DEPARTMENT OF EMPLOYMENT AND PRODUCTIVITY

SAFETY, HEALTH AND WELFARE

Ionising Radiations: Precautions for Industrial Users

NEW SERIES No. 13

FIVE SHILLINGS NET

ER MAJESTY'S STATIONERY OFFICE

A list of the booklets available and in preparation in the series is given on the back cover, and copies are obtainable from Her Majesty's Stationery Office at the following addresses:
49 High Holborn, London WC1
13a Castle Street, Edinburgh 2
Brazennose Street, Manchester M60 8AS
258 Broad Street, Birmingham 1
109 St Mary Street, Cardiff CF1 1JW
50 Fairfax Street, Bristol BS1 3DE
7 Linenhall Street, Belfast BT2 8AY
or through any bookseller

First published November 1961
Second edition 1969

Prepared by the Department of Employment and Productivity and the Central Office of Information

The booklets in this series

are designed to give up-to-date facts and advice about the best practices in safety, health and welfare in industrial and other employment. The material is based on the wide experience of HM Factory Inspectors, and much help has been given by representatives of industry and others with special knowledge. Information is given about the provisions of the law where necessary, but there is no intention to provide an interpretation of legal requirements

CONTENTS

INTRODUCTION

Ionising radiations are now widely used in industry for a variety of purposes. Although such radiations are powerful allies for industry and research it must never be forgotten that there are potential hazards to health from such radiations and appropriate precautions must be taken in connection with their use. The hazards are such that, in the words of the Medical Research Council Reports of 1956 and 1960 on the Hazards to Man of Nuclear and Allied Radiations: 'Adequate justification should be required for the employment of any source of ionising radiations on however small a scale'.

This booklet deals with the risks associated with, and precautions necessary in and legislation made under, the Factories Act 1961 which apply to the use of

(a) X-ray machines and other apparatus which emit ionising radiations, and

(b) sealed and unsealed radioactive substances.

Although the general principles of radiological protection discussed here also apply to the operation of nuclear reactors, these form a special subject outside the scope of this publication. Nor are the questions of transport of radioactive substances outside the factory and the disposal of radioactive waste dealt with in detail in this booklet because the legal requirements applying to these are the responsibility of the Ministry of Transport and Ministry of Housing and Local Government respectively. In Scotland the responsibility for waste disposal rests with the Scottish Development Department.

Because there are so many industrial applications of ionising radiations it is not possible to give a complete list but the more common ones are given below:

Gamma and X-ray radiography
X-ray fluoroscopy
X-ray crystallography and spectroscopy
Static elimination
Thickness, level and density gauging
Package monitoring
Luminising
Tracer work

HAZARDS

Despite the great variety of uses in factories to which ionising radiations are being put, experience so far has indicated that if adequate precautions are taken the health of workpeople need not be in danger. If, however, there is no justification for fear, there is equally none for carelessness or complacency.

Ionising radiations can produce both somatic and genetic effects. The somatic effect is that which occurs to the individual who receives the radiation while the genetic effect is that to the subsequent offspring of the individual who receives the radiation as a result of the radiation effect on his or her gonads.

Persons can be irradiated by sources outside the body; this is known as *external radiation;* or from sources deposited within the body and this is known as *internal radiation.*

It must not be overlooked that some radioactive materials present toxicological as well as radiological hazards, thus constituting an added reason for care in their use.

The radiations with which we are mainly concerned industrially are alpha (α) particles, beta (β) particles, gamma (γ) rays, X-rays, bremsstrahlung and neutrons (n).

ALPHA PARTICLES

These are doubly positively charged nuclei of helium atoms and produce intense ionisation in short distances. Alpha particles are almost entirely absorbed in the horny layer of the skin and there is thus little danger from them outside the body. Conversely, they are very dangerous when emitted inside the body where they can irradiate unprotected tissue. If, for example, radium, an alpha emitter, is taken into the body by ingestion it tends to collect and become fixed in the bones. Since the bone marrow is the normal source of the red blood cells and of certain classes of white cells and other formed elements of the blood, the resulting irradiation may bring about a reduction in the number of these important elements, or lead to the appearance in the circulation of immature forms. The consequent anaemia and leucopenia may bring about a diminution of resistance to infections. Leukaemia is a possible late effect. Alpha particle bombardment in the skeleton can also damage the bone building cells and eventually possibly the bone structure itself, bringing about the development of bone cancer. Moreover, if alpha-emitting material such as radon is inhaled, damage to lung tissue, including cancer, may result.

BETA PARTICLES

These are streams of fast moving electrons. Beta particles are somewhat more penetrating than alpha particles but although not penetrating much deeper than the skin can cause burns, radiological dermatitis, dryness and cracking of the nails and skin, and wart formations which may develop into skin cancer. The eyes can be affected by beta particles, and prolonged excessive exposure to the more energetic particles may lead to cataract formation. Inhalation or ingestion of beta emitters can similarly lead to internal tissue and blood cell damage.

GAMMA AND X-RADIATION AND BREMSSTRAHLUNG

Gamma and X-radiation are penetrating electro-magnetic radiations. Bremsstrahlung is a type of electro-magnetic radiation produced when beta particles are slowed down, especially when passing through materials of high atomic number. The energy of the bremsstrahlung will depend upon the energy spectrum of the beta particles.

The effects of gamma and X-rays and bremsstrahlung are essentially similar. Since these rays can pass through the body without appreciable attenuation, except in the case of low energy X-rays, they can irradiate the blood-forming organs and so cause changes similar to those produced by alpha emitters in the body, namely, anaemia and leucopenia, and they may also induce leukaemia.

They can cause bad skin burns and other skin effects similar to those caused by beta particles. Because X-ray beams are often much more concentrated and intense than gamma ray beams, particular care is needed to guard against skin burns.

There is the possibility of producing impaired fertility or temporary sterility, though not impotence, from exposure of the gonads to excessive amounts of radiation.

Finally, there are possibilities that excessive radiation may produce deleterious genetic effects. It is important, therefore, to ensure that the irradiation of persons of reproductive capacity is kept within the maximum permissible levels.

NEUTRONS

These are particles having no electric charge. They are very penetrating and produce ionisation by secondary action. Neutrons in the region of 1 MeV and above are called fast neutrons. Those which have been slowed right down and are in thermal equilibrium with their surroundings have an energy of about 0·025 eV and are called thermal neutrons. Between these extremes, qualitative terms such as 'slow' and 'intermediate' are used. Fast neutrons when incident on the human body cause the ejection of protons from the hydrogenous constituents of the body. Protons are positively charged particles which cause high local ionisation and consequent cell damage. The absorption of slow neutrons by body constituents results in the production of gamma rays.

PROPERTIES OF RADIOACTIVE MATERIALS

HALF-LIFE

Half-life is the period of time in which the activity of a radioactive substance falls to half its original value. Half-lives vary from fractions of a second to millions of years. This is of importance in radiological protection because the half-life will determine how long the activity of the source will be such as to present a hazard. Some of the more common nuclides used in industry are listed below:

Nuclide	Half-life (in years, days and hours)	Principal radiations emitted (energies in MeV)	
		Beta	Gamma
Tritium (Hydrogen–3)	12·26y	0·018	
Carbon–14	5,760 y	0·155	
Cobalt–60	5·3 y	0·31	1·17 and 1·33
Krypton–85	10·6 y	0·15–0·67	0·51
Strontium–90	28 y	0·54, 2·2*	
Caesium–137	30 y		0·66
Promethium–147	2·6 y	0·22	
Iridium–192	74·4 d		0·31–0·61
Thallium–204	3·9 y	0·77	

The half-lives of radium, thorium and uranium are 1,620 years, $1{\cdot}41 \times 10^{10}$ years and $4{\cdot}5 \times 10^{9}$ years respectively. They are members of complicated decay chains, details of which are given in the Radiochemical Manual (Bibliography No. 39).

*The 2·2 MeV Beta particle is emitted by the daughter product of Strontium–90, Yttrium–90, whose activity is maintained at the same value as that of the parent Strontium.

SPECIFIC ACTIVITY

The activity of a radioactive material is measured in curies (Ci). This unit is a measure of the rate at which a given source is decaying. One curie is defined as being that quantity of radioactive material which is decaying at a rate of $3{\cdot}7 \times 10^{10}$ disintegrations per second.

An important characteristic of a radioactive material is its specific activity

$$\text{Specific activity} = \frac{\text{Activity (Ci)}}{\text{Weight (g)}}$$

In the Ionising Radiations Regulations, a radioactive substance is defined as any substance whose specific activity exceeds 0·002 micro-curies per gramme of substance. Specific activities (for the pure state) are given below of some radionuclides used in industry:

Radionuclide	Specific activity (μCi/g)
Tritium (as gas)	$9{\cdot}7 \times 10^{9}$
Carbon–14	$4{\cdot}6 \times 10^{6}$
Krypton–85	$4{\cdot}0 \times 10^{8}$
Radium–226	1×10^{6}
Natural Uranium	0·3
Natural Thorium	0·1

BASIC PRINCIPLES OF PROTECTION

The radioactive source in any apparatus or device should be of the minimum practicable activity. The lower the activity of a particular radionuclide the lower the quantity of radiation emitted and consequently the less the amount of protection necessary. Not only should the lowest activity be used but also the least hazardous radionuclide which is practicable should be chosen for any particular application.

Consideration should be given to this during the design of any new installation because it is at this stage that modifications can be most easily incorporated which can lead to the use of less hazardous sources.

Similarly the lowest practicable X-ray kilovoltage and tube current should be used.

EXTERNAL RADIATION

There are three principles of protection which can be used against external radiation. These are shielding, distance and time, and one or any combination of these principles must be used.

1 Shielding

This means the interposition of some material between the source and the individual either to stop the radiation completely, or to attenuate down to a safe level, the intensity of radiation from reaching the person.

ALPHA PARTICLES

These can travel only some 3 in. in air and can be stopped by as little as a sheet of paper.

BETA PARTICLES

These can be stopped by a few millimetres of most solid materials, their range depending directly on their energy and inversely on the density of the medium through which they are passing. Most beta radiation can be stopped by $\frac{1}{2}$ in. of plastic material such as Perspex. However, beta particles are often associated with bremsstrahlung which is more penetrating, and additional shielding may be necessary to attenuate the bremsstrahlung.

GAMMA AND X-RADIATION

Dense materials such as lead and steel or considerable thicknesses of concrete or brick are necessary to reduce the intensity of the radiation to a safe level.

NEUTRONS

Hydrogenous material such as paraffin wax, polythene, and water will slow down fast neutrons, although very fast neutrons may be reduced in energy initially by shields of high-density materials such as iron or steel. When the energies of neutrons are at thermal levels they may be absorbed by cadmium or boron.

2 Distance

The greater the distance from the source of radiation the less the intensity of the radiation. Gamma and X-radiation emitted by point sources obey the inverse square law, that is, the radiation intensity decreases with the square of the distance.

3 Time

The shorter the time a person spends in a field of radiation the less the dose he will receive. Biological effects depend principally on the dose accumulated over months or years. Time limitation is thus a useful short-term control measure.

INTERNAL RADIATION

To protect against internal radiation it is necessary to prevent the inhalation, ingestion or absorption through the skin or open wounds of radioactive substances.
Therefore,

- a the unsealed sources must be contained as far as practicable
- b the premises in which they are used must be kept as clean as possible, and
- c the persons working with the sources must maintain a high standard of personal cleanliness.

LEGISLATION AND CODES OF PRACTICE

Legal requirements for the protection of workers against ionising radiations in premises subject to the Factories Act 1961 are contained in the Ionising Radiations (Sealed Sources) Regulations 1969 (Bibliography No. 1) and the Ionising Radiations (Unsealed Radioactive Substances) Regulations 1968 (Bibliography No. 2). These Regulations are enforced by HM Inspectors of Factories of the Department of Employment and Productivity. The 'Sealed Sources' Regulations apply not only to sealed radioactive sources but also to any machine and apparatus intended to produce ionising radiations and to any machine or apparatus emitting ionising radiations in which charged particles are accelerated by a voltage of not less than five kilovolts, with the exception of television sets to which the Regulations apply only when the operating voltage is greater than 20 kilovolts.

A radioactive substance is defined as 'Any substance which consists of or contains radionuclides whether natural or artificial and whose activity exceeds 0·002 of a microcurie per gramme of substance: in the case of a chain of radionuclides consisting of a parent and daughters the only nuclide to be taken into consideration is that having the highest activity of those present'.

The Ionising Radiations (Unsealed Radioactive Substances) Regulations apply to radioactive substances other than sealed sources.

Radioactive waste disposal is controlled by the Radioactive Substances Act 1960 (Bibliography No. 4) and the Orders made thereunder, which are enforced by Radiochemical Inspectors of the Ministry of Housing and Local Government.

Inspectors of Nuclear Installations are responsible by virtue of the Nuclear Installation Act 1965 (Bibliography No. 5) for issuing and enforcing licences for nuclear reactors in premises other than those occupied by the United Kingdom Atomic Energy Authority.

Regulations dealing with the carriage of radioactive material by road are being prepared by the Ministry of Transport.

The precautions necessary for persons employed in research and teaching establishments and in hospital and dental surgeries are given in two Codes of Practice (Bibliography Nos. 6, 7). Advice on the research and teaching Code can be obtained from the Advisory Unit of the Department of Employment and Productivity and from the Radiological Protection Service who will also advise on the Hospital and Dental Code.

INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION AND MAXIMUM PERMISSIBLE LEVELS

The International Commission on Radiological Protection (ICRP) makes recommendations, *inter alia*, as to maximum permissible doses, maximum permissible body burdens and maximum permissible concentrations of radioactive substances in air (Bibliography Nos. 10, 11, 12). The various Regulations and Codes of Practice are designed to try to ensure that these maximum permissible levels are not exceeded.

The maximum permissible doses in the Schedules of the Ionising Radiations (Sealed Sources) Regulations and the Ionising Radiations (Unsealed Radioactive Substances) Regulations are based on the recommendations adopted by ICRP in 1965 (Bibliography No. 12). The Schedule is reproduced as Appendix A.

In the Regulations, the doses in the Schedules relate only to external radiation and do not include radiation used for the prevention, diagnosis or treatment of illness or injury.

The doses are expressed in the unit 'rem' which is the unit of dose equivalent. It is numerically equal to the absorbed dose in rads multiplied by appropriate modifying factors.

A rad is the unit of absorbed dose and is defined as an energy absorption of 100 ergs per gramme. The full definition and values of the modifying factors are given in a publication of the International Commission on Radiological Units (ICRU) (Bibliography No. 40).

The maximum permissible air concentrations and maximum permissible body burdens recommended by ICRP which are changed from time to time may be found in the periodic reports of ICRP Committee II (Bibliography Nos. 10, 11).

GENERAL REQUIREMENTS APPLICABLE TO REGULATIONS MADE UNDER FACTORIES ACT

ADEQUATE SHIELDING

The Regulations require that all sources of ionising radiation shall, where reasonably practicable, be adequately shielded. The definition of adequate shielding is: 'Adequate shielding in relation to any source of ionising radiations means having provided and properly maintained around that source of ionising radiations, shielding or a demarcating barrier, being shielding or a barrier outside which the radiation dose rate averaged over any one minute, does not exceed 0·75 millirems per hour, or where only classified workers are affected, 2·5 millirems per hour'.

The dose rate is laid down in these terms, that is, an hourly rate averaged over any one minute, in order to allow for the averaging necessary in respect of certain machines which emit pulses of radiation in fractions of a second. In most cases the measuring instrument itself will automatically average the dose rate, but in other cases it may be necessary to perform a calculation.

Adequate shielding is regarded as a means of introducing intrinsic safety into the arrangements for the protection of workers. For example, in the extreme case, a person who spent forty hours a week for fifty weeks a year immediately outside shielding on which the dose rate was not greater than 0·75 mrem per hour would not receive more than three-tenths of the maximum permissible dose. Adequate shielding is required only where reasonably practicable; however, its presence or absence will often determine whether persons working with radiations are 'classified workers'.

CLASSIFIED WORKERS

In the Ionising Radiations (Sealed Sources) Regulations a classified worker is defined in effect as a person employed

1 in work involving the storage, manipulation, maintenance, operation, use or installation of a sealed source or the operation or use of an X-ray machine or apparatus emitting ionising radiations, and

2 who works at some time in a radiation area, that is, an area where the dose rate exceeds 0·75 mrem per hour.

It is important to note that both conditions must be satisfied before the person becomes a classified worker as defined.

The definition of a classified worker in the 'Unsealed Radioactive Substances' Regulations is rather more involved and the Regulations should be consulted. In essence he is a person who is employed both in work involving unsealed sources and in specially defined areas.

These criteria are designed to ensure that workers whose radiation doses might exceed three-tenths of the annual maximum permissible doses given in Schedule 1 to the Regulations are subject to special health supervision and personnel monitoring.

MONITORING

General

Except at acutely damaging doses, ionising radiation is not detectable by any of our senses and, therefore, its presence has to be measured by suitable instruments known usually as monitors. Monitors must be of the appropriate type for the particular measurement to be made, and when in doubt occupiers should seek expert advice. Monitors must be maintained in efficient working order and be readily available for use when required. They are often battery powered and if the monitor is used infrequently it may be found that the battery has run down when it is required for use unless it is checked regularly.

The Regulations require that monitors should be tested by a qualified person when first taken into use and subsequently re-tested at least once in every period of 14 months and also after any repair of a defect which could affect its accuracy. A register giving particulars of these tests should be kept.

