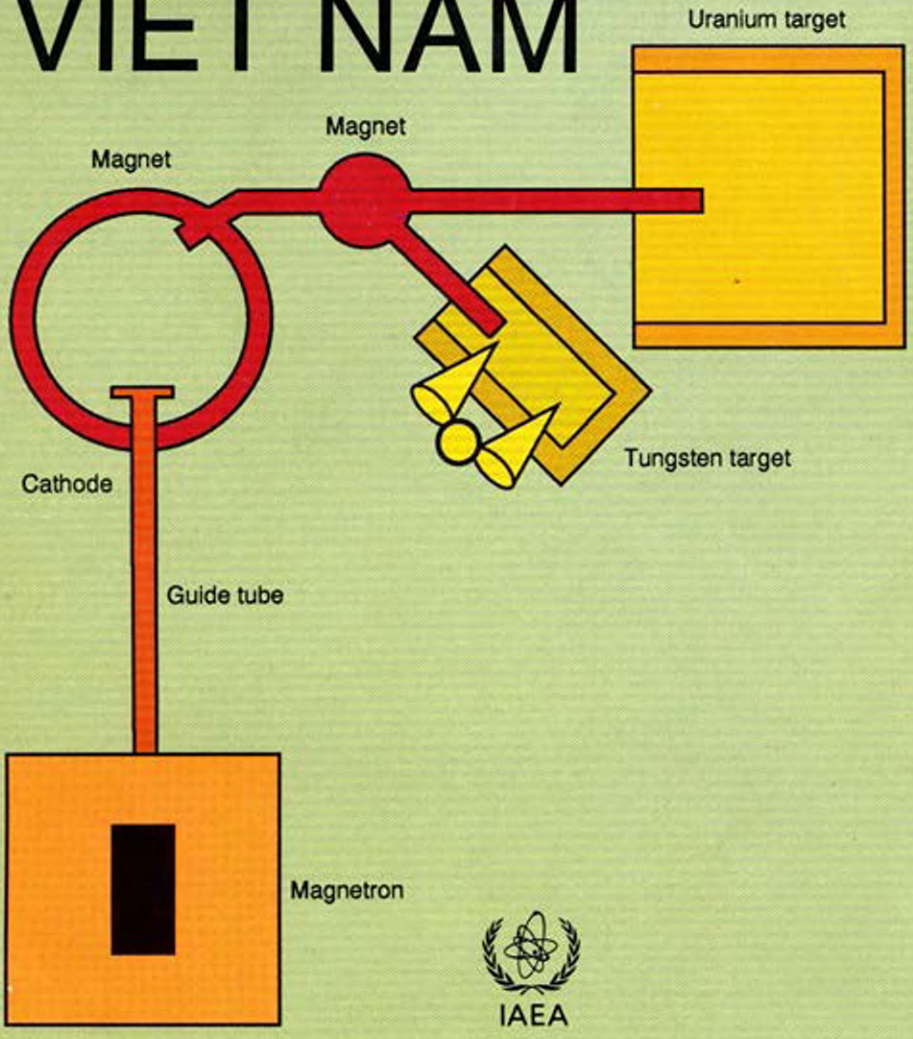
AN ELECTRON ACCELERATOR ACCIDENT IN HANOI, VIET NAM



IAEA

AN ELECTRON ACCELERATOR ACCIDENT IN HANOI, VIET NAM

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
BANGLADESH
BELARUS
BELGIUM
BOLIVIA
BOSNIA AND HERZEGOVINA
BRAZIL
BULGARIA
CAMBODIA
CAMEROON
CANADA
CHILE
CHINA
COLOMBIA
COSTA RICA
COTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DENMARK
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ESTONIA
ETHIOPIA
FINLAND
FRANCE
GABON
GERMANY
GHANA
GREECE
GUATEMALA
HAITI
HOLY SEE
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
LEBANON
LIBERIA
LIBYAN ARAB JAMAHIRIYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAYSIA
MALI
MARSHALL ISLANDS
MAURITIUS
MEXICO
MONACO
MONGOLIA
MOROCCO
MYANMAR
NAMIBIA
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORWAY
PAKISTAN
PANAMA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
ROMANIA
RUSSIAN FEDERATION
SAUDI ARABIA
SENEGAL
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
THAILAND
THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA
TUNISIA
TURKEY
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VENEZUELA
VIET NAM
YEMEN
YUGOSLAVIA
ZAIRE
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

Printed by the IAEA in Austria
April 1996

AN ELECTRON ACCELERATOR ACCIDENT IN HANOI, VIET NAM

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1996

THIS PUBLICATION WILL ALSO BE ISSUED
IN FRENCH, RUSSIAN AND SPANISH

VIC Library Cataloguing in Publication Data

An electron accelerator accident in Hanoi, Viet Nam. — Vienna : International Atomic Energy Agency, 1996.
p. ; 24 cm.
STI/PUB/1008
ISBN 92-0-100496-6
Includes bibliographical references.

1. Electron accelerators—Viet Nam—Accidents. 2. Radiation dosimetry. I. International Atomic Energy Agency.

VICL 96-00144

FOREWORD

Industrial and medical applications of ionizing radiation continue to bring benefit to millions of people around the world. More than 160 large gamma irradiation facilities and more than 600 electron beam irradiation facilities are operating in IAEA Member States. Experience with this irradiation technology has demonstrated its safety. Continued improvement in design and careful operation by qualified, trained operators have led to a good safety record.

Nevertheless, on occasions safety systems or procedures are ignored or bypassed and serious radiological consequences ensue. On 17 November 1992 one such event took place at an electron accelerator facility in Hanoi, Viet Nam. An individual, entering the irradiation room without the operators' knowledge, unwittingly exposed his hands to the X ray beam. His hands were seriously injured and one had to be amputated.

A review was undertaken by the IAEA to document the circumstances and causes of the accident and to draw general lessons for all responsible for facility safety and for treating radiation injuries. The present report — one in an IAEA series on lessons learned from radiological accidents and the first involving an accelerator — details the circumstances of the accident, its medical consequences and the governmental response.

EDITORIAL NOTE

Although great care has been taken to maintain the accuracy of information contained in this publication, neither the IAEA nor its Member States assume any responsibility for consequences which may arise from its use.

CONTENTS

1. INTRODUCTION

A November 1992 radiological accident involving a research X ray accelerator at the Hanoi Institute of Nuclear Physics (HINP), Viet Nam, resulted in severe exposure of the hands of a member of the staff. The individual — the irradiator facility director — entered the irradiation room without the operators' knowledge. He was adjusting a sample to be irradiated when, owing to the lack of safety systems or procedures to prevent it, the operator switched on the machine. Exposure to the individual's hands was only for a few seconds but at a very high dose rate, and the severity of radiation damage led within months to amputation of the whole of one hand and of two fingers on the other.

In March 1993, at the request of the Vietnamese Government, the IAEA sent a team of specialists to Hanoi to assist in the medical treatment of the injured man and to assess the lessons to be learned from the accident. This report details the circumstances of the accident, its medical consequences and the governmental response, and recommends actions for preventing similar accidents from happening again and for improving the emergency response of organizations which may be required to help deal with actual or suspected cases of radiation overexposure.

1.1. BACKGROUND TO THE IAEA POST-ACCIDENT REVIEW

Technologies that make use of radiation continue to expand around the world. Millions of people are employed in radiation related occupations and hundreds of millions of people benefit from these applications. Facilities using intense radiation sources for purposes such as nuclear research require special care in design and operation to prevent radiation injury. Experience has shown that while such technology is generally being safely used, safety systems and procedures have sometimes been ignored and serious radiation injury has been the result.

Although the causes of accidents are highly case specific, review of the circumstances in which they have arisen can yield generally applicable lessons to help prevent other accidents and improve the response to those that do occur. This was the motivation for IAEA post-accident reviews of several events at irradiators using radioactive sources: in Brazil (1987) [1], El Salvador (1989) [2], Israel (1990) [3] and Belarus (1991) [4].

There have also been accidents at irradiation facilities that use radiation induced by accelerators, rather than radiation from a radioactive source. There are more than 600 electron beam facilities around the world, many in developing countries, that produce radiation for research and for medical and industrial applications. The few accidents which have happened at such facilities have been described in Refs [5–7]. The post-accident review reported here is the first IAEA publication to address an accident — albeit a non-fatal one — at an accelerator facility.

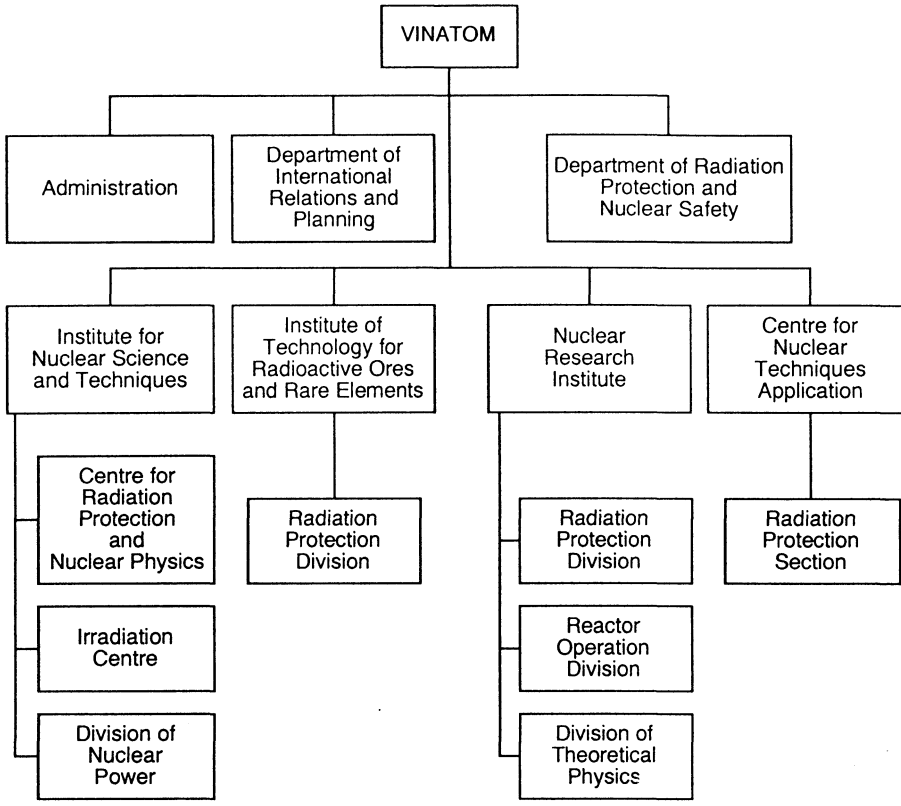


FIG. 1. Radiological protection within VINATOM (former organizational chart of the Viet Nam Atomic Energy Commission).

