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H. Sc
OCCUPATIONAL HYGIENE

MIRZA SALMAN KHALAF

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AN INVESTIGATION INTO THE EFFECTS OF
RADIATION PROTECTION PROCEDURES IN THE HANDLING OF
SEALED AND UNSEALED SOURCES AND X-RAY EMITTING EQUIPMENT

A thesis submitted to the University of Manchester
for the Degree of Master of Science in
Occupational Hygiene in the Faculty of Medicine

1990

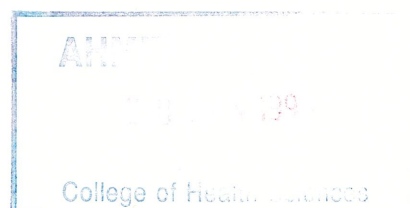
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M . Sc
OCCUPATIONAL HYGIENE

MIRZA SALMAN KHALAF
1990

UNIVERSITY OF MANCHESTER



DEDICATION

TO: "MY BELOVED WIFE, WHO SHARED ALL MY EFFORTS AND HAD
SUCH PATIENCE DURING THE PRODUCTION OF THIS WORK".

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ABSTRACT

In this study the subject of ionising radiation was reviewed and survey measurements were made to investigate the effects of radiation protection procedures in the handling of unsealed and sealed sources, and X-ray emitting equipment, in the University of Manchester, University of Manchester Institute of Science and Technology (UMIST) and Petro Spec Company Limited.

Thus, based upon the survey results discussed, it was determined that:-

1. in the first part of this study (unsealed sources), three measurement methods were used to assess the radiation doses in five biochemistry laboratories. These measurements (surface contamination measurement method, air monitoring method and dosimetric method) indicated results at much lower than recommended levels.
2. in the second part (X-ray emitting equipment) where also three methods of surveying was used. Two of these (direct measurement and fixed film badge, which were used as alternatives), indicated low levels of leakage. The third method (an investigation method), indicated some breaches of the standards and regulations.
3. in the final part of this study (sealed sources), a direct measurement method was used to measure the doses or exposure to radiation in four techniques (Chapter IV). It was determined that the highest dose rates were recorded from the irradiation technique in the Pharmacy Department in Manchester University. This originated from the cable hole port and from the ventilation stack outside building facility. However, advice and protection procedures were recommended for each chapter

and in general according to the handling method of each radiation source with suggestions for further studies, which were not covered by this investigation.

DECLARATION

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other University or other Institution of learning.

STATEMENT

Since my graduation from Curtin University of Technology, in Perth, Australia, I have worked in the Occupational Health Department in Bahrain as a Senior Occupational Health Inspector.

I have been to Aston University in Birmingham (United Kingdom) for the advanced experience course in Occupational Hygiene and Safety. Furthermore, I have been trained in noise and radiation pollution for six weeks in France and attended an advanced course on water, soil and air pollution at Ghent University, Belgium.

I have done two projects in the state of Bahrain. The first one was about the management and disposal of toxic wastes, presented in a workshop held in Damascus by the World Health Organisation (WHO). The second study was entitled Pollution from Chemical and Petrochemical Industries and was presented at Ghent University, Belgium by the United Nations Industrial Development Organisation.

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I would like to present my sincere thanks and appreciation to all those whom without whose help I would not have been able to produce this piece of work.

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INTRODUCTION

The interest of Governments and private sectors in controlling the effects of radiation exposure on workers and their environment has increased, and in turn has led to a growing awareness and concern amongst many national and international organisations.

As a result, these organisations issued recommendations and standards of assessment to protect the workers who are subjected to ionising radiation. Therefore, individuals working with ionising radiation and/or radioactive materials have a duty to protect both themselves and others from hazards which arise from their work. Individuals must not expose themselves or others to ionising radiation and/or radioactive materials, to a greater extent than what is reasonably necessary to perform their work.

However, the main purpose of this study is to provide proper data and information for the following uses:-

- a) to assess and make a comparison between similar uses of radiation sources whether unsealed, sealed, or X-ray emitting equipment;
- b) to study dose accumulation patterns of workers;
- c) to demonstrate compliance with occupational exposure limits.

Thus, all this data and information will be of importance in radiological protection, such as in assessing the degree of exposure or which doses arise from a particular area, e.g., industry, laboratory, etc. If the amount of radiation, emitted from radionuclides that are present in one of the above areas, is measured or calculated and the resulting doses to individuals and groups are assessed from this data, an indication of the level of risk can be made.