It is essential that the response of a monitoring instrument to radiations of various types and energies should be established, particularly in respect of the radiation(s) for which it is intended to be used. This study, often termed calibration, requires special equipment such as monoenergetic sources of known strengths, and rigorous procedures. Routine testing, however, may, with suitable precautions, utilise much simpler methods.

Personal dosemeters

The most effective method of confirming that the precautions taken have ensured that a person has not received an excessive amount of external radiation is to measure and record the total doses received during the full working period when a person is liable to be exposed to ionising radiations. The method of measurement required by the Regulations is for the person to wear a film badge or other approved personal dosemeter obtained from and assessed by an approved laboratory (e.g. the Radiological Protection Service).

A film badge consists of a film, mounted in a holder, incorporating an open window and various filters. The degree of blackening of the film under the filters enables an assessment to be made of the dose received by the film. Film badges are used to monitor gamma, X- and beta radiation. If a cadmium filter is used, slow neutron doses can be assessed. Fast neutron doses can be measured using special photographic emulsions in which proton tracks are produced which can then be counted under a microscope.

The film badges should normally be worn on the front of the body, between the waist and shoulder, on the outside of normal working clothing. However, there are instances when the exposure to radiation may not be uniform over the body. For example, in operations involving the manipulation of radioactive sources the hands may receive a much greater dose than other parts of the body and in such cases it may be necessary for a personal dosemeter to be worn on the hand or wrist. Wrist filmholders are available but thermoluminescent dosemeters are probably more suitable because they can be worn on the finger-tips. Thermoluminescent substances such as lithium and calcium fluoride, if heated after being irradiated by ionising radiations, emit an amount of light which is proportional to the dose of radiation received. Another instance where a finger-tip dosemeter is useful is in work with X-ray crystallographic apparatus where there may be exposure to narrow but high intensity beams of radiation.

Neither the film badge nor the thermoluminescent dosemeter is a direct reading device. In work such as site radiography, where radiation dose rates may be comparatively high for short periods, it may be desirable to wear dosemeters from which an immediate reading can be obtained at any time throughout the working period. The quartz fibre electroscope is a dosemeter of this type. It should be noted, however, that this type of dosemeter is not sensitive to all the radiations which can be measured with film badges and thermoluminescent dosemeters and that it completely fails to measure doses in excess of the maximum figure for which it was designed.

The Regulations require all classified workers who work in radiation areas to wear a film badge or other approved dosemeter. Additionally, the Regulations give power to HM Chief Inspector of Factories to require any other person employed to wear a film badge or other personal dosemeter when it is necessary.

Workers must be particularly careful not to leave their film badges etc. behind in any area where there is a significant dose rate. When not in use, they should be stored well away from sources of radiation. It is vital that any film badge or thermoluminescent dosemeter is completely identified with the wearer and he must wear only the film or dosemeter which has been issued to him and only one person should wear a particular film or dosemeter.

RADIATION DOSE RECORDS

The keeping of careful records of radiation doses received is of great importance (Bibliography No. 41). The maximum permissible doses include a cumulative dose covering the working lifetime of the person concerned and, therefore, there is a requirement in the Regulations for the keeping of radiation dose records and for their preservation through any changes of employment. The records must be retained for thirty years after the last entry. When a classified worker leaves employment he must be given a transfer record (Bibliography No. 42) which is a copy of the relevant entries in his radiation dose record. His employer at the same time must send a copy of this transfer record to HM District Inspector of Factories.

OVERDOSES

When any person receives a dose in excess of the maximum permissible under the Schedule to the Regulations, the occupier of the factory should

1 notify the Appointed Doctor
2 notify the Inspector for the District
3 make an investigation or arrange for an investigation to be made
4 keep a record of the circumstances.

When the Appointed Doctor has been notified of an excessive exposure the person concerned should be medically examined by the Appointed Doctor without delay where the excessive dose either

a exceeds 10 rems of gamma rays, X-rays or neutrons in the case of a whole body dose, or
b in other cases exceeds the maximum permissible dose in the Schedule. The Appointed Doctor can, of course, examine the person even if the dose has not exceeded 10 rems, if he considers it to be desirable.

MEDICAL SUPERVISION

The Regulations require that classified workers should be medically examined by the Appointed Doctor and certified fit for such employment before commencing work. This medical examination must include a blood examination unless the report of an earlier suitable blood examination is known and available to the doctor.

Further medical examinations are necessary at periodic intervals, usually not exceeding 14 months. There is an exception in the case of a person who is a classified worker by reason only of the fact that he worked in a radiation area. In his case, no periodic medical examination is required if in the preceding year he has not received a dose in excess of three-tenths of the maximum permissible dose.

Medical supervision is important in premises in which ionising radiations are used. Pre-planning against possible incidents is essential and suitable first-aid facilities should be provided.

Where unsealed radioactive sources are present, any person who sustains a cut or other break in the skin should have it treated without delay. Contamination of a break in the skin is potentially serious and no one should work with unsealed radioactive sources unless breaks in the skin are protected to prevent the entry of any radioactive substance.

SUPERVISION AND TRAINING

General instruction

No person employed should be exposed to ionising radiations unless he has received appropriate instructions concerning the hazards involved and the precautions to be observed. The extent of this instruction will vary according to the circumstances of the employment of the persons involved. It may be that a worker not actually engaged in work with ionising radiations may require no more instruction than to be told to take due note of warning notices restricting access to certain areas. On the other hand, appropriate courses of instruction may be necessary for workers engaged in using ionising radiations. Where a considerable amount of instruction on a continuing basis has to be given, a properly trained person should be appointed for the purpose.

Competent person

The Regulations require the appointment of one or more 'competent persons' to exercise special supervision with regard to the Regulations and to assist in enforcing the observance of them. In general, the competent person should be made responsible for working out protective measures and safe working techniques and seeing that they are observed. He must have sufficient technical knowledge to carry out his duties and he must be given the appropriate authority with the full support of the management.

Authorised person

In addition to the appointment of a competent person the regulations require an occupier to appoint 'authorised persons' for various purposes which include

- a treatment of contaminated wounds
- b transport of radioactive substances within a factory
- c action in the event of spills or accidental escapes
- d permits to enter total enclosures or fume cupboards

e decontamination of personnel
f entry into radiography enclosures; and
g dose rate monitoring.

The competent person may, in a small factory, be authorised for some or all of these purposes, but in larger establishments it is envisaged that there will be a need for many more persons authorised for specific tasks. These authorised persons should be supervised by the competent person as part of his duties.

LABELLING

Containers and devices housing radioactive substances should be labelled with the internationally accepted sign for ionising radiations, shown in Figure 1 (British Standard 3510: 1968).

The sign should be in a conspicuous position and should be kept clean.

It is recommended that the word 'Radioactive' should be included under the sign and also a label giving details of the type of radionuclide inside the container or device, together with its activity at a specified date.

Fig. 1 The basic symbol to denote the actual and potential presence of ionising radiation BS 3510 : 1968

ACCOUNTING FOR RADIOACTIVE SUBSTANCES

A record should be kept showing the whereabouts of radioactive sources. This is necessary both for sealed and unsealed sources, although it is appreciated that there are difficulties in accounting accurately and in detail for unsealed sources.

The type of information which should be kept, particularly for sealed sources, includes:

1 the distinguishing number or other identifying mark
2 the date of receipt into the control of the occupier
3 the nature of the radioactive substance
4 the radioactive strength of the substance at a date specified in the record
5 the date and manner of disposal of the source when it leaves the control of the occupier.

Only authorised persons should be made responsible for the issue of radioactive sources. The person in charge of the sources and the records should check at sufficiently frequent intervals that sources have not been lost or mislaid and are where they should be. The record of sources should be kept up to date on each working day.

If a source is lost or mislaid, immediate steps should be taken with a view to finding it and if it is not accounted for within 24 hours, the fact should be reported to HM District Inspector of Factories.

STORAGE

When not in use, all radioactive sources should be kept in a secure store separated for the purpose and providing adequate shielding. Where possible the store should be within or close to the area in which the sources are used so as to reduce the need to convey them through other areas. For instance, it is preferable for the store for gamma radiography sources to be inside the radiography enclosure and the luminising compound inside the luminising room.

The exact form of the store is not particularly important although there is much to be said for boreholes or pits in the ground being used for the storage of gamma radiography sources. The earth sides act as natural shielding and the pits can be provided with padlocked covers. If the source is in a shielded container, the amount of shielding to be provided by the cover may be quite small, bearing in mind that the depth of the borehole or pit will cause a reduction in dose rate at the cover due to the inverse square law.

If more than one radioactive source is stored, each should preferably be kept in a separate, individually shielded compartment or container to reduce to a minimum the dose rate to which a person withdrawing or replacing a source is liable to be exposed. This is of course more important with gamma emitters such as sources used for radiography or radium activated luminous compound, than for beta or alpha emitters.

Stores containing sources liable to emit a radioactive gas, e.g. radium, tritium, krypton–85 and iodine–131 should be mechanically ventilated to the open air. The discharge of the ventilation pipe should be in a position such that the gas does not enter the air of any workroom. The ventilation may have to run continuously in stores containing unsealed radioactive sources if there is a real risk of gas being evolved but where this is not necessary it should be run for not less than two minutes before the store is opened.

The interior of a store, particularly for unsealed radioactive sources, should be capable of being easily de-contaminated and it should be checked regularly to determine whether or not it is contaminated. Where a number of small unsealed radioactive sources is stored, it is suggested that they be placed on a tray which can contain any leakage or spillage.

Sources should be removed from stores only by or under the supervision of an authorised person. All stores must be secured or locked so as to prevent unauthorised persons from gaining access to the sources.

SPECIAL REQUIREMENTS OF THE IONISING RADIATIONS (SEALED SOURCES) REGULATIONS 1969

MONITORING

The two main types of monitor available are those using ionisation chambers and those using geiger tubes. Usually they are designed to be held in the hand and have scales marked in units of dose rate. Although certain monitors can be used to measure gamma, X- and beta radiation the scale reading will not necessarily give the dose rate directly for all of these radiations, and correction factors may have to be applied. These will be determined when the instrument is calibrated.

Monitors for the measurement of neutron dose rates are also available.

The scale ranges should be such that dose rates of 0·75 mrem/h and 2·5 mrem/h can be clearly seen.

Ionisation chamber monitors will give a direct reading only if the radiation field fills the chamber and, therefore, they may be inappropriate for narrow beams of radiation such as those which can emerge from X-ray crystallographic apparatus. Suitable photographic film can be used to locate such narrow beams of radiation.

A comprehensive monitoring survey should be made of any new installation when it is taken into service or when any substantial changes have been made to an existing installation. A survey is necessary after any maintenance of an installation particularly if any of the shielding has been moved. The frequency of routine monitoring under normal operating conditions must be decided upon on the particular circumstances. During site radiography regular monitoring will be required possibly each time the X-ray set is energised or gamma ray source exposed, and it is difficult to see how conditions can be checked and known to be satisfactory on a site unless frequent monitoring is undertaken. On the other hand a thickness gauge containing a few millicuries of a beta emitter will require to be monitored comparatively infrequently if no alterations are made to it.

RADIOGRAPHY

Gamma and X-radiation are used for industrial radiography. The operating voltages of the majority of X-ray sets lie in the range 100 kV to 400 kV although they can range up to 2 million volts. Even higher energy beams are available from linear accelerators and betatrons.

The most generally used gamma emitters are cobalt–60, iridium–192, caesium–137 and thulium–170. Activities up to about 20 curies are in common use although up to 1,500 curies of cobalt–60 have been used for thick walled articles such as nuclear reactor pressure vessels.

Except in special circumstances, radiography should be carried out inside a walled enclosure which provides adequate shielding and from which non-authorised persons are effectively excluded. However, there are certain types of work for which it may not be reasonably practicable to use a walled enclosure. Typical examples are:

1 site radiography or

2 where the size of the articles to be radiographed is excessively large or

3 where the amount of radiography undertaken is small.

Nevertheless, it should not be taken for granted that the use of a walled enclosure is always impracticable in these types of work.

Where it is not reasonably practicable to do the radiography within a walled enclosure it must be separated from other work and carried on inside a suitable enclosure, or where this is not reasonably practicable within a suitable marked area from which all except authorised persons are excluded.

There are many safety precautions common to gamma and X-radiography but there are certain differences in practical detail in achieving them. They are therefore dealt with separately in this booklet.

X-radiography

Every X-ray tube used for industrial purposes should be of the shockproof, self-protecting type, in which protection according to its maximum rated voltage and current is incorporated integrally in its housing so that, in general, it limits the leakage radiation at a distance of one metre to one rem/h. The size of the useful beam should be limited to the minimum practicable for the work. This can be achieved with a lead diaphragm of adjustable aperture or with lead-lined cones. Where rod anode tubes are in use, the unused radiation can be masked off with lead sheeting or by the use of the cap normally supplied by the manufacturer of the set. X-ray high-voltage generators and associated high-voltage cables ought to be of the corona-free type, and it should not be overlooked that some high-voltage equipment contains rectifying valves which can produce adventitious X-rays and may need to be adequately shielded.

WALLED ENCLOSURES

The construction of the walled enclosure, which should be of ample area, should be such as to give adequate shielding under all operating conditions against direct and scattered radiation, to all persons outside the enclosure whether they are on the same floor level or in rooms above or below the enclosure. The radiation dose rate at doors or windows in the enclosure should be no greater than that outside the walls. If the enclosure is open topped or has a roof which provides only little shielding some radiation can be scattered by the air above back down into the surrounding area. This can happen particularly if the beam is directed well above the horizontal. It is possible for the dose rate close to the enclosure wall to be less than 0·75 mrem/h or 2·5 mrem/h but much higher several feet away. This area should also be monitored.

Special attention must be given to the prevention of excessive penetration of radiation round door frames, observation windows, ventilation ducts and other parts where there is a possibility of a break in the continuity of the protection. Such continuity should have been ensured in the original construction of the enclosure, care being taken, for example, that all screws, bolts etc. piercing the lead protection, are covered with an appropriate thickness of lead and that all lead sheeting overlaps at joints and corners. Sliding doors should run in a groove in the floor.

Assuming that there is no occupied room below or the flooring of the X-ray enclosure affords adequate shielding, it is desirable that the useful beam should be directed towards the floor so that protection by the walls and ceiling will be needed only against scattered radiation. The scatter itself can be minimised by standing the work to be radiographed on a lead sheet.

Where two or more X-ray rooms are constructed side by side, an X-ray set in one room may be in operation while radiography staff may be setting up or doing other work in an adjoining room. The intervening wall must therefore provide adequate shielding.

The walls of X-ray enclosures are usually constructed of concrete, brick or lead. The lead is often sandwiched between sheets of plywood to prevent its creeping. Data is available to enable the requisite amount of shielding to be calculated but its use requires expertise, and unless the user is familiar with the method he should seek the advice of an expert organisation, such as the Radiological Protection Service.

DOOR INTERLOCKS

When X-radiography is carried out within a walled enclosure, all doors should be efficiently interlocked so that the X-ray tube cannot be energised while a door is open and is automatically de-energised if a door is opened. Any interlock switch should be sited and installed so that it cannot be interfered with (Figure 2). The electrical interlock should operate in the primary circuit of the high-voltage transformer and not in the contactor coil circuit to exclude the risk of the tube remaining energised if the contacts of the contactor should stick in the closed position. It has been found that until the filament is cold, certain constant potential X-ray sets can continue to emit X-rays after the energising voltage has been switched off. In such cases, it is advisable for the interlocks to be designed to ensure that the current to the filament is switched off as soon as possible after the tube has been de-energised.

MEANS OF EXIT, CONTROL OR SHIELDING

Means should be provided within the enclosure either to enable persons accidentally shut inside to leave without delay or to enable the X-ray tube to be de-energised. Alternatively, an area can be shielded off within the enclosure inside which a person can stand in an acceptable dose rate until he can be released. In practice, with X-ray enclosures, one or other or both of the former methods is used. When an emergency switch is provided inside an enclosure, it should be clearly labelled. The siting of exits and emergency switches should be such that a person will not have to pass through the useful beam of radiation to reach them. If reliance is placed on a quick means of exit from the enclosure, the doors must not be capable of being locked. If the enclosure has a sliding door and it does not slide on the inside of the enclosure, the path of travel of the door should be shrouded to prevent the movement of the door from being inadvertently obstructed.

WARNING SIGNALS

Adequate warning to all persons inside the room must be given that a set is about to be energised and that it is energised. Except in those rare instances where the noise level is too great, the pre-warning signal should be an audible one. The signal indicating that the set is actually energised can take the form of warning lights or illuminated panels. A person will normally see a warning light only if he is looking at it, and therefore it is preferable for the signal within the enclosure to be in the form of a rotating or flashing light.

These warning signals should be given automatically. The X-ray control panel, which must be outside the enclosure, should incorporate a time-delay device which comes into operation when the high-voltage switch is depressed, at which time the pre-warning signal should sound. This warning should continue for a predetermined time at the end of which the tube should become energised without any further action on the part of the operator. The length of the warning period must be such as to enable any person inside to reach a position of safety. Five or ten seconds is all that is needed in the majority of enclosures.

Where overhead travelling cranes can pass over open-topped or partially shielded enclosures, adequate warning signals must be given to the crane driver to indicate whether the set is energised. Interlock switches can be provided on the crane track so that if the crane approaches too close to the enclosure the X-ray set is automatically de-energised and cannot be re-energised until the crane has returned to a safe position.

MEANS OF COMMUNICATION

Suitable means of communication should be provided to enable persons accidentally shut inside a walled enclosure to summon help from outside. This may be a telephone or a warning bell or siren. The essential feature is that someone should be present at the receiving end who knows what action to take.