2. REGULATORY CONTROL IN VIET NAM

At the time of the accident a primary responsibility of the Viet Nam Atomic Energy Commission (VINATOM) was to develop the peaceful uses of atomic energy in Viet Nam and thus operate facilities involving sources of ionizing radiation (Fig. 1). However, VINATOM has another responsibility, namely to oversee and regulate ionizing radiation safety everywhere in Viet Nam, including the HINP accelerator irradiation facility. Viet Nam is a Member State of the IAEA and VINATOM serves as the appointed national competent authority and point of contact in all Viet Nam's relationships with the IAEA. The radiation protection infrastructure of Viet Nam, a developing country, is relatively new, but development work is under way, with assistance from the international community, including the IAEA.

VINATOM is charged with: (1) drafting regulations and subsidiary documents (codes of practice, guides, etc.) for the safe use of nuclear energy in Viet Nam; (2) licensing facilities using radiation sources and nuclear materials; (3) inspecting radiation safety in licensed facilities; (4) making an inventory of and registering all radiation sources and nuclear materials used in Viet Nam; (5) assisting national emergency planning; (6) working with other Viet Nam agencies to establish and develop the national radiation protection infrastructure; and (7) assessing international agreements relating to radiation safety matters and advising the Government on their implementation.

Temporary regulations from 1972 were superseded in 1988 by *Safety Regulations for Ionizing Radiation* and *Regulations for the Safe Transport of Radioactive Material.* VINATOM has also published a booklet on *Radiation Protection Terms and Definitions* that gives guidance and general recommendations for the use of ionizing radiation.

VINATOM is empowered by law to inspect all radiation facilities and to control the use, transport and storage of radiation sources (Article 38 of Viet Nam 1991 Labour Decree and paragraph 28 of the *Guide to the Labour Decree).* However, prior to the accident, VINATOM had not, for lack of resources, appointed trained inspectors. (Viet Nam has since appointed inspectors and in late 1993, in co-ordination with the IAEA, carried out a national training course in radiation protection.) There were also some formal difficulties for the inspection of HINP since the head organization — the National Centre for Scientific Research — to which the HINP belonged was on the same level as VINATOM in terms of governmental structure.

One of the lessons learned from this accident is the need to separate the radiation regulatory body from radiation source users and facility operators in order to have an effective and efficient regulatory control. In accordance with this principle, Viet Nam has recently reorganized VINATOM (The Prime Minister's Decree of September 1993). VINATOM has been put under the Ministry of Science, Technology and Environment (MSTE). The Department of Radiation Protection and Nuclear Safety is

now separated from VINATOM and comes under MSTE. It plays the role of the regulatory body for Viet Nam (Prime Minister's Decree of August 1994). The new organizational chart is presented in Fig. 2.

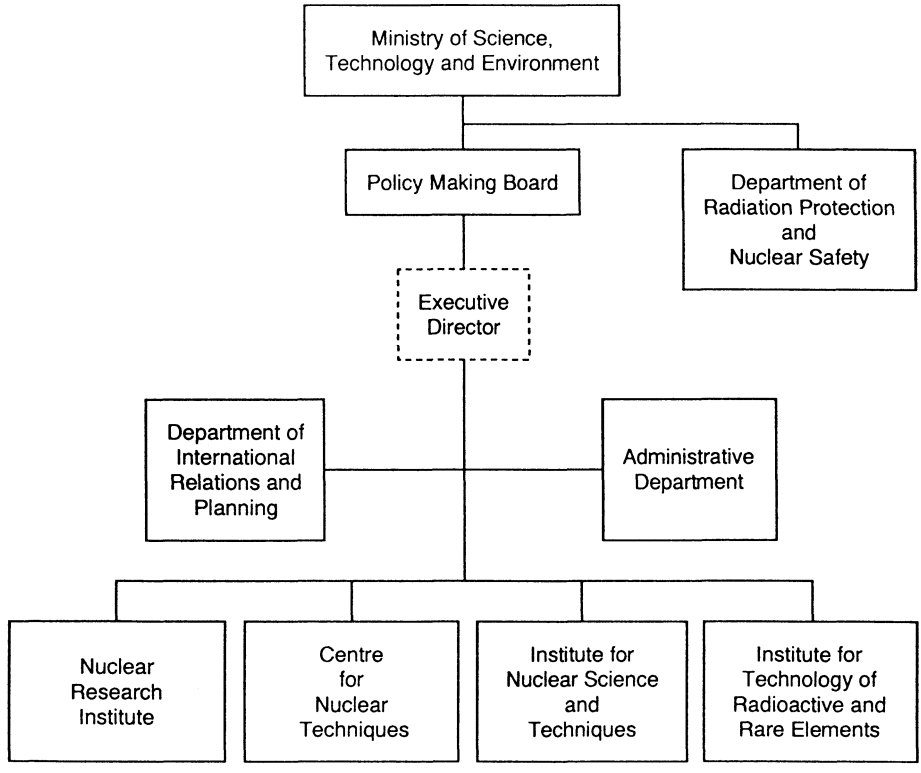


FIG. 2. New organizational chart of VINATOM.

3. THE IRRADIATION FACILITY

3.1. FACILITY ORIGINS AND LAYOUT

A governmental entity entirely separate from VINATOM, the Viet Nam National Centre for Scientific Research (NCSR), also operates many facilities using ionizing radiation sources (Fig. 3). The facility discussed in this report was, in fact, at the HINP, a unit of NCSR.

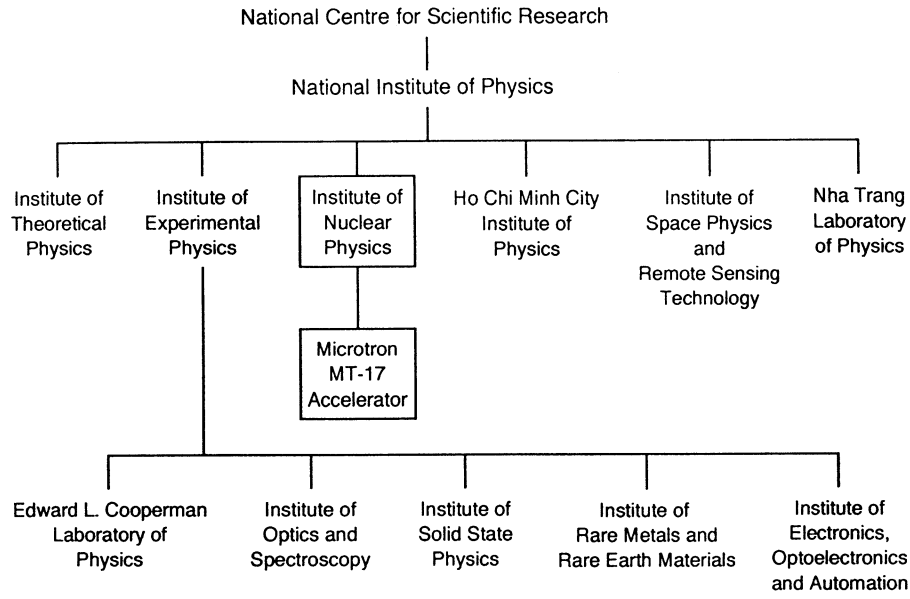


FIG. 3. Organization chart for the National Institute of Physics (organization of the Viet Nam National Centre for Scientific Research).

HINP research includes work on: (1) photon- and neutron-induced nuclear reactions, such as (γ,γ'), (γ,n), (γ,p), (γ,np), (γ,α), and (γ,f) reactions induced by bremsstrahlung and cross-section determinations using nuclear reactions induced by 14 MeV neutrons; and (2) nuclear methods development and applications, such as material analysis using photon and neutron activation and X ray fluorescence spectrometry, and geology, medicine, agriculture, industry and environmental applications of nuclear techniques.

HINP has two accelerators to carry out such work. The first, obtained from Hungary in 1974, can produce 14 MeV neutrons and has an automatic sample changer, built-in timer and multichannel analyser. However, this machine has not been used since the vacuum pump failed in 1991 as the pump has been difficult to replace because of its high cost and the lack of easy availability. The second accelerator, the device involved in the present accident, is a Microtron MT-17 that produces neutrons and X rays from electrons accelerated up to 15 MeV.

HINP's MT-17 was an experimental model originally built in 1973 at the Joint Institute for Nuclear Research (JINR) at Dubna (then USSR) and operated there until 1980. In 1982, it was given to Viet Nam by the former USSR and shipped to HINP, which had had close links with JINR for many years. HINP staff who had worked with the MT-17 in Dubna assembled it in Hanoi. They installed it in a facility they designed from outline measurements they had made in Dubna, as there were no Vietnamese language manuals (only the Russian language manuals were supplied with the machine) specifying the type and density of materials or special construction techniques. Their only design criterion appears to have been that wall thicknesses and room dimensions be similar to those in Dubna. The HINP MT-17 room layout and the relation to the control room are shown in Fig. 4. The room walls were reported to be 1.8 m thick and the maze wall 1.4 m — made of concrete of unspecified density. No other details of wall and roof construction were available.

Several cable and ventilation ducts pass perpendicularly through the walls instead of through angled ducts as is normal practice elsewhere. There had been no audit of the completed installation's safety systems or even a dose rate survey outside the room to assess the efficacy of the shielding. While the HINP staff had the highest academic qualifications, virtually the only radiation protection training or experience they had was at the Dubna laboratory. Owing to lack of funding, there was little in the way of radiation monitoring equipment. Moreover, there were only handwritten instruction manuals addressing equipment operation, but not the associated safety systems, room design or radiation protection procedures.

