 8. The source in its housing.

(14) The unshielded source(s) is/are thought to have remained in the yard until 27 or 28 December 1998. The scrap metal (apart from the lead: see item (16)) was then loaded by hand and with a shovel onto a truck and taken to a larger scrap metal dealer in the same area, Ziya Gökalp (see Fig. 5 and Photograph 10).

(15) The pieces of the containers were placed with a pile of other scrap. At this time, the scrapyard owners, who normally lived at the yard, were away. They did not return to work until 4 January 1999, by which time most of the scrap metal had been taken to a large metal smelting factory 90 km east of Istanbul. It is thought that the outer steel casings of the containers were smelted at this factory on 3 January 1999. The source(s) and one of the drawer units were not, however, taken away (it is suspected that they were too small to be picked up by the mechanical grab used at the yard).

(16) Sometime during this period the lead shielding was returned to the father-in-law's house, where it was buried. The reasons for this are unclear but it is thought that the lead shields had come to be considered a health hazard and were buried to protect other persons. These lead shields were later recovered by the national authorities (Photograph 11).

(17) The persons who dismantled the source housings continued to feel unwell; typical symptoms included weakness, loss of appetite and weight, and bleeding

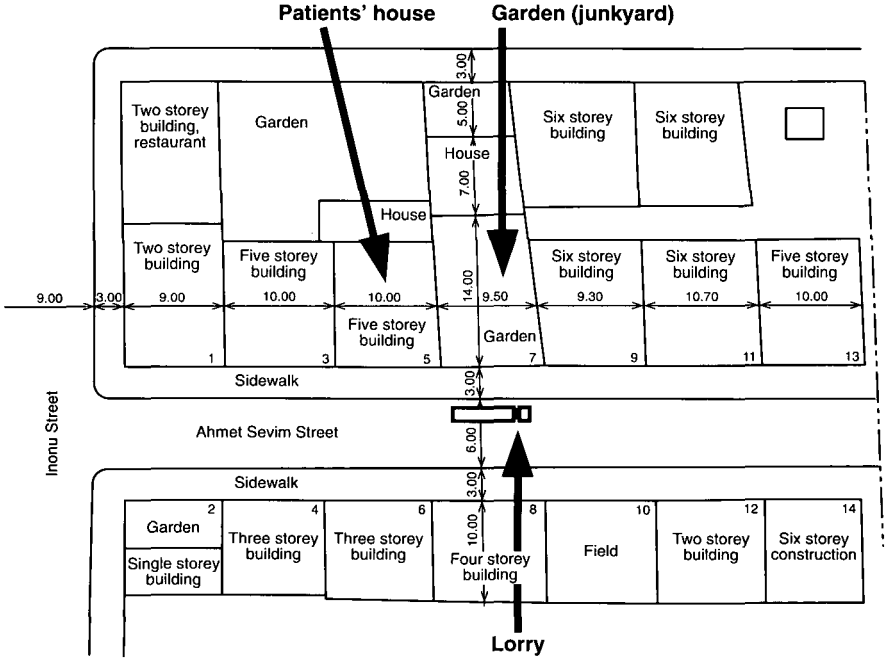
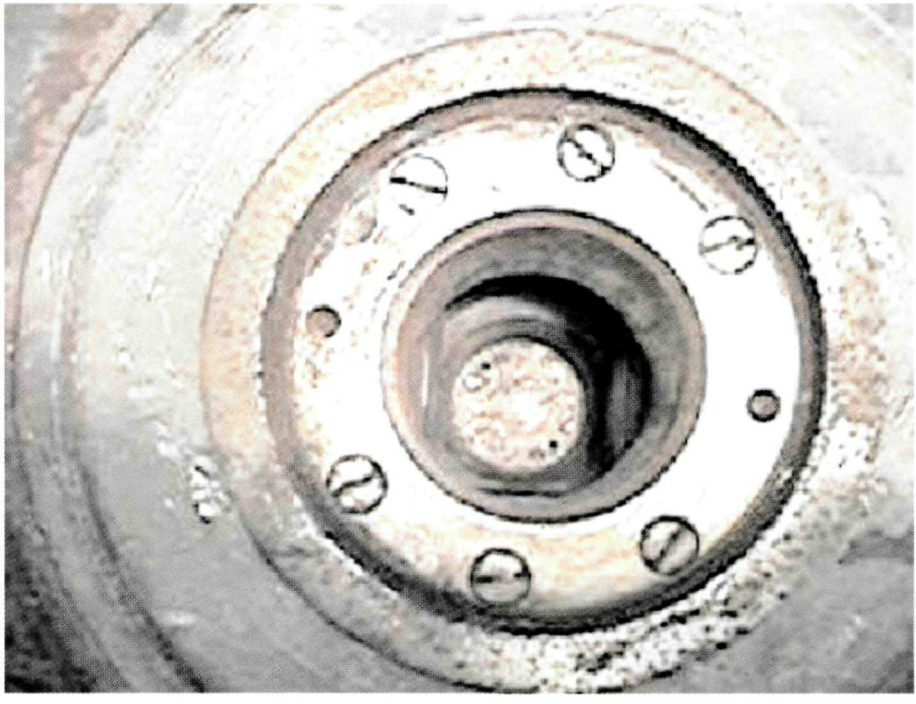


FIG. 6. Location of the house of patients 1 MI and 2 NI in Mehmet Akif (distances in metres).

gums. They apparently continued to seek medical assistance at small local clinics but the cause of their symptoms was not identified and they were not admitted for treatment. On the morning of 8 January 1999, two persons (Patients 2 NI and 5 II) sought medical assistance at a larger private hospital in the area. They were examined by a doctor who questioned them about their activities. They described working with lead containers (they suspected that their symptoms may have been caused by lead poisoning). The doctor suspected that the lead might have been used as radiation shielding and concluded that their symptoms might have been caused by radiation exposure. His assessment was supported by the evidence of the son of one of the patients admitted to hospital who, while visiting his father at the hospital, mentioned having seen a trefoil sign on the container.

(18) At 11:30 on 8 January, the doctor informed ÇNAEM, in the same district of Istanbul (see Fig. 5), of the case. The biodosimetry laboratory of ÇNAEM then arranged for blood samples to be taken from the patients and from six other persons with similar symptoms.



Photograph 9. The brass collar.

Photograph 10. The scrapyard (Ziya Gökalp).

Photograph 11. Damaged containers.

(19) Representatives of the national authorities interviewed the patients and visited the sites in Istanbul involved in the accident. They arrived at the scrap dealer's yard at 15:00 on 8 January and detected high dose rates at the entrance.

4. RESPONSE TO THE ACCIDENT

4.1. RECOVERY OF THE SOURCE AT THE SCRAPYARD

The presence of a radioactive source at the scrapyard was ascertained at 15:00 on 8 January 1999 by staff of ÇNAEM. The source was surrounded by scrap metal which provided some shielding (see Photograph 10). The results of the initial dose rate survey are shown in Fig. 7. The scrapyard workers were evacuated and by 16:30 the area had been completely cordoned off and secured by the national authorities and police. The remainder of the source recovery operation was then planned and executed by staff of the national authority. All persons involved in the source recovery operation were issued with film badge dosimeters and direct reading pocket dosimeters. Key personnel were issued with additional direct reading electronic dosimeters, the results of which were reviewed and recorded at regular intervals.

4.1.1. Source recovery operation: Day 1

A cylindrical drawer assembly (Photograph 5) from one of the exchange containers was identified on the ground in the scrapyard. At this time, it was assumed that two sources were present and that each would be contained within such an assembly. Consequently, the procedure to recover this item was as follows:

(1) An emergency shielded container was assembled using lead bricks inside a square steel container. This was loaded onto the back of a truck.
(2) The scrapyard had a truck mounted mechanical grab that was used to move, load and unload scrap consignments. Three operators of the grab from the scrapyard were asked to assist in the source recovery operation.
(3) A piece of scrap metal piping similar in size to the drawer assembly was selected. The three operators then practised picking this up with the mechanical grab (Photograph 12).
(4) The truck with the grab and the truck with the shielded container were reversed into the scrapyard until they were within reach of the drawer assembly.
(5) The drawer assembly was picked up (on the first attempt) and transferred to the shielded container.

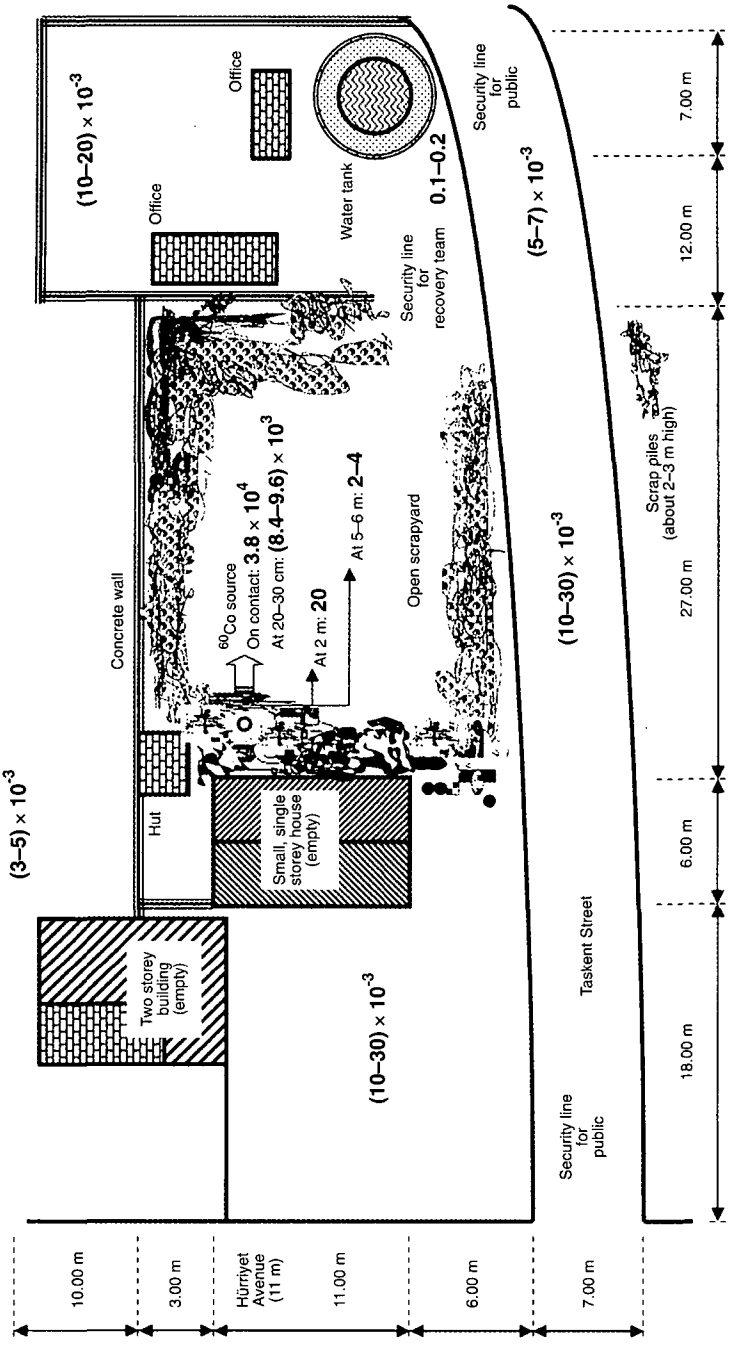


FIG. 7. Dose rates (mGy/h) at the Ziya Gökalp scrapyard.

A dose rate survey showed that there were still high radiation levels in the scrapyard. These were initially taken to indicate a second source but a survey of the shielded container quickly established that there was no source in the drawer assembly that had been recovered. Further surveys indicated that the radiation source was located further back in the yard underneath a pile of scrap metal.

It was decided to remove material carefully from this pile using the mechanical grab. Each batch of material removed was monitored to check whether the source had been picked up. However, removal of the scrap caused the radiation dose rate in the scrapyard to increase owing to the loss of local shielding, and the operation was therefore suspended to review the options for recovering the source(s). With no guarantee that the source(s) could be quickly located and recovered, it was decided to halt the operation until the following day.