SUITABLE ENCLOSURES OR SUITABLY MARKED AREAS

Where for valid reasons the construction of a walled enclosure is not reasonably practicable, the radiography should be isolated from other work and all except authorised persons excluded from a suitable enclosure or a suitably marked area around the X-ray tube and the work being radiographed. The area should preferably be demarcated by solid railings of the type used to marshall crowds, or portable picket fencing. In more difficult circumstances the use of substantial ropes (or tapes) supported by firm stanchions or bollards may be acceptable. The extent of this area should be so determined that by taking into account

1 The time for which the radiography will be in progress, and
2 The dose rate at the periphery

no person having access to it will receive a dose in excess of the maximum permissible dose. On the strictest interpretation, set by the cumulative permissible doses and by workers being regarded as continuously exposed to radiation during their employment, this would mean fixing the area so that the dose rate outside it does not exceed 0·75 mrem/h. If this standard is reasonably practicable it should be used. However, there is considerable flexibility afforded by the fact that the ultimate permissible dose rates are effectively set on a quarterly not an hourly basis and that this type of work rarely proceeds continuously for a full forty hours a week for thirteen weeks a quarter.

The operator of the X-ray set or other authorised person should be adequately protected from direct and scattered X-radiation by the provision of protective lead screens around the work. These screens can be mounted on wheels to facilitate easy movement. Additionally, lead-lined cones or lead diaphragms should be used to reduce the amount of scattered radiation as much as possible. Wherever possible, the useful beam should be pointed away from areas where people are at work, and in devising these various safeguards, the possibility of overhead crane drivers entering the danger area should not be overlooked.

Suitable warning notices capable of being easily read, should be displayed at the boundaries of the demarcated areas, and it is highly desirable that a person with the necessary authority should be stationed in the vicinity to prevent unauthorised persons from crossing the boundaries when the X-ray tube is energised. The warning notices should give definite instructions such as 'Keep Out' or 'Do Not Pass' rather than 'Danger—X-rays'. When not in use warning notices should be removed or masked. Flashing or rotating warning lights are an added safeguard but they should be illuminated only when the set is about to be or is energised. Lights can be difficult to see in bright sunlight.

Identifying numbers or letters of lead, iron etc. are often affixed to objects being radiographed. Should these symbols become displaced during actual exposures, it is essential that no attempt be made to refix or replace them by hand before switching off the X-ray tube. Neglect of this precaution has resulted in a most serious injury to an industrial radiographer.

Linear accelerators—betatrons

High-energy X-ray machines of the order of one million volts or more, or linear accelerators or betatrons should be used in walled enclosures. Great care must be taken to prevent the machine from

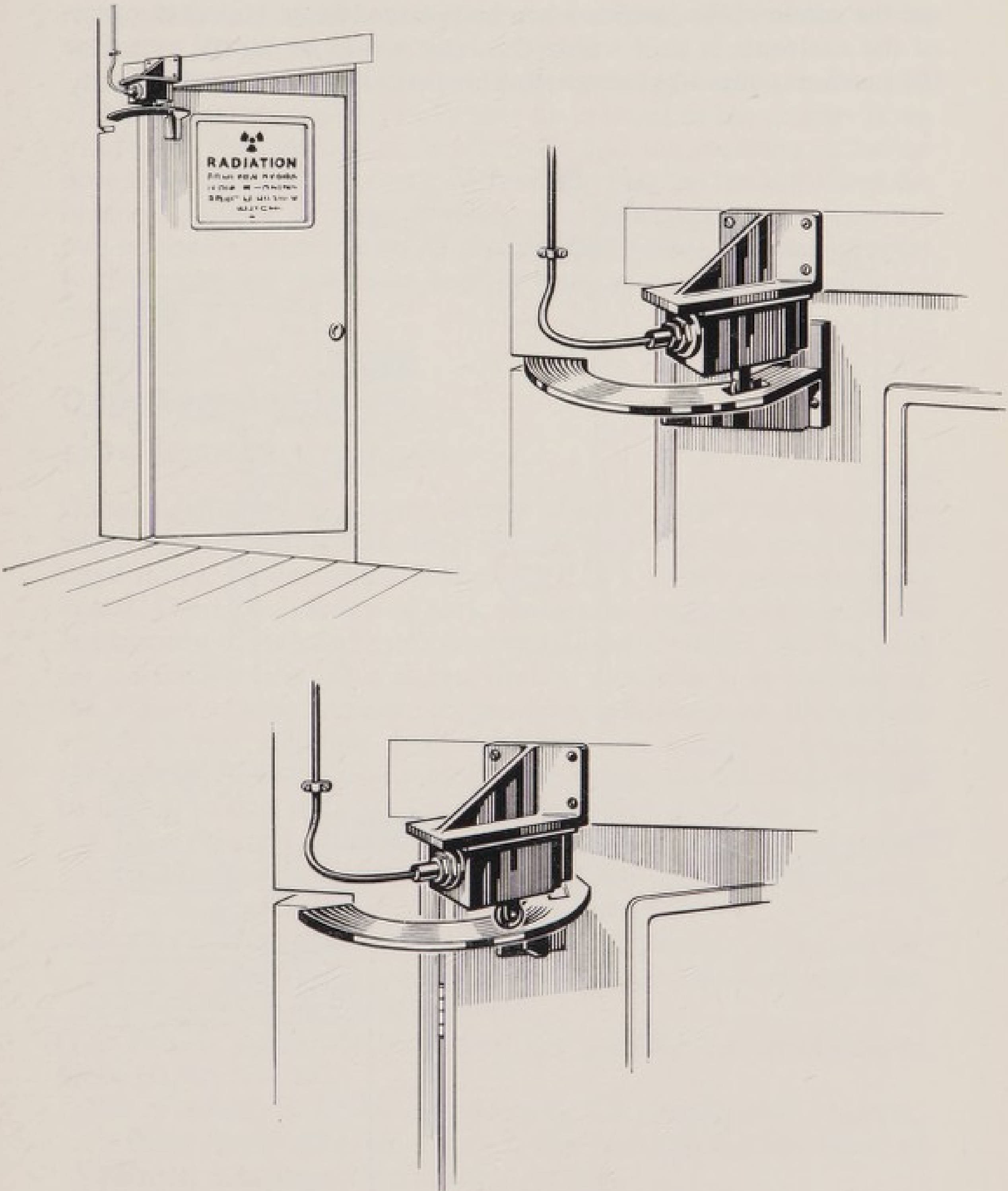

Fig. 2 (a)
Electrical interlock on the hinged door of a walled enclosure used for radiography

being energised when a person is inside the walled enclosure, and the operator should, therefore, inspect the interior of the enclosure before the apparatus is switched on. One method of ensuring that someone goes into the room and personally checks whether anyone is present is to fit time-delay switches inside the enclosure which must be operated before the machine can be energised. The switches should be positioned so that the person has an opportunity to see the whole of the interior when he operates them. Unless the door of the enclosure is shut within the time period set by the switches, the machine cannot be energised. This period should be only slightly

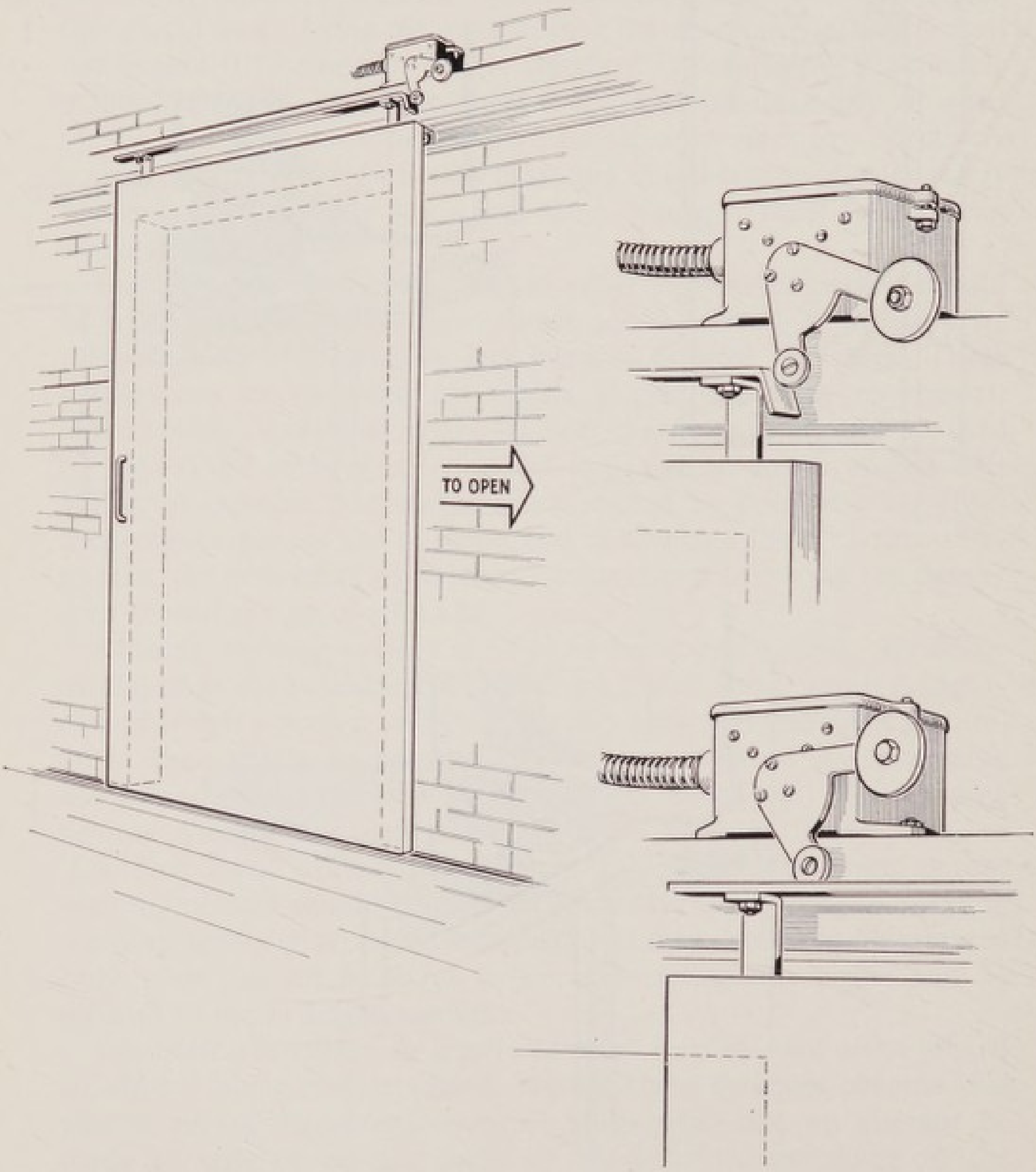

Fig. 2 (b)
Electrical interlock on the sliding door of a walled enclosure used for radiography

longer than the time taken to operate the switches and close the door. This should ensure that no one can then enter the enclosure unbeknown to the operator between the time the time-delay switches are operated and the door closed. If the door is opened subsequently before the machine has been energised, it is necessary to repeat the procedure (Figures 2 (a) and 2 (b)).

Ozone and nitrous fumes can be produced by the effects of high-energy radiation and because these are both toxic the interior of the enclosure should be adequately ventilated.

If the energy of the radiation is sufficiently high as in the case of a 31 MeV betatron, radioactivity may be induced in the articles being irradiated. The amount of this activity and the resulting radiation dose rates should not be particularly serious because the half-life of the induced activity is comparatively short. Nevertheless, dose-rate measurements should be made in any new installation or new process to determine the maximum level of induced activity and radiation dose rate.

Gamma radiography

EXPOSURE CONTAINERS

Gamma radiography sources consist of small metal capsules inside which the radioactive material is sealed. These capsules are normally fitted into a holder which is then kept in a larger protective container. There is a variety of such containers commercially available but because of the conflicting considerations of weight and the need for portability it is often impracticable, particularly in the case of the higher activity sources, to produce containers on the surface of which the radiation dose rate does not exceed 2·5 mrem/h. Where adequate shielding cannot be achieved, the container should be loaded so that the following standard is not exceeded:

1 The average dose rate at 1 metre from the source should not exceed 2 mrem/h and the maximum dose rate should not exceed 10 mrem/h; and

2 The average dose rate at 5 centimetres from the surface of the container should not exceed 20 mrem/h and the maximum dose rate should not exceed 100 mrem/h.

(The British Standards Institution has published a specification: Bibliography No. 33.)

The containers available commercially fall roughly into 3 classes:

1 those from which the source is not removed and the beam of radiation is exposed by removing a cover,

2 those from which the source is removed on a handling rod, preferably at least 3 feet long, and

3 those from which the source is projected out of the container mechanically, electrically or pneumatically.

Type 3 is to be preferred for panoramic exposures because the operator will be at a distance from the source. Such remotely controlled containers become almost essential when sources much above 1 curie cobalt–60 or 5 curies caesium–137 or iridium–192 are in frequent use for panoramic exposures. The time an operator can spend close to the exposed source is only a few minutes a day, even at 1 metre from the source if he is not to exceed his maximum permissible dose.

It is possible to use a time controlled meter to expose and return the source at pre-determined times so enabling the radiography, if desired, to be done automatically at night in the complete absence of workers.

Many containers for the higher-activity sources are mounted on wheels and have a handle about 1 metre long to keep the operator the requisite distance away.

Capsules have been lost because they have dropped out of or been knocked out of the holder, and to reduce this possibility the holder should be provided with an end cap, and in addition the capsule should be held inside the holder with a spring clip arrangement.

Radiography sources must never be picked up in the hands. When handling rods are used, they should be held so that the source is as far away from the body as possible.

WALLED ENCLOSURES

As with X-radiography, gamma radiography should be carried out where reasonably practicable inside a walled enclosure. The thickness of the walls of a gamma radiography enclosure will normally be greater than those of an X-radiography enclosure. Consequently, it is often impracticable to provide a door with the necessary amount of shielding, and therefore labyrinth entrances may have to be provided (Figure 3). The door to the enclosure is then required to prevent only unauthorised entry.

If the enclosures are open topped or have only thinly shielded roofs, the possibility of the radiation being scattered back down into the workroom must be considered. The radiation dose rate should be measured both at the outside walls and up to several feet away from the walls. It is possible to have a wall that provides adequate shielding at or near the surface and yet have dose rates in excess of the accepted levels several feet away.

If the shielding provided by the walls of the enclosure is not sufficient unless the source is exposed only in a limited area within the enclosure, then that area should be clearly marked, e.g. by painting lines on the floor.

To safeguard maintenance workers, contractors and others who may need access to roofs above gamma radiography rooms where such roofs do not provide adequate shielding

1 Warning notices should be provided at access points
2 A roof warning light should be operated during actual exposure, and
3 A 'permit-to-work' system should be instituted.

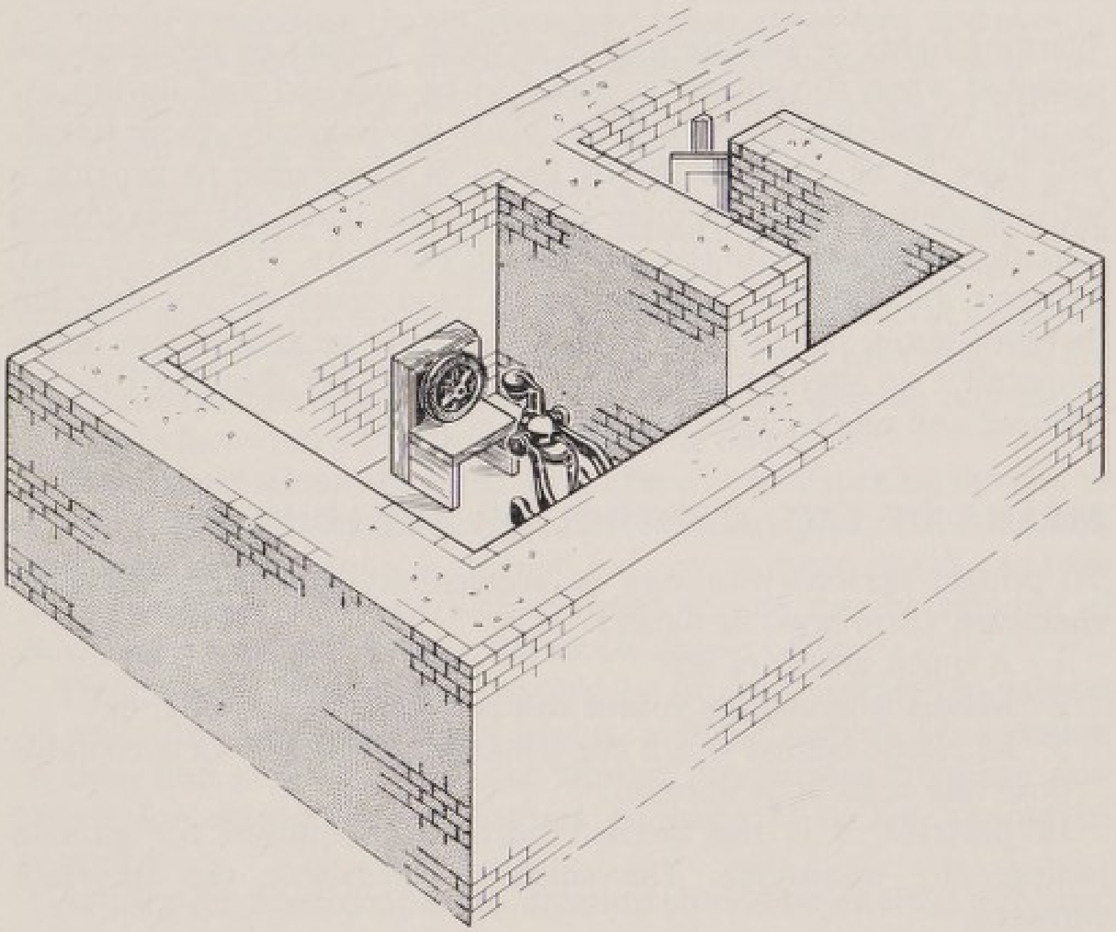

Fig. 3 Labyrinth entrance for a walled enclosure used for gamma radiography

All persons other than authorised persons should be excluded from the walled enclosure during exposures. The authorised persons themselves should be inside the enclosure when the source is exposed only for the minimum time necessary to open the container at the beginning of the exposure, and close it at the end. This must be done under conditions ensuring adequate protection for themselves.