3.2. ACCELERATOR DESIGN AND OPERATION

A general view of the accelerator room is shown on Plate 1. The MT-17 accelerator operates on principles similar to those of betatrons, accelerating electrons in a circular orbit and directing them to an appropriate target material. It is fitted with two guide tubes, one with a tungsten target to produce X rays and the other with a uranium target to produce neutrons. (A schematic diagram of the equipment is given in Fig. 5.) At the time of the accident, the electrons, accelerated to 15 MeV, were directed through a horizontal guide tube into the 2 mm thick tungsten target, producing a conical (6^{o} solid angle) X ray beam for use in a (γ,n) activation experiment. The beam current was variable and at times had been run up to 16 μA but the maximum attainable

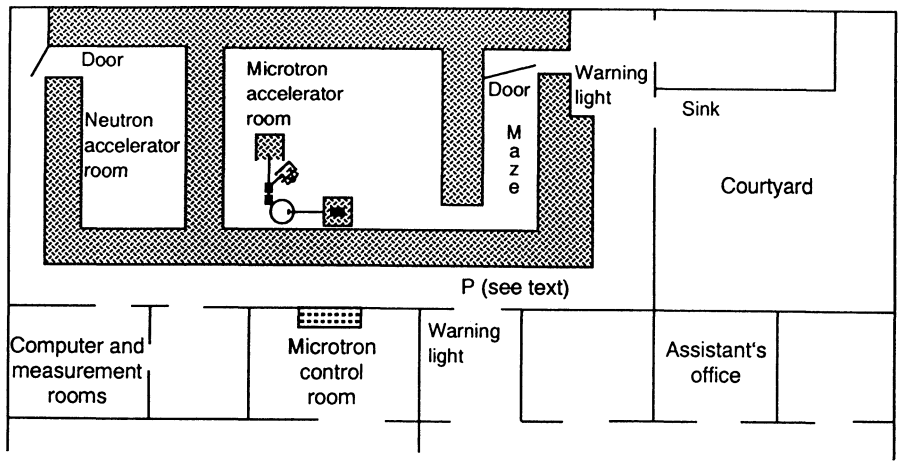


FIG. 4. Schematic diagram of accelerator facilities and offices at the Institute of Nuclear Physics.

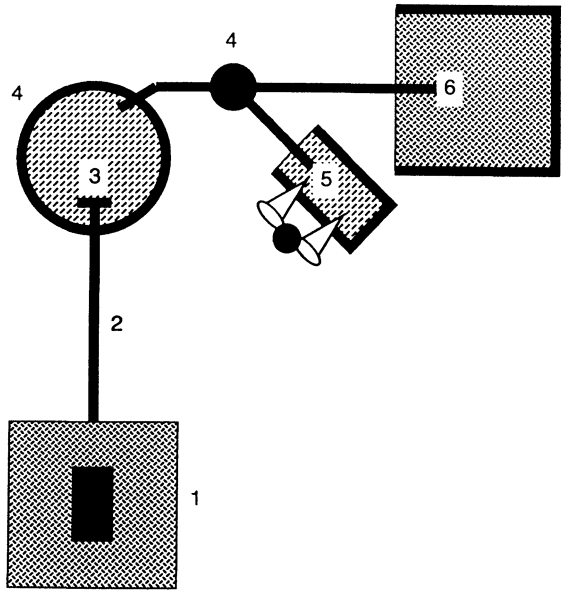


FIG. 5. Schematic diagram of the MT-17 Microtron accelerator at HINP: (1) magnetron; (2) guide tube; (3) cathode; (4) magnets; (5) tungsten target; (6) uranium target.

current had decreased over the years. At this time it was run at only 6 μA, the maximum then attainable. (By March 1993 only 3 μA was attainable.) Table I details the typical currents and workloads of the machine.

TABLE I. OPERATING REGIMES OF MT-17 MACHINE

Period	Beam current (μA)	Operating time (h)
1982–1985	14–16	250
1986	10–14	360
1987–1990	5–10	300
1991–1993	3–6	360

Control console and its operation. The control console (Plate 2) has no master key, but it was considered unlikely that the machine would be used by unauthorized persons, as all the controls were labelled in Russian. Moreover, the switch-on procedure is complicated:

(1) The vacuum pumps, water cooling, air conditioning and three-phase generator must first be switched on and allowed to reach their operating pressures, temperatures, etc.
(2) The phase control, cathode current and electromagnet must then be switched on in the correct order and their parameters slowly adjusted to the required levels.
(3) The magnetron current can then be switched on and slowly increased whilst the other parameters are balanced. The magnetron pulse is displayed on the oscilloscope on the control console.

Sample transfer and counting. Samples can be remotely transferred into and out of the accelerator room, if desired, through a hollow plastic tube that leads from the accelerator room to the counting room. The accelerator room end is manually positioned in front of either the tungsten or the uranium targets before the experiment commences. Compressed air is then used to drive the sample into or out of the room. (This system was said to have been operational when the accident occurred, but was not used because the sample was to be changed after only an hour.) The accelerator has no timing device or dose control cut-out and irradiation times are measured by wrist watch. After the sample has been irradiated for the required time, the activation products are normally measured by the high purity germanium detector and multichannel analyser, which is situated in the measurement room that is adjacent to the microtron control room.

3.3. SAFETY SYSTEMS AND PROCEDURES

Interlocks and warning lights. At the time of the accident there were no safety systems to warn persons who might have been inside the room that radiation was about to be, or was being, generated, nor was there an interlock on the door to the room. There was a radiation detector positioned halfway down the maze, but its ratemeter was in the control room above the console. Immediately outside the accelerator room door and in the corridor to the control room were signs that were illuminated when the beam current was switched on. The radiation detector and both illuminated signs were said to have been operating at the time of the accident. HINP staff relied on word of mouth to ensure that no one was inside the accelerator room and that the machine could be switched on.

Radiation monitoring. The output of the single radiation detector (in the maze) was in counts-per-second and the system was not calibrated. Thus, it did not give quantitative dose rate information but merely indicated the presence of radiation. At the time of the accident the total inventory of portable radiation monitoring equipment at the Institute consisted of a single end-window Geiger tube connected to a ratemeter scaled in counts-per-minute, and two quartz fibre electroscopes, neither of which had been calibrated (Plate 3). Owing to lack of equipment and training, no radiation monitoring had ever been done outside either of the accelerator facilities.

Radiological safety at the Institute. At the time of the accident there was a group responsible for radiation protection but owing to the lack of rigorous work rules and resources, it was ineffective. Several staff members had attended short training courses but no one had ever received systematic, comprehensive radiation safety training. Written procedures were available but concentrated on accelerator operation, not on radiation safety matters. Owing to the difficulty in obtaining spare parts and the high price of such parts, the accelerator operations group carried out routine preventative maintenance on the machine, but made no checks on the safety systems.

4. THE ACCIDENT AND THE RESPONSE

4.1. THE ACCIDENT

In mid-afternoon on 17 November 1992 (day 1), a research group led by the facility director was doing experiments involving irradiation of gold ore samples. As noted earlier, samples could be changed remotely using the compressed air system, but in this case the first sample was to be changed in just an hour, so they decided to do it by hand. The first experiment went according to plan, with the director and two assistants entering the accelerator room and removing the first sample.

After positioning the second sample close to the tungsten target, they left the accelerator room and walked towards the control room. When they were halfway there (Fig. 4, position P), the director asked one assistant to get him some soap and he turned around as if to head towards a sink outside in the courtyard. The assistant, having to pass close to the control room to get the soap, told the operator that the experiment was ready and the machine could be switched on.

However, instead of proceeding outside, the director re-entered the MT-17 room to check the sample's position and decided it was not quite correct. Using some wax blocks stored in the room, he adjusted the position (see Fig. 6). He later recalled handling the sample about three times. In doing so, his hands were only 3–30 cm from the target. Unfortunately, at some time during this period the accelerator had been switched on without his being aware of it.

The assistant got the soap and went outside to give it to the director, but he was not in the courtyard. She shouted for him several times and, receiving no reply, ran to the MT-17 room, where she found the door open. She again shouted his name, but got no reply. (With the generator, air conditioning and cooling systems operating, the ambient background noise in the room is high and the director probably could not hear the shouting. However, when the magnetron current is switched on, it makes a distinctive noise discernible above the ambient noise. The director vaguely recalled hearing it, but did not react to its implications.) The assistant then ran to the control room and told the operator to stop the accelerator immediately. The MT-17 had been on for about 2–4 min at a beam current of 6 μA.

The operator and the assistant ran back to the accelerator room. The door was open about 60 cm, and they saw the director handling some wax blocks at the corner of the maze. Not realizing what had happened, the director calmly proceeded outside to wash his hands. When informed that the accelerator had been switched on a few minutes earlier, possibly whilst he had been in the room, he went very quiet, but at this point it was not clear whether in fact he had been exposed.

After a few minutes he considered that if his hands had been irradiated, they may have become activated, so he and the assistant went to the measurement room to use the germanium crystal gamma spectrometer. Within 30 s a well defined peak at

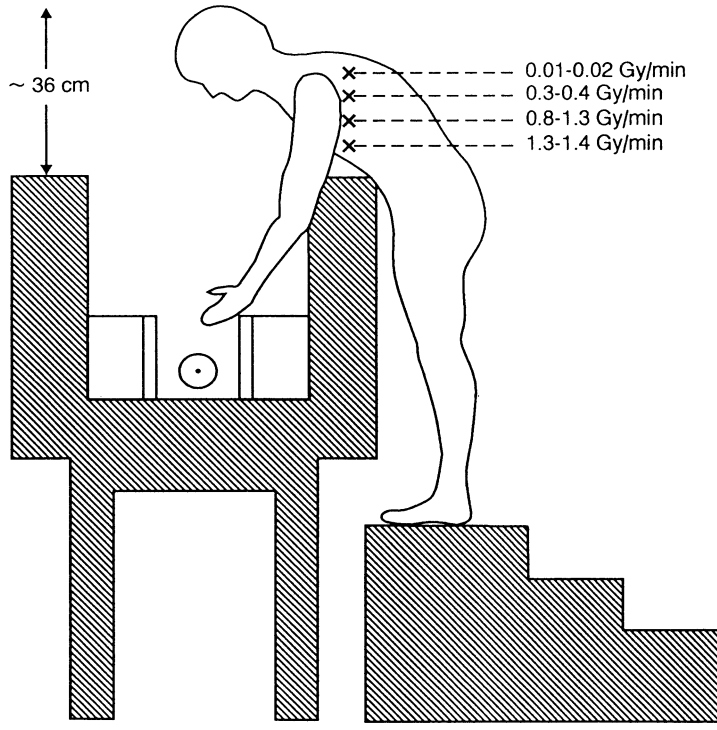


FIG. 6. Diagram of exposure position.