In the first part of this study, there were three methods used to carry out these measurements:-

- i) contamination surveying by measuring surfaces, such as floors, benches and sinks in both "controlled" and "supervised" areas;
- ii) air monitoring by measuring the airborne contamination from radionuclides in the laboratory environment;
- iii) dosimetric methods by using thermoluminescent detectors (TLDs) and/or film badges. TLDs were used to measure finger doses while film badges were used to measure whole body doses.

In the second part (X-ray emitting equipment), surveying was carried out by direct measurement with fixed film badges as an alternative method to detect any leakage. Also a questionnaire was prepared, which asked for details of the uses of ionising radiation, such as:-

- a) for what purpose is ionising radiation used?
- b) kind of radiations;
- c) range of tube voltages;
- d) number of X-ray machines, maximum kV, mA output;
- e) number of staff involved;
- f) average working hours/week;
- g) number of procedures/week;
- h) dosimeters used;
- j) medical check-up performed;
- k) radiation protection methods adopted.

The last part of this study was on uses of sealed isotopes in the industrial field. Measurements were taken during the course of work to find out the level of dose exposure.

This study will enable a transfer of modern techniques, related to ionising radiation, to Bahrain (my own country)

and will assist in training my colleagues in measurement and control of radiation exposure. It will also contribute effectively in formulating the new ionising radiation protection regulations through benefiting from British expertise in this field (Appendix 1).

CHAPTER I

REVIEW OF LITERATURE

1.1. HISTORICAL REVIEW

Since the industrial revolution took place in Europe in the 18th century, scientific and technological discoveries have been achieved constantly. These discoveries have no doubt caused a great deal of development and prosperity in all walks of life.

In contrast, some of these discoveries could do as much harm to humanity as a result of misuse or accidental faults while in use; Robert Frost said "To err is Human" (2).

Among those discoveries which have both negative and positive effects is Ionising Radiation. Ionising radiation, unlike light and heat, cannot be detected by our senses. It gives no immediately visible indication of its presence or its absorption, except in extremely large doses for instance in criticality accidents. It produces no sensation, and its harmful effects are normally delayed.

Ionisation is produced from sub-atomic particles or electromagnetic radiation having sufficient energy to drive electrons from their atomic or molecular orbits. Therefore radiation can be summarised under the following headings:-

- a) Corpuscular: includes alpha particles, which are helium ions, carrying two positive charges, and beta particles which are high speed electrons;
- b) Electromagnetic: energy propagated through space or matter in the form of waves. The level of energy depends on the wave length of the electro-magnetic radiation, and includes (in order of increasing length), gamma rays, X-rays, ultra-violet rays, visible light,

infra-red (heat) rays, hertzian or radio-waves;

- c) Ionising: any electromagnetic or corpuscular radiation capable of producing ions.

Generally, the most common ionising radiations are, X-rays, gamma-rays, neutrons and alpha and beta particles.

It is noteworthy, that ionising radiation was first observed or recorded in 1895, when X-rays were discovered by a German physicist, Wilhelm Roentgen (21). In 1896, Henri Becquerel, a French scientist (16), was conducting an experiment in which he developed photographically unexpectedly a mineral containing uranium. He found that his photographic plates had been affected and this led to the discovery of radioactivity.

Later, in 1898, Marie (Polish) and Pierre Curie (21) discovered that when uranium gave off radiation the new elements polonium and radium (shining element) were found.

However, these scientists's work led to further discoveries and developments in the field of modern atomic and radiation physics. Some examples of such discoveries are (21):-

- Rutherford found two kinds of radiation, which he named "alpha" and "beta" which, are emitted from uranium (1899);
- Villard discovered gamma-rays, emitted from radium (1900);
- the atomic nucleus was discovered by Rutherford in 1911;
- Mueller discovered, in 1927, that ionising radiation produced genetic mutation;
- the positron was discovered by Anderson in 1932;
- the neutron was discovered by Chadwick in 1932;

- Joliot-Curie and Joliot produced artificial radio-isotopes in 1934.

Also various national and international organisations, were formed to consider radiation problems and to provide formal recommendations, to be used as guidance for protection from ionising radiation hazards. An example of such an organisation is the British Roentgen Society which was established in 1915 (21). It is believed to have been the first organisation established to tackle radiation hazards.

The International Commission on Radiological Protection (ICRP) was formed in 1928 (7) and is another example of such an organisation.

All these findings and other discoveries associated with ionising radiation have their advantages and benefits as well as disadvantages (potential hazards and danger).

Energy resulted from ionising radiation has become an alternative for coal, oil and gas especially in electricity generation.