DOOR INTERLOCKS

Because many gamma radiography containers are operated manually, it is not possible to interlock the movement of the source or the exposure of the beam with the doors to the enclosure. Therefore, the doors should be locked when left unattended. A radiation monitor should be readily available so that any person entering the enclosure can check the dose rate if he is in any doubt whether the source is in the shielded position.

When the container is electrically or pneumatically controlled, it is normally possible to provide door interlocks so that the source:

1 Retracts into the shielded position when the door is opened, and

2 Cannot be exposed while the door remains open.

WARNING SIGNALS

Warning lights or audible signals, or both, should be provided and operated when the source is about to be exposed and during exposure. When the exposure is not made mechanically, these signals will have to be switched on by hand. It is possible to provide a warning signal which operates automatically when the background radiation increases with the exposure of the beam. If these are used, however, they must be maintained in good order so that they can be relied upon. If lights are used there should be at least two lamps in parallel or alternatively one lamp to indicate that the beam is exposed and one to indicate that it is shielded.

MEANS OF EXIT, CONTROL OR SHIELDING

To protect persons who may be accidentally shut inside a walled enclosure, there must be either:

1 A quick means of exit

2 Means whereby the source can be shielded promptly, or

3 Shielding behind which the person can stand in an acceptable dose rate until he is released.

In practice, 3 is the method normally employed for gamma radiography enclosures. The shield is invariably the labyrinth entrance.

MEANS OF COMMUNICATION

As in the case of X-radiography enclosures, a means of communication must be provided from the inside to outside. The telephone or operating point should be in the labyrinth entrance.

SUITABLE ENCLOSURE OR SUITABLY MARKED AREA

When it is not reasonably practicable to carry out the radiography inside a walled enclosure, the radiography should be isolated from other work and all except authorised persons excluded from a suitable enclosure or suitably marked area around the work. The considerations governing the size and method of marking the restricted area are given on pages 25 and 26.

X-RAY FLUOROSCOPY

Short of working at screen illumination levels where eye-strain may develop, all fluoroscopic examinations should be done with the lowest practicable X-ray beam intensities and smallest tube apertures. Wherever practicable, the fluorescent screen should be viewed indirectly by the use of inclined mirrors, closed-circuit television or other means. Direct viewing presents a potential hazard because the beam is directed towards the face of the viewer. Failure, for instance, to replace the lead glass screen may result in the viewer's receiving the unattenuated beam at his face and eyes.

The X-ray apparatus should be completely contained in a protective cabinet or walled enclosure which provides adequate shielding and from which all persons are excluded while the apparatus is energised. The screen itself will need to be adequately shielded by a sufficient thickness of lead glass, the actual amount depending upon the kilovoltage of the X-ray tube and on the tube current. The cabinet should be monitored after installation and at intervals thereafter to check the continuity of the protection provided, particularly around the edges of the screen, to detect whether any radiation leaks have developed through wear and tear in use.

The cabinet should be fitted with effective interlocking devices to ensure that when the fluorescent screen or any part of the cabinet, such as an access door, is opened for any purpose, the X-ray tube is de-energised. Any interlock switches should not be capable of being operated by hand when the access door is open.

The machine control panel should be situated outside the cabinet or enclosure. If the cabinet or enclosure is big enough for a person to enter and to be shut inside it similar precautions to those described for radiography enclosures on page 23 *et seq.* should be provided.

Articles for fluoroscopic examination should be inserted into, and orientated in, the useful beam by methods which preclude the possibility of the operative's hand or forearm or other parts of the body getting into the beam itself or into a radiation area. Such methods will include the use of conveyors, turntables, sliding trays, dial feeds, tongs or other mechanisms which can be operated from outside the enclosed cabinet. It should never be necessary for the operatives to have to wear leaded rubber gloves or aprons.

Where conveyor belts and similar arrangements are used to feed articles for examination into and out of the cabinet, extension tunnels from the cabinet opening should be provided, protected each end across their full width by hanging flexible flaps etc. of lead rubber, split into a number of strips of the order of an inch or so in width, so that the articles passing through lift the minimum possible number of strips each time. Tunnels should be of sufficient length to prevent a worker's arm from being pushed far enough down to reach the useful beam of radiation or enter a high radiation dose rate. If the articles on the conveyor have gaps between them, it may be necessary to provide two or more flexible curtains at such a distance apart that one curtain is always sealing the opening when the other is raised by the articles passing through.

Faulty articles disclosed by the fluoroscopic examination and needing to be identified, should be marked by a device operated from outside the cabinet. Alternatively, by operating a plunger the offending article can be pushed off the conveyor down a chute into a suitable receptacle. Under no circumstances should an industrial fluoroscopy unit be used by workers for observations of the human body.

The viewing position should be situated in a darkened room to facilitate viewing. This room should be well ventilated.

NEUTRON GENERATORS

Neutron generators are used for the activation analysis of samples, as a technique in production control. The samples to be investigated are irradiated by a beam of neutrons which make the appropriate constituents of the sample radioactive. These activities can then be measured by means of suitable counting equipment. A particularly useful application is the estimation of oxygen in steel.

The most commonly used neutron generator consists of a tube along which a beam of deuterons is accelerated to strike a tritium target to produce a beam of 14 MeV neutrons.

Appropriate shielding must be provided against:

1 The neutrons

2 The bremsstrahlung produced by the electrons which drift within the accelerating tube and strike metal parts

3 The delayed radiation induced in the target holder and target backing material

4 The gamma radiation produced by the slowing-down of the fast neutrons.

The most effective method to shield fast neutrons is to surround the target area with an hydrogenous material such as water, paraffin wax or concrete.

If water is used, it is essential to fit in the tanks level gauges which are connected with an audible alarm signal to indicate if the level of water falls below a safe level. They should also be interlocked so as to de-energise the generator automatically. If paraffin wax is used, its potential contribution to a fire should not be neglected and, therefore, the wax should be contained in fire-resisting tanks. The neutron generator should be inside an enclosure providing adequate shielding and the doors of the enclosure should be interlocked in much the same way as in X-radiography enclosures (Figure 3).

Time-delay switches of the type described (page 28) for enclosures in which linear accelerators or betatrons are used should be provided to ensure that the operator inspects the interior of the cell before the generator is energised.

Appropriate warning signals and means of communication similar to those necessary for X-radiography enclosures, should be installed.

The induced activity will depend upon the material irradiated, the flux and the time for which it was irradiated. Dose rates of the order of 300 mrem/h at 10 cm. from a target can occur. Therefore it is essential to monitor the interior of any neutron generator enclosure when entering it. If it is known that an unacceptable dose rate occurs for a few minutes after the generator has been de-energised, a time-delay lock can be fitted on to the door so that it cannot be opened until that period has elapsed.

The radioactivity induced in the irradiated samples will have a short half-life of the order of seconds and they will therefore decay very quickly.

Some tritium is released from the target during irradiation and will be removed by vacuum pumps. The vacuum forepumps should be ventilated to the outside, and care should be exercised in handling any components on which tritium may have been absorbed, particularly if they are coated with grease. Tritium particularly in the form of tritium oxide or tritiated grease will rapidly enter the body through the skin.

Neutrons can also be produced by the interaction of nuclear particles with certain light elements. For example, the alpha particles from radium will cause the production of neutrons from beryllium as will the gamma rays from sodium–24 from deuterium. Americium/beryllium sources have industrial application in neutron moisture meters where the interaction of the neutrons with the water content of, for instance, soil, into which the source is placed, is measured, to give an indication of the quantity of water present. Neutron sources of this type can also be used for activation analysis.

The hazards which may arise in the use of neutron sources are as follows:

1 The neutrons themselves
2 Gamma radiation from the radioisotope used
3 The risk of dispersal of the radioisotope if the source is broken or involved in fire. Many of the radioisotopes used in neutron sources are extremely radio-toxic.

HIGH-INTENSITY IRRADIATION CELLS

High-intensity radiation fields are being used for the sterilisation of hypodermic syringes, surgical dressings, sutures etc. They can be used for the polymerisation of plastics and for the disinfestation of grain and other foodstuffs. Cobalt–60 is the radionuclide usually employed and activities of the order of thousands of curies are necessary. Plants are in use which have been designed to utilise 500,000 curies. High-energy machines are also used.

Because of the exceedingly high radiation dose rates produced by these sources and machines, they must be used only inside walled enclosures providing adequate shielding. The thickness of the walls will probably be of the order of five to six feet of concrete. Under no circumstances should a person be present inside the enclosure when the source is exposed or the machine energised. Therefore, the time delay switch arrangement described previously (see page 28) to ensure that the interior is inspected before being put into use is absolutely essential.

Similar warning signals and means of communication such as those provided for X-radiography enclosures are also required. These plants are highly specialised and expert advice must always be sought in their design.

As with linear accelerators (page 27), the high levels of radiation will result in the production of ozone and nitrous fumes. Because these are toxic, the interior of the irradiation cell should be ventilated.

X-RAY CRYSTALLOGRAPHY

For crystallographic applications, only soft X-radiation generated at around 30 to 60 kV is used and since this is readily absorbed by solids, the thickness of shielding required to attenuate the radiation is not great, being of the order of one or two millimetres lead. However, the soft radiation is utilised as intense narrow beams so that dangerous X-ray burns to fingers or other parts of the body can readily be produced through carelessness or inadvertence in a few seconds' exposure. One man lost several fingers as a result of an exposure of the order of sixty seconds to the beam of an X-ray fluorescent spectrometer.

Probably the most satisfactory method of protection is to enclose the X-ray apparatus completely inside a cabinet or screening providing adequate shielding against the useful beam and scattered radiation. The access doors or panels should be provided with interlocks so that the X-ray tube cannot be energised unless they are closed. They can be made sufficiently large so that when they are open or folded back there is complete and convenient access to the X-ray tube and camera or geiger counter or other components needing adjustment.

The dose rate is dependent upon the operating voltage and current of the tube and, therefore, the lowest practicable voltage and current should be used. Particular care must be taken when 'lining up' the apparatus to prevent the exposure of operators' eyes. This is usually effected with the aid of a small fluorescent screen to indicate the centring of a specimen or the correct passage of the useful beam through a camera-slit system. This can be done even with the apparatus inside a cabinet because the fluorescent screen can be built into the wall of the cabinet. Where, however, this is not practicable, neither the eye nor any other part of the body should be in a direct line with the main beam, which should be stopped by a lead disc or other absorber, preferably fixed permanently to the camera or table of the instrument.

When it is not possible to enclose the apparatus totally in a cabinet, alternative precautions are necessary and they vary according to the two main conditions of use, which are:

1 Where a camera or diffraction apparatus is attached directly to the X-ray tube window and there does not have to be a gap between the two, and

2 Where there has to be a gap between the tube window and the diffraction apparatus, e.g. in the open type of construction usual with counter-diffractometers such as those used for checking quartz crystals.

In both cases, suitable shutters at the X-ray tube windows are necessary. Shutters must move easily in their guides without the risk of sticking in the open position and they should operate in such a way that, in the event of failure of the electrical supply, they fall under gravity into the closed position.

When the camera or other apparatus is attached directly to the window (condition 1) an interlock should be provided so that

1 The shutter cannot open unless the camera and other apparatus is in position and will close when the camera is removed, or

2 The X-ray tube cannot be energised unless the camera is in position and will be de-energised when the camera is removed.

In practice it is not usual for the X-ray tubes of diffraction apparatus to be switched on and off frequently because this can affect the stability of the radiation outputs.

Because a single interlock can be inadvertently operated, it is preferable for two interlocks to be fitted. They must be located very carefully because they must operate only when the camera is in the exact position and no leakage of radiation between the window of the tube and the camera is possible.

Appreciable scattering can occur in the gap between the X-ray tube and the camera etc. and the design of the coupling between the camera and the window should be such as to prevent this happening. This is usually achieved by making the coupling a labyrinth which produces a multiple path for the scattered radiation.

When the apparatus is of the open-type construction (condition 2) protection can be provided either by:

1 Local shielding which covers the gap between the window and the diffraction apparatus, camera, counter etc., or

2 A proximity switch which closes the shutter if the operator's hand or other part of his body approaches too near to the unshielded beams of radiation.

When local shielding is used, it should be mechanically connected to the shutter so that closing the shield opens the shutter and vice versa (Figure 4). It must be adjusted so that the shutter does not open until the shielding is in place; this means that the shutter must open only on the last few millimetres of travel of the shield.

Proximity switches may be of the photo-electric type with light beams passing across the apparatus in such positions that they must be interrupted by the operator's hand before he reaches into an excessive dose rate. An alternative system is that based on the alteration of the capacity of a tuned circuit. A circular metal plate fitted under the goniometer table, acting as a capacity guard ring, can be connected to a tuned circuit which controls the shutter solenoid. When the operator places his hand close to the apparatus, the capacity is altered causing the shutter to close. The proximity switch can be useful in applications where large numbers of articles are being tested at frequent intervals because no time has to be spent in opening and closing a shield or access panel. However, great care must be taken in the design of the control circuit to ensure that it fails to safety.

In all open-type construction apparatus, a beam-trap shield is essential to attenuate the primary beam when no article is in position. The beam trap can be connected to the X-ray tube-housing framework so that it remains in the appropriate position whichever way the X-ray tube is moved.

It is absolutely essential that clear and unambiguous warning signals be provided. They are necessary not only for the safety of the operator but for other persons in the vicinity of the apparatus and perhaps most important of all for persons maintaining or adjusting the apparatus, who may have removed parts of the shielding or even disconnected or by-passed the interlock circuit. The warning will normally be a light and can take the form of an illuminated panel with suitable wording. This panel should be placed as close to the apparatus as possible and should be visible from any side of the apparatus to which a person has access. Where the X-ray tube is housed inside a console or cabinet, e.g. a fluorescence spectrometer, additional warning lights should be fitted inside the console or cabinet so that it may be seen by any person bending down close to the X-ray tube, to whom an outside light may not be visible. The signal should be used only to indicate that the tube is actually energised and not that the mains supply is on or that the filament is on. If it is necessary to indicate these conditions, additional and clearly distinguishable lights should be used.

It is better to provide two lamps in parallel at each warning point to reduce the risk of a person's assuming a condition of safety when all that has happened is that a light bulb has failed.

Warning light assemblies can be used in which the current passing through the filament of the lamp is monitored in such a way that unless the lamp is illuminated and passing approximately the correct current, the X-ray tube cannot be energised.

Where more than one window is provided for the X-ray tube, and this number may vary to a maximum of four, an additional warning signal is desirable to indicate the shutter or shutters which are open or closed.

In order to reduce additional protective requirements, the X-ray tubes used should be mounted in protective housings for which the leakage radiation at any accessible point at a distance of 5 cm. from the surface does not exceed 25 mrem/h.

THICKNESS GAUGES

Installed or fixed

Thickness gauges operate by either (a) the transmission or (b) the backscattering of radiation.

In a transmission gauge, the material to be measured is introduced between the source of ionising radiation and an appropriate detector.

In the backscatter type the source and detector are both mounted on the same side of the material to be measured. The detector is shielded from the primary beam of radiation but receives radiation scattered back from the surface upon which the primary beam is incident.

The majority of thickness gauges utilise beta sources such as strontium–90, thallium–204, ruthenium–106, cerium–144, promethium–147 and krypton–85. The active source material, of an activity of the order of 5–20 mCi, consists of a radioactive foil or plaque. The source is usually mounted in a holder which provides shielding at the back and sides. The useful beam emerges through a 'window' in the holder. To protect the source, the window can be covered with metallic foil or other suitable thin material and then further protected from mechanical damage by a metal grille. The active surface itself, therefore, cannot be touched and providing there is no leakage of radioactive material from the source the only risk to be considered is that from direct and scattered external gamma, beta and bremsstrahlung radiation.

The gap between the source and the object being measured and the source and the detector should be kept as small as possible to limit the amount of scattered radiation and to reduce the possibility of a person inserting his hand into the useful beam. If, with the minimum practicable gap, adequate shielding has not been achieved, then the provision of additional shielding in the form of flange plates of suitable width, fitted above and below the gap, may achieve this or if not, will at least reduce the radiation dose rate at the point of access. These flanges can act as a guide for workers feeding materials being processed through the gauge gap when starting up the machines. Examples of suitable shield thicknesses would be 3 mm. of Perspex for thallium–204, 9 mm. for strontium–90 and 15 mm. for ruthenium –106; or 0·5 mm. of metal for thallium–204, 1 mm. for strontium–90 and 2 mm. for ruthenium–106.

Some form of shutter must be provided to cover the source and attenuate thereby the useful beam of radiation when the gauge is not in use. Where practicable, the shutter should provide the same degree of shielding as that afforded by the rest of the gauge housing. It is preferable for the shutter to be operated mechanically, e.g. electrically or pneumatically, so that it closes automatically whenever there is no material being measured. The presence of the material can be detected by photo-electric or similar devices. Shutter-control circuits should be designed so that the shutter does not open automatically whenever anything is placed

1 In front of the source
2 In the light beam associated with the photo cell, or
3 In a position to operate any other sensing device which may be employed.