511 keV was visible on the screen. The director realized then that his hands had been irradiated, but not the seriousness of that exposure. (Owing to the lack of equipment, dose rates in the main beam were never measured. Although HINP staff recognized that the MT-17 could produce high radiation levels, they did not appreciate the implications.) Fifteen or twenty minutes later the director remeasured his hands in the gamma spectrometer, but no peak appeared.

(A neutron activation experiment suggested later by a member of the IAEA team confirmed the validity of the reported gamma spectrometer peak. A fresh chicken leg irradiated in the main X ray beam for 4 min showed a 511 keV peak in just a few seconds. HINP scientists found that the effective half-life of the activation product(s) was about 9 min and that the peak was probably annihilation radiation from positron emitters activated in the tissue by gamma–neutron reactions.)

4.2. THE RESPONSE

Within hours everyone at the Institute had heard about the accident but no one seemed to appreciate the implications and no one, including the director, took any immediate action. That evening his hands began to feel 'strange', but since he had rheumatoid arthritis, he did not link this feeling with the incident that day. He merely washed his hands in warm, salty water as recommended for his arthritis. For the next eight days he continued to go to work as usual. An annual medical examination on day 10 did not raise serious questions and even after he sought a hospital examination of his swollen hands, radiation was not considered the cause. It was more than two weeks after exposure before he was hospitalized with obviously serious injury and only then was it concluded that the damage was due to radiation. (The medical chronology is described in more detail in Section 5.)

In late January 1993, nearly two and a half months after the exposure, VINATOM heard of the event and asked the NCSR for an official report on the accident. NCSR promptly discussed the matter with HINP and sent a report to VINATOM on 2 February. In mid-February, VINATOM was informed of the progress of the medical treatment at the National Centre for Burns (NCB). The NCB physicians estimated the exposure to the patient's hand to be more than 25 Gy. In early March, VINATOM made the first dose rate measurements in the MT-17 accelerator room and found that the exposure dose to the patient's hands ranged from 20 to 80 Gy depending on the exposure time (ranging from 1 to 4 min) and that the whole body exposure was low. On 8 March, VINATOM wrote to the Director General of the IAEA, informing him about the accident and requesting assistance. During the last two weeks of March, an IAEA team of experts — a physician and a health physicist — visited Hanoi to assist in the medical treatment and to study the accident and assess the lessons to be learned.

Meanwhile, HINP had fitted both a magnetic interlock and a padlock to the MT-17 room door. The magnetic interlock was wired such that if the door was open, a light on the control console illuminated. (The operators reported that the accelerator could not be operated if the room door was open, but this was not demonstrated to the IAEA team during the visit.) The manually operated pre-warning system — a bell inside the accelerator room that the control room operators could sound just prior to switching on the beam current — had also been repaired. A second button in the accelerator room had been added to warn the operators not to switch the machine on. (The team noted inside the accelerator room a broken light that might once have served to warn that radiation was being generated.)

5. MEDICAL MANAGEMENT

5.1. BEFORE HOSPITALIZATION

During the evening on the day of the accident (probably 6–8 h after exposure) the director felt tension and clumsiness in the fingers, but as he had rheumatoid arthritis, he did not link this strange feeling with the incident. He used a warm salt water bath for his hands as prescribed for his arthritis. The next day he rode to work on his motor cycle as usual. His hands and face looked very grey ("almost black," one person said), but he had no problems using his hands. During the following ten days he worked as usual and continued to drive his motor cycle.

On day 10, during his annual medical check-up, a slight desquamation of the palms of both hands and slightly higher than normal blood pressure were found. He told the doctor that his hands had probably been exposed to radiation, but she considered the desquamation a vitamin deficiency and recommended he see a dermatologist. The next day his hands were swollen and painful. He went to the general hospital, where blood samples were taken but nothing was done for his hands. The blood test results appeared normal and he was not hospitalized, although changes to the skin progressed.

He continued to bathe his hands in salt water. On day 14, he photographed his hands to record the bright erythema and pronounced oedema, especially on the right hand (Plate 4(a)). Pain in the hands progressed day by day and vesicles on fingers appeared that turned into large bullae by day 22. Finally, he went to a specialized hospital — the NCB — on day 24 (11 December 1992) and was hospitalized with oedema, deep ulcerations and skin necrosis in both hands. The doctors were certain then that the damage was due to radiation exposure.

5.2. IN HOSPITAL IN HANOI

On day 24, the patient had: all fingers (except the first of the left hand) swollen; dark blue skin erythema; pussy blisters; difficulty in moving fingers; some pain, but not severe (controlled with simple analgesics); no X ray defined pathology. The diagnosis was of radiation (γ ray) induced third to fourth degree burns of both hands (4% of body surface). Systematic antibiotic therapy, along with tranquilizers, was administered, and the hands were dressed with a plant oil cream of sulphadiazine. Blood analysis showed no abnormalities except a slight leucocytosis (8.6×10^9 L^{-1}).

On day 28 (14 December), the patient was examined by the director of the NCB. Bullae were opened and all 'necrotic skin' was removed surgically, the usual method for treatment of thermal burns (Plate 4(b)). Several 'domestic' medicines, including something considered 'radioprotective', were added to the treatment. Later, the patient

was treated more intensively. On day 36 (22 December), doctors used frog skin as a biological dressing to stimulate regeneration. Direct blood transfusions, as well as transfusions of stored frozen plasma, were made several times when a slight anaemia appeared. On day 37 (23 December), erythrocytes were found to be 3.8×10^{12} L^{-1} and haemoglobin was 11 g/L, typical for severe burns.

On day 50 (5 January 1993), the first skin graft was done using skin from the patient's shoulder. All injured surfaces except the third right finger were covered with transplants (about 150 cm^2). Three days later a second operation covered about 70 cm^2 more of the third right finger, again using skin from the shoulder. The first grafting held, but not the second, as the third right finger remained an open wound without signs of regeneration. The next attempt to graft skin, on day 95 (19 February), also failed.

While at the NCB the patient was examined carefully for signs of whole body irradiation: blood was analysed two or three times a week, sternum bone marrow was examined, and chromosome aberration analysis of peripheral lymphocytes was made. None of these tests revealed signs of acute radiation syndrome. During the fourth month after exposure, necrosis of the third right finger progressed. X ray examination on day 113 (9 March) showed widespread osteoporosis of all right-hand fingers and arthrosis of some joints. Photographs of the hands taken on that day are presented in Plate 4(c).

The day after her arrival in Hanoi, the physician in the IAEA team examined the patient (day 123, 19 March). Her diagnosis was of highly severe, acute radiation injury to both hands, with incomplete recovery complicated by necrosis of the third right finger and extensive osteoporosis of all other fingers. She confirmed that the hands had been exposed to highly penetrating radiation and estimated that the absorbed dose probably exceeded 50 Gy. She found no evidence of clinical symptoms to indicate significant total body exposure. At her recommendation the necrotic finger was amputated (exarticulated) on day 127 (23 March). The bone, together with the cotton shirt the patient had been wearing on the day of the accident, were sent to the Institute of Biophysics in Moscow for electron spin resonance (ESR) dosimetry, which is considered very useful for exposure evaluation in the case of accidents [7, 8]. The results are discussed in Section 6.

5.3. SPECIALIZED TREATMENT IN PARIS

In accordance with the recommendation of the IAEA experts and in agreement with local physicians it was decided that the patient should be transferred to a specialized hospital better equipped to diagnose and treat radiation injuries, especially in the late stages. On day 154 (19 April), the IAEA Emergency Response Unit (ERU) was called by Viet Nam officials with a request for urgent assistance to facilitate the transfer since the patient's state had deteriorated. The IAEA, acting under the international

Convention on Assistance in the Case of a Nuclear Accident, worked with the Institut de protection et de sûreté nucléaire (IPSN) of the French Commissariat à l'énergie atomique and arranged to transfer the patient, at Viet Nam and French Government expense, to the Boucicaut Hospital in Paris, where he was admitted on day 159 (24 April).

On arrival in Paris, the patient evidenced no fever, was mentally clear and had normal mobility. (In succeeding days, however, a high undulant fever set in, with signs of severe bacteraemia.) The right hand was infected at the amputation site, with significant pain; the back and palm of the hand showed infected wet epithelitis in the distal metacarpal region and on the thumb and index finger. The left hand showed apparent healing, large de-pigmented zones at the dorsal part of the fingers and normal nail growth. Hand functions were very limited in terms of both movement and strength.

On day 161 (26 April), the distal part of the third metacarpus was excised to clean the amputation site. On day 171 (6 May), the third right metacarpus was removed, and the right hand fingers and upper palm were embedded in subcutaneous tissues of the left inguinal (abdominal) region in the hope of preventing re-infection, encouraging revascularization and enhancing the chances of future skin graft success. The amputated third metacarpus was sent to Moscow for ESR dosimetry to compare with previous measurements.

By day 182 (17 May), the patient's general condition had improved and pain become more tolerable. The left hand was quickly recovering mobility and strength, which were already sufficient for everyday living; some escharotic lesions still remained on the distal parts of the fingers and de-pigmented areas were unchanged. The right hand did not exhibit any particular problems. On day 190 (25 May), the right hand was taken out of its 'natural pocket' and a skin graft attempted on the distal part of the thumb. The left hand continued to improve, both physically and functionally.

Over the next month (up to day 213, 17 June) the patient was in very good general condition. His left hand was totally functional. However, the right hand, despite all the therapeutic measures taken, was in poor condition. Necrosis was accentuated and pain was resistant to analgesics. The doctors decided that the second right finger should be amputated within a week, depending on developments and the survivability of the right thumb.

On day 226 (30 June), the second finger (forefinger) of the right hand was amputated in the hope of saving the thumb. However, these palliative surgical attempts did not succeed; necrosis progressed and pain increased. On 9 July, with the patient's assent, the remainder of the right hand was amputated at the wrist level. After the operation the wound healed normally and on day 256 (30 July) the patient was discharged from the hospital. He then received, on an outpatient basis, specialized rehabilitative care in Vanves, a Paris suburb.