In the medical field ionising radiation is used for many purposes connected with diagnosis, treatment and sterilisation of medical and surgical material. In addition to this, ionising radiation is used in industrial fields, for process control and quality inspection. For example, it can be used in:-

- welding tests (gamma radiography);
- examination of manufactured articles such as spark plugs, (X-ray-fluoroscopy);
- measurement of thickness, etc.

Moreover scientific research and experimental work is another field in which ionising radiation has had an

important role. For instance, X, gamma and beta radiation are used for pharmaceutical product studies, and for chemical changes and analysis.

Another example, is that of unsealed radioisotopes or open sources which are used for labelling processes, e.g., much research has been carried out on iodine species and metabolism (31).

Other uses include such diverse things as:-

- i) preservation of food stuffs;
- ii) pest control;
- iii) smoke detectors;
- iv) electronic technology, etc.

Disadvantages of ionising radiation as a result, of misuse or accidental faults in various fields can be illustrated as follows:-

- i) in hospitals: ionising radiation may become hazardous to patients as a result of misuse of diagnostic X-rays, radiotherapy, etc, during treatment or diagnosis;
- ii) in nuclear power plants: the Chernobyl accident 26/4/1986 in the Soviet Union (Appendix 2), is a good example of a serious accident;
- iii) human fault or error: the use in 1945 during the second world war of the atomic bombs on Japan (21).

1.2. SOURCES OF IONISING RADIATION

a) Natural sources

Throughout the history of the earth, radiation has fallen on its surface from outer space and risen from radioactive materials in its crust.

The latest review on radiation exposure for the United

Kingdom (UK) population (16 and 29), mentioned that 87% of the total is from natural radiation, with half of this from radon exposure indoors (Graph 1).

Thus man has evolved subject to radiation from outer space, from the earth, from living in buildings and even from within his own body in the ground. In other words, man has lived always in background radiation from naturally occurring sources. This means that the major contribution to the doses received by mankind comes from natural radiation sources which include external sources such as cosmic rays and radioactive substances, in the ground and in building materials and internal sources which result from the inhalation and ingestion of naturally occurring radioactive substances in air, water and diet.

A report issued in 1985 by the United Nations Environment Programme (UNEP) (37), noted that studies in France, West Germany, Italy, Japan and the United States of America (USA) indicated that about 95% of the people live in areas where the annual average dose rate varies from 0.3/0.6 millisieverts (mSv)., but some people receive much greater doses because the levels of terrestrial radiation differ from place to place around the world, as concentrations of those materials in the earth's crust vary.

For example, in the UK, the annual effective dose equivalent from cosmic rays differs from place to place (28). As stated in this reference, the annual effective dose equivalent is about 300 microsieverts (Sv) on average, because most people live at low altitudes but this can change from 280 Sv in the South of England to 310 Sv in the North of Scotland, because of the increase

in latitude. Table 1 gives the latest summary of the average annual effective dose as reported by the National Radiological Protection Board (NRPB) in 1989 (29).

b) Man-made sources (artificial radiation)

As a matter of fact, the exposure level of natural sources of radiation may vary little from year to year and involve the whole population (in all parts of the world) to about the same extent, while man-made sources may vary significantly with time and the resulting exposure may differ substantially from one population group to another. Most people receive a relatively small amount of artificial radiation but a few get many times the amount they receive from natural sources.

Man-made sources can be controlled more properly than most natural ones, except perhaps exposure to irradiation due to fallout from previous nuclear explosions. For example, exposure due to cosmic rays from the atmosphere or from the earth cannot easily be controlled. However, the man-made sources are as follows:-

i) Sources from the medical field

Sources from medical uses include the highest activity amongst the man-made sources, with the exception of those linked with nuclear reactors or nuclear warfare.

Diagnostic and therapeutic exposures are the two main sources of medical irradiation. Diagnostic exposure includes X-ray examinations, nuclear medicine examinations and the uses of radio-isotopes for specific diagnostic reasons, while therapeutic exposures are used for treatment of

diseases - mainly cancers.

The approximate annual incidence of medical procedures in the UK by the NRPB in 1989 (29) was estimated at:-

- medical and dental X-ray examinations 36 million
- nuclear medicine procedures 0.5 million
- radiotherapy treatment 0.15 million

Also, other studies have been observed/recorded in industrialised countries. For example Japan has estimated that the annual effective dose equivalent was in the order of 20manSv/10⁶ persons or an annual effective dose equivalent of 20 Sv. Collective effective dose equivalents have been found to range from 20manSv per million people in Australia to about to about 150manSv in the USA (37).

ii) Radiation sources from weapons tests

Testing weapons in atmosphere or in the open air will spread the radioactivity throughout the environment or the world and gives rise to fission products, activation products and actinide elements, (e.g., plutonium isotopes). This radioactivity may be injected to the upper atmosphere, from which it is transferred slowly to the lower atmosphere and more quickly carried with the air mass circulating over the earth. This radioactivity in the air mass will be inhaled directly or ingested in diet, and will cause internal exposure to the body. In addition, soil deposition will lead to external irradiation.