4.1.2. Source recovery operation: Day 2

An alternative strategy to recover the source was adopted, as follows:

(1) A special lead shielded cylindrical drum container was fabricated and attached to the end of a truck mounted crane that had been hired for the source recovery operation.

Photograph 12. Trial operation.

(2) A radiation detector capable of measuring very high dose rates was attached to the end of a long boom. This was mounted on the back of a truck and a 50 cm thick wall of barite concrete blocks was assembled to shield the boom operator (Photograph 13). The truck was reversed into the yard and the detector was used to locate the source.

(3) Ten teams of two persons each were organized. One member of the team dislodged pieces of scrap from the pile using a long pole. The other member would then pick up any suspicious objects with an extended (2–3 m) shovel and tip them into the shielded container. The container would then be lifted by the crane and monitored to check whether a source had been recovered.

(4) It was expected that no more than ten attempts (no more than one attempt per team) would be required to recover the source and an individual dose constraint of 2 mSv was set on this basis. A 1 mSv dose constraint was applied for each of the three grab operators, who worked in rotation.

Despite an attempt by each team, the source was not recovered and so the options available were again reviewed. To minimize any further exposures, one option considered was to pump concrete over the scrap in order to produce a shielded block that would be suitable for immediate disposal. However, this would have made it impossible to identify the source(s) involved and hence this option was rejected. Instead, the doses received by the teams (as recorded on electronic dosimeters) were reviewed and found to be still within the dose constraint originally set. Consequently,

Photograph 13. Truck equipped with a ratemeter to measure high dose rates.

it was agreed that one further attempt would be made by each team. On the fourth attempt (the fourteenth in total) the source was recovered.

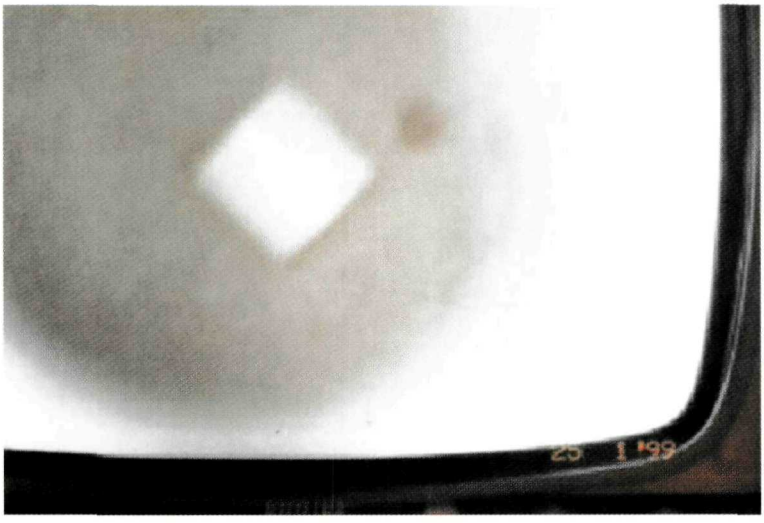
The source in the shielded container was taken away by the national authorities for examination and subsequent disposal. The scrapyard was extensively surveyed but no evidence of a second source or of leakage of radioactive material from the recovered source was found.

The recovered source capsule showed no external damage and there was no leakage of radioactive material (Photograph 14). On the basis of dose rate measurements, the activity of the source was estimated to be 3.3 TBq (88 Ci).

4.1.3. Doses received by personnel in the recovery operation

Most of the persons involved in the source recovery were already subject to individual dose assessment and these persons were wearing their film badge dosimeters. The only other persons involved were the operators of the mechanical grab and these persons were specially issued with a film badge dosimeter and direct reading pocket dosimeters. All dosimeters were returned for immediate assessment at the end of the operation.

The doses received by persons are summarized in Table III. The dose received (as recorded on a film badge) by the individual who actually retrieved the source was 0.6 mSv.



Photograph 14. Recovered ^{60}Co source in a newly built container.

TABLE III. SUMMARY OF FILM BADGE DOSES (mSv) FOR PERSONS INVOLVED IN SOURCE RECOVERY OPERATION

Recorded doses		Number of persons
>0 – <0.5		3
≥0.5 – <1		8
≥1 – <2		6
≥2 – <4		1
≥4 – 6		1
Summary:	Average dose	1.15 mSv
	Maximum dose	5.47 mSv
	Collective dose	22 man mSv

The highest dose, of 5.47 mSv, was received by a senior member of the health physics team who undertook the initial dose rate survey and also participated in the source recovery operation (the next highest recorded dose was 2.05 mSv). It is considered that the doses received are low for a relatively complex recovery of a high activity source.

4.2. INITIAL RESPONSE TO ASSESS PUBLIC HEALTH

As a result of investigations upon recognition of the accident, 404 persons who might have been close to the unshielded source were interviewed by specialists of the national radiation protection authorities and public health authorities, underwent a medical check-up and had a blood sample taken. On the basis of the results, 18 persons were admitted to the Haseki State Hospital in Istanbul for continued observation and treatment. Ten of these persons were diagnosed with acute radiation syndrome within four days (on 12 January 1999). The medical aspects of their treatment are covered in Section 5.

4.3. SEARCH FOR A SECOND SOURCE

According to the company's statement, there had been four transport containers in its warehouse in Ankara. One was reported as being empty and the other three as each containing a spent ^{60}Co source. Two of the containers that reportedly housed sources were transferred to Istanbul. It was initially assumed that there had been a source in the second container involved in the accident and the whereabouts of this

supposed second source were a major concern. The other areas where the source containers had previously been taken were systematically surveyed but no evidence of elevated dose rates or radioactive contamination was detected. An extensive survey was undertaken at the metal smelting works (Photographs 15 and 16) to which metal scrap from the scrapyard where the source had been taken was sent. In addition, a car-borne survey of all the connecting routes between the scrapyard and the smelting works was carried out. No evidence of a second source was found.

Photograph 15. Scrap metal pile in the field of the smelting factory in Izmit.

Photograph 16. Iron wire produced from the scrap metal.

The failure to locate a second source by means of radiation surveys gave rise to the suspicion that the second container, coded as B in Table I, had either been empty all along or perhaps contained a source of much lower activity than initially assumed. This suspicion was supported by the absence of any other reported radiation injuries that would have been expected from exposure to an unshielded 23.5 TBq (636 Ci) ^{60}Co source. As a result of this, an audit of the company's source records was initiated. The supplier in the USA was also asked to provide whatever relevant information it had on returned sources and an attempt was made to match the records. This, however, proved inconclusive. In particular, the US supplier's records reportedly indicated that the source with the serial number 2570 had been returned to the USA, while the company's records indicated that this source, coded as C in Table I, was still in Turkey. Also, the records of the same supplier reportedly indicated that the source with the serial number 2567 had not been returned to the USA, while the company's records indicated the opposite. It was therefore not possible to use either of the source records to confirm whether in fact there was a second source in Turkey and, if so, where it might be. On the basis of the available information the indication was that there had been no source in the second container, but this could not be demonstrated unequivocally.

4.4. TAEK'S RESPONSE TO PREVENT THE RECURRENCE OF SIMILAR ACCIDENTS

The TAEK took the following immediate actions to prevent any recurrence of the circumstances of this accident:

- All radiotherapy centres (46 in total) in Turkey were inspected. Licence conditions were reviewed and details of the ^{60}Co sources were compared with the TAEK inventory. Licensees were informed once more of the procedures for re-exporting used teletherapy sources.
- The outputs of all ^{60}Co teletherapy machines were checked with TLDs supplied by the TAEK's Secondary Standard Dosimetry Laboratory.
- According to the revised Radiation Safety Regulations, used sources should be kept in a TAEK approved store at the facility prior to re-export. Interim off-site storage of sources is forbidden. In exceptional circumstances, for example if the source supplier or consignee stopped its activity, sources could be kept in the Waste Treatment Section of ÇNAEM.
- Companies which apply to the TAEK to re-export sources are required to specify the exact date of dispatch. The re-export must take place not later than 15 days after the application and the consignor must ensure that the consignee confirms acceptance of the source.

4.5. RESPONSE FROM THE IAEA

On Monday, 11 January 1999, the IAEA Emergency Response Centre (ERC) was alerted to a potential radiological incident via routine monitoring of news media reports. It had been stated in Turkish news reports that there had been a case of 'radiation poisoning' stemming from a ^{60}Co source in Turkey.

The ERC contacted the TAEK, which confirmed that there had been a 'radiological incident' in Istanbul and that:

— The shield of a radiotherapy ^{60}Co source had been broken into pieces by scrap dealers, but the source capsule was not ruptured.
— Two scrap dealers were injured and were under treatment.
— TAEK experts had found the source, the accident area was under control and the source was safely stored at ÇNAEM.

The ERC transmitted a facsimile to the TAEK offering the IAEA's good offices under the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency. The assistance offered was to send medical experts specialized in diagnosis and treatment of patients exposed to radiation as soon as the request for assistance was received. On Tuesday, 12 January 1999, the Turkish authorities sent an official request for medical assistance. The medical team of three doctors (including an IAEA staff member) left for Istanbul late in the afternoon of the same day (12 January 1999). The IAEA notified the World Health Organization (WHO) of the actions undertaken.

On 13 January 1999, the IAEA medical team sent its preliminary report to the ERC after examining 15 persons under investigation in two hospitals. The team was satisfied with the treatment being given to all the patients by the Turkish medical authorities. Blood samples were taken for cytogenetic dosimetry purposes. Samples were taken to the United Kingdom National Radiological Protection Board (NRPB) and the Curie Institute in France, and were sent by the Turkish authorities to the Leiden University Medical Centre (LUMC) in Leiden, Netherlands.

On 14 January 1999, the Turkish Permanent Mission to the International Organizations in Vienna sent a fax to the ERC stating that it had been informed by the President of the TAEK that a further ^{60}Co source was missing. The Mission requested suggestions from IAEA experts in order to find this source. In response, on Friday, 15 January 1999, an IAEA field team with monitoring equipment left for Istanbul.

On Saturday, 16 January 1999, the IAEA field monitoring team carried out extensive radiation surveys around the Ikitelli area of Küçükçekmece district (see Fig. 5). The areas checked included: the building where the source had been stored (location: Marmara Estate); the house of the scrap dealer who initially purchased the source (location: Mehmet Akif); the house of the scrap dealer's father-in-law to which

the damaged containers had been taken (location: Bayramtepe); and the scrapyard where the source had been found (location: Ziya Gökalp). No radiation above background levels was detected.

On Sunday, 17 January 1999, the IAEA monitoring team travelled 90 km to the east of Istanbul (see Fig. 4) to the smelting works where some of the scrap had been taken previously. The team performed extensive radiological surveys but again no radiation levels above background were detected. Photographs 15 and 16 suggest the extent of the difficulty in monitoring large amounts of scrap.

After carrying out these extensive surveys the team made various recommendations to the Turkish authorities, as follows:

(1) To prepare a press release to inform the public about the situation, to provide the police and fire brigade with pictures and drawings of the missing stainless steel canister source, and to urge members of the public to report any relevant information;
(2) To alert medical personnel and hospitals to report any suspicious cases with symptoms of radiation sickness to the TAEK;
(3) To continue with the police investigation on the hypothesis that the source could have been sold illegally to other unknown persons in the country or abroad;
(4) To update the inventory of radiation sources and equipment in Turkey;
(5) To forthwith inspect the storage conditions of radioactive sources and substances in institutions and enterprises in Turkey;
(6) To assess the necessity of informing, directly or through the IAEA, those States which may be physically affected (as specified in Article I of the Convention on Early Notification of a Nuclear Accident) and the IAEA itself of the missing source;
(7) To continue with the car-borne radiological survey of all possible sites for the lost source, expanding the search area;
(8) To study the feasibility of using an aerial survey;
(9) To install a radiation monitor immediately at the Colakoglu metal production factory in Izmit;
(10) To interview the factory's engineer responsible for the nucleonic level gauges;
(11) To check the factory records with the aim of identifying the biggest single sales on a weekly basis over the previous nine months, identifying the purchaser and monitoring the construction or structures for which the metal was intended;
(12) To investigate together with the factory administration the possibility of scrap having been sold to or exchanged with other factories;
(13) To obtain data on the size of the furnaces and the approximate amount of recycled steel produced in order to estimate possible activity concentrations in the steel;

(14) To survey potential land dumps and municipal general dumps.