Three months later (October 1993), however, some further late effects of radiation injury appeared in the left hand. Pain, skin ulceration and then necrosis developed in the fourth and fifth fingers. Conservative treatment at Boucicaut Hospital was

unsuccessful and on day 370 (22 November 1993) the fourth finger had to be amputated. The fifth finger was also amputated on 3 February 1994. At the end of 1993, two prostheses for the right hand were provided; on a subsequent visit in 1994, it was observed that the prostheses seemed to be helpful for the patient.

Further outpatient treatment continued into 1994 because of recurrent problems of localized infection and also in order to provide adequate physiotherapy for the left hand, which exhibited stiffness related to radiation induced fibrosis. The patient's condition was judged satisfactory by the end of June and he was consequently discharged. He returned to Hanoi at the end of July 1994.

6. ASSESSMENT OF THE DOSE TO THE PATIENT

6.1. POST-ACCIDENT MEASUREMENTS AT THE FACILITY

Prior to the arrival of the IAEA team, some assessment of the dose to the patient's hand had been carried out. In January, NCB physicians, on the basis of the symptoms, estimated the dose to the patient's hands to be more than 25 Gy. On 6 March, VINATOM, using Fricke dosimeters, estimated the mean dose to the patient to be between 20 and 80 Gy, depending on the exposure time. The whole body dose was assessed as low, although some symptoms presented by the patient, such as the change in skin colour of the face and diarrhoea (February), caused some concern about the magnitude of the whole body dose. Further thermoluminescent dosimeter (TLD) measurements estimated the whole body dose to be between 1 and 2 Gy.

The IAEA team's health physicist, with assistance from VINATOM, made a radiation survey as a basis for assessing the dose to the patient. He also surveyed the radiation in areas surrounding the accelerator facility to assess worker exposure. Despite their many uncertainties, these measurements indicated significant dose rates in nearby offices, laboratories and corridors when the MT-17 was operating. Details of dose rates and estimated annual occupational doses are given in the Annex. Estimates of levels of scattered photon radiation, based on measurements using TLDs and film badges at the approximate position where the exposed man was standing when handling the sample, are given in Fig. 6. Dose rates found in the main radiation beam are given in Fig. 7. At the time of the accident the accelerator was operating at a beam current of 6 μA, whereas at the time of the measurements it could only be operated at 3 μA owing to operational difficulties. So the measured results were doubled to calculate dose rates for a beam current of 6 μA.

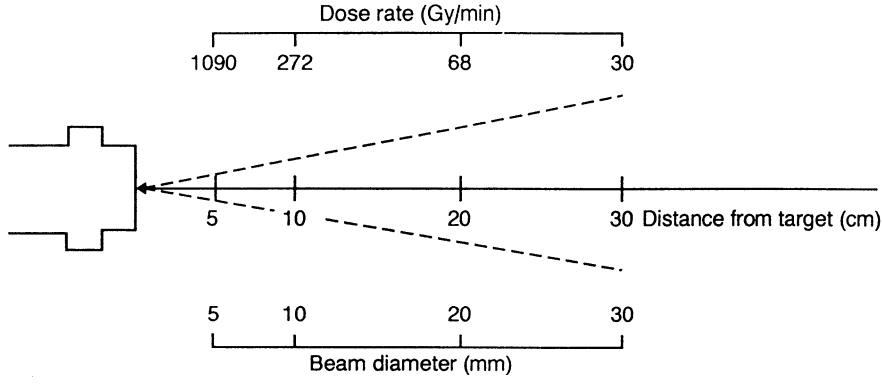


FIG. 7. Dose rates in the accelerator beam.

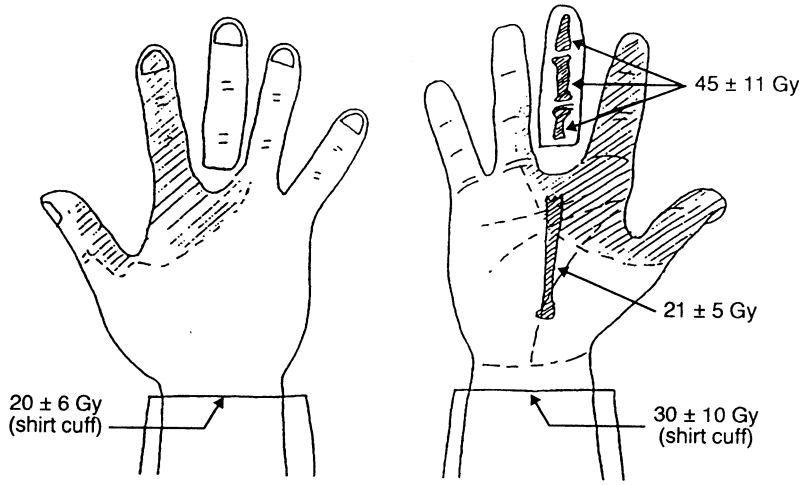


FIG. 8. ESR estimated dose to right hand.

The results should be treated with caution. The measurements showed very steep gradients, both at the edge of the wooden box over which the exposed man was leaning and close to the tungsten target where his hands would have been. To complicate matters, film badge measurements of scattered radiation indicated a wide energy spectrum of both photon and electron radiation from bremsstrahlung in accelerator components such as bending magnets and the guide tube, from target backscatter and from scatter off lead shielding. Moreover, buildup under the skin of dose rates from high energy photon and electron radiation (maximum dose rates might be several centimetres beneath the skin, depending on radiation energy and type) also affects dose estimates. (Physical dosimetry measurements made two months later on day 185 (20 May) by HINP indicated that the dose rate at the approximate location of the patient's thorax did not exceed 2.4 Gy/min at 10 cm depth.)

Nevertheless, such measurements, and even more detailed ones using sophisticated radiotherapy depth–dose equipment and phantoms, do not provide an adequate basis for estimating patient dose without a good estimate of his distance from the target and of the time he spent there. The operators reported that the MT-17 had been on for about 4 min but it is unlikely his hands were exposed that long because otherwise the biological damage would have been much worse. He himself could not remember just how long he was near the target, how many times he picked up the sample, or how many trips he made into the maze to get wax blocks. Thus, a reasonable estimate of patient exposure from field measurements is not feasible.

6.2. MATERIALS EXPOSED IN THE ACCIDENT

ESR measurements. As noted above, the patient's amputated bone and the shirt he was wearing when exposed were sent, at the suggestion of the IAEA team, to the Institute of Biophysics in Moscow for ESR analysis. The results on days 191 and 202 (26 May and 6 June 1993) on bone samples were that the mean dose to the third right finger was 45 ± 11 Gy, with a 21 ± 5 Gy mean dose to the third right metacarpus. On the basis of ESR measurements of the cuffs of the patient's shirt, the estimates were 30 ± 10 Gy to the outer (cuff link area) wrist of the right hand and 20 ± 6 Gy to the inner part (see Fig. 8) and 8 ± 3 Gy to the left wrist.

Chromosome aberration measurements. Blood samples were analysed in the Paris laboratories of the IPSN. Results on day 162 (27 April 1993) showed 5 dicentric anomalies per 500 cells, indicating that the exposure was about 0.3 Gy (95% interval: 0.1–0.5 Gy) mean whole body dose. After correction for delay between exposure and analysis and for uneven exposure, the upper body dose was estimated to be about 1.5 Gy. (On day 211 (15 June 1993), neurophysiological dosimetry was also carried out in Paris; EEG slow waves indicated an irregularly distributed cephalic dose of about 1–2 Gy, with a dose to the face of about 5 Gy.)

On the basis of a physical dosimetry calculation using all information available on 5 June 1993 (e.g. well defined beam with 100% efficiency at 2.5–3 cm depth), a most probable value of 10–25 Gy was estimated in Paris for the left hand and 20–50 Gy for the right one, roughly consistent with the estimates made in Moscow from shirt cuff ESR measurements and fully corroborating the IAEA team member's initial 50 Gy observational estimate.

7. LESSONS LEARNED

7.1. CONCLUSIONS

Viet Nam, like other developing countries, has given first priority to meeting the immediate needs of its people for housing, education and economic development. HINP's limited budget made the purchase of scarce spare parts much more difficult and this contributed to the likelihood of an accident. Moreover, the HINP staff had the highest academic qualifications but they lacked sufficient training in radiation protection and failed to build an adequate safety infrastructure. These weaknesses were compounded by inadequacies, again for lack of resources, in regulatory oversight and expert radiation protection advice at the national levels. (Many of these problems had been noted earlier in the report of a 1988 IAEA mission to Viet Nam.) The need for a stronger infrastructure was made all the more necessary by inadequacies in the safety system documentation available for the MT-17 accelerator.

The standard of radiation safety at HINP before the accident was so low that an accident was not unlikely, especially as the extremely high dose rates in the MT-17 beam can cause severe radiation damage in seconds. Improvements to the safety systems and procedures are essential to prevent another accident, possibly with life threatening consequences. Moreover, the radiation shielding of the accelerator room is likely to be insufficient to control exposure to workers in adjacent areas if the accelerator were to be used more intensively.

Although the patient had pointed out the radiation incident to physicians on two occasions (at a medical checkup and again at a hospital), the signs of radiation injury were not recognized. Only when he again — more than three weeks after the exposure — sought attention at the NBC was the radiation induced nature of the injury recognized and action taken. Moreover, even the NBC physicians, although highly experienced in treating thermal chemical burns, knew very little of radiopathology. Their knowledge was insufficient to deal effectively with the more protracted nature of radiation injury effects.

Implementing some of the recommendations concerning specific hardware or procedural steps to upgrade safety in the future may require further local, national or international resources. However, much can be done to avert future accidents, more promptly recognize their seriousness and more effectively alleviate their consequences. Those responsible for design, construction or operation, for regulatory oversight, or for medical response can, at their own initiative, take effective steps to ensure safety and to limit the consequences of safety failure. There is a fundamental need to inculcate a sense of responsibility for safety — a 'safety culture' — in all concerned if the net benefit of radiation uses is to be maximized. In particular, designers and constructors can make greater efforts to anticipate and prevent possible misuses of a facility; maintenance personnel can identify patterns suggesting safety weaknesses;

operators can insist that safety take priority over production; regulators can visit all facilities within their jurisdiction to assess their safety; and the medical community can update educational curricula to include basic information to help ensure that physicians promptly identify the earliest signs of radiation injury and act upon that recognition.