NRPB, 1989 (29), indicated that the average

effective dose equivalent from fallout in the UK is about 5 Sv for a year and the collective effective dose equivalent is 280 manSv. The world's total collective effective dose equivalent, as reported by (UNEP, 1985) (37), from atmospheric nuclear explosions amounts to 30,000,000 manSv. Twelve percent of this had been delivered by 1980, the rest will reach man over millions of years.

iii) Sources from nuclear power stations

Nuclear power or nuclear reactor stations have increased rapidly throughout the world, since the first one, installed in the UK. The operations (production of electrical energy), in these stations involves many steps, started from mining and milling of uranium ores to conversion to various chemical forms, which are arranged as follows:-

- enrichment of the isotopic content of uranium-235;
- fabrication of the fuel elements;
- production of power in nuclear reactors;
- re-processing of irradiated fuel;
- transportation of materials between the various installations;
- disposal of radioactive wastes.

Therefore, it should be realised that from each of these operational steps and/or procedures of processing, there will be radioactive wastes which of course will be discharged into the environment and will deliver doses to workers and the public. These doses will be strongly dependent on the location of persons relative to reactors and

installations. This means that the further a person lives from a nuclear installation, the less radiation he/she will receive from it. The dose will also depend on the time after the practice is terminated, owing to the radionuclides that remain in the environment. Generally speaking, these installations emit a variety of radionuclides which decay at different rates, most are of only local importance, because they decay rapidly. Some live long enough to spread right around the world, and some remain in the environment virtually for ever.

Thus people can be exposed to radiation exposure from nuclear reactors, particularly from pathways of discharge of liquid and gas, contained in radioactive materials. These pathways can lead to radiation doses which, therefore, depend mainly on the reactor system, site situation, weather and the habits of the population. For example, liquid discharges from reactors were estimated (33) in the UK to result in an annual collective effective dose equivalent of less than 0.3 manSv. The maximum dose to a critical group in 1987 was 250 Sv to the consumers of fish caught in the lake in North Wales into which the Trawsfynydd nuclear power station discharges liquid effluent.

There are five main types of reactors in operation (37):-

- water reactors and boiling water reactors, which were originally developed in the USA and are now the commonest types in the world;
- gas-cooled reactors, developed and

predominantly used by the UK;

- heavy water reactors, largely confined to Canada;
- light water cooled graphite moderated reactors, which are in operation only in Russia (USSR), e.g., Chernobyl.

Also there are four fast breeder reactors which are envisaged as the next generation of nuclear power plants in Europe and the USSR. Table 2 gives the world nuclear power stations.

iv) Occupational sources

The over-exposure of radiation from occupational sources is always the result of an emission or over dose/over exposure, leakage or accident resulting from equipment failure, or misuse or careless work.

The dose distribution depends on the job category, it may not be necessary for workers ever to receive more than very low doses whereas occasionally workers may have to be exposed to high doses fairly routinely.

The exposure of workers contributes to the collective effective dose equivalent of the entire population and hence to somatic and genetic detriment in the population. The annual collective effective dose equivalent generally from occupational exposure is about 0.03% of natural levels (30). In 1989 the UK average dose in the annual exposure of the population from occupational sources was 5 Sv (29). However, workers may be exposed to the following sources occupationally:-

a) Medical uses (occupationally)

Doses to workers involved in the use of radiation for medical purposes are highly variable and sometimes are characterized by extremely non-uniform distribution over the body. It is not possible to identify and quantify the beneficial output of all medical work, however, it is estimated that the exposure of medical personnel engaged in radiological work contributed about one manSv per million people to the collective equivalent dose in the countries with a high standard of medical care (37). Industrialized countries like the UK, for example, the total average annual dose distributed to a sample of workers in diagnostic radiology was 0.16 mSv. The dose to workers in radiotherapy was 0.41 mSv and in nuclear medicine was 0.12 mSv (12).

b) Nuclear power industries

Persons who work in the nuclear power industry generally receive the largest doses of radiation. The exposures depend on the part of the nuclear fuel cycle. Mining, for example, is responsible for about 90% of the whole exposure dose (37).

Underground uranium miners, as an example, have traditionally received the highest average doses compared to surface miners or open-cast miners because they were exposed to higher concentrations of radon and its daughter products.