On 20 January 1999, following discussions between IAEA staff and the Turkish Permanent Representative to the IAEA, it was decided to send a further expert to Istanbul to complement the work already carried out by the medical and field monitoring team. His major task was to help in the collection of all relevant information for the preparation of a report on the circumstances leading up to the accident. The expert flew to Istanbul on 24 January 1999.

On 26 January 1999, the Turkish Government, in the framework of the Convention on Early Notification of a Nuclear Accident, notified neighbouring States of the missing source. It also requested the IAEA to inform all other national contact points in States that are signatories to the Convention.

4.6. PUBLIC CONCERN IN TURKEY

The radiation accident in Istanbul was the first known major radiological accident in Turkey. News of the accident was reported soon after its discovery and it was the subject of the leading headline on TV the same day and in the next morning's daily papers. The news media's coverage of the incident continued for several days and created much anxiety. Both the TAEK and the medical authorities had to deal with many inquiries from members of the public who were concerned about their health.

After the accident, there was considerable confusion on the part of the public and the media, who initially compared the event with the Chernobyl accident, significantly overestimating its effects. Many public discussions focused on identifying those responsible. Journalists were free to interview radiation protection experts and the authorities regularly provided information on the actions being taken to minimize the effects of the accident on health and the environment.

The successful recovery of the abandoned source was reported by the news media and this, in conjunction with the open public information policy of the TAEK administration, reportedly helped to allay the public's concern.

The psychological impact of the accident on the public was high, as may have been expected. The family which was most involved in the accident reportedly suffered from anxiety and suffered social isolation from friends and relatives.

Reportedly, public concern regarding nuclear questions was previously centred on the operation of nuclear power plants, nuclear weapon tests and the production of radioactive isotopes at research centres. This accident reportedly created a more general awareness that medical and other applications of radioactive materials can also potentially pose a considerable hazard to the public and require strict regulation.

5. SUMMARY OF MEDICAL ASPECTS OF THE ACCIDENT

5.1. CHRONOLOGY OF PROGRESSION OF MEDICAL CONDITIONS AND THEIR MANAGEMENT

The affected individuals reportedly first noticed what were in fact the clinical symptoms of overexposure to radiation at about 16:30 on 13 December 1998, the day when the first attempts were made to dismantle the containers. Six of the ten persons who were present during the dismantling (either working or observing) felt unwell, started to vomit and continued to do so throughout the night. On the next day they went to a nearby private clinic, where they were diagnosed with food poisoning and treated with normal saline. After this single outpatient treatment they returned home. Patient 4 KI vomited again four days later, most probably after working near the pile of scrap metal covering the source.

Seven days after exposure some reddening appeared on the tips of the second and third fingers of the right hand of patient 1 MI, who on 10 December 1998 briefly inserted these two fingers into one of the containers through the hole of the removed drawer assembly.

The accident victims reportedly consulted several medical doctors over the following four weeks, complaining of weakness, emesis, diarrhoea and/or loss of appetite. However, no haematological check-ups were performed and acute radiation syndrome was not suspected.

Patient 5 II felt sick and unusually fatigued on 28 December 1998 after he had loaded a truck with pieces of the containers and some other scrap metal, but he did not vomit.

On 8 January 1999, two scrap collectors, patients 2 NI and 5 II, felt sick and went to another private hospital, where radiation sickness was first suspected and was reported to ÇNAEM. That a radiation accident had occurred was confirmed on the same day. On 9 January 1999, the first blood samples were taken from the two scrap collectors, patients 2 NI and 5 II, as well as from patients 7 AI and GI (the visiting son and wife of patient 5 II) for cytogenetic dose assessment by the Biodosimetry Laboratory of ÇNAEM.

On 9 January 1999, patients 2 NI, 5 II and 7 AI were transferred to Haseki State Hospital. Four other adults (patients 1 MI, 4 KI, 9 AS and 10 ED), who had also participated in dismantling the containers four weeks earlier and had suffered discomfort and weakness since that time, were admitted to the same hospital. During the next two days four more adults (11 in total) and seven children were admitted to the Haseki Hospital. One adult (AY) and three children were discharged after 1–3 days of

observation as they were found to be healthy. Both whole blood and platelet transfusions were given to patients 1–7 (all adults), who were in the worst condition with very poor haematological parameters. The white blood cell counts of patients 1–5 were at a level of about 10% of the mid-value of the normal range, and lymphocytes were not detectable, while the platelet count was as low as 1–3% of the normal values. Detailed initial blood counts from 9 and 10 January 1999 are given in Table II–I in Annex II together with the patients' codes.

Over the period 9–15 January 1999, 404 persons concerned about their possible exposure applied for a medical or haematological check-up following the issuing of public information by ÇNAEM and media reports about the accident. Triage was made according to patients' lymphocyte, granulocyte and platelet counts [14]. Medical examinations and interviews reportedly indicated that in most cases there were no clinical signs or symptoms relating to radiation exposure. Acute radiation syndrome (ARS) was diagnosed in ten persons. Twelve other persons showed signs of leucocytosis, five of leucopenia (i.e. higher and lower counts of white blood cells, respectively, than normal). Medical examinations and interviews at the place of residence indicated that in most cases, these conditions did not relate to radiation exposure. On 11 January 1999, blood samples were taken from ten other persons for biodosimetry assessment in ÇNAEM.

On 12 January 1999, the five most severely affected patients (1–5) were transferred from the Haseki Hospital to strictly isolated single rooms at the Department of Haematology of the Cerrahpasa Medical Faculty of Istanbul University, and bone marrow stimulation (with granulocyte colony stimulating factor (G-CSF) and cytokine) therapy was started for patients 1–7. The status of the patients at that time was as follows:

— Patient 1 MI showed moist desquamation on a small part of the palmar surface of the second and third fingers of the right hand, without local pain, and had no signs of bleeding, in spite of a very low platelet count (see Table II–I in Annex II). No fever was reported.
— Patient 2 NI showed some minor bleeding spots into the skin (cutaneous ecchymoses and petechiae). No fever was reported.
— Patient 3 HI presented a few minor bleeding spots into the skin and into the gums (gingivorrhagia). The patient's temperature was 39°C on admission to the Haseki Hospital.
— Patient 4 KI showed a few minor bleeding spots into the skin and some viral (herpes-like) infection above the upper lip at the right corner of the mouth. This infection is rather common in patients with aplasia. No fever was reported.
— Patient 5 II showed some minor bleeding spots into the skin and into the submucosa of the oral cavity (mouth). An episode of nose bleeding (epistaxis) was reported. The patient's temperature was 39°C on admission to the Haseki Hospital.

On 13 January 1999, the IAEA's medical team (see also Section 4.5 and Annex I), in consultation with the Turkish medical specialists in charge, examined all 15 patients admitted to hospital with confirmed or suspected ARS.

The IAEA medical team came to the following findings, conclusions and recommendations:

(a) The team considered the medical investigation and the management of patients to have been fully appropriate in both hospitals.

(b) The team concurred with the dose estimates made on the basis of both the clinical picture and the haematological values. The doses to patients 1–5 who were in the Cerrahpasa Medical Faculty were estimated to be between 2 and 4 Gy, and the doses to patients 6–10 in the Haseki Hospital to be between 1 and 2 Gy (on the basis of the clinical and haematological values in IAEA Safety Reports Series No. 2 [14] and the haematological charts in Annex II (see Figs II–1 and II–2) [15]).

(c) The team stressed the need to do the following:
- Maintain the treatment and strict isolation of the patients to prevent infection;
- Continue stimulation of blood cell production in bone marrow (until blood values were normalized);
- Continue platelet transfusions where clinically appropriate;
- Prevent infection of the localized injury to the two fingers of patient 1 MI.

(d) The team recommended:
- Massive transfusions of platelets to patients 1, 2, 4 and 5 to reduce the risk of bleeding, which would be life threatening, owing to the extremely low platelet counts;
- The prompt discharge from hospital of two young patients, as their medical data, including blood counts, did not indicate any significant radiation exposure.

Despite their having been given massive platelet and whole blood transfusions (between 9 and 12 January 1999), very low blood cell counts were recorded in the samples taken on 13 January 1999 for patients 1–5. The results are given in Table II–II in Annex II. Massive platelet transfusions were given in the first week in hospital to prevent any severe bleeding. In particular, patient 1 MI received 14 units of platelets and patient 5 II was given a total of 31 units. In addition, whole blood cell and erythrocyte transfusions were also given (see Table II–III in Annex II).

The results of the first bone marrow biopsy for patients 1–5 on 13 January 1999 showed severely hypocellular bone marrow (see Table II–IV in Annex II). After a

week of treatment, marked improvements were observed in the haematological parameters of all ARS patients. The white blood cell counts in most of the patients became normal within a few days. However, the lymphocyte levels remained just below the normal range for a long time. The platelet levels reached the lower end of the normal range in two weeks, on average (see Figs II–3 and II–4 in Annex II). The haematological evolution and hence the treatment scheme for patients 1–5, those most severely exposed, were very similar (see Figs II–3 and II–4 and Table II–V in Annex II).

By 24 January 1999 (following a 12–14 day hospital stay), the following conditions prevailed:

— For all ten patients, the bone marrow had recovered.
— Cytokine (G-CSF, Neupogen) therapy had been stopped after 11–12 days of administration of cytokines for patients 1–4 and after 6 days for patients 5–7 (see Table II–V and Figs II–3 and II–4 in Annex II).
— None of the patients needed any further transfusion of blood components.
— None of the ARS patients had become systemically infected and all had good prognoses.

Three of the patients were discharged from the Haseki Hospital on 25 January 1999.

Patients 1–5 were treated in a similar manner with the same antibacterial, antiviral and antifungal drugs and dosages of cytokines. The total dose of G-CSF used for bone marrow stimulation in the period 12–23 January 1999 was 48 million units (48 MU) for patients 1–5 (8 μg/kg body weight per day), while for patients 6 and 7, who were in a less severe condition, a daily dosage of 5 μg/kg body weight was applied and in total 30 MU were administered. The daily doses of antibacterial, antiviral and antifungal drugs administered to patients 1–5 for the three weeks from 12 January to 1 February 1999 are given in Table II–VI in Annex II. These proved to be very effective in the prevention of complications involving infections.

On 17 February 1999, the results of the second bone marrow biopsy showed normocellular bone marrow and indicated a full haematopoietic recovery for all patients (see Table II–IV in Annex II).

On 24 February 1999, the five most severely affected patients were discharged from the Cerrahpasa Medical Faculty with good prognoses. This was on day 45 of their hospital stay (see Fig. II–5 in Annex II). At this stage, the condition of the two fingers of patient 1 MI showed good epithelialization and no ulceration. There was no sign that amputation would be necessary.