7.2. RECOMMENDATIONS TO ORGANIZATIONS OPERATING IRRADIATION FACILITIES

Safety systems improvements

1. *In all accelerator rooms*, a number of important safety systems should be installed, including: automatic pre-warning, automatic warning, emergency cut-out buttons, door interlock system, search and lock-up system, area radiation monitors, warning signs and a closed circuit television system. These safety systems, especially the interlock system, should be regularly checked and properly maintained (with written records) if the intended degree of safety is to be achieved. These systems are described more fully below.

(a) Automatic warning signals before and during radiation generation

Before radiation can be generated, an audible or visible warning (e.g. a rotating yellow beacon) must operate for 10–15 s or more. *During* radiation generation a second audible or visible warning (e.g. a rotating red beacon) which is clearly distinguishable from the pre-warning signal must operate. These warning signals must be fully automatic, i.e. not rely on an operator pressing a button. Audible warnings must be clearly distinguishable above ambient noise. Visible warnings must have a sufficient number of lamps to be clearly visible anywhere in the room. Moreover, these warning devices must be designed as fail-to-safe, i.e. any component failure must prevent radiation generation until the fault is repaired. Signs that clearly explain the significance of the warnings must be displayed inside and outside the irradiation room.

(b) Emergency cut-out buttons

On each wall of the accelerator room there should be at least one switch that can be pressed to stop further radiation generation automatically and immediately, to sound an alarm bell outside the room, and to prevent restart until the operator has entered the room and reset the switch. All emergency cut-out buttons must be clearly labelled.

(c) Door interlock system

The accelerator room door must have an interlock system such that if the door is open, radiation cannot be generated, or if the door is accidentally opened

during radiation generation, generation is automatically terminated (see Fig. 9 for recommended interlock mounting method). Given the greater precaution needed in such a high radiation intensity facility, a single interlock is not sufficient, and a second interlock should be installed that operates in a different mode from the first (e.g. using mechanical position switches, with the contacts on one normally closed and the other normally open). The correct operation of any interlock system should never be assumed. Regular checks must be carried out and written records maintained.

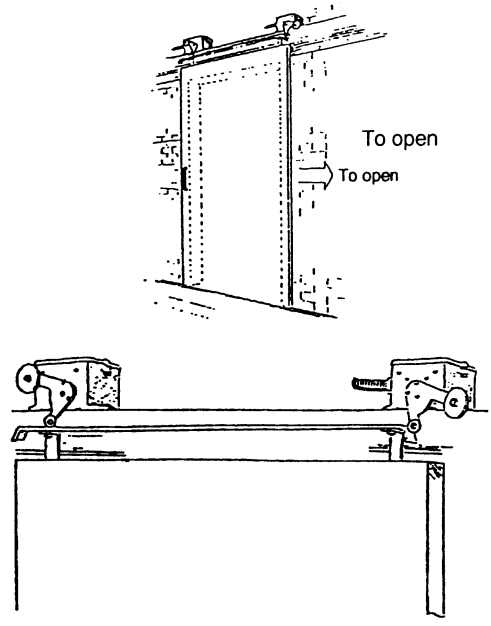


FIG. 9. Sliding door mounting method. (The use of two position switches, one with contacts normally open and the other with contacts normally closed, provides a higher degree of safety.)

(d) Search and lock-up system

A system should be installed that incorporates a time delay switch inside the room to be activated by the operator immediately prior to returning to the

control console. If the accelerator is then not switched on within a pre-set time (e.g. 30–60 s), radiation generation should be prevented until the operators physically check inside the room and re-set the time delay switch.

(e) Area radiation monitors

At least one permanently installed area radiation monitor should be mounted inside the room to sound an alarm or illuminate a rotating beacon if radiation is present above ambient background levels. This warning should operate independently from and in addition to the other warnings described above.

(f) Warning signs

Inside the accelerator room, large notices should be displayed which clearly and concisely state the significance of the various warnings and what must be done in an emergency (e.g. "Press nearest emergency stop switch and leave the room immediately.")

(g) Closed circuit television system

A closed circuit television system would be useful to allow the operators to view inside the room from the control console.

2. *Outside accelerator rooms*, **pre-warning and warning devices** similar to those inside should be installed, and a **security key and a timer on the control console** should be installed to limit the duration of radiation generation.

Shielding

3. Radiation exposure from the operation of irradiating facilities should be constrained by appropriate shielding to be as low as reasonably achievable. Particular attention should be paid to the roof, doors, ventilation and cable ducting to ensure no direct radiation leakage path. The use of maze entrances and shield plugs is essential to reduce radiation fields at the point of exit to acceptable levels. The amount of shielding required should be determined by reference to dose rate requirements specified by the competent authority.

4. A **detailed dose rate survey** should be performed outside accelerator rooms using a range of appropriately calibrated monitors so as to provide a sound basis for logical and cost effective shielding improvements. Particular care should be taken to measure all areas outside the room and to take account of: (a) air scattered radiation in buildings and offices adjacent to, and above accelerator rooms; (b) areas where cable or ventilation ducts pass through the walls into the accelerator room (see Fig. 10 for recommended cable ducting methods); and (c) radiation levels in the area immediately outside the accelerator room door.

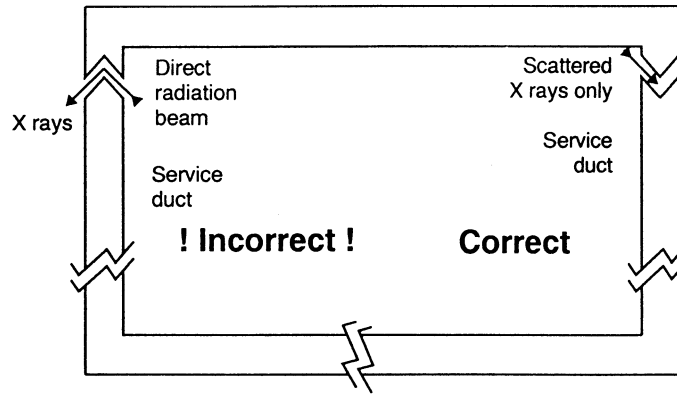


FIG. 10. Cable ducting method.

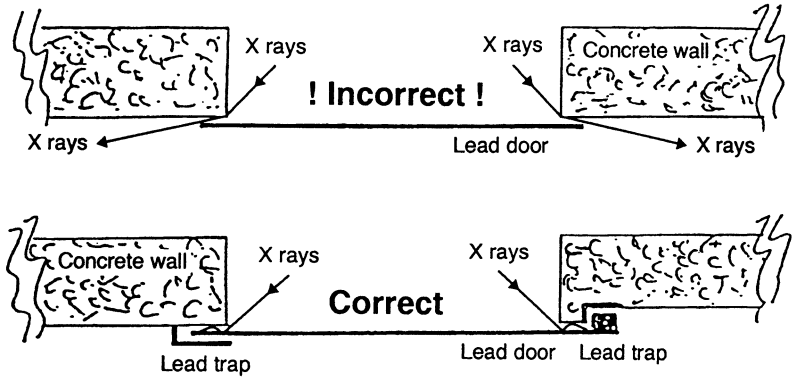


FIG. 11. Interlock mounting method.

(Notes: Care should be taken to distinguish between dose rates due to radiation transmitted through the door and dose rates from stray radiation around the door frame. To reduce leakage radiation, it is recommended that a sliding door be used which overlaps the walls and can be recessed into the floor to provide greater shielding (see Fig. 11). With some high energy accelerators, neutrons can 'stream' around the wall and cause high dose rates outside the entrance to the maze; in that case boron tiles on the maze wall can be used to absorb the neutrons.)

Procedural controls

5. All facilities should have a well trained radiation protection officer.

6. **Local rules** must be drafted to include: (a) the name of the radiation protection officer(s) and their responsibilities; (b) the names of persons authorized to operate the equipment; (c) procedures for ensuring the radiation safety of all persons; (d) procedures for regular radiation monitoring outside the facilities, with the names of those responsible for carrying out such monitoring; and (e) emergency procedures clearly stating what is to be done in the event of fire, mechanical damage, component failure, etc.

7. **Radiation warning signs** that conform to international standards should be displayed on the doors to accelerator rooms, at the start of the maze and, if access is not physically barred, on the roof of the accelerator room.

Training in radiation safety

8. **Radiation protection training** must be given to all persons involved in operating or maintaining accelerators. Special training on medical aspects should be given to local physicians responsible for surveillance of exposed workers.

Monitoring worker exposure

9. **Personal dosimeters** (TLDs) should be issued to all those working with accelerators to continually monitor their exposure.

10. **A routine monitoring programme** using properly calibrated equipment that permits thorough dose rate surveys around accelerators should be established.

7.3. GENERAL RECOMMENDATIONS TO REGULATORY AUTHORITIES

1. **It should be required that radiation protection officers be appointed and trained** at all major establishments where ionizing radiations are used.

2. The appointed (and trained) inspectors should **audit all major ionizing radiation users** in the country. A written report of inspection results that details required improvements should be sent to the user. A follow-up visit (after a suitable time period) should be made by the inspectors to ensure that all recommendations have been implemented.

Monitoring

3. Inspectors should check exposure rates around the facilities, using a range of suitable monitors, including:

Dose rate monitors. A range of monitors should be available that can measure dose rates from environmental levels, through protection levels, up to high dose rates. A suitable selection of ionization chambers, Geiger detectors and scintillation detectors is recommended, including some small-area detectors capable of measuring leakage radiation. The inventory should include monitors that can measure beta, gamma and neutron radiation of all relevant energies.

Contamination monitors. The range of contamination monitors should include probes capable of detecting alpha, beta and gamma radiation from low to high energies. In addition to end-window Geiger detectors, scintillation probes should be available as they have proved to be robust, reliable and fast responding.

4. A national calibration centre should be established to calibrate a full range of recommended monitors so that all monitoring equipment meets national and international standards.

Codes of practice

5. The regulatory authority should prepare codes of practice and supplementary guidance for all users of ionizing radiation sources.

National inventory

6. The regulatory authority should seek to develop a national inventory of radiation sources.

Licensing

7. Licensing procedures should be established at the national level.

7.4. RECOMMENDATION TO MEDICAL AUTHORITIES

Medical doctors should have a knowledge of radiopathology which is adequate to assess symptoms of overexposed persons and provide first aid treatment prior to referral to specialist hospitals [11, 12].