The control to open the shutter should have to be operated manually and should function only when there is material present in the gap. This ensures that the opening of the shutter occurs only after a deliberate action on the part of some person and not accidentally. The shutter should always close whenever there is a power supply failure and it should not be capable of being opened automatically until the power supply has been restored.

Where a shutter cannot be fitted, a cover should be provided which can be placed over the window to provide the necessary shielding. This cover should be capable of being held while it is being fixed or removed in such a way that the operator's hands are not exposed to an excessively high radiation dose rate.

In the absence of a shutter, the equivalent protection can be provided by rotating the source within the housing. In these cases, the source is attached to a back-plate providing the appropriate amount of shielding.

It is clearly advisable, if the choice is open, to install thickness gauges so that the useful beam is directed downwards to the floor, or inwards into the machines rather than the opposite. However, this is not always appropriate; for instance the gauge may have to be mounted above an access gangway between two sections of a machine and, in these circumstances, it would be preferable for the beam to be directed vertically upwards. It is desirable for warning signals to be provided which indicate clearly whether

1 The shutter is closed or open, or
2 The source is in the shielded or unshielded position.

The warning signal must be readily visible to a person approaching the gauge or working at the gauge.

Operatives must take particular care if it is necessary to do maintenance or other adjustment work on the machine in the immediate vicinity of the source when the shutter is open.

Some thickness gauges utilising gamma radiation or bremsstrahlung are available. The gamma sources are usually cobalt–60 and caesium–137 and the bremsstrahlung is derived from a beta source such as strontium–90 or tritium. There are also thickness gauges utilising X-ray tubes. These have an important safety advantage over gauges containing radionuclides because they can be switched off when not in use. Therefore, during installation and maintenance, the risk of accidental exposure is reduced. Automatic warning signals should be provided to indicate that the X-ray tube is about to be energised and that it is energised. When a shutter is fitted, additional signals are necessary to indicate whether it is open or closed. Illuminated panels bearing appropriate wording provide useful warning signals. At least two lamps connected in parallel should be used in each panel (Figure 4).

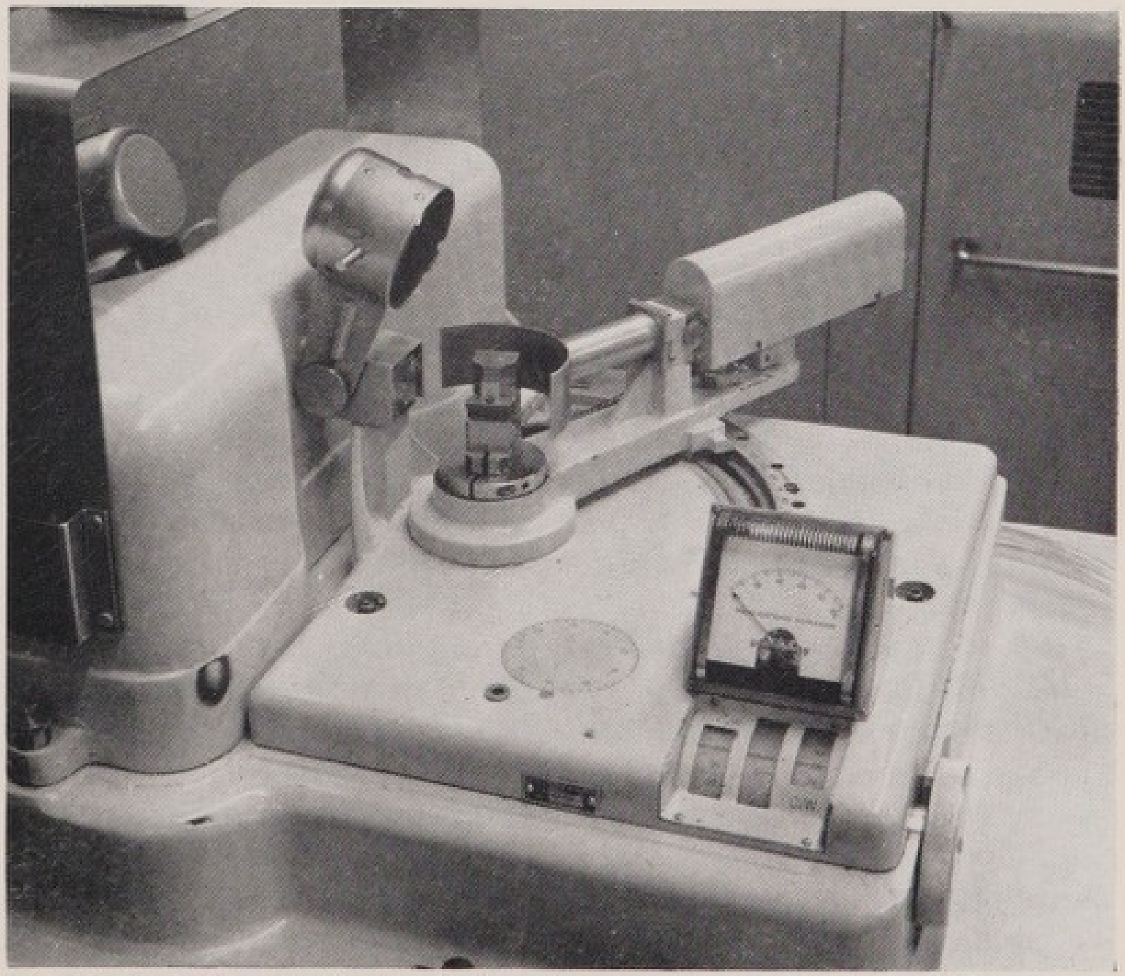

Fig. 4 Provision of effective devices to prevent access to the useful beam of an X-ray crystallography set

The fitting or removal of gauge sources on the plant is normally carried out by the makers but, if not, it should be done only by, or under the immediate supervision of, a qualified person.

Portable

Most portable thickness gauges are of the backscatter type. Because the gauge is held in the hand it is essential that the dose rate at the part which is held is such that the person holding it does not exceed the maximum permissible dose. It is therefore preferable for the gauge to be provided with a handle so that the operator does not have to hold the part housing the source.

An automatic shutter should be incorporated which opens to expose the useful beam only when the gauge is in contact with the surface being measured. The shutter should close immediately the gauge is lifted off the surface. If no built-in shutter is fitted, a shielding end cap or cover should be provided.

Additional shielding can be built into the carrying case, and portable thickness gauges should always be kept in their carrying cases when not in actual use.

LEVEL GAUGES AND PACKAGE MONITORS

Installed or fixed

Level gauges and package monitors operate on broadly the same principles as thickness gauges and in design are very similar. On large storage vessels the radioactive source, which will be in a shielded housing, can be fixed securely to one side of the hopper and the detector placed on the other side. The level of radiation required to operate the detector will usually be less than 1 mrem/h and probably no additional precaution will be required on the detector side. Adequate shielding should be provided by the container where possible but, if not, additional shielding or covers can be built around the container to reduce the dose rate. As with thickness gauges, the container must be fitted with a shutter and there should be a signal to indicate whether it is open or closed.

It is essential to ensure that persons cannot enter or work inside a vessel to which such a gauge is attached when the shutter is open. If necessary, the shutter can be interlocked with the access panel to the vessel. In some cases the source may have to be removed and placed in a shielded container before anyone enters the vessel.

Portable

Portable level gauges are used for the measurement of liquids in cylinders such as liquid carbon dioxide fire extinguishers. The source is usually in one arm of a U-shaped holder and the detector is in the other arm. When in use, it is not possible to shield completely the radioactive source and the person using the gauge therefore must take care not to hold the source unnecessarily close to his body. A carrying case is provided for these gauges into which the appropriate shielding can be built, and the gauge should be kept in this case whenever it is not in use.

DENSITY GAUGES

These are used to check continuously the density of liquid materials flowing through pipes. The source is fixed to one side of the pipe and the detector to the other. As with thickness gauges and level gauges, the container housing the source should provide, if possible, adequate shielding but, if not, the source housing can be fitted with additional shielding or a cover providing distance protection. A shutter and warning signal system must also be provided.

NEUTRON GAUGES

Neutron sources are used in portable gauges for moisture content and soil density measurements. Sufficient shielding must be provided by the housing of the gauge and carrying cases to enable the gauge to be carried and used without the operator exceeding his maximum permissible dose. The gauge should always be kept in the carrying case when it is not in actual use. Portable gauges should be designed so that they can be manipulated with the operator's hand as far away from the source as possible and in the position of the lowest radiation dose rate. Gauges for soil density measurements may become very dirty and coated with mud, and appropriate cleaning devices such as long-handled brushes or scrapers should be provided, so that the user does not have to wipe the surface of the gauge with a rag in his hand.

STATIC ELIMINATORS

In design, these are very similar to thickness gauges but usually utilise alpha-emitting sources, such as americium–241, although tritium sources have been developed for this purpose.

It is usually not possible to fit a solid protective screen in front of the source because this might completely attenuate the radiation. Nevertheless, some protection against damage to the source is necessary and it is usual to fit a wire mesh grille in front of it. A shutter should be fitted to attenuate the useful beam when the eliminator is not in use. If possible, the shutter should be interlocked so that the opening of parts of the machine near the eliminator or parts of any cabinet enclosing it for the purpose of local maintenance and adjustment automatically closes the shutter. In the absence of an interlocked shutter, covers should be provided which can be easily and quickly placed in position, similar to those described for thickness gauges.

Static eliminators are often used in the presence of flammable solvents as a means of reducing the risk of a spark from static electricity. If a fire does occur in the vicinity of an eliminator, the eliminator may well become very dirty with sooty deposits. It must be cleaned with extreme care so as not to damage the source and release contamination, and any cleaning should be done as quickly as possible by someone fully qualified for the purpose. Whenever a source has been involved in a fire, it should be tested for leakage to check whether or not any radioactive material has escaped.

Side sheets of Perspex or similar materials or thin sheets of aluminium or steel can be used to reduce the radiation dose rate at working positions and also to prevent access to the source and useful beam.

BREAKAGE AND LEAKAGE OF SEALED SOURCES

A sealed source is one that is so bonded in material or sealed in a container that the radioactive substance in it is not liable to escape to an extent greater than may be approved. The most common types are radiography capsules and radioactive foils. Sealed sources are specially designed to prevent leakage and great care is taken by the manufacturers to this end. In normal use it is necessary to take precautions only against external radiation.

There is, unfortunately, a possibility that a sealed source may suffer mechanical damage or corrosion, resulting in the leakage of radioactive material, causing contamination. Sources should therefore be installed and used in such a way as to minimise this risk.

Sealed sources should be tested for leakage at least once every twenty-six months. The test, which is approved by the Chief Inspector, must be carried out by a qualified person (Bibliography No. 44).

If a sealed source is broken or damaged, or if it is found to be leaking beyond the approved extent, the following precautions should be taken:

1 The sealed source should be placed in a leak-proof container at once and not brought into use again until the necessary repairs have been effected

2 The area around the source should be roped off

3 The competent person should be notified and if necessary assistance sought from persons with suitable experience who are

properly equipped for the purpose of surveying and decontaminating any affected areas (e.g. Radiological Protection Service)

4 All practicable steps should be taken to prevent the dispersal of the radioactive material to the environment, for example, by covering with a damp cloth or by damping down the affected area with water, taking care to avoid any dispersal into drains

5 A careful survey should be carried out to check that all surfaces which may have become contaminated are properly cleansed.

APPARATUS PRODUCING IONISING RADIATIONS ADVENTITIOUSLY

Apparatus in which electrons are accelerated and strike a target may often emit X-radiation. They are not designed to produce a useful beam of radiation, the electron stream is there just to produce a conducting current. The quantity of radiation emitted is determined by such factors as the operating voltage, the electron current and the thickness and nature of the wall material of the device. Examples of such apparatus are cathode-ray tubes, electronic valves—particularly high-voltage rectifying valves, e.g. those used in colour television equipment—and klystrons and magnetrons used in radar equipment.

The Ionising Radiations (Sealed Sources) Regulations apply to such apparatus if the operating voltage exceeds 5 kV except in the case of television sets when the operating voltage must exceed 20 kV.

The operating voltages of this type of apparatus are comparatively low and therefore the energy of the emitted X-radiation is such that thin metal covers over the areas concerned can provide the necessary shielding. Most apparatus of this type when in use is installed inside a cabinet which provides the necessary shielding and it is, therefore, only during manufacture, maintenance and repair that a hazard may exist. Where practicable, therefore, the components should be tested inside cabinets or enclosures fitted with interlocked access doors or panels. Often the amount of shielding necessary can be provided by a sheet of lead glass and this will ensure visibility. When components have to be provided with shielding, the shielding should be labelled to the effect that it must be kept in place when the component is energised. Because such apparatus may be associated with RF generators, the method of measuring the dose rate must be chosen with care because the RF can interfere with the monitor, which may then give a false reading. Fortunately monitors are available which are comparatively immune to RF interference. Although more time consuming, photographic film of the type used in personal dosemeters can be used for this purpose.

This type of apparatus employs high voltages and the risk of electrical shock may well be the greatest hazard.

SPECIAL REQUIREMENTS OF THE IONISING RADIATIONS (UNSEALED RADIOACTIVE SUBSTANCES) REGULATIONS 1968

GENERAL

Unsealed radioactive substances present both external and internal radiation hazards. The general aims of these regulations are:

1 The restriction of external exposure to ionising radiations using the principles of shielding, distance and time outlined earlier in this booklet

2 The prevention of inhalation, ingestion or absorption of radioactive substances using the principles of containment and cleanliness and in particular by

   a the avoidance of direct contact between the worker and the radioactive substance

   b the maintenance of surface and personal contamination levels below the specified maxima (see Appendix B) and

   c the avoidance of such concentrations of airborne or gaseous radioactive substances which might give rise to the intake, by a person employed, of a significant amount of radioactive substances.

The parts of the premises in which unsealed radioactive sources are used may fall into one of several categories defined in the Regulations and are listed below:

1 Active area
2 Total enclosure
3 Radiation area
4 Tracer area
5 Decontamination area

ACTIVE AREA

Probably the most important concept is that of the 'active area'. This is defined as a 'part of a factory, other than a tracer area or the inside of a total enclosure or of a fume cupboard, in which any operation involving the manipulation or use of any radioactive substance is carried on as a result of which there is, or under normal operating conditions is liable to be,

1 contamination to a level in excess of the levels specified for category D in Schedule 2 to these Regulations; or,

2 airborne or gaseous radioactive substances in the atmosphere to such an extent that persons employed in the area are likely to inhale, ingest or absorb a significant amount.'

An active area is so designated because the work carried on within it is such that it cannot be said that a person employed in it on work specified in Reg 18 (1) is most unlikely to receive less than three-tenths of the appropriate maximum permissible doses recommended by ICRP. Under these circumstances it is necessary

1 That persons doing specified work in an active area should be classified workers and

2 That more stringent precautions should be applied in order to minimise the risk.

From the definition of active area, it follows that the level of surface contamination is used as a major control parameter for the purposes of the Regulations.

Surface contamination cannot be quantitatively related to radiation dose because the dose received depends greatly upon the circumstances associated with the contamination. Nevertheless, it has been shown that in the majority of cases where the surface contamination is kept below the levels in the Schedule it will not cause the recommended ICRP maximum permissible doses and body burdens to be exceeded.

In deciding whether an area is liable to be contaminated in excess of the specified levels, judgment will be required especially in relation to the probability of such occurrences. For example, it will normally be unnecessary to grade a corridor as an active area simply because of a probability, which is judged remote, that an unsealed radioactive substance carried along it in a container might be dropped and the contents spilt on the floor. On the other hand the probability is higher that a person working at a bench may knock over some unsealed radioactive substances awaiting use. This circumstance would require grading of the area as active. Again, there is a similar probability that withdrawal of such material from a total enclosure may lead to contamination of bench, floor or the operator himself and this again could cause the area to be graded as active.

There will, of course, be some instances where surface contamination measurements will not be a sufficient control, the most obvious being those workplaces where gaseous or volatile radionuclides such as tritium, krypton–85 or iodine–131 are present. In such cases a decision as to whether the area is an active area or not will depend on whether a person is likely to inhale, ingest or absorb a significant amount of radioactive material.

In determining whether on any particular occasion or at any particular time the amount is significant, one must take into account, amongst other things,

a the nature of the radioactive substance present

b the concentration of the radioactive substance in the air, and

c the time for which it is present.

It may also be necessary to consider the time a person is likely to spend in the area. Any decision must involve a consideration of the maximum permissible doses in the Schedule and the current ICRP recommendations as to maximum permissible body burdens and maximum permissible concentrations in air. If the dose received as a result of the inhalation, ingestion or absorption of a radioactive substance is most unlikely to exceed three-tenths of the appropriate maximum permissible dose recommended by ICRP then the concentration of the radioactive substance may be considered insignificant. Conversely, if it cannot be said that the dose received by the inhalation, ingestion or absorption of a radioactive substance is most unlikely to exceed three-tenths of the appropriate maximum permissible dose, then there may be a significant intake of radioactive substance by persons employed, and the area will be deemed to be an active area.

It is difficult to put numerical values to the word 'significant'. but the extremes can be stated. For instance it is reasonable to assume that a person may take in a significant amount of radioactive material if he works for most of the time where the air concentration exceeds the maximum permissible recommended by ICRP for a 40-hour working week. On the other hand, a person working in an area where the air concentration is always less than one-tenth of the maximum permissible is most unlikely to take in a significant amount. It is the area between these two limits where judgment is necessary.