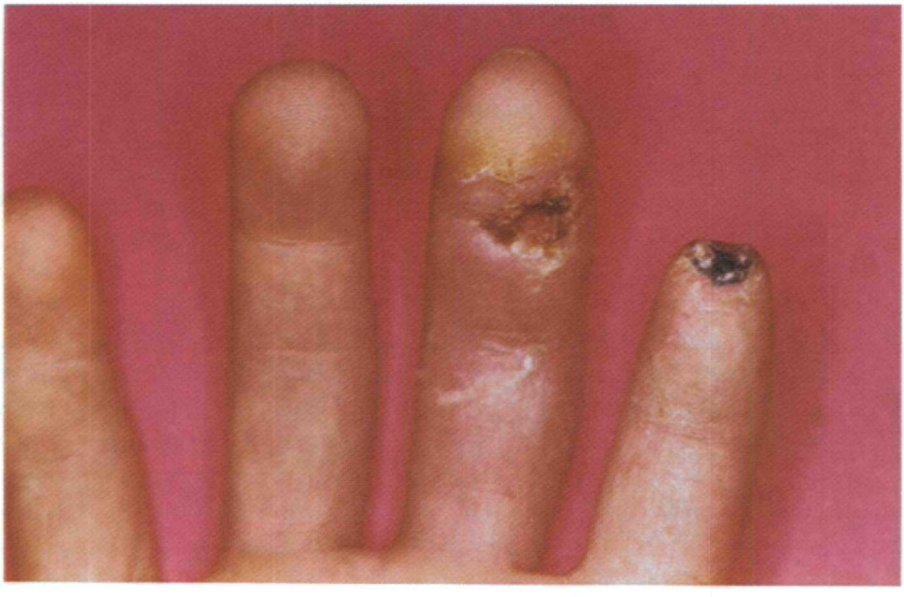
Since February 1999, all ten ARS patients admitted to hospital have been kept under regular observation as outpatients at the Haseki Hospital. In April 1999, haematological examination indicated a further improvement of blood counts. Platelet

counts were in the normal range for all subjects. White blood cells were normal in seven patients, and in three patients (1 MI, 2 NI and 4 KI) they were just below the normal range. However, lymphocyte counts in patients 1–5 remained significantly below the normal range, which necessitated continued caution and care to prevent any infectious disease.

By March 2000, no special clinical symptoms or complications were identified, but the patients continued to complain of fatigue, occasional headaches and some psychological effects.

The progression of the local radiation injury to the right hand of patient 1 MI was followed up by the Gülhane Military Medical Academy, Ankara. The following is a summary of the results of the examinations:

— In April 1999, an X ray examination of the right hand showed a slightly thinner bone tip of the first phalanx of the second finger, where the skin had also become thinner.
— In July 1999, the three phase bone scintigraphy showed slightly decreased perfusion and X rays revealed osteoporosis and soft tissue atrophy on the tip of the first phalanx of the second finger. Flexion limitation of the proximal interphalangial joint was noticed. There was no sign of infection or pain.



Photograph 17. Ulcerated third finger of patient 1 MI 14 months after an acute radiation exposure in Istanbul on 13 December 1998. The first phalanx of the second finger was amputated in November 1999. Since then some ulcerative–necrotic changes have developed.

Abnormal sensation on the tip of the second finger was expressed. The other fingers were functioning normally.

— In November 1999, the atrophic distal (end) phalanx of the second finger was removed.

— In February 2000, 14 months after the acute local radiation exposure, the distal phalanx of the third (middle) finger and also the tip of the middle phalanx of the second finger at the amputation line showed ulcerative changes (Photograph 17). The late phase bone scan showed increased uptake by the middle and end phalanxes of the middle finger due to hyperaemia or osteomyelitis in this part of the finger. A surgical treatment of the finger appeared necessary at this stage.

5.2. CONCLUSIONS ON THE MEDICAL TREATMENT

(1) Patients 1–5 presented with life threatening thrombocytopenia at the time of admission to hospital. Initial transfusions of a few (1–3) units of platelets proved to be marginally effective in the first two days, leading to the prescription of massive platelet transfusions in the night of 12–13 January 1999. These transfusions stopped the haemorrhages in the two patients who had some bleeding and allowed an increase of the platelet counts up to a safer range. However, although patient 5 II recovered rapidly after a massive platelet transfusion of 24 units, all other patients showed marked recovery in platelet counts only after completion of G-CSF treatment. Such a delay in recovery of platelets had previously been reported and is sometimes attributed to a negative impact (on platelets) of G-CSF [16, 17]. However, such a recovery chronology could also be consistent with spontaneous recovery of the platelet lineage [18].

(2) Whether or not the massive platelet transfusions given in the night of 12–13 January 1999 were more effective than the usual dosage for administration of platelets (1 unit per 10 kg body weight) cannot be ascertained. However, it may be noted that for patient 5 II, who received by far the highest number of platelet units (24), these massive transfusions seemed to have been able rapidly and definitively to correct a severe thrombocytopenia, without the delay that was observed in the other patients.

(3) The very low neutrophil and lymphocyte counts were equally life threatening in patients 1–5 at the time of admission to hospital. With the exception of patient 4 NI, who presented a viral herpes-like perilabial lesion (above the upper lip at the right corner of the mouth), no patient suffered from patent bacterial, viral or fungal infection (see Table II–VI in Annex II). Strict reverse isolation of all ten ARS patients admitted to hospital and massive use of wide

spectra antibiotic, antiviral and antifungal pharmaceuticals were fully justified to prevent hospital infections.

(4) Patients clearly benefited from bone marrow stimulation by G-CSF, starting on 12 January 1999. This growth factor induced a rapid recovery of the white cell lineage, which reached a level of $10^5/mm^3$ in all patients in 4–11 days. As usual, after a leucocyte 'peak' due to G-CSF, the white blood cell counts normalized within a few days (see Figs II–3 and II–4 and Table II–V in Annex II).

6. SUMMARY OF BIOLOGICAL DOSIMETRIC ANALYSES

6.1. PARTICIPATING LABORATORIES

Biological dosimetry was carried out in four laboratories at the following centres:

— Çekmece Nuclear Research and Training Centre (ÇNAEM), Istanbul, Turkey;
— Institute for Protection and Nuclear Safety (IPSN), Clamart, France;
— National Radiological Protection Board (NRPB), Chilton, United Kingdom;

TABLE IV. POOLED RESULTS OF ESTIMATED DOSES FOR PATIENTS 1–10 ON THE BASIS OF ANALYSES OF DICENTRIC ABERRATIONS AND MICRONUCLEI FREQUENCIES CONDUCTED IN TWO LABORATORIES

Patient	Assumed exposure time on 13 Dec. 1998 (h)	Protracted dose by dicentrics ± standard error (Gy)	Estimated dose based on micronuclei frequencies (Gy)
1 MI	6	2.2 ± 0.3	2.1
2 NI	7	2.3 ± 0.4	2.5
3 HI	6	3.1 ± 0.3	2.7
4 KI	7	2.5 ± 0.2	2.5
5 II	7	2.5 ± 0.5	2.2
6 HG	6	1.8 ± 0.2	1.6
7 AI	2	0.9 ± 0.1	0.7
8 HS	2	0.6 ± 0.1	—
9 AS	3	0.8 ± 0.2	0.7
10 ED	2	0.6 ± 0.2	—

— Department of Radiation Genetics and Chemical Mutagenesis, Leiden University Medical Center (LUMC), Leiden, Netherlands.

The results are based on blood samples taken on 9 and 11 January 1999 for ÇNAEM, 13 January 1999 for NRPB and IPSN, and 14 January 1999 for LUMC. Blood samples from ten patients with confirmed ARS were conveyed to each institute, where they were processed by the laboratories' routine procedures. IPSN examined blood from patients 1–5 and the other three laboratories examined all ten patients who showed symptoms of ARS. In addition, ÇNAEM examined a further 20 subjects who were assessed to have received lower doses.

All laboratories undertook routine analyses for dicentric chromosomal aberrations scored in first division metaphases from two-day cultures. Additionally, IPSN and LUMC carried out analysis of micronuclei using the assay for micronuclei in cytochalasin-B blocked binucleate lymphocytes. IPSN, NRPB and LUMC also examined two-day cultured metaphases for translocations using fluorescence in situ hybridization (FISH).

6.2. ANALYSIS OF DICENTRICS

For this analysis, minor details of method, such as the choice of culture medium, differed between laboratories but in essence all protocols conformed to the criteria outlined in IAEA Technical Reports Series No. 260 [19]. ÇNAEM was able to provide initial approximate estimates of acute doses, on the basis of dicentrics, of 1.0 Gy and 2.0 Gy, respectively, for patients 7 AI and 2 NI on 12 January 1999, some 51 hours after blood sampling. Preliminary results provided shortly afterwards by NRPB agreed with these values, despite the fact that the blood cell counts had suggested considerably higher radiation exposures. Further data from the laboratories were reported for the ARS cases over the following days. Table IV shows pooled basic data for dose estimation according to the frequency of dicentric chromosomal aberrations from the four laboratories for all ten ARS patients. The estimates were made on the basis of the assumption that the protracted exposure occurred on 13 December 1999. Dose estimates based on micronuclei frequencies are also presented here for comparison. These are discussed in Section 6.3 and Annex III. The method of pooling data is described in Annex III, together with the number of cells and dicentrics scored (by four laboratories) and distributions of dicentrics among the scored cells (see Table III–I in Annex III).

Thus the biological doses estimated on the basis of the frequencies of dicentric chromosomes and micronuclei indicated whole body doses of between 2 and 3 Gy in patients 1–5, of about 2 Gy in patient 6 HG and in the range 0.5–1.0 Gy for patients 7–10. In addition to these ten ARS patients, the accidental doses to other

subjects were also investigated by ÇNAEM. These subjects included three brothers (KA, AA and SA), owners of the Ikitelli scrapyard where the source was recovered on 10 January 1999. Their exposure patterns were also complex. Exposure commenced on 28 December 1998, when the scrap was transported to their yard. From interviews it was reportedly ascertained that KA and AA assisted patient 5 II to unload the truck, at which time they could have received an acute exposure. SA, however, did not participate in unloading the truck and was exposed only to scattered radiation at a much lower dose rate. Exposure lasted for two weeks, although it was fractionated owing to the absence of the subjects at nights and weekends. KA and AA also worked in the scrapyard over this time, and thus it may be assumed that their protracted exposures were similar to that of SA. The total doses of KA and AA were estimated as 0.8 Gy each, and that of SA as 0.4 Gy. The method of calculation and the results are presented in Annex III (Table III–II).

Seventeen other persons were also examined by ÇNAEM. Five were children who had been admitted to a paediatric clinic. The other 12 were adults, nine of whom exhibited blood counts slightly below normal values. Two of the adults examined were members of II's family and one was a crane operator who had worked in the first dismantling procedure. Nine of the adults exhibited blood counts slightly below normal values. In seven cases, doses in the range 0.2–0.5 Gy were estimated. In the remaining ten cases (including the nine with slightly low blood counts) the doses were below the limit of detection.

The ÇNAEM laboratory undertook a follow-up of dicentric yields in the five patients with the most severe ARS; the results are summarized in Table III–III in Annex III. This showed that the dicentric yields had declined over the period January–March 1999. This phenomenon is considered more fully in Section 6.4, where the data from FISH are discussed.

6.3. MICRONUCLEI ASSAY

The micronuclei (MN) test is considered a possible alternative technique to assay of dicentrics [20–22]. An MN measurement represents an integrated picture of radiation induced production of chromosome aberrations over time. The dose was estimated by LUMC and IPSN from the MN yields scored in binucleate cells according to their respective calibration curves. The doses calculated by LUMC were very close to those obtained by IPSN for the first four patients. This justified pooling the scored data, which are presented in Table III–IV. Doses were estimated for patients 1–4 on the basis of pooled data from IPSN and LUMC; for others only LUMC data were available. For control, the value of 15 MN/1000 BNC was used, this being the average of historical control values from the two groups. The dose estimates

obtained using the MN test were in good agreement with the values obtained on the basis of pooled frequencies of dicentric chromosomes (see Table IV).

6.4. TRANSLOCATIONAL ANALYSIS BY FISH

The data in Table III–III in Annex III suggest that the yields of dicentrics decrease with time. If this is correct, the doses in Table IV, estimated on the basis of blood samples taken one month after exposure, may be underestimates. This possibility has been investigated by using FISH analysis to detect translocations in lymphocytes from the first five ARS patients. Translocations are considered to be stable with time and thus should reflect the initial dose. The three laboratories (IPSN, NRPB and LUMC) used different cocktails of whole chromosome probes and their own standard protocols [23–25]. At present the FISH technique has not been standardized for retrospective dosimetry. Nevertheless, it was considered worth trying this experimental technique in view of the literature reports that dicentric yields decrease rapidly following overexposure sufficient to cause deterministic effects [26].