7.5. RECOMMENDATIONS TO EQUIPMENT SUPPLIERS

All organizations which install ionizing radiation generators/radioactive sources should ensure that the equipment is left in a 'safe' condition. This should be done by the installers or an independent organization carrying out a commissioning survey to ensure that adequate shielding has been provided and that all safety control systems operate correctly. The depth and detail of the commissioning survey should be commensurate with the complexity of the equipment and the potential for operators (or others) to receive a significant radiation exposure. However, even for simple commissioning surveys, a written report should be provided by the person or organization carrying out the work. These requirements should be discussed and contractually agreed before the equipment is supplied.

PLATE 1. General view of accelerator room equipment.

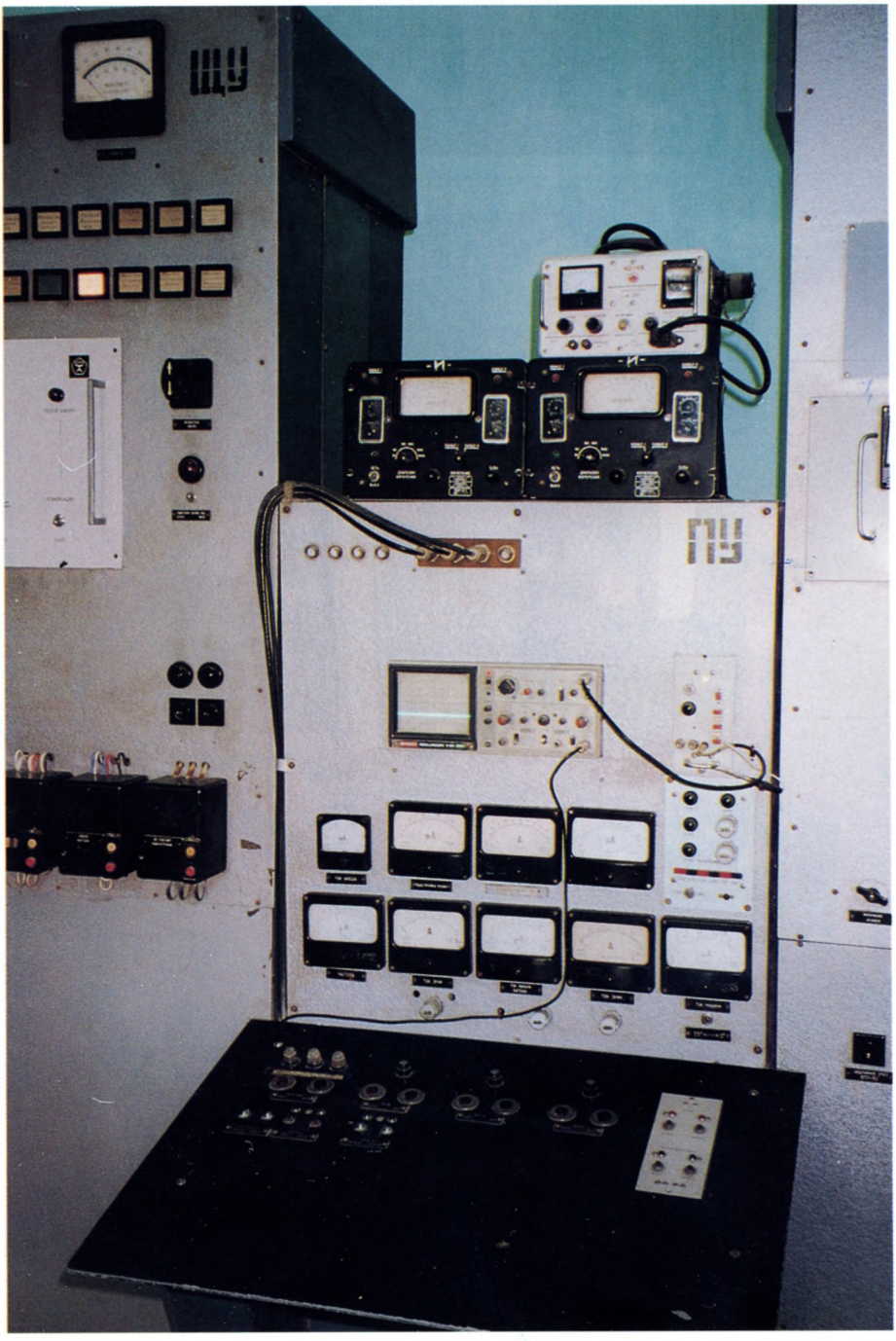


PLATE 2. Control console for the MT-17 accelerator at HINP.

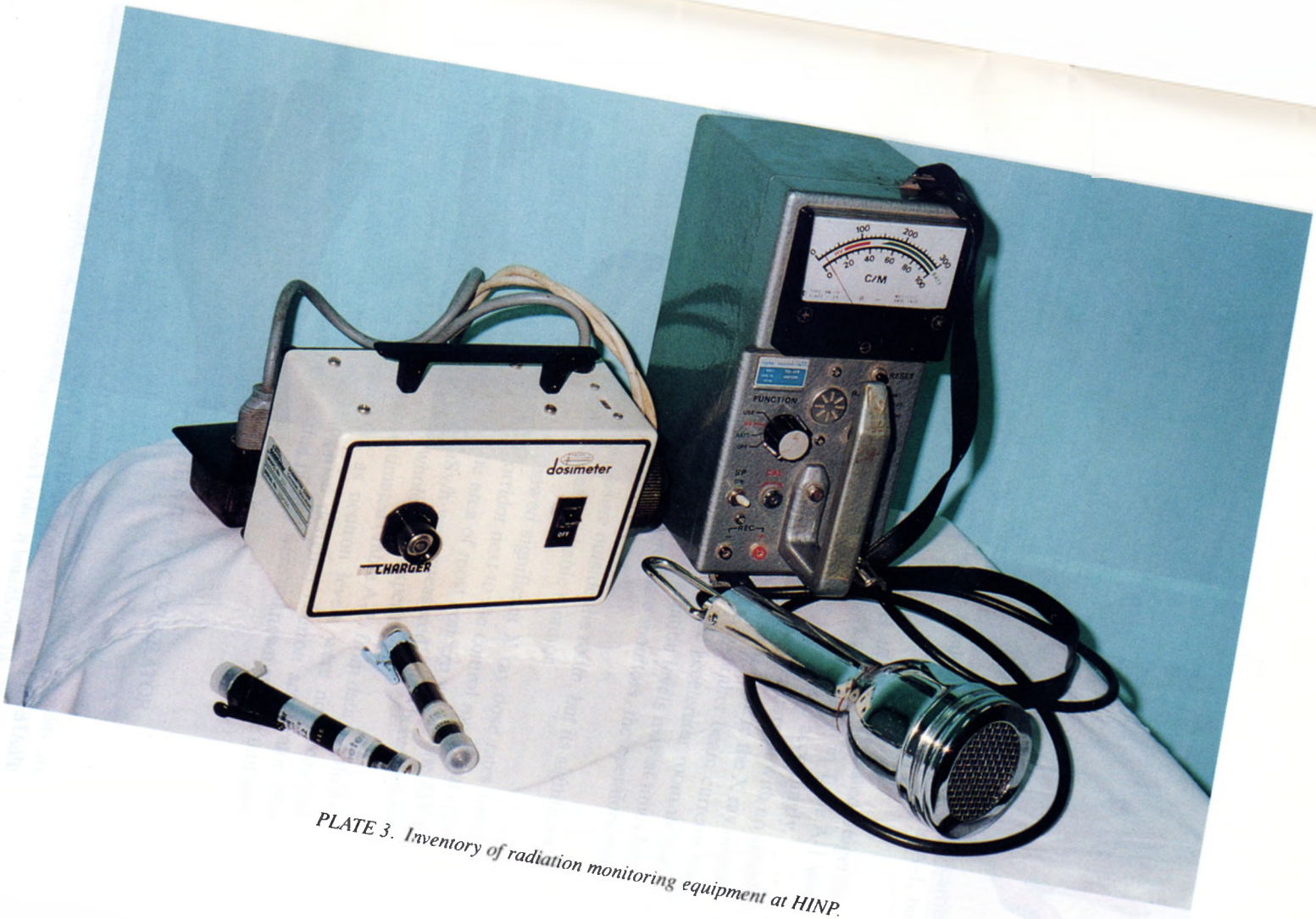


PLATE 3. Inventory of radiation monitoring equipment at HINP.