DECONTAMINATION AREA

It should be noted that an active area is not created necessarily just because a contaminated article is present. If the articles are being decontaminated but neither the contaminated articles themselves nor work on the contaminated articles causes the levels of contamination of the surroundings to exceed the maximum permissible levels of contamination specified for category D in Schedule 2 of the Regulations, then the area is a decontamination area, not an 'active area'. A typical example might be an aircraft engine contaminated with radioactive fall-out which is so fixed to the surface that it does not shake off during transport through the factory and can be removed in such a way that the surrounding area does not become contaminated. Therefore the presence of an article contaminated above the level in category D will not automatically make the place in which it is present an active area.

However, if an area used to decontaminate highly radioactive articles is liable to be contaminated above the level specified for category D in Schedule 2 of the Regulations, then this will be an active area. It is important to note that a decontamination area is not defined solely by the function carried on there but by the function plus the liability of the surroundings to be contaminated above the specified level.

TRACER AREA

In many factories unsealed radioactive substances are manipulated or used for the purpose of investigating working methods or investigating the operating of machines, plant, apparatus or processes or for the purposes of design or of production control. This work is called tracer work and tracer area is defined in the Regulations as 'a part of a factory in which the only work being done involving any unsealed radioactive substance is tracer work or in which there is as a result of tracer work:

1 contamination to a level in excess of the levels specified for category D in Schedule 2 to these Regulations; or

2 airborne or gaseous radioactive substance in the atmosphere to such an extent that the persons employed in the area are likely to inhale, ingest or absorb a significant amount.'

It can be seen from the definition that if tracer work is actually in progress the area automatically becomes a tracer area.

If tracer work has been concluded but a risk, as specified in paragraphs (a) and (b) of the definition, remains, then the area will still be designated as a tracer area until the risk has been removed.

In effect the designation of an area as a tracer area as distinct from an active area relaxes some of the precautions required for an active area due to the special nature of tracer work. The relaxations include:

1 Particulars identifying tracer areas are not required to be recorded

2 A worker who works only in tracer areas for not more than 14 days in any year, and who would not be a classified worker for other reasons, need not be classified

3 Boundaries of tracer areas need be marked only with suitable warning signs. Barriers are not required.

4 Tracer work is not required to be carried on in total enclosures or fume cupboards

5 The construction and furniture of tracer areas are not required to be specially designed

6 Special washing facilities are not required.

MONITORING

Surface contamination

1 INANIMATE SURFACES

The two main techniques used for surface contamination monitoring are:

a to scan the surface with a probe; and

b to wipe the surface with an absorbent material such as filter paper and measure the activity on the paper.

Whichever technique is used, it must be capable of measuring down to $10^{-5}\mu$Ci/sq.cm. alpha activity and $10^{-4}\mu$Ci/sq.cm. beta activity, which are the lowest levels specified in Schedule 2. Measurements made by probe will not indicate directly whether the contamination is fixed, although this can be determined if after the first measurement the surface is cleaned and then monitored again. If the wipe technique is used it should be assumed that only 10% of the contamination present has been transferred to the paper unless the actual amount transferred can be or has been determined.

Where the nuclide being measured is one of a radioactive chain, the number of microcuries for the purposes of the Schedule to the Regulations is the total activity measured, not the activity of any particular nuclide in the chain.

It is of considerable practical advantage in monitoring to allow averaging over an area rather than to attempt to measure the contamination on indivudual square centimetres. In the case of floors, ceilings or walls, the area over which measurements are averaged should not exceed 1,000 sq. cm. and for all other surfaces the area should not exceed 300 sq. cm. In practice this means that probes with areas no greater than these two figures should be used.

Where the only radioactive substance present is a luminising compound an ultra-violet lamp may be used instead of a monitor for detecting contamination. The lamp should be used under appropriate conditions of darkness. Because the use of a UV lamp alone will not indicate quantitatively the level of surface contamination it must be assumed that any luminosity detected will indicate an unacceptable level of contamination unless measurements made with a monitor prove otherwise.

2 SKIN MEASUREMENTS

It is usual for skin measurements to be made either with hand-held probes or by placing the hands into a fixed monitor. For the parts of the body other than the hands the contamination may be averaged over an area not exceeding 100 sq.cm. and in the case of the hands over the whole area of the hand.

Where the radioactive substance is a luminising compound, ultra-violet lamps can be used instead of monitors. It is desirable in luminising workrooms to have an ultra-violet lamp in the vicinity of the washing facilities so that luminisers can check their hands and protective clothing easily and quickly.

Air Contamination

Routine air monitoring will be needed in very few industrial establishments. It should be necessary only in the following circumstances:

- a when gaseous or volatile materials are handled in quantity
- b in plutonium production and processing
- c in the handling of any radioactive material under conditions which cause frequent and heavy contamination of workplaces.

Monitors for particulates usually take the form of a suction pump which pulls air through an appropriate filter. The activity on the filter is then assessed and from a knowledge of the volume of air pulled through, the concentration of radioactive substance in the air can be determined. Monitors for gaseous material usually operate on the principle of measuring the activity in a given volume of air in the chamber of the instrument.

In deciding whether the amount of contamination in the air is likely to result in the inhalation, ingestion or absorption of a significant amount of radioactive substance, considerations similar to those indicated in the definition of active areas should be taken into account (see page 46).

Experience has shown that it can be impracticable to interpret short-term air sampling results in terms of the probable intake of individual workers. Therefore, when air sampling is necessary great care must be taken in deciding

- a the period over which samples are taken, and
- b the positions in which the samples are taken.

If air monitoring is necessary, expert advice should be sought.

Personal air samplers are available which can be worn by individuals and which should give a more accurate picture of the concentration in the workers' breathing zone.

Body burdens

If adequate precautions are taken workers are unlikely to take into their bodies such amounts of radioactive substances as to require personal monitoring for internal contamination. This has been found to be true in the majority of industrial installations. Nevertheless, radioactive material can be inhaled, ingested or absorbed through cuts or breaks in the skin and even through the unbroken skin as in the case of tritium. There is a need, at times, therefore, for measuring internally deposited radioactive material, and this is done in one of two ways, namely:

1 to measure the external radiation emitted from the body, or

2 to measure the radioactive content of the breath, urine or faeces.

Of these methods, the most widely used in industry is urine monitoring. This has been found to be an effective way of determining whether a luminiser working with tritium-activated compound has taken tritium into the body. Radon-in-breath measurements have been used to determine the quantity of radium deposited in luminisers working with radium-activated compound.

Accurate measurements of external radiation emitted from the body have usually to be carried out in a whole-body counter in a low background area, and specially shielded chambers for the purpose are available in a few centres in the UK. In general, these are not mobile and persons are examined in them only when it is considered essential, e.g. after an incident involving leakage of radioactive material.

Portable monitors are, however, becoming available and it may be practical to carry out more body burden measurements *in situ* in the future.

Body burden measurements are necessary only when it is considered that there has been a significant intake. As a guide it is suggested that a measurement of the body burden is necessary where the intake of radioactive material irrespective of route is sufficient or likely to be sufficient to cause a dose to be delivered which is equal to or greater than three-tenths of the maximum permissible annual dose as given in the Schedule to the Regulations (Appendix A).

In practice it is difficult to predict whether conditions in any workplace are such as to give rise to potential intakes of this magnitude, even if the data provided by air sampling is available. Thus there is a tendency to set the investigation level much lower (say at that level where doses of the order of one-twentieth of the maximum permissible annual dose may be delivered) in order to be sure that all workpeople who may have a significant intake are examined. Nevertheless the occasions where body burden measurements will be necessary in factories are expected to be few and will probably be confined mainly to persons who are involved in incidents where high levels of air or surface contamination have been experienced.

CONTAINMENT

The most positive method of containing unsealed radioactive substances is to manipulate them only within a total enclosure such as a glove box (Figure 5). This is a cabinet fitted with openings to which are permanently attached gauntlet rubber or plastic gloves. The operator puts his hands in the gloves which remain connected to the box. There is no contact between the interior of the box and the air of the workroom. In addition, the gloves which may be con-

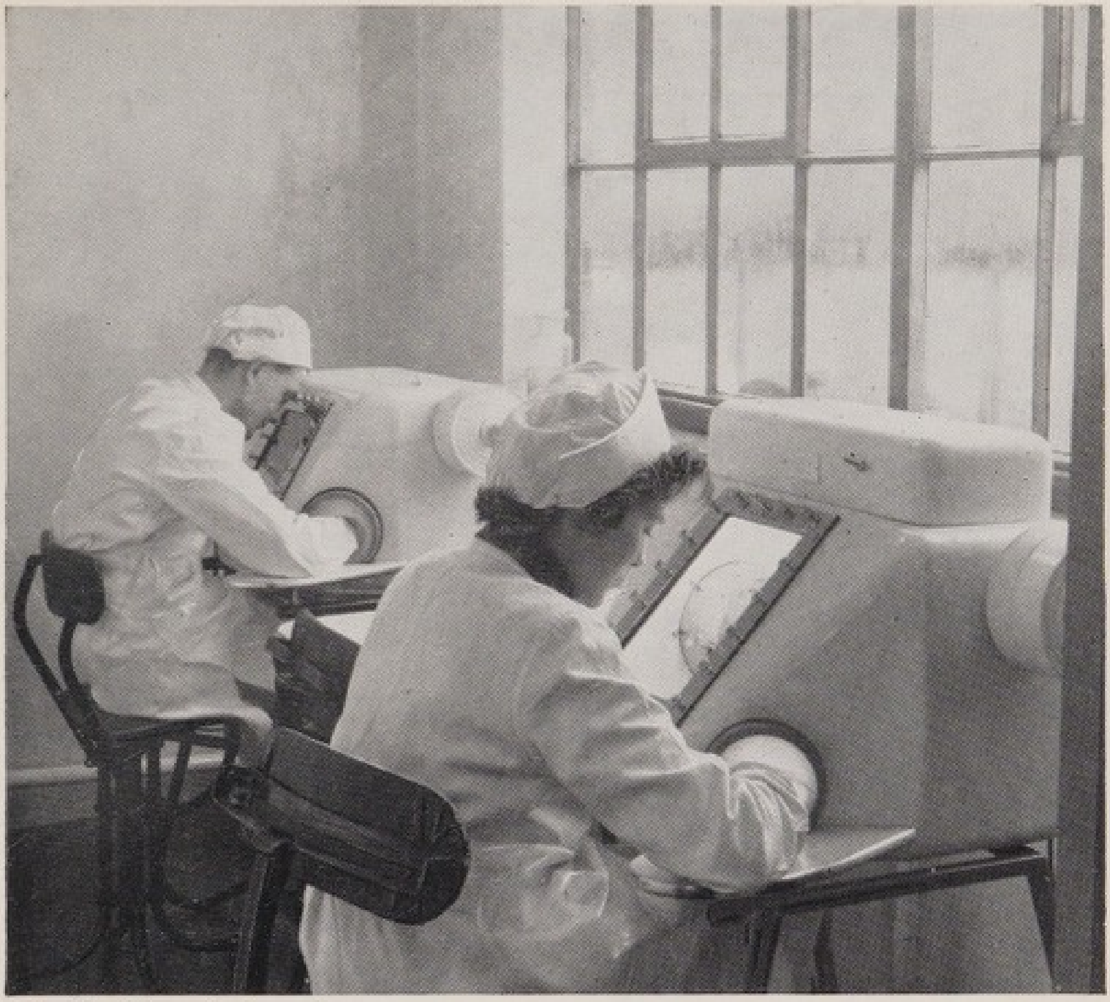

Fig. 5 Use of glove box

taminated are not disconnected when the operator removes his hands. Gloves should be examined regularly to check that they are in good condition. To avoid punctures operators should not wear watches and rings. Articles are inserted and removed from a glove box either through a transfer box (Figure 6), or through plastic bags via an opening in a side or the base of the box (Figure 7). Gloves and plastic bags can be changed by using the double ring technique, illustrated in Figure 8. The doors of the transfer box can be mechanically interlocked so that only one door can be open at any one time.

A negative pressure of about 1 in. water gauge should be maintained inside the box so that any slight leaks which might occur will be inwards. It is usual to fit a suitable filter in the exhaust ventilation pipe and this pipe should discharge to atmosphere in a position such that no radioactive material enters the air of any occupied room.

Good visibility of the interior is necessary and where the external radiation dose rate permits, transparent plastic panels may be used for this purpose. Lamps should be fitted outside the box so that they

Fig. 6 Use of a transfer box for inserting and removing articles from a glove box

do not become contaminated. It is desirable to install as much as possible of the ancillary equipment, such as motors or vacuum pumps, outside the box.

The interior of the glove box should be smooth and easily decontaminated. Some are vitreous enamelled, others painted with hard gloss paint, and many are made from glass fibre with the interior coated with a strippable plastic film of the vinyl acetate or chloride type. Drip trays on which the radioactive material is actually manipulated assist in preventing the spread of contamination, particularly in the event of a spillage. Consideration should be given to ergonomics in the design of the box to make conditions as comfortable as possible for the operator.

When glove boxes are not practicable, fume cupboards or enclosures based on the fume cupboard principle should be used (Figure 9). Openings should be kept as small as practicable and they should be of such a shape and size that the operator does not have to put his head inside while working at the cupboard. Air should be drawn in through the openings at a linear velocity of not

Fig. 7 Use of plastic bag to remove articles from a glove box

less than 50 cm./sec., although it may well have to be considerably more, for example, where tritium gas is used. It is preferable for fume cupboard openings to be closed when the enclosure is not in actual use and it is essential that they are kept closed when the ventilation system is switched off, unless either there are no unsealed sources inside or the levels of contamination are less than the maximum permitted for inactive areas. If the fume cupboard has a variable opening it is useful for the air flow to be regulated automatically so that the air inlet velocity is reasonably constant.

No persons should open up any glove box or other total enclosure or enter any such enclosure or fume cupboard in which the contamination level is liable to be in excess of that permitted for active areas unless a 'permit to work' has been issued in accordance with regulation 52. This is an authorisation which should be signed jointly by the competent person or someone authorised by him and by the supervisor, foreman or other person in charge of the enclosure.

The permit should state:

a the name of the person or persons in respect of whom it is issued

b the enclosure, cupboard and work to which it relates

c any special conditions under which the work is to be carried out

d the period for which it is valid, and

e the date of its issue.

Containment also implies restriction on the places where unsealed sources are used. Where notices are required at access points or at boundaries they should be clear and legible so that persons are readily aware of the category of the area they are entering.