The data obtained from the three laboratories were in reasonable agreement. Each laboratory converted the translocation yields to dose using their own dose–response curve and applied the *G* function to the dose squared coefficient, as was done with the dicentric data (see Annex III). Mean dose estimates are shown in Table V and the comparable values for the dicentric analysis are reproduced from Table IV. On average, the dose estimates derived from translocations were about 20% higher than those from dicentrics. This could indicate that over the first month the

TABLE V. ESTIMATES OF PROTRACTED DOSES (Gy) BASED ON ANALYSES OF TRANSLOCATIONS AND DICENTRICS

Patient	Dose based on translocations	Dose based on dicentrics
1 MI	2.8	2.2
2 NI	3.2	2.3
3 HI	3.9	3.1
4 KI	3.0	2.5
5 II	2.7	2.5

dicentric (and micronuclei) yields did indeed decrease and thus the dose values presented in Table IV may be underestimates by about 20%.

6.5. FINDINGS FROM BIODOSIMETRY

Similar doses were estimated by all three methods used, account having been taken of the dose protraction and the sampling delay. For patients 1–5, the estimated doses were about 3 Gy each, for patient 6 HG the estimated dose was 2 Gy, while for all other persons for whom analyses were undertaken, including patients 7–10, estimated doses were below 1 Gy.

7. FINDINGS, CONCLUSIONS AND LESSONS TO BE LEARNED

The primary objectives of the follow-up investigation of the accident in Istanbul were: to ascertain the causes of the accident; to review the effectiveness of the official response; to draw conclusions on the basis of the findings; and to consider the lessons to be learned. A number of the lessons are not unique to this accident and are worth repeating in this report. The specific findings and conclusions from the accident are given in the following, together with general lessons to be learned (given in italics).

7.1. OPERATING ORGANIZATIONS

(1) The sources were stored in Istanbul without the permission of the regulatory authority (TAEK). The company's arrangements to ensure the security of sources at the Istanbul warehouse were inadequate and no periodic inventory checks were carried out. These significant factors allowed an unauthorized sale of the containers to take place, and this in turn led to the accident.

The BSS [1] establish requirements for ensuring that radioactive sources are kept secure and require that this function be the prime responsibility of the 'legal person' (the source shipping company in this case). As seen in this accident, the arrangements for source security extend beyond the physical structure of stores. The BSS also require that legal persons make a safety

assessment of the protection and safety of radiation sources for which they are responsible.

(2) The investigation highlighted inadequacies in the company's source inventory records. In particular, it was not possible to confirm which source, if any, was inside the second container. This caused problems in both the immediate response to the accident and the subsequent investigation. Furthermore, the records of the source supplier in the USA were reportedly not sufficient to establish which sources had been returned to them.

Legal persons need to maintain accurate inventory records of their radioactive sources. The purpose of these records is to identify the current location of sources, enabling any losses to be quickly identified. The records of suppliers of radioactive sources need to be comprehensive, recording details of where sources are sent and verifying serial numbers of returned sources prior to disposal.

7.2. NATIONAL AUTHORITIES

(1) At the time of the accident, the national regulations for controlling radiation sources were being revised to meet the requirements of the BSS. The national authorities reported that the model regulations given in IAEA-TECDOC-1067 on Organization and Implementation of a National Regulatory Infrastructure Governing Protection against Ionizing Radiation and the Safety of Radiation Sources [2] were a useful aid in this process, and that they had also drawn on the experience of events in this accident.

National authorities are invited to make use of IAEA-TECDOC-1067 [2] in considering the implementation of the provisions of the BSS. Such authorities may also find it useful to consider whether their own regulatory system is sufficiently robust to prevent such a sequence of events as described in this report and other IAEA reports on accidents [3–7].

(2) The Turkish authorities have a national emergency plan for dealing with transboundary radioactive fallout arising from nuclear power plants or weapon tests outside the country, as well as radiation risks associated with the operation of research reactors. At the time of the accident described in this report there were no national emergency plans for dealing with the situation. Once the presence

of the source had been confirmed in the scrapyard, the authorities, however, reportedly demonstrated an effective response. Rehearsal of the recovery operation with a dummy source, regular reviews of progress and the assessment of different recovery options are examples of good practices in radiation protection, enabling doses to be kept to a minimum.

The BSS [1, para. V.1] presume that States will have determined in advance the allocation of responsibilities for the management of interventions in emergency exposure situations between the regulatory authority, national and local intervening organizations and registrants or licensees. National authorities are invited to make use of IAEA-TECDOC-953 on Method for the Development of Emergency Response Preparedness for Nuclear or Radiological Accidents [27].

(3) The presence of a radioactive source was not detected at the scrapyard and the source could easily have been transferred to a metal processing works, incorporated into metal products and shipped around the world.

The presence of radioactive sources in scrap metal appears to be an increasingly widespread problem. National authorities need to develop strategies for detecting and dealing with such sources. Workers such as scrap metal dealers/processors, exporters, customs officers, etc., who may be occupationally exposed need to be provided with suitable information and guidance.

(4) The sources involved in this accident had been taken out of use five years before the accident. The manner of the long term storage of the sources by the company was undoubtedly a significant contributory factor in the accident. There appears to have been no direct instruction or request from the national authorities or the original supplier to return the sources within a specified period.

The extended storage of spent sources makes avoidable demands on security arrangements and makes accidents more likely. Ideally, binding agreements would be in place before sources are supplied to ensure their safe disposal.

(5) Members of the public have difficulty in distinguishing between radiological and nuclear risks. As a consequence, unnecessary alarm may be caused by reports of radiological accidents.

National authorities may wish to consider ways in which appropriate information could be made available to help the public understand the different risks.

(6) The sequence of events leading to this accident is similar in many ways to those described previously in other IAEA accident reports [6, 7]. These similarities are a cause for concern.

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

7.3. INTERNATIONAL CO-OPERATION

(1) As in the case of this accident, the IAEA can provide assistance, upon request, to Member States in relation to radiation emergencies, in the framework of the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency. The assistance provided may include: (a) technical advice on emergency planning, preparedness and response; (b) assistance with a radiological survey; (c) assistance with the retrieval of sources; (d) assistance with in situ verification of the radiological conditions and technical advice; and (e) medical advice in relation to overexposed persons.

The governments of all countries in which major radiation sources are used are invited to subscribe to the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.

(2) The trefoil symbols on the source containers failed to convey the potential radiation hazard. Another symbol might provide a more effective warning to the public of the potential hazard.

For sources readily capable of causing deterministic effects it may be appropriate to provide additional wording and symbols on containers to indicate that the contents are dangerous. More generally, there may need to be an international review of the purpose of the trefoil symbol, whether it is intended as a warning or simply to inform of the presence of radiation. If words are used in addition to symbols they must be in a language which is understandable to the local public and workers.

7.4. EQUIPMENT SUPPLIERS

(1) It was possible, reportedly, to dismantle the shipping containers with relatively simple tools, allowing access to high dose rates.

Defence in depth and engineering controls designed into the construction of shipping containers could help to prevent the unauthorized removal of shielding and the subsequent extraction of the source.

7.5. MEDICAL COMMUNITY

(1) The persons exposed in the accident reported to hospitals, but their symptoms were not initially diagnosed as being caused by radiation exposure. In many reported accidents, medical doctors are unable to recognize a radiation injury. Early diagnosis and treatment can be crucial and in some cases could be life saving.

Medical doctors need information and training about the basic symptoms of radiation exposure and the types of radiation sources that might cause such effects. They need to contact the regulatory authority to ensure the safety of the public if they suspect that a patient's symptoms might be radiation induced.

(2) Discrepancies between the biological dosimetry based on analysis of the frequency of chromosome aberrations in lymphocytes and the clinical doses estimated on the basis of the white blood cell and platelet counts were most probably due to the following:

— Blood samples for biodosimetry were taken one month after the accident; thus many of the lymphocytes having dicentric chromosomes would have been removed from the blood, since lymphocytes with dicentric chromosomes cannot divide and therefore die.
— The doses estimated on the basis of haematological effects were in better agreement with those based on dicentrics and micronuclei if account was taken of the 6–7 h protraction of the exposure on 13 December 1998.
— Even better agreement is obtained between the clinical (haematological) and biological (cytogenetic) estimated doses if the higher translocation frequencies are taken as evidence of a decrease in the dicentric yield by about 20% in the first month after exposure.

Blood samples for haematological and cytogenetic dose assessment need to be taken as soon as possible and further samples need to be taken at intervals following radiation exposure to facilitate the estimation of doses, which is necessary for prognosis. Some blood (a few millilitres) may be kept for biodosimetric purposes prior to whole blood transfusion(s). The FISH method has

proved its usefulness for dose estimation in the case of delayed blood sampling following overexposure.

(3) By means of adequate supportive care, platelet transfusions and leucocyte lineage stimulation (by G-CSF), safe levels of blood cell counts were achieved within a few days. The clinical evolution following this accident confirms that even with rather severe haematopoietic syndrome due to whole body irradiation with a dose of a few grays, the use of allogenic bone marrow transplantation is not indicated. Indeed, it would be considered contraindicated because of the complications that would be anticipated with grafting [14].

Use of cytokines assisted the haemapoietic recovery even one month after the radiation exposure (with a dose of 2–4 Gy to the whole body). This is a useful means of treatment in such cases; it shortened the period of neutropenia and thus prevented the development of systemic infections (sepsis) that may lead to fatality. No adverse effect of G-CSF on platelet recovery was observed.

Use of cytokines can be recommended for treatment of radiation induced severe bone marrow aplasia when spontaneous haemapoietic recovery has not yet started according to extensive bone marrow examination.

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Annex I

CHRONOLOGY OF EVENTS

Date	Event/action	Identification numbers/initials of persons [a]	Location
February 1998	Two radiotherapy source transport containers transferred from licensed premises in Ankara to unoccupied and unauthorized premises in Istanbul for storage	Source shipping company	1 (Marmara Industrial Estate)
9 Nov. 1998	Sale of premises where containers are stored		1
8 Dec. 1998	New owners of premises sell containers to local scrap collectors	1 MI (P) 2 NI (P)	1
	Containers carried away by truck and taken to the family house of the scrap collectors	1 MI (P) 2 NI (P)	2 (Mehmet Akif)
10 Dec. 1998	Containers taken by truck to the father-in-law's house and dismantling started	1 MI (P) 2 NI (P) 4 KI (P)	3 (Bayramtepe)
	Containers taken by truck back to the family house	1 MI (P) 2 NI (P)	2
13 Dec. 1998 09:00–16:30	Dismantling of container parts and cutting process continued	1 MI (P) 2 NI (P) 3 HI (P) 4 KI (P) 5 II (P) 6 HG (P) 7 AI (P) 8 HS (P) 9 AS (P) 10 ED (P)	2
16:30–later	Illness symptoms started	1 MI (P) 2 NI (P) 3 HI (P) 4 KI (P) 5 II (P) 6 HG (P)	2

[a] P: patient; S: scrapyard worker.