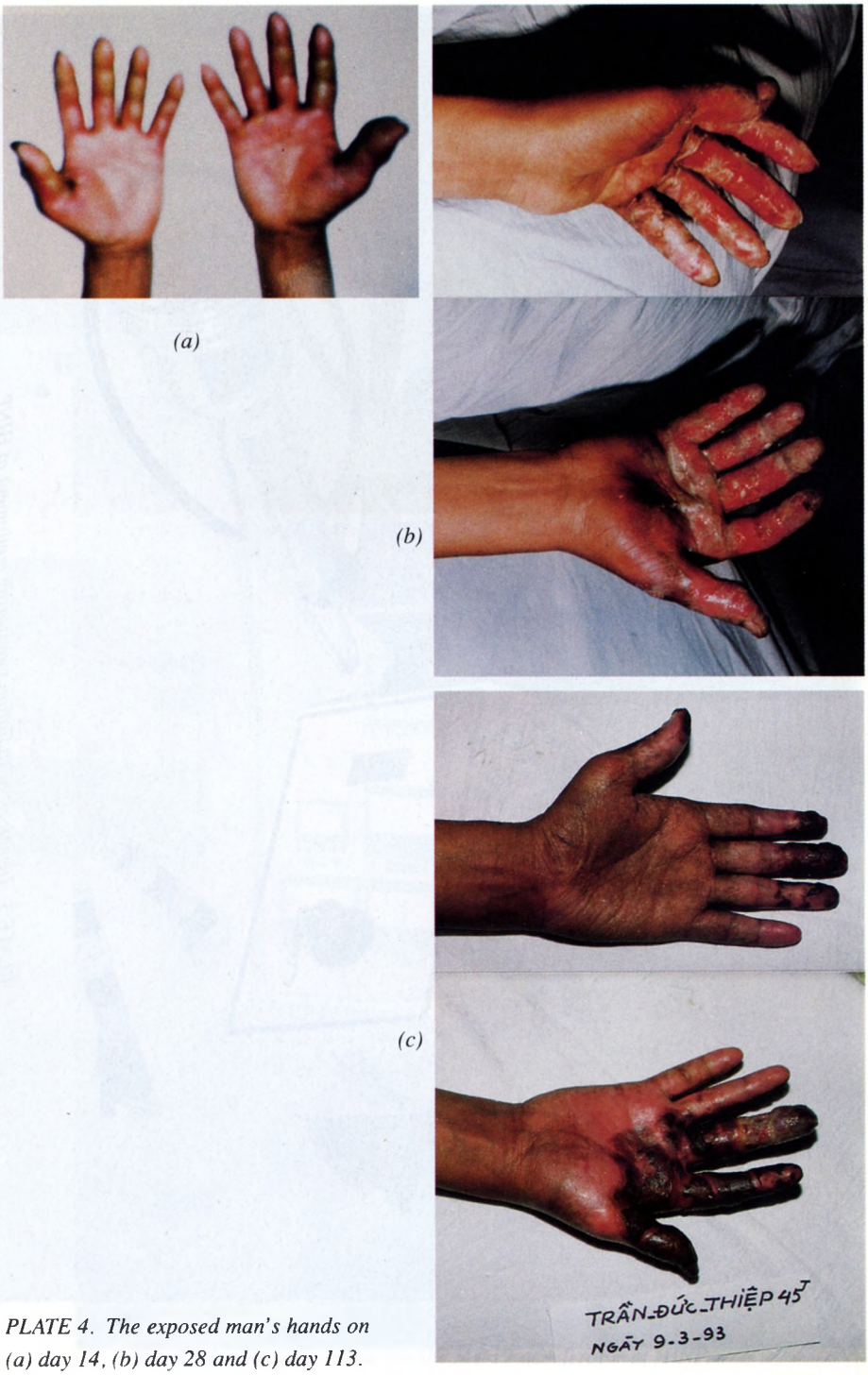


PLATE 4. The exposed man's hands on (a) day 14, (b) day 28 and (c) day 113.

Annex

ACCELERATOR AREA RADIATION SURVEY AND WORKER DOSE ASSESSMENT

DOSE RATE MEASUREMENTS OUTSIDE THE MICROTRON ROOM

An initial survey of the levels of X ray radiation outside the facility was carried out by an IAEA radiation protection expert. The results are given in Table A-1, but several points must be noted:

(a) The monitor used was a relatively new FAG FH-40 F2 compensated Geiger but, as no calibration details were available, the dose rates given in Table A-1 were 'as read' from the digital display and should be interpreted accordingly.

(b) The accelerator was at the time operating at a 3 μA beam current with no sample in position but with lead and wax shielding positioned close to the X ray output. (The accelerator log book showed that significantly higher beam currents had been used previously and, as dose rates outside the accelerator room increase more or less linearly with beam current, past radiation levels may at times have been excessive and, given the lack of appropriate monitors, the operators may have been unaware of it.)

(c) Neutron radiation contributes to exposure outside the room, but its significance could not be assessed owing to lack of a suitable monitor.

Despite these caveats, the survey showed significant X ray dose rates immediately outside the room door and in the corridor next to the control room, but occupancy of these areas was probably low. The area of most concern was in the MT-17 control room, where dose rates up to 25 μSv/h were measured and where operators could be at the control console during the whole of an experiment.

Annual doses to the operators were estimated (Table A-2) from data supplied by HINP and account only for X radiation, as neutron levels were not measured. Moreover, the added dose from the Hungarian designed neutron accelerator also cannot be estimated, as dose rates outside that facility were unknown and the unit was not operational.

DOSE ASSESSMENT OF OPERATORS IN THE MT-17 ACCELERATOR CONTROL ROOM

Estimates of dose to nearby workers from accelerator produced photons are given in Table A-2. The estimates are based on HINP supplied beam-on times and beam current values and on the IAEA team's survey of X radiation in the MT-17

control room. The estimates assumed: (a) an average beam current; (b) uniform operating frequency over the years; and (c) a 100% control room occupancy factor. (Assessment of exposure to accelerator induced neutrons would require a neutron survey.)

TABLE A-1. DOSE RATE MEASUREMENTS OUTSIDE THE MICROTRON ROOM

Measurement position	X ray dose rate (μSv/h)
Control cabin area	(a) 10–25 in general cabin area (b) 50 on wall near to accelerator room
In the corridor, close to the measurement room door	200
Surface of accelerator room door and surrounding area	100–200
On roof of accelerator room	300
In first floor rooms that overlook the accelerator room	(a) up to 35 next to windows (b) up to 2 in general working areas
On top of main roof overlooking accelerator room	120 at edge of roof

TABLE A-2. DOSE ASSESSMENT OF OPERATORS IN THE MICROTRON CONTROL ROOM

Period	Beam current (μA)	Operating time (h)	Annual dose (mSv)
1982–1985	14–16	250	5
1986	10–14	360	25
1987–1990	5–10	300	3
1991–1992	3–6	360	5

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, IAEA, Vienna (1988).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in San Salvador, IAEA, Vienna (1990).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Soreq, IAEA, Vienna (1993).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident at the Irradiation Faclity in Nesvizh, IAEA, Vienna (in preparation).

[5] LANZL, L.H., et al., Injury due to accidental high dose exposure to 10 MeV electrons, Health Phys. **13** 3 (1967) 241–251.

[6] SCHAUER, D.A., et al., A radiation accident at an industrial accelerator facility, Health Phys. **65** 2 (1993) 131–140.

[7] ALEKHIN, I.A., et al., Experience from application of radioluminescence and electron paramagnetic resonance to dosimetry of accidental irradiation, Atom. Ehnerg. **53** 2 (1982) 546–550.

[8] VIET NAM NATIONAL ATOMIC ENERGY COMMISSION, Country Report at the Seminar on Nuclear Safety and Regulation, Japan International Co-operation Agency, Tokyo (1992).

[9] CARAELLY, J., TERRILLE, M.C., MASCHARENNAS, S., Electron spin resonance dosimetric properties of bones, Health Phys. **50** (1986) 259–263.

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Safety of Gamma and Electron Irradiation Facilities, Safety Series No. 107, IAEA, Vienna (1992).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, What the General Practitioner (MD) Should Know about Medical Handling of Overexposed Individuals, TECDOC-366, IAEA, Vienna (1986).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Medical Handling of Accidentally Exposed Individuals, Safety Series No. 88, IAEA, Vienna (1988).

CONTRIBUTORS TO DRAFTING AND REVIEW

Barabanova, A.	International Atomic Energy Agency
Wheatley, J.	National Radiological Protection Board, United Kingdom
Kenneke, A.	United States of America
Kleschenko, E.	Institute of Biophysics, Russian Federation
Nenot, J.C.	Commissariat à l'énergie atomique, France
Le The Trung	National Centre for Burns, Viet Nam
Oresegun, M.O.	International Atomic Energy Agency
Ortíz-López, P.	International Atomic Energy Agency
Ung, T.	VINATOM, Viet Nam

Consultants Meetings

Vienna, Austria, 22–23 June 1993
Vienna, Austria, 21–25 February 1994

HOW TO ORDER IAEA PUBLICATIONS

No. 2, January 1996

☆☆ **In the United States of America and Canada**, the exclusive sales agents for IAEA publications, to whom all orders and inquiries should be addressed, is:

UNIPUB, 4611-F Assembly Drive, Lanham, MD 20706-4391, USA

☆☆ **In the following countries** IAEA publications may be purchased from the sources listed below, or from major local booksellers. Payment may be made in local currency or with UNESCO coupons.

AUSTRALIA	Hunter Publications, 58A Gipps Street, Collingwood, Victoria 3066
BELGIUM	Jean de Lannoy, 202 Avenue du Roi, B-1060 Brussels
CHINA	IAEA Publications in Chinese: China Nuclear Energy Industry Corporation, Translation Section, P.O. Box 2103, Beijing
CZECH REPUBLIC	Artia Pegas Press Ltd., Palác Metro, Narodni tř. 25, P.O. Box 825, CZ-111 21 Prague 1
DENMARK	Munksgaard International Publishers Ltd., P.O. Box 2148, DK-1016 Copenhagen K
EGYPT	The Middle East Observer, 41 Sherif Street, Cairo
FRANCE	Office International de Documentation et Librairie, 48, rue Gay-Lussac, F-75240 Paris Cedex 05
GERMANY	UNO-Verlag, Vertriebs- und Verlags GmbH, Dag Hammarskjöld-Haus, Poppelsdorfer Allee 55, D-53115 Bonn
HUNGARY	Librotrade Ltd., Book Import, P.O. Box 126, H-1656 Budapest
INDIA	Viva Books Private Limited, 4325/3, Ansari Road, Darya Ganj, New Delhi-110002
ISRAEL	YOZMOT Literature Ltd., P.O. Box 56055, IL-61560 Tel Aviv
ITALY	Libreria Scientifica Dott. Lucio di Biasio "AEIOU", Via Coronelli 6, I-20146 Milan
JAPAN	Maruzen Company, Ltd., P.O. Box 5050, 100-31 Tokyo International
NETHERLANDS	Martinus Nijhoff International, P.O. Box 269, NL-2501 AX The Hague Swets and Zeitlinger b.v., P.O. Box 830, NL-2610 SZ Lisse
POLAND	Ars Polona, Foreign Trade Enterprise, Krakowskie Przedmieście 7, PL-00-068 Warsaw
SLOVAKIA	Alfa Press Publishers, Hurbanovo námestie 3, SQ-815 89 Bratislava
SPAIN	Díaz de Santos, Lagasca 95, E-28006 Madrid Díaz de Santos, Balmes 417, E-08022 Barcelona
SWEDEN	Fritzes Customer Service, S-106 47 Stockholm
UNITED KINGDOM	HMSO, Publications Centre, Agency Section, 51 Nine Elms Lane, London SW8 5DR

☆☆ Orders (except for customers in Canada and the USA) and requests for information may also be addressed directly to:

Sales and Promotion Unit
International Atomic Energy Agency
Wagramerstrasse 5, P.O. Box 100, A-1400 Vienna, Austria

Telephone: +43 1 2060 22529 (or 22530)
Facsimile: +43 1 2060 29302
Electronic mail: SALESPUB@ADPO1.IAEA.OR.AT

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA
ISBN 92–0–100496–6