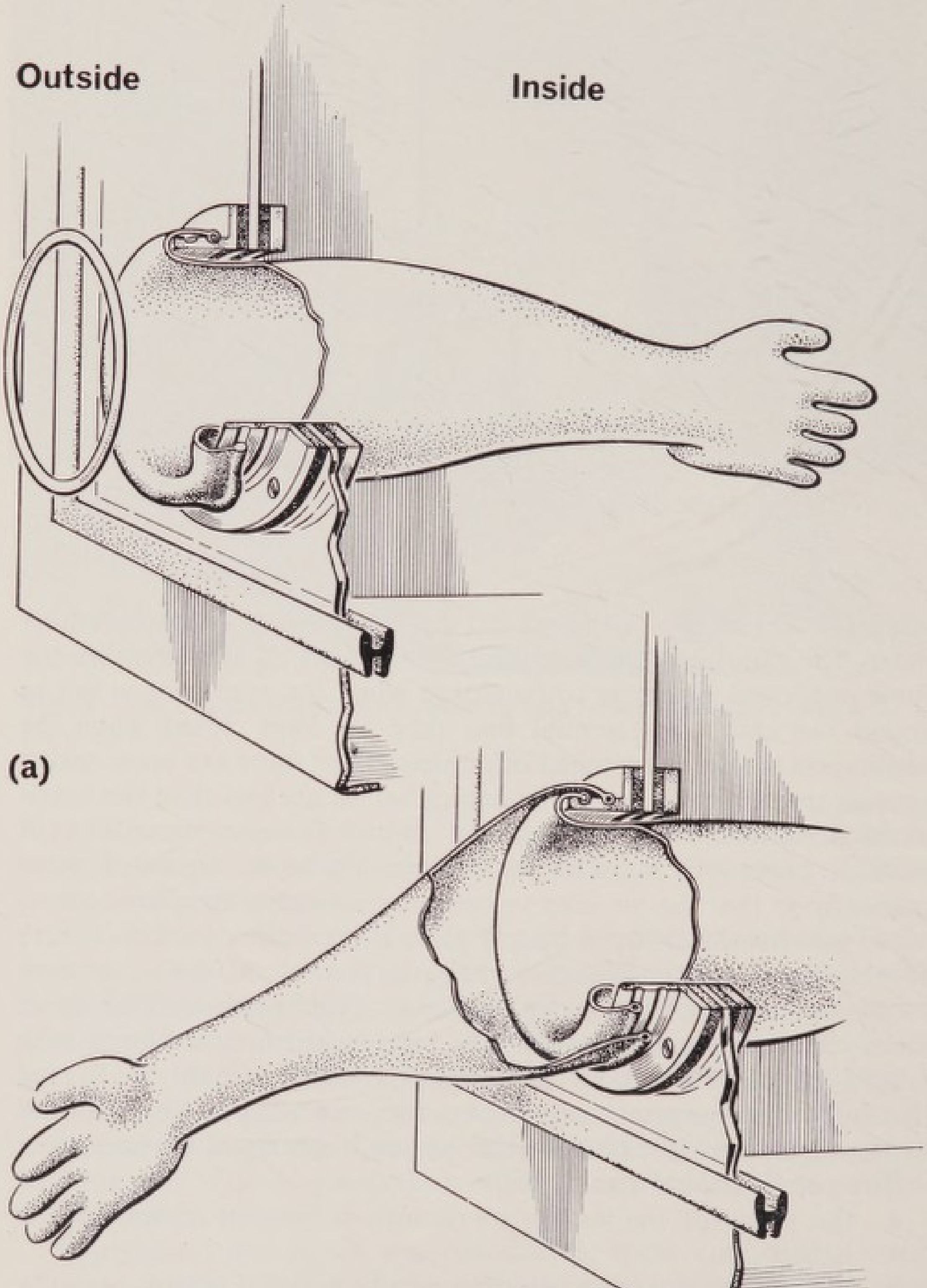

Fig. 8 Changing the gloves of a glove box using the double ring technique

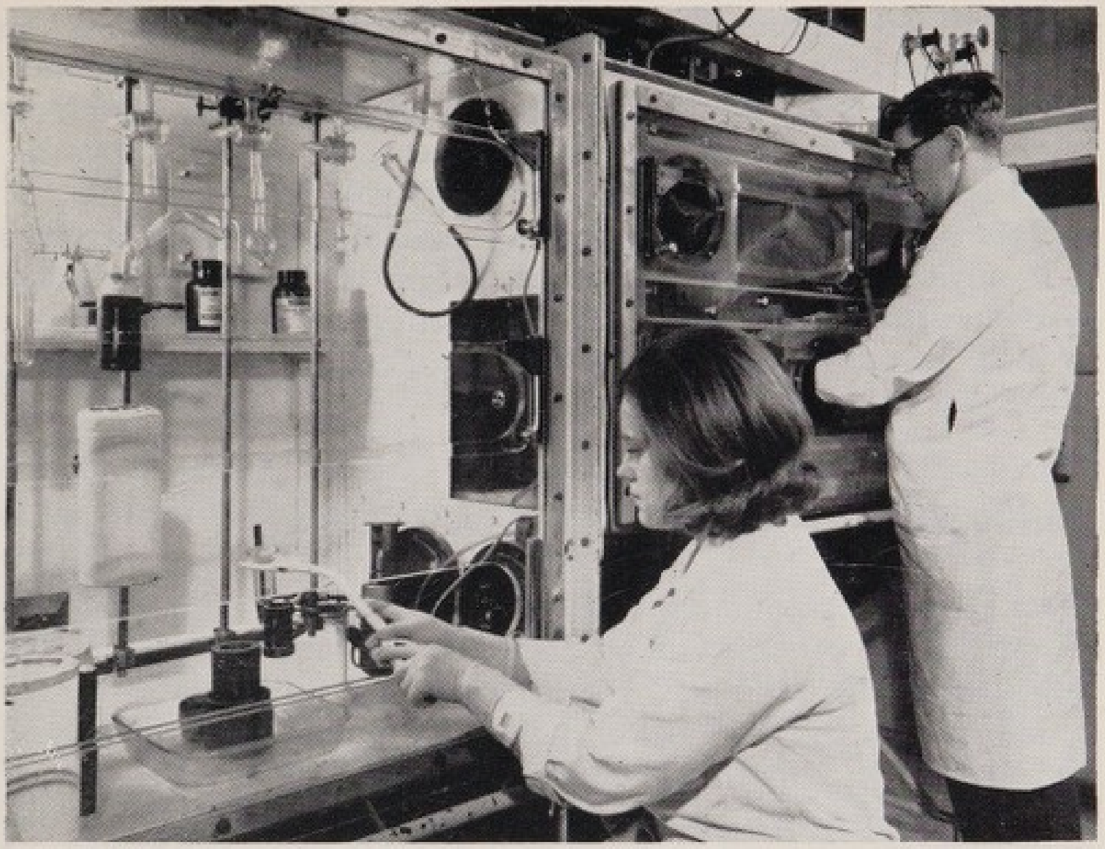

Fig. 9 Enclosures based on the fume cupboard principle to provide containment for radioactive substances

CLEANLINESS

It is preferable for rooms in which unsealed sources are to be used to be designed specially for the purpose. Difficulties have arisen, for instance, in luminising in private houses converted to factories because the interiors have become contaminated and it has not proved possible to decontaminate them without stripping out the fittings, including the fireplace. Rooms can be adapted for the purpose, but much depends upon the type of work to be undertaken and expert advice should be sought.

Surfaces in active areas should have a smooth finish free from cracks and crevices and the joints between walls and the floor and ceiling should be radiused or coved. Surface pipes, electrical conduit and other surface fittings should be either flush fitted and sealed or supported clear of the surface so that they can be decontaminated around and behind them when necessary.

There are many suitable floor surfacings including epoxy resin screeds, asphaltic materials, plastic sheeting or tiles and linoleum. In the majority of industrial establishments plastic floor covering or linoleum is usually sufficient. Any joins should be as tight as possible and any that are exceptionally wide should be filled in with a compatible jointing compound. The floor covering should be given a protective coating, e.g. wax polish, so that in the event of a spillage it may be possible to clear it up simply by removing the wax coating.

Epoxy type floor paints can be used on smooth unbroken surfaces but only when traffic is light and infrequent.

Walls should be painted with a high gloss paint.

Hard plastic surfaces are extremely suitable for benches although it is advisable to protect any bench with a sheet of disposable material such as polyethylene, PVC or kraft paper. It can be secured in place by adhesive tape which can itself be used as a temporary protection for awkward shaped objects.

CLEANING AND WASTE DISPOSAL

Cleaning of workrooms should be done sufficiently frequently to ensure that the contamination is kept below the maximum permitted levels. It should be done by methods which avoid the spread of contamination and dispersal of radioactive material into the general air. In practice this means that wet methods should be used. If vacuum cleaners are used they should not be of the type which discharge the filtered air into the workroom. Articles used for cleaning should not be used for any other purpose and these should be kept in a separate cupboard. When their useful life is over they should be disposed of as active waste.

Radioactive waste and contaminated articles such as cleaning tissues should be placed in receptacles reserved exclusively for this purpose. They should have an inner lining which should be large enough to extend over the top so as to reduce the possibility of the interior of the receptacle being contaminated.

Advice on the disposal of radioactive waste should be sought from the Ministry of Housing and Local Government in England and Wales and from the Scottish Development Department in Scotland. Normally an authorisation from these Authorities will be required for the disposal of waste.

CHANGING ROOMS

Where there is a real risk of the active area, or the shoes or overalls of the operator becoming contaminated, it is advisable for access to the area to be via a 'Change Room'. This is in effect an area set apart between the main access corridor to the active area and the active area itself. In this Change Room any protective clothing should be put on and removed so that if any contamination is brought out on the shoes or clothing it should get no further than the Change Room. A Change Room can vary from an area formed simply by erecting a low barrier a little way inside the access door over which persons must pass into and out of the active area, to a large room containing full washing and sanitary accommodation, clothing accommodation and personal contamination monitoring equipment.

Suitable accommodation should be provided both for the storage of the personal protective equipment and for clothing not worn during working hours. The accommodation should obviously be separate to prevent cross-contamination.

WASHING FACILITIES

Adequate washing facilities must be provided conveniently situated to the areas in which the sources are used. There should be at least one washbasin or 60-cm. length of trough for every five persons employed. Hot and cold or warm water should be laid on and the taps should be capable of being operated without using the hands. Floor operated taps are available and are particularly useful for this purpose (Figure 10). Soap, towels and soft nail brushes should be provided. The washbasins and troughs should be kept clean and monitored regularly, particularly the waste outlet and drain pipe. Employees should be allowed adequate time for washing themselves properly and monitoring where necessary.

Fig. 10 Use of foot-operated taps to reduce contamination

PERSONAL PROTECTION

In order to prevent the ingestion of radioactive material there should be no eating, drinking or smoking in active areas, decontamination areas or tracer areas, nor should snuff taking be allowed. Similarly, women should not be allowed to apply cosmetics in these areas. Disposable paper handkerchiefs should be provided and used in place of normal handkerchiefs. Nothing should ever be put into the mouth. Pipetting should be carried out using manually operated pipette fillers or syringes. No mouth-operated glass blowing should be undertaken.

It is important that cuts and scratches should be avoided and, therefore, as far as practicable, items with sharp points or sharp edges should be avoided. Any cuts, wounds or abrasions received while at work should be treated immediately by an authorised person. Cuts, abrasions and other wounds should always be covered when working in active areas.

PERSONAL PROTECTIVE EQUIPMENT

Personal protective equipment has the dual function of protecting the wearer and preventing the spread of contamination outside the working area. It should be such as to prevent contamination of the skin, hair and personal clothing in excess of the maximum permissible levels.

Protective clothing can range from a laboratory coat to a full change into a boiler suit and rubber boots. When contamination is heavy, as, for example, in special maintenance areas, complete suits with boots, gloves and helmets connected to air supply lines may have to be used.

In active areas a change of shoes is usually desirable and for comfort these should normally be a special issue of ordinary walking shoes although fabric or plastic overshoes can be used for short periods and for visitors.

Gloves should be worn when handling items which are likely to have radioactive material on them. These may be cotton gloves for handling finished uranium or thorium metal but for most other circumstances rubber or plastic gloves are necessary. Plastic or rubber gloves which have been worn for the direct manipulation of radioactive materials, for example in a fume cupboard, should be washed before they are taken off.

BREATHING APPARATUS

Where there is a risk that radioactive substances may be inhaled or ingested breathing apparatus may have to be worn. There should be few instances, other than in the larger atomic energy establishments, where breathing apparatus will be necessary for routine operations. It may have to be used when maintenance work is being carried out or in an emergency resulting in the escape of large quantities of radioactive material.

In atmospheres contaminated with particulates, full-face dust respirators are probably satisfactory if the air concentration does not exceed about 50 times the appropriate maximum permissible concentration in air recommended by ICRP. Where radioactive gases are present in significant quantities, direct air line helmets or self-contained breathing apparatus should be used. Wearers of all types of breathing apparatus must be properly trained in its use and the apparatus must be maintained in efficient working order and examined once a month.

INCIDENTS INVOLVING ESCAPE OF RADIOACTIVE SUBSTANCES

In the event of escape of unsealed radioactive substances, prompt and appropriate action is necessary to minimise the spread of the material. Emergency procedures should be drawn up in anticipation of possible incidents and all those likely to be involved should be fully aware of their duties and trained in their application.

Where it is not practicable to have readily available on the premises all the equipment which might be necessary in the event of an emergency, prior arrangements should be made with a suitable outside specialist organisation which can get to the premises at short notice, e.g. Radiological Protection Service, the UKAEA, CEGB.

The Local Fire Authority should be advised that radioactive sources are kept or used on the premises and should be informed of their usual location.

The action necessary in an emergency will depend upon the particular circumstances, but the type of measures which will be appropriate are listed below:

1 Any incident resulting in the possible loss or release of a significant amount of radioactive material should be reported immediately to the competent person

2 The area should be segregated by closing doors or erecting temporary barriers

3 All workers except those authorised to deal with the situation should be excluded from the area

4 Workers who might have been contaminated should be monitored and, if necessary, decontaminated. If no monitoring instrument is immediately available such persons should be regarded as being contaminated and should wash thoroughly. Any con-

taminated clothing should be removed and placed in a disposable container or paper or plastic sheeting to prevent it contaminating the floor or other items

5 No article should be taken out of the area unless it has been checked for contamination

6 If a gaseous radioactive substance escapes and there is no risk of contamination, *any exhaust fans* should be turned on and the room ventilated. If the source is non-gaseous the fans or air conditioners should be turned off

7 Appropriate surface contamination measurements should be made of the affected parts of the area and if necessary the concentration in the air determined

8 Normal work should not be resumed in the affected area until the competent person has decided that conditions are satisfactory.

LUMINISING AND TRACER WORK

Luminising and tracer work are probably the most common uses of unsealed sources outside atomic energy establishments and ancillary factories. While the general principles of protection specified for unsealed radioactive substances on pages 46 *et seq.* are applicable to this process; some aspects deserve special mention.

LUMINISING

Luminising with radioactive material has been undertaken since before the 1914–18 war. Until comparatively recently the radioactive material used was radium but compounds activated by tritium and promethium–147 are now available. Strontium–90 activated compound was introduced several years ago but the beta dose rate associated with it was too great and its use was discontinued.

The Factories (Luminising) Special Regulations 1947 were introduced to control the hazard from luminising but these were revoked when the Ionising Radiations (Unsealed Radioactive Substances) Regulations were made.

It is quite practicable to use a glove box for luminising (Figure 11). Elbow rests have been provided on the cabinet in the illustration and the sides of the box have been angled to provide a more comfortable working position. Even if luminising is carried out inside a glove box, brushes should not be used to apply the luminous compound.

Tritium and promethium–147 are weak beta emitters (0·018 MeV and 0·22 MeV respectively) and, therefore, the amount of shielding necessary against external radiation is small. More is required to attenuate the gamma radiation from radium luminising compound but if only the small amount necessary for the purpose of the work is kept inside the box a window consisting of a sheet of lead glass should provide adequate shielding.

Machines used for luminising on a continuous scale should be enclosed on the fume cupboard principle.

An important difference between luminous compound and other unsealed radioactive sources is that it can be detected by ultra-violet light. This is a particularly effective method of locating contamination and it is strongly recommended that a UV lamp should be available in every factory in which luminising is undertaken. It is also useful to have a lamp close to the washing facilities so that

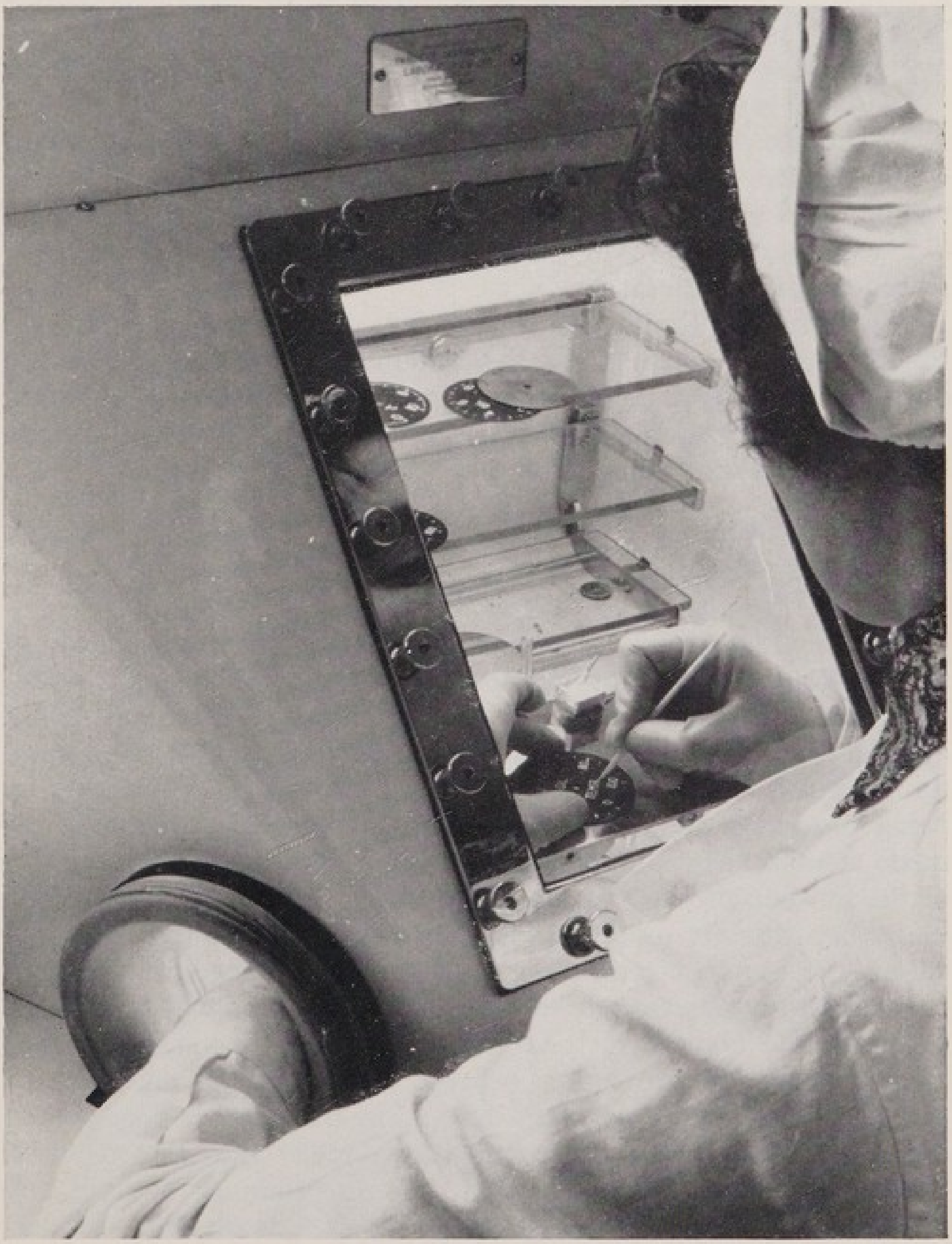

Fig. 11 The use of a glove box for luminising

workers can check their hands and clothing quickly. Monitoring for contamination using a UV lamp should be carried out in a darkened room to obtain the highest sensitivity from the method.

In the UK luminising compound is labelled according to its 'Grade'. For radium activated compound the Grade number is the number of microcuries per gramme of compound; for example, 1 gramme of 5-Grade radium activated compound contains 5 microcuries of radium.