Date	Event/action	Identification numbers/initials of persons [a]	Location
14 Dec. 1998	Medical help sought	1 MI (P) 2 NI (P) 5 II (P) 6 HG (P)	2, Basak Clinic
15 Dec. 1998	Lead shielding carried back to the father-in-law's house and buried	5 II (P) CA	3
10 to 27–28 Dec. 1998	Dismantled pieces left lying in yard adjacent to the family house	I. family and neighbours	2
27–28 Dec. 1998	Metal pieces loaded onto truck by hand and with a shovel, and taken to the scrapyard for sale	5 II (P) KA (S) AA (S)	4 (Ziya Gökalp)
8 Jan. 1999 morning	Sick scrap collectors seek medical help from larger hospital Suspected case of radiation sickness	2 NI (P) 5 II (P) Dr. ÇC	Günes Private Hospital
11:30	Radiation exposure diagnosed by the doctor and reported to ÇNAEM by telephone	Dr. ÇC MYÖ	Günes Private Hospital and ÇNAEM
12:00	Team of health physicists sent to hospital	MA AT MK	Günes Private Hospital
	Interview with patients and preliminary investigation started	MA AT MK 1 NI (P) 5 II (P)	Günes Private Hospital
13:00	Buried containers are dug up and carried to scrapyard	ÇNAEM Team	3, 4
14:30	High radiation dose rates recorded at the scrapyard, which is immediately evacuated	MA AT MK	4
15:00	Governer of Küçükçekmece and police are informed of the accident	MYÖ YA (District Governor), HK (Police Chief)	Küçükçekmece
	TAEK is alerted	CY (President of TAEK)	Ankara

Date	Event/action	Identification numbers/initials of persons [a]	Location
15:30	Second team sent to scrapyard	MYÖ AK MY	4
16:00	Safety precautions imposed around scrapyard and area cordoned off	ÇNAEM Team and Police Force	4
	Involvement of Co-60 recognized. Import company identified	Company	ÇNAEM and RSGD
16:30	Cylindrical drawer assembly identified and assumed to be a source holder	ÇNAEM Team	4
17:00	Patients hospitalized	2 NI (P) 5 II (P)	Günes Private Hospital
18:00	Media coverage started	Various representatives of the press and TV	Istanbul
9 Jan. 1999 07:30	Radiation control and monitoring at the scrapyard. Damaged lead shielding transported to ÇNAEM	MYÖ DY MT	4
11:30	Manufacturing of the special shielding started, transport container prepared and taken to scrapyard	ÇNAEM Team	ÇNAEM
	Radiation cytogenetics group goes to hospital	GK FSP	Günes Private Hospital
	Blood samples collected from four persons for biological dose assessment	2 NI (P) 7 AI (P) 5 II (P) GI (P)	
12:00	Vehicles prepared for handling and carrying the unshielded source	ÇNAEM Team	ÇNAEM
13:00	Assessment meeting at TAEK headquarters. RSGD experts sent to Istanbul	CY (President), ZK (Vice President), MAA (Vice President), FG (RGSD Expert), KE (RGSD Expert)	TAEK, Ankara

Date	Event/action	Identification numbers/initials of persons [a]	Location
13:30	Recovery operation started. Drawer assembly picked up at first attempt and transferred to the container. After the survey of the container is carried out, it is realized that the source was not in the recovered drawer assembly		4
15:30	Operation temporarily suspended to allow assessment of alternative strategy		
20.00–24.00	Arrival of TAEK officials and assessment work carried out	ZK CY MAA FG KE	ÇNAEM
10 Jan. 1999 02:00	Police inquiry	GM ZK	ÇNAEM
	Police custody of the owner of the company	BÇ	Küçükçekmece
08:30–13:30	Preparation of special equipment for recovery operation	ÇNAEM Team	ÇNAEM
10:00	Radioactive source inventory prepared. Actual size and possible activity of the source determined. A dummy source taken from company sent to ÇNAEM. ÇNAEM informed on details of the company licence. The responsible person of the company invited to TAEK, to establish contact with the original source supplier	RSGD Experts	Ankara
12:30	Patients moved to state hospital	2 NI 5 II 7 AI MS	From Günes Private Hospital to Haseki State Hospital
14:00	Second recovery operation with special equipment and vehicles is started	ÇNAEM Team	4
17:00	Illumination of the area	Istanbul Civil Defence Group	

Date	Event/action	Identification numbers/initials of persons [a]	Location
19:00	Source is recovered and placed in a shielded container. Radiation survey at the scrapyard confirms there is no contamination and no second source. Recovered source transported to ÇNAEM with police escort. Safety zone precautions are lifted. Operation terminated	ÇNAEM Team	
11 Jan. 1999	Monitoring continued for the possible second source at metal smelting factories and in the region	MA AT	Izmit 1, 2, 3, 4
10:00	IAEA informed. A crisis desk established. (The crisis desk was disbanded upon conclusion of its mandate on 24 January 1999.) Activities involving international affairs, informing of public and media initiated	Members of crisis desk, RSGD experts	Ankara
11 Jan. 1999	Second group of blood samples collected from 10 patients for biological dose assessment	FSP II 1 MI (P) 3 HI (P) 4 KI (P) 6 HG (P) 7 HS (P) FI (P) ZI (P) TS (P) ZS (P) RY (P)	Haseki State Hospital
22:00	First biological dose results made available for three of the exposed persons	GK FSP II 2 NI (P) 7 AI (P) GI (P)	ÇNAEM
Evening	Medical consultant of TAEK from Gülhane Military Medical Academy, Ankara, arrives	Dr. BG	

Date	Event/action	Identification numbers/initials of persons [a]	Location
12 Jan. 1999	Monitoring continues for the possible second source in the region	ÇNAEM Team	1, 2, 3, 4
08:00–15.00	Medical consultant of TAEK examined all hospitalized patients, provided the first clinical dose estimate and ordered patients 1–5 to be moved to isolation wards of the Haematology Department of Cerrahpasa Medical Faculty of Istanbul University	Dr. BG 1 MI (P) 2 NI (P) 3 HI (P) 4 KI (P) 5 II (P)	Haseki State Hospital and Cerrahpasa Medical Faculty
13:00	Emergency assessment meeting with Istanbul City Governor and other governmental representatives	EÇ, YA and other official representatives	ÇNAEM
13 Jan. 1999 00:30–02:30	IAEA assistance I: Medical experts (from France, United Kingdom and IAEA) arrive. Detailed briefing about 16 hospitalized patients on arrival at the hotel	Dr. JMC Dr. CS Dr. IT Dr. BG	Kalyon Hotel, Istanbul
08.00–15.00	Medical experts consulted 15 hospitalized patients (including 5 children) and took blood samples from 10 ARS patients for dose assessment to IAEA Collaborating Biodosimetry Laboratories in France and the United Kingdom	Dr. JMC Dr. CS Dr. IT Dr. BG 1 MI (P) 2 NI (P) 3 HI (P) 4 KI (P) 5 II (P) 6 HG (P) 7 AI (P) 8 HS (P) 9 AS (P) 10 ED (P)	Haseki State Hospital and Cerrahpasa Medical Faculty
14 Jan. 1999	Activity of the recovered source measured	ÇNAEM	ÇNAEM
Morning	Medical experts' second meeting	Dr. IT Dr. BG Dr. KE Dr. TS	Haseki State Hospital, Cerrahpasa Medical Faculty

Date	Event/action	Identification numbers/initials of persons [a]	Location
Afternoon	Exploration tour at the scrapyard. Monitoring continues in the region	Dr. IT Dr. BG MYÖ MA MK AT MT	1, 2, 3, 4 smelting factory, other local scrapyards and dump sites
15:00	Preliminary (Turkish) biological dose results evaluated	Dr. IT Dr. BG Dr. GK Dr. FSP II	ÇNAEM
15 Jan. 1999 morning	Assessment by walk-through of the accident zone	ZK MYÖ MK MA	1, 2, 3, 4
Afternoon	IAEA assistance II: Two radiation safety experts of the IAEA's ERC arrive	CNO JH BGG IY	Atatürk Airport, ÇNAEM
	Blood samples collected on 14 Jan. 1999 from patients 1–10 are sent to Netherlands by Ministry of Health, Turkey	1 MI (P) 2 NI (P) 3 HI (P) 4 KI (P) 5 II (P) 6 HG (P) 7 AI (P) 8 HS (P) 9 AS (P) 10 ED (P)	
16 Jan. 1999 morning	Evaluation tour around the accident zone and further monitoring	CNO JH MYÖ	1, 2, 3, 4
	Assessment meeting, IAEA recommendations considered	MK MA BGG	ÇNAEM
	An empty container belonging to company transported to ÇNAEM	RSGD	Ankara, Istanbul

Date	Event/action	Identification numbers/initials of persons [a]	Location
17 Jan. 1999 10:00–16:00	Reinvestigation at the smelting factory	CNO JH MYÖ MA	Izmit
16:00–20:00	Risk evaluation meeting	CNO JH BGG MYÖ	ÇNAEM
21:00–23:00	Meeting continued and concerns reported to the officials	MA BÇ CÇ	Kalyon Hotel, Istanbul
18 Jan. 1999	Emergency operation meeting. Emergency monitoring operation for the missing source in the entire accident zone, street by street	All emergency teams of ÇNAEM and District Governor. Local officials of locations 1, 2, 3 and 4: AB, MS, YB and NA	ÇNAEM 1, 2, 3, 4
19 Jan. 1999 17:00	Review of the status. Discussion with TAEK headquarters by conference telephone link	CNO JH BGG ZK	Kalyon Hotel, Istanbul, and TAEK headquarters, Ankara
24 Jan. 1999 23:50	IAEA assistance III: Accident review expert arrived from United Kingdom	PS BGG	Atatürk Airport
25 Jan. 1999	Blood samples collected from two patients for biological dose assessment	FSP II 9 AS (P) 10 ED (P)	Haseki State Hospital
	Accident evaluation work with the expert regulatory review	PS BGG MK	ÇNAEM
	Notification of Member States and IAEA about a missing source according to the Convention on Early Notification of a Nuclear Accident		Ankara

Date	Event/action	Identification numbers/initials of persons [a]	Location
26 Jan. 1999	Blood samples collected from four scrap metal workers for biological dose assessment	GK FSP II KA (S) AA (S) MA (S) SA (S)	ÇNAEM
	Visit to the accident zone	PS BGG MA	1, 2, 3, 4
27–28 Jan. 1999	Interview with medical doctors involved in previous medical treatment and diagnosis of the accident	PS BGG Dr. ÇC Dr. AI Dr. AB Dr. HU Dr. ZB	Günes Private Hospital, Basak Clinic
29 Jan. 1999	Inventory assessment of the import company	PS FA BGG	ÇNAEM
3 Feb. 1999	Inspections of radiotherapy centres according to Convention on Early Notification of a Nuclear Accident started (completed on 16 Feb. 1999)		Istanbul inspected by ÇNAEM; all other cities inspected by RGSD
9 Feb. 1999	Follow-up study initiated and second blood samples collected from overexposed patients	GK FSP GD II 1 MI (P) 2 NI (P) 3 HI (P) 4 KI (P) 5 II (P) 6 HG (P) 7 AI (P) 8 HS (P) 9 AS (P)	Cerrahpasa Medical Faculty, Haseki State Hospital

Date	Event/action	Identification numbers/initials of persons [a]	Location
9 Feb. 1999 (cont.)	Blood samples collected from remaining three suspected exposed persons	IÇ CA HA	2, 3

Note: Blood count values were obtained for 127 persons at Haseki State Hospital and 299 persons at Küçükçekmece Outpatient Department.

Annex II

MEDICAL DATA

TABLE II–I. INITIAL BLOOD COUNTS OF THE ISTANBUL RADIATION ACCIDENT VICTIMS ON THE DAY OF THEIR HOSPITALIZATION

Patient	Date of hospitalization	White blood cells (10^3/μL)	Lymphocytes (10^3/μL)	Platelets (10^3/μL)	Hb [a]	Hct [b]
1 MI	9 Jan. 1999	0.6	ND[c]	1.0	8.8	25.5
2 NI	9 Jan. 1999	0.4	ND	6.0	8.6	26.5
3 HI	10 Jan. 1999	0.4	ND	1.0	9.8	31.2
4 KI	9 Jan. 1999	0.9	ND	3.0	7.4	22.5
5 II	*9 Jan. 1999*	*0.3*	*ND*	*1.0*	*9.6*	*30.0*
6 HG	10 Jan. 1999	1.4	0.6	17.0	11.0	34.6
7 AI	9 Jan. 1999	3.0	0.7	32.0	11.3	36.0
8 HS	9 Jan. 1999	5.0	1.9	61.0	14.0	44.0
9 AS	11 Jan. 1999	3.8	1.0	26.0	14.0	38.0
10 ED	11 Jan. 1999	3.7	1.2	40.0	13.3	37.4
Normal range (10^3/μL)		4.3–11.0	1.5–4.0	150.0–350.0	14–18	43–52

[a] Hb: haemoglobin.

[b] Hct: haematocrit.

[c] ND: not detectable.

TABLE II–II. RESULTS OF BLOOD COUNT ANALYSIS BY IPSN, FRANCE, ON SAMPLES TAKEN ON 13 JANUARY 1999

Patient	White blood cells (10^3/μL)	Lymphocytes (10^3/μL)	Platelets (10^3/μL)
1 MI	0.33	0.23	15.0
2 NI	0.31	0.27	35.0
3 HI	0.52	0.42	22.0
4 KI	0.25	0.15	64.0
5 II	1.15	0.49	20.0

TABLE II–III. NUMBER OF UNITS OF BLOOD COMPONENTS TRANSFUSED TO PATIENTS 1–5 AND 7 WITHIN 12 DAYS

Patient	Whole blood	Platelets	Erythrocytes
1 MI	1	14	5
2 NI	1	22	3
3 HI	1	3	0
4 KI	2	19	8
5 II	6	31	0
7 AI	1	9	0

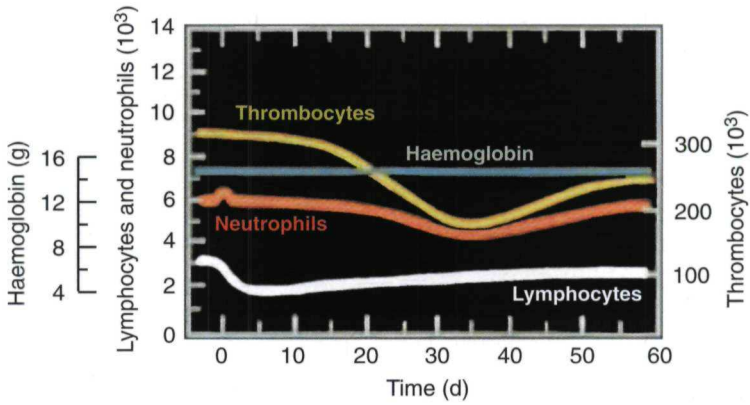

FIG. II–1. Haematological response to 1 Gy whole body exposure to ionizing radiation.

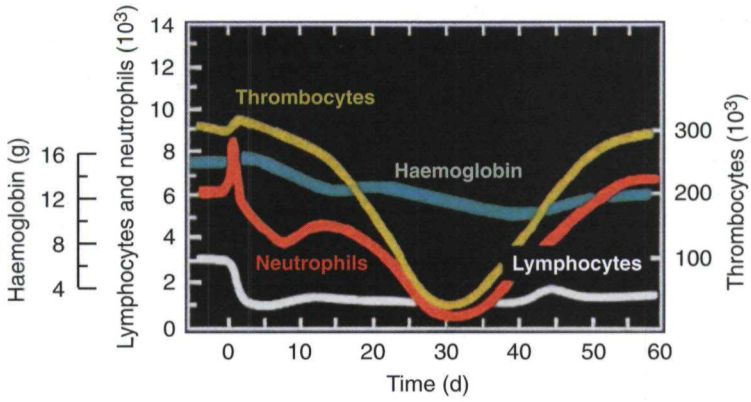

FIG. II–2. Haematological response to 3 Gy whole body exposure to ionizing radiation.

TABLE II–IV. RESULTS OF BONE MARROW BIOPSY OF PATIENTS 1–5

Patient	13 Jan. 1999	17 Feb. 1999
1 MI	Highly hypocellular bone marrow. Marrow areas were occupied with fat cells. There was no precursor haematopoietic cell. Only a few lymphocytes and plasma cells were identified	Normocellular bone marrow (40% cellularity); erythroid hyperplasia, normoblastic maturation, focal megaloblastic differentiation, high Fe score, relative decrease in myeloid series, continuous maturation and normal megakaryopoiesis
2 NI	Hypocellular bone marrow (5% cellularity), rare erythroid islands, normoblastic maturation, relative increase in lymphocytes and plasma cells	Normocellular bone marrow (50% cellularity); erythroid hyperplasia, normoblastic maturation, focal megaloblastic differentiation, high Fe score, relative decrease in myeloid series, continuous maturation, focal increase in megakaryocytes and slight dysmegakaryopoiesis
3 HI	Hypocellular bone marrow (15% cellularity); significant increase in immature cells (promyelocytes), absence of mature myeloid cells and megakaryocytes, rare erythroid islands. Normoblastic maturation. Relative increase in lymphocytes and plasma cells. Findings of recovery from plasia	Normocellular bone marrow (35% cellularity); erythroid hyperplasia, normoblastic maturation, focal megaloblastic differentiation, high Fe score, relative decrease in myeloid series, continuous maturation, sufficient megakaryocytes and slight dysmegakaryopoiesis
4 KI	Hypocellular bone marrow (2% cellularity), relative increase in lymphocytes and plasma cells	Bone marrow cellularity 20–40%; erythroid hyperplasia, normoblastic maturation, focal megaloblastic differentiation, high Fe score, relative decrease in myeloid series, continuous maturation, sufficient megakaryocytes and slight dysmegakaryopoiesis
5 II	Hypocellular bone marrow (20% cellularity), promyelocyte increase, absence of mature myeloid cells, high Fe score, relative increase in lymphocytes and plasma cells	Normocellular bone marrow (35% cellularity); erythroid hyperplasia, normoblastic maturation, focal megaloblastic differentiation, high Fe score, relative decrease in myeloid series, continuous maturation, sufficient megakaryocytes and slight dysmegakaryopoiesis

TABLE II–V. HAEMATOLOGICAL AND TREATMENT DATA OF PATIENT 3 HI

Dates in 1999	WBC	Lympho.	Platelets	Hb	Hct	Transf.	Other
10 Jan.	400	ND	1 000	9.8	31.2	1P, 1WB	
11 Jan.	500	ND	24 000	9.6	30.3		
12 Jan.	500	300	22 000	9.8	29.2	2P	Neupogen
13 Jan.	500	400	21 000	10.2	29.2		Neupogen
14 Jan.	700	400	13 000	10	28.9		Neupogen
15 Jan.	1 200	500	9 000	11.1	32.2		Neupogen
16 Jan.	2 600	500	18 000	9.3	28.4		Neupogen
17 Jan.	7 400	900	21 000	9.7	29		Neupogen
18 Jan.	9 900	800	11 000	9.5	27.7		Neupogen
19 Jan.	15 400	800	22 000	9	26.5		Neupogen
20 Jan.	11 800	900	26 000	9.3	27		Neupogen
21 Jan.	8 800	1 100	42 000	9.6	28.3		Neupogen
22 Jan.	7 400	1 100	46 000	9.2	27.1		Neupogen
23 Jan.	7 100		80 000	9.9	28.8		
24 Jan.	5 800		92 000	9.7	28.4		
25 Jan.	5 800	1 100	122 000	9.8	28.4		
26 Jan.	6 200	1 200	92 000	10	29.3		
27 Jan.	5 400	1 200	182 000	10.6	31.2		
28 Jan.	5 800	1 200	191 000	10	29.5		
29 Jan.	5 700	1 100	201 000	10.3	29.3		
30 Jan.	4 600	1 000	180 000	8.4	25.7		
31 Jan.	4 300	1 100	181 000	8.6	26		
1 Feb.	5 700	1 200	203 000	9.9	28.7		
2 Feb.	4 500	1 200	192 000	10.1	28.4		
3 Feb.	5 500	1 200	172 000	9.8	28.1		
4 Feb.	6 100	1 100	177 000	9.5	27.6		
5 Feb.	5 800	1 200	221 000	10	28.3		
6 Feb.	5 200	1 000	173 000	9.4	26.1		
7 Feb.	5 200	1 000	173 000	9.4	26.1		
8 Feb.	5 300	1 100	165 000	10.3	29.2		
9 Feb.	5 400	1 100	186 000	10.5	30.1		
10 Feb.	6 400	1 300	215 000	11.3	32.5		
11 Feb.	6 400	1 300	197 000	11.2	32.4		
12 Feb.	5 400	800	166 000	11.7	33.3		
15 Feb.	6 300	1 100	207 000	11.6	34.4		
24 Feb.	5 900	1 298	129 000	11.4	33.5		
3 Mar.	6 400	1 000	158 000	13.1	38.3		
11 Mar.	8 800	1 300	187 000	14.2	41.8		
16 Mar.	6 900	1 100	170 000	13.8	38.2		

Note: WBC: white blood cells; Lympho.: lymphocytes; Hb: haemoglobin; Transf.: transfusion; ND: not detectable; P: platelets.

TABLE II–VI. PREVENTIVE THERAPY OF INFECTIOUS COMPLICATIONS IN THE HOSPITALIZED ARS PATIENTS

Dates	Medications
12–22 Jan. 1999	Meronem (Meropenem), i.v. 3 × 1 g Amikasin (Amikacin), i.v. 1 × 1 g Vancocin (Vancomycin), i.v. 3 × 500 mg Acyclovir (Zovirax), i.v. 3 × 250 mg Triflucan (Flukanazol), i.v. 1 × 200 mg Bactrim forte (Trimethoprim-sulfamethoxazole), p.o. 2 × 800/160
23 Jan.–1 Feb. 1999	Cipro (Ciprofloxacine 1 × 1), p.o., 2 × 500 mg Triflucan (Flukanazol), i.v. 1 × 100 mg Bactrim forte (Trimethoprim-sulfamethoxazole), p.o. 2 × 800/160

Note: i.v.: intravenous; p.o.: oral.

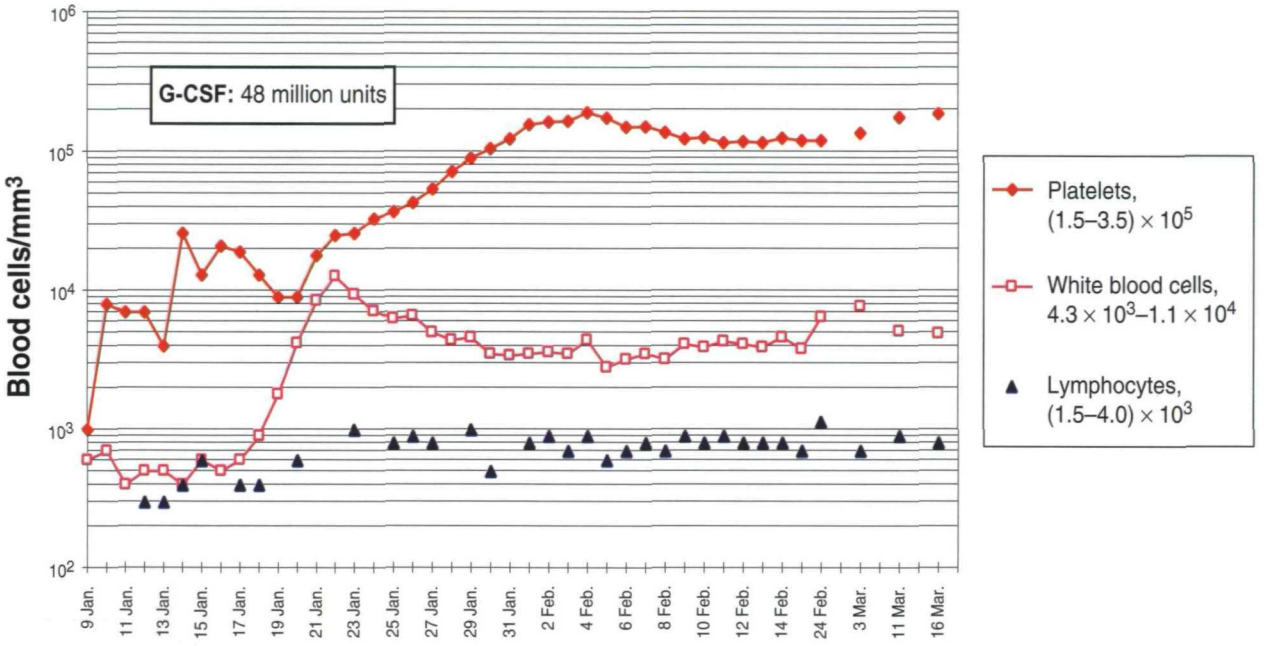

FIG. II–3. Haematological chart of patient 1 MI, hospitalized from 9 January to 24 February 1999.