Higher activities per gramme are necessary for promethium–147 and tritium activated compounds for the same degree of luminosity and as a rough guide to determine the activities of these compounds it is necessary to multiply the Grade number by 200 or 5,000 respectively; for example

2 grammes of 5-Grade radium activated compound contain 10 microcuries of radium whereas:

2 grammes of 5-Grade promethium activated compound contain 2 millicuries of promethium

and

2 grammes of 5-Grade tritium activated compound contain 50 millicuries of tritium.

The Ionising Radiations (Unsealed Radioactive Substances) Regulations will not apply if the amount of luminising compound does not exceed 10 microcuries of radium activated compound, 2 millicuries of promethium activated compound, or 50 millicuries of tritium activated compound.

TRACER WORK

There is an increasing use of unsealed radioactive substances in tracer work. This is a technique in which sources are used to investigate working methods or the operation of machines, plant apparatus or processes or for the purposes of design or of production control. Generally a source is introduced into the material being processed at one point in the plant and measurements are made at subsequent points along the production line or in a sample of the finished product to determine the movement of the material or its constituents or the effectiveness of the mixing process. Invariably it is not a continuous process. The radioactive source is brought to the appropriate part of the plant where it is to be used in a suitable container. It is usually necessary to make *ad hoc* arrangements for protection because tracer experiments may be performed only on a single occasion in any one place. Tongs should be used when pouring the concentrated tracer into the material. Unless tracer work is undertaken on more than 14 days in any calendar year the persons employed in the area in which it is undertaken will not be classified workers.

Suitable notices should be displayed at the boundaries of a tracer area to indicate this work is being done and giving clear instructions to the persons in the vicinity that unsealed radioactive substances may be present inside the barrier. The notices should be removed or masked whenever there is no source present and conditions are known to be safe.

The radionuclides used should preferably have half-lives only a little longer than the duration of the experiment. The use of beta emitters is desirable for small samples but gamma emitters will be necessary for measurement in large volumes or where the material being measured is inside enclosed plant. Typical radionuclides are sodium–24 (half-life 15 hrs.), potassium–42 (12·5 hrs.), manganese–56 (2·58 hrs.), lead–212 (10·6 hrs.) and bromine–82 (36 hrs.).

BIBLIOGRAPHY

Relevant legislation

1 The ionising Radiations (Sealed Sources) Regulations 1969
2 The Ionising Radiations (Unsealed Radioactive Substances) Regulations 1968 (SI 1968 No. 780). HMSO London. 2s 9d
3 Radioactive Substances Act 1948. HMSO London, 1s 6d (1s 10d)
4 Radioactive Substances Act 1960. HMSO London. 2s 4d (2s 7d)
5 Nuclear Installation Act 1965. HMSO London. 3s (3s 4d)

Official publications

6 Code of Practice for the protection of persons exposed to Ionising Radiations in Research and Teaching. HMSO 1968. 6s 6d
7 Code of Practice for the protection of persons against Ionising Radiations arising from Medical and Dental use. HMSO 1964. 12s 6d
8 Radioactive Contamination of Aircraft—Code of Practice, HMSO 1966. 4s 6d (5s)
9 Electrical Limit Switches and their Applications—Safety, Health and Welfare New Series Booklet No. 24. HMSO. 2s 6d (2s 10d)

ICRP publications

10 Recommendations of ICRP Report of Committee II on Permissible Dose of Internal Radiation (1959). ICRP Publication 2, Pergamon Press (1960)
11 Recommendations of ICRP (as amended 1959 and revised 1962). ICRP Publication 6, Pergamon Press (1964)
12 Recommendations of ICRP (adopted 1965). Publication 9, Pergamon Press (1966)

IAEA publications

13 Safe Handling of Radioisotopes—Safety Series No. 1. First edition with revised Appendix 1. 1962. HMSO. 9s 0d (10s 0d)
14 Safe Handling of Radioisotopes—Safety Series No. 2. Health Physics Addendum. 1960. HMSO. 9s 0d (9s 6d)
15 Safe Handling of Radioisotopes—Safety Series No. 3. Medical Addendum. 1960. HMSO. 9s 0d (9s 6d)
16 Regulations for the Safe Transport of Radioactive Materials—Safety Series No. 6. 1967 (Revised). HMSO. 17s 8d (18s 4d)
17 Regulations for the Safe Transport of Radioactive Materials. Notes on certain aspects of the Regulations—Safety Series No. 7. 1961. HMSO. 9s 0d (9s 6d)

18 The Use of Film Badges for Personnel Monitoring—Safety Series No. 8. 1962. HMSO. 9s 0d (9s 4d)
19 Basic Safety Standards for Radiation Protection—Safety Series No. 9. 1967 (Revised). HMSO. 14s 2d (14s 10d)
20 The Provision of Radiological Protection Services—Safety Series No. 13. 1965. HMSO. 12s 0d (12s 6d)
21 The Basic Requirements for Personnel Monitoring—Safety Series No. 14. 1965. HMSO. 16s 0d (16s 4d)
22 Manual on Environmental Monitoring in Normal Operation—Safety Series No. 16. 1966. HMSO. 9s 0d (9s 6d)
23 Techniques for Controlling Air Pollution from the Operation of Nuclear Facilities—Safety Series No. 17. 1966. HMSO. 15s 0d (15s 8d)
24 Respirators and Protective Clothing—Safety Series No. 22. 1967. HMSO. 14s 2d (14s 10d)
25 Radiation Protection Standards for Radioluminous Timepieces—Safety Series No. 23. 1967. HMSO. 7s 2d (7s 8d)
26 A Basic Toxicity Classification of Radionuclides—Technical Report Series No. 15. HMSO. 6s 0d (6s 4d)
27 Training in Radiological Protection: Curricula and Programming—Technical Report Series No. 31. 1964. HMSO. 15s 0d (15s 8d)

ILO publications

Manuals of Industrial Radiation Protection

28 Part II Model Code of Safety Regulations (Ionising Radiations). ILO. ILO Branch, 40 Piccadilly, London W1. 1959. 4s 6d
29 Part III General Guide on Protection against Ionising Radiations. ILO. 1963. 8s 9d
30 Part IV Guide on Protection against Ionising Radiations in Industrial Radiography and Fluoroscopy. ILO. 1964. 7s 0d
31 Part V Guide on Protection against Ionising Radiations in the application of Luminous Compound. ILO. 1964. 7s 0d

BSI publications

32 Recommendations for data on Shielding from Ionising Radiations: Part I: Shielding from gamma radiation. BS 4094: Part I 1966
33 Gamma Radiography Exposure Containers for Industrial Purposes and their Source Holders. BS 4097: 1966
34 Specification for Film Badges for Personnel Radiation Monitoring. BS 3664: 1963
35 Specification for Gamma Radiography Sealed Sources. BS 3513: 1967

36 Symbols for Ionising Radiation. BS 3510: 1968

37 Specification for Direct Reading Personal Dosemeters for X and Gamma Radiation. BS 3385: 1961

38 General Recommendations for the Testing, Calibration and Processing of Radiation Monitoring Film. BS 3890: 1965

Other publications

39 The Radiochemical Manual. Radiochemical Centre, Amersham. 50s 0d (54s 6d)

40 Report of the International Commission on Radiological Units and Measurements (ICRU) 1959. National Bureau of Standards Handbook 78. Supt. of Documents, US Government Printing Office, Washington 25, DC. 1961. 65 cents

Forms available for use in connection with the Ionising Radiations (Unsealed Radioactive Substances) Regulations 1968 and the Ionising Radiations (Sealed Sources) Regulations 1969

41 Radiation Dose Record: Form No. F2065. HMSO. 1s 9d (2s 1d)

42 Transfer Record: Form No. F2066. HMSO. 3d

43 Health Register: Form No. F2067. HMSO. 2s 6d (2s 10d)

44 Sealed Sources Test Record: Form No. F2068. HMSO. 3d

45 Radiation Dosemeter Test Record: Form No. F2069. HMSO. 3d

46 Supplementary Radiation Dose Record: Form No. F2305. HMSO. In prep

APPENDIX A: SCHEDULE 1 OF THE IONISING RADIATIONS (UNSEALED RADIOACTIVE SUBSTANCES) REGULATIONS 1968

MAXIMUM PERMISSIBLE RADIATION DOSES

Application of Schedule

1 The doses specified in this Schedule relate to ionising radiations (other than alpha particles emitted by radioactive substances) that originate (otherwise than from radioactive substances within the human body) either in a factory or in a place outside a factory in which any work of a kind specified in Regulation 22(2) (a)(ii) is carried on

- a from any radioactive substance; or
- b from any machine or apparatus that is intended to produce ionising radiations or in which charged particles are accelerated by a voltage of not less than five kilovolts not being X-ray apparatus exclusively used (in a room specially set apart for the purpose) for the prevention, diagnosis or treatment of illness or injury,

and for the purposes of this Schedule other ionising radiations shall not be taken into account.

Maximum permissible doses

2 1 Except as provided in paragraph 3 of this Schedule, in any calendar year the maximum permissible sum of doses for persons employed in a factory from any ionising radiations shall be

- a 75 rems to the hands, forearms, feet and ankles of which not more than 40 shall be received in any calendar quarter
- b 15 rems to the lenses of the eyes of which not more than 8 shall be received in any calendar quarter and
- c 30 rems to other parts of the body of which not more than 15 shall be received in any calendar quarter.

The provisions of (c) of this sub-paragraph shall be without prejudice to the provisions of sub-paragraph (2) of this paragraph.

2 2 Except as provided in paragraph 3 of this Schedule, the sum of doses received in any calendar quarter by any person to parts of the body other than the eyes, hands, forearms, feet and ankles from all or any one or more of the following, that is to say, X-rays, gamma rays and neutrons shall not exceed 3 rems (or in the case of women 1·3 rems), and the number of rems in the total cumulative

dose received therefrom to those parts of the body shall not at any time exceed five times the number of years from the first day of January of the year in which that worker attained the age of eighteen. For the purpose of calculating the said doses a part of a year shall be counted as a year.

2 3 If the occupier is aware that any person employed was during any period-

a in protected employment; or

b in employment which, if it had occurred after the coming into operation of any Regulations under the principal Act, would have been protected employment; or

c in any other work involving exposure to ionising radiations, for which no information is available to the occupier as to the doses that person received during that period of the kinds, and to the parts of the body, specified in sub-paragraph (2) of this paragraph, that person shall, for the purpose of calculating his total cumulative dose referred to in the said sub-paragraph, be deemed to have received doses at the rate of five rems a year during that period.

Maximum permissible doses for pregnant female persons

3 In the case of any female person whom the occupier knows, or has reasonable cause to believe, to be pregnant the maximum permissible sum of doses from all or any one or more of the following, that is to say, X-rays, gamma rays and neutrons during the remaining period of her pregnancy shall be one rem.

APPENDIX B: SCHEDULE 2 OF THE IONISING RADIATIONS (UNSEALED RADIOACTIVE SUBSTANCES) REGULATIONS 1968

MAXIMUM PERMISSIBLE LEVELS OF CONTAMINATION AND METHODS OF ASSESSMENT

1 The maximum permissible levels of contamination of surfaces (other than contamination which cannot be removed by normal methods) shall be as follows:

<table>
<tr><th>Category</th><th>Surface</th><th colspan="3">Maximum Permissible Level ($\mu Ci/cm^2$)</th></tr>
<tr><td>A</td><td>Surfaces of the interiors and contents of total enclosures and fume cupboards.</td><td colspan="3">The minimum that is reasonably practicable</td></tr>
<tr><td rowspan="3">B</td><td rowspan="3">Surfaces (other than surfaces in category A) of active areas and plant, apparatus, equipment (including personal protective equipment), materials and articles within active areas.</td><td colspan="2">From alpha emitters</td><td rowspan="2">From emitters other than those specified in the preceding two columns</td></tr>
<tr><td>In Class I</td><td>In Class II–IV
of the Table in Schedule 3 to these Regulations</td></tr>
<tr><td>10^{-4}</td><td>10^{-3}</td><td>10^{-3}</td></tr>
<tr><td>C</td><td>Surfaces of the body</td><td>10^{-5}</td><td>10^{-5}</td><td>10^{-4}</td></tr>
<tr><td>D</td><td>All other surfaces</td><td>10^{-5}</td><td>10^{-4}</td><td>10^{-4}</td></tr>
</table>

2 Contamination that can be rubbed off on an absorbent material shall be treated as contamination that can be removed by normal methods, and in assessing such contamination it shall be assumed

(except where the fraction transferred is capable of determination) that one-tenth of the removable contamination has been transferred to the absorbent material from the area over which the material has been rubbed.

3 1 Where measurements of contamination are made in the case of floors, ceilings or walls over an area not exceeding one thousand square centimetres, or in the case of other surfaces (other than of the body) over an area not exceeding three hundred square centimetres, the results of the measurements may be averaged over the whole of the area measured.

3 2 Where measurements of contamination are made in the case of the person (other than the hands) over an area not exceeding 100 sq. cm., or in the case of the hands, over the whole area of the hand, the results of the measurements may be averaged over the whole of the area measured.

ACKNOWLEDGMENTS

Acknowledgments are made to the following organisations for their assistance in providing illustrations:
Pandect Instrument Laboratories Limited (for figures 6 and 11)
Atomic Energy Research Establishment (for figures 7, 9 and 10)

THE ROYAL SOCIETY
FOR THE PROMOTION
OF HEALTH

BUCKINGHAM PALACE ROAD, LONDON, S.W.1

... comply with the following by-laws governing ... Council of the Society.

... may be borrow...

SAFETY, HEALTH AND WELFARE BOOKLETS

New Series

16	The Structural Requirements of the Factories Act ...	2s (2s 6d)
17	Improving the Foundry Environment ...	(4s ...d)
18	Industrial ... Measures ...	2s 6d (2s 10d)
19	Safety in Laundries ...	4s (4s 6d)
20	Drilling Machines: Fencing of Spindles and Attachments ...	In prep
21	Organisation of Industrial Health Services ...	2s 6d (2s 10d)
22	Dust Explosions in Factories ...	4s (4s 6d)
23	Hours of Employment of Women and Young Persons ...	2s (2s 4d)
24	Electrical Limit Switches and their Applications	2s 6d (2s 10d)
25	Noise and the Worker ...	1s 6d (1s 10d)
26	Safety in the Use of Biscuit-making Machinery	7s 6d (8s)
27	Precautions in the Use of Nitrate Salt Baths...	2s (2s 4d)
28	Plant and Machinery Maintenance ...	3s (3s 6d)
29	Carbon Monoxide Poisoning: Causes and Prevention ...	3s 6d (4s)
30	The Bulk Storage of Liquefied Petroleum Gas at Factories ...	2s (2s 4d)
31	Safety in Electrical Testing ...	1s 6d (1s 10d)
32	Repair of Drums and Tanks: Explosion and Fire Risk ...	2s (2s 6d)
33	Safety in the Use of Guillotines and Shears ...	1s 9d (2s 1d)
34	Guide to the Use of Flame Arresters and Explosion Reliefs ...	2s 3d (2s 7d)
35	Basic Rules for Safety and Health at Work ...	2s 6d (3s)
36	First Aid in Factories ...	1s 3d (1s 7d)
37	Precautions in the Handling, Storage and Use of Liquid Chlorine ...	1s 9d (2s 1d)
38	Electric Arc Welding ...	2s (2s 4d)
39	Lighting in Offices, Shops and Railway Premises ...	4s 6d (4s 10d)
40	Means of Escape in case of Fire in Offices, Shops and Railway Premises...	In prep

Prices in brackets include postage

Published by Her Majesty's Stationery Office, and obtainable from the Government Bookshops at the addresses listed on cover page ii or through any bookseller

Printed in England for Her Majesty's Stationery Office
by McCorquodale & Co. Ltd., London

HM 3186 Dd. 151810 K 72 2/69 McC. 3309 SBN 11 360107 7

DEPARTMENT OF EMPLOYMENT AND PRODUCTIVITY
HM FACTORY INSPECTORATE

SAFETY, HEALTH AND WELFARE BOOKLETS
New Series

1	Lifting and Carrying	1s	(1s 4d)
2	Canteens, Messrooms and Refreshment Services ..	3s	(3s 6d)
3	Safety Devices for Hand and Foot Operated Presses ..	3s 6d	(3s 10d)
4	Safety in the Use of Abrasive Wheels		In prep
5	Cloakroom Accommodation and Washing Facilities ..	2s 6d	(3s)
6A	Safety in Construction Work: General Site Safety Practice	1s 6d	(1s 10d)
6B	Safety in Construction Work: Roofing	1s	(1s 4d)
6C	Safety in Construction Work: Excavations	1s 3d	(1s 7d)
6D	Safety in Construction Work: Scaffolding	2s	(2s 4d)
6E	Safety in Construction Work: Demolitions		In prep
6F	Safety in Construction Work: System Building	3s	(3s 6d)
7	Radioactive Markers in Go-Devils: Safety Precautions	1s	(1s 4d)
8	Dust and Fumes in Factory Atmospheres ..	3s 6d	(3s 10d)
9	Safety in the Use of Machinery in Bakeries	8s 6d	(9s 2d)
10	Fire Fighting in Factories ..	2s	(2s 4d)
11	Guarding of Hand-fed Platen Machines	1s	(1s 4d)
12	Safety at Drop Forging Hammers	2s 6d	(2s 10d)
14	Safety in the Use of Mechanical Power Presses ..		In prep
15	Dry Cleaning Plant: Precautions Against Solvent Risks ..	1s 3d	(1s 7d)

Prices in brackets include postage

continued inside back cover