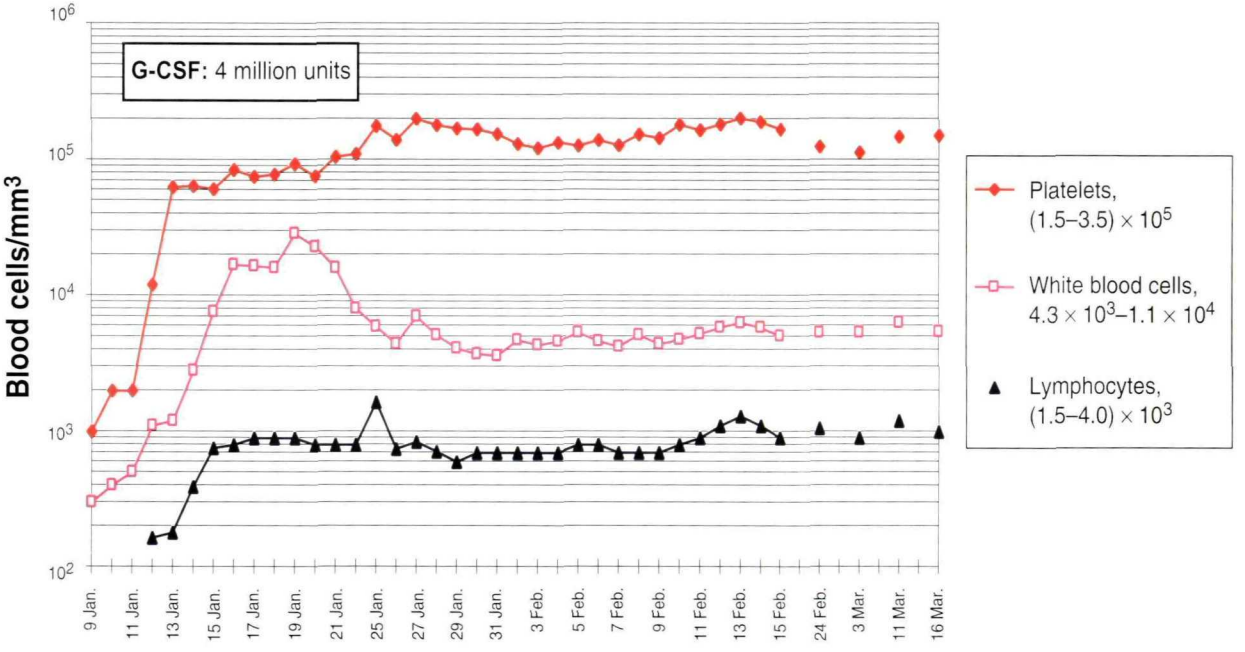

FIG. II–4. Haematological chart of patient 5 II, hospitalized from 9 January to 24 February 1999.

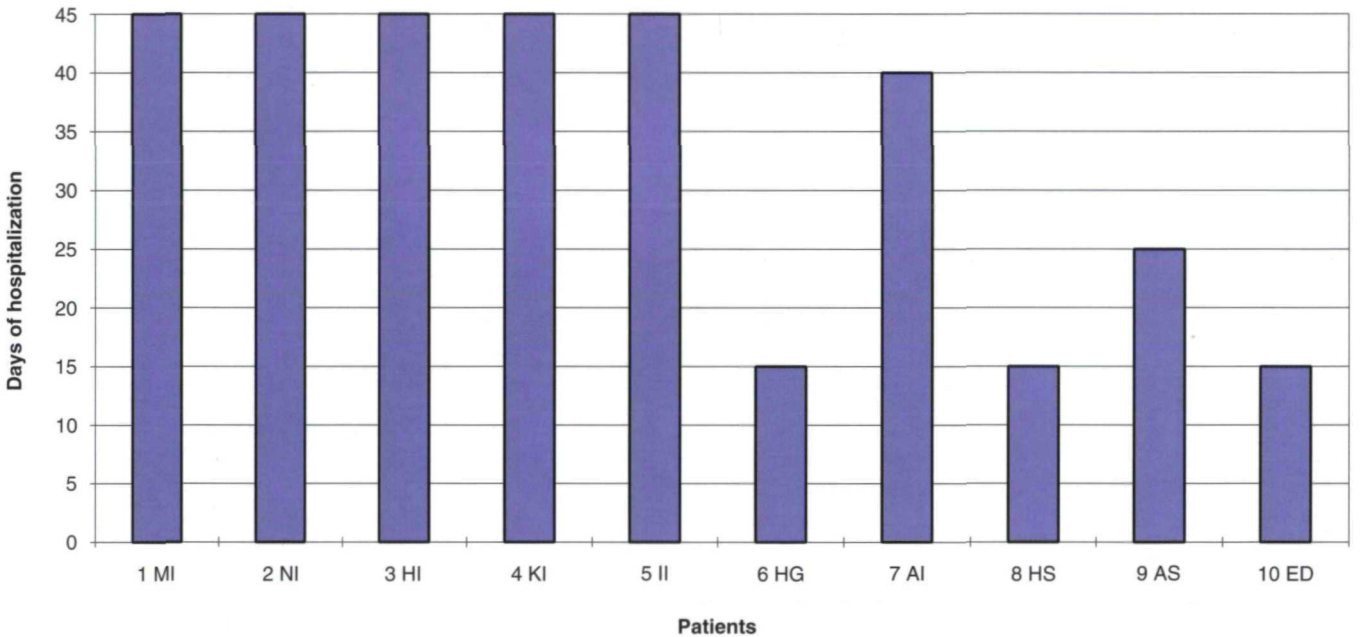

FIG. II–5. Period of hospitalization of ARS patients in Istanbul.

Annex III

BIOLOGICAL DOSE ESTIMATION

In order to estimate doses, the dicentric yields shown in Table IV in the main text were referred to a dose–response curve for acute in vitro exposure to ^{60}Co. The curve follows the linear quadratic form

$$Y = 0.001 + 0.030D + 0.060D^2$$

where Y is the dicentric yield per cell and D is the dose in grays. The coefficients shown above are rounded average values based on the individual dose–response curves of the four laboratories, it having been established that all four were in close agreement.

A simplifying assumption has been made to take some account of dose protraction. It was assumed that the major component of dose for the ten persons was received on 13 December during the dismantling of the shipping containers. The individual periods of exposure on that day have been assessed from repeated interviews as having ranged from 2 to 7 hours (Table IV, column 2). These times have been incorporated into time dependent G factors fully described in Ref. [III–1]. This enabled modifications to be made to the acute dose squared coefficient in the dose–response equation and thus allowed for the effect of the different periods of dose protraction for the different individuals. The resultant dose estimates are shown in Table IV, column 3. These therefore represent the best estimate of doses obtained from dicentric analysis, but subject to sampling delay, by pooling the resources of the four laboratories and taking account of the available information on the time pattern of exposures.

Standard errors (SEs) shown on the pooled dicentric yields (Table III–I, column 4) were based on Poisson assumptions but enhanced for any inhomogeneity between laboratories as shown by a chi-square test. The SEs on dose estimates were obtained from the SEs on yields by the simplified version of method B described on p. 47 of Ref. [III–1]. This takes no account of the uncertainties on the dose–response yield coefficients, which in some situations, such as where large numbers of dicentrics have been scored, is important. This component of the uncertainty has been included by increasing the SEs on doses to 10% in those cases where the SEs which were derived purely from the yields were <10%.

TABLE III–I. DICENTRIC DISTRIBUTION AND RESULTS OF TESTING FOR CONFORMITY WITH THE POISSON DISTRIBUTION

Patient	Cells scored	Dicentrics scored	Yield (dicentrics/ cell ± SE)	Dicentric distribution among cells						*U* value
				0	1	2	3	4	Variance (mean ± SE)	
1 MI	1132	224	0.198 ± 0.038	943	159	26	3	1	1.17 ± 0.04	4.03
2 NI	852	167	0.196 ± 0.047	703	131	18			1.02 ± 0.05	0.43
3 HI	1363	474	0.348 ± 0.052	997	281	65	17	3	1.22 ± 0.04	5.71
4 KI	688	157	0.228 ± 0.018	549	122	16	1		1.02 ± 0.05	0.29
5 II	1317	303	0.230 ± 0.079	1058	221	33	4	1	1.11 ± 0.04	2.76
6 HG	1200	179	0.149 ± 0.011	1039	146	12	3		1.09 ± 0.04	2.12
7 AI	1102	75	0.068 ± 0.009	1029	71	2			0.99 ± 0.04	–0.33
8 HS	1180	39	0.033 ± 0.005	1142	37	1			1.02 ± 0.04	0.47
9 AS	1100	54	0.049 ± 0.012	1049	48	3			1.06 ± 0.04	1.49
10 ED	1100	38	0.035 ± 0.011	1063	36	1			1.02 ± 0.04	0.45

In Table III–II, the doses have been estimated by reference to the acute in vitro dose–response curve of the ÇNAEM laboratory:

$$Y = (2.09 \times 10^{-2})D + (7.11 \times 10^{-2})D^2.$$

The dose estimate for SA was based on the linear yield coefficient, and for the others their additional dicentric yield was referred to the whole curve. As the number of dicentrics scored is low, uncertainties in dose estimates are expressed as 95% confidence intervals (95% CI).

TABLE III–II. BIOLOGICAL DOSE ESTIMATES FOR KA, AA AND SA, OWNERS OF THE IKITELLI SCRAPYARD

Person	Cells scored	Dicentrics/ cell	Estimated dose (Gy) (and 95% CI)		Estimated total dose (Gy)
			Acute dose	Protracted dose	
KA	100	0.030	0.4 (0.04–0.5)	0.4 (0.2–0.9)	0.8
AA	235	0.034	0.4 (0.05–0.5)	0.4 (0.2–0.9)	0.8
SA	224	0.009	0	0.4 (0.2–0.9)	0.4

TABLE III–III. FOLLOW-UP OF DICENTRIC YIELDS IN PATIENTS 1–5

Patient	Dicentrics/cell (95% CI)		
	9–11 Jan. 1999	9 Feb. 1999	10 Mar. 1999
1 MI	0.15 (0.11–0.22)	0.08 (0.04–0.14)	0.08 (0.04–0.14)
2 NI	0.30 (0.19–0.42)	0.20 (0.11–0.30)	0.16 (0.09–0.24)
3 HI	0.30 (0.19–0.40)	0.20 (0.11–0.30)	0.17 (0.10–0.25)
4 KI	0.19 (0.11–0.30)	0.12 (0.08–0.21)	0.13 (0.08–0.22)
5 II	0.30 (0.19–0.42)	0.15 (0.09–0.22)	0.15 (0.09–0.22)

TABLE III–IV. RESULTS OF MICRONUCLEUS ASSAY

Patient	No. of BNC scored	No. of MN	Distribution of MN in BNC (%)							Yield MN/ BNC	Dose[a] (Gy)
			0	1	2	3	4	5	>5		
1 MI	2158	693	74.3	20.3	4	0.7	0.6	0	0.1	0.32	2.1
2 NI	595	241	70.2	22	6.5	1.0	0.3	0	0	0.40	2.5
3 HI	2466	1197	63.4	27	7.5	1.7	0.2	0.2	0	0.49	2.7
4 KI	464	188	71	22	6.6	0.3	0.1	0	0	0.41	2.5
5 II	500	173	73.8	19.6	5	1.4	0.2	0	0	0.35	2.2
6 HG	1000	205	85	10.5	3.7	0.6	0.2	0	0	0.21	1.6
7 AI	900	75	93	5.9	1	0.1	0	0	0	0.08	0.7
8 HS	1000	40[a]	96.1	3.8	0.1	0	0	0	0	0.04	—
9 AS	1000	80	92.7	6.7	0.5	0.1	0	0	0	0.08	0.7
10 ED	1000	30[a]	97.5	2	0.5	0	0	0	0	0.03	—

[a] For two individuals, 8 HS and 10 ED, no dose estimate was made according to micronuclei frequencies owing to uncertainties (more cells should be analysed).

Note: BNC: binucleate cells; MN: micronuclei.

REFERENCE TO ANNEX III

[III–1] INTERNATIONAL ATOMIC ENERGY AGENCY, Biological Dosimetry: Chromosomal Aberration Analysis for Dose Assessment, IAEA Technical Reports Series No. 260, IAEA, Vienna (1986).

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Consultants Meetings

Vienna, Austria: 16–18 February 1999; Chilton, United Kingdom: 12–15 April 1999; Istanbul, Turkey: 10–12 May 1999

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