The principal hazard, to the public, comes from the inhalation of uranium dust or dust

containing radioactive substances. Other steps such as processing include purification and enrichment as mentioned previously are primarily occupational hazards. Table 3 summarizes the doses from nuclear exposure in the UK.

c) General industry

As stated previously ionising radiation is used widely in general industry. Most of these uses involves sealed isotopes, open sources (unsealed isotopes) and X-ray sources. The largest sources are used mostly in construction, engineering and installation, and are used, therefore, they are well shielded so that the operator and other workers will normally receive little or no radiation dose. But, as mentioned previously, under some circumstances workers can receive appreciable doses, sometimes due to leakage or an accident. These doses can be in excess of the annual dose limit. An analysis of annual doses to workers in 1987 has been made and is shown in Table 4.

d) Research and teaching

Many research and teaching establishments carry out research into the application of radionuclides or radiation and/or use radioisotopes as research and teaching tools. Recently, however, due to the availability of these radioisotopes, there has been a dramatic increase in their use.

e) Other sources/miscellaneous

There are many other sources from uses of both

sealed and unsealed isotopes, ranging from tracer experiments to large sources. These are:-

- radiation sources from electronic equipment (e.g., television receivers);
- sources used in smoke detectors;
- X-ray equipment used for inspections at airports;
- luminous watches, etc.

1.3. THE EFFECTS OF IONISING RADIATION

a) The effects

All ionising radiation sources are potentially hazardous. They can give rise when outside the body to external exposure and when inside the body to the irradiation of certain organs and tissues, producing biological damage. However, the health effects of ionising radiation on man are caused by the following sources:-

i) Occupationally

Workers may be exposed occupationally to an excessive amount of radiation as a result of negligence, human error or accident (see Section 1.2. Man Made Sources).

ii) Medical procedures

Patients may be exposed to radiation as part of their medical treatment diagnostically or therapeutically (Section 1.2).

iii) Nuclear weapons/nuclear reactor accidents

People might be affected by radiation through the use of nuclear weapons during wars, reactor accidents and to fallout from weapons tests (Section 1.2).

iv) Hereditary defects

Ionising radiation produces growth and developmental defects in children and fetuses. The studies in Hiroshima and Nagasaki (7), on the children born to irradiated survivors showed that the "end points" considered were congenital defects. The average conjoint gonad exposures for the parents was about 0.5 Gy (based on Ds-86 dosimetry).

It was reported in The Guardian newspaper on 16th February 1990 that excess cases of leukaemia had been found in children where fathers had received high radiation doses.

Besides the biological effects of ionising radiation there is also the chemical effects. Specifically chemical changes in water (21). However, the biological effects depend on the dose, type of radiation and observed end point. Table 5, shows that some effects occur relatively quickly while others may take years to appear.

There are two types of biological effects of ionising radiation (7):-

- 1) Early or acute effect These effects appear within hours to a few months after exposure, of the whole or part of the body, to high doses of radiation during short periods of time. Death may result.
- 2) Late or long term effect These effects can occur after many years, sometimes generations after exposure. Cancers and hereditary disease are the principal types of these effects. In many cases this latent period may be attributed to the interdependence of the cells, tissues and organs of the

body (7). Generally speaking the larger the dose, the earlier is the appearance of injury.

b) Determination of biological effects

i) Dose response relationships

There is a quantitative relationship between the extent of damage and dosage. If we plot dose versus effect for various tissues there are, in general, two forms in which the graph may appear (Figure 1) Curve A illustrates the common type of biological response to most physical and chemical agents. Here the effect is not measurable until a certain minimum or threshold dose is exceeded. The resultant curve is not linear, but generally approaches an S shape. The majority of the acute effects of radiation are thought to be this type. It may be, however, that as more sensitive means are found to detect radiation effects, more of them will be seen to be non-threshold types.

Curve B represents the non-threshold case in which a linear relationship exists between a dose and the effect. A minimum dosage is not essential to produce an effect and furthermore any given dosage in this case produces the same effect regardless of any previous dose. It is a well established fact that genetic effects of radiation follow this type of dose effect curve. Considerable evidence has accumulated that the life span shortening and carcinogenetic effects also follow this non-threshold type of effect (7).

ii) The type of ionising radiation

The various types of radiation will result in different degrees of tissue damage for the same quantity of energy absorption. The extent of

damage depends upon the ionisation produced by the incident radiation. The greater the ionisation produced by the radiation the greater the biological damage, for equal amounts of energy absorption per unit mass of tissue.

iii) Rate of absorption

The rate at which the radiation is administered or absorbed is most important in the determination of what effects will occur. Since a considerable degree of recovery occurs from the acute effects of radiation, a given total dose will produce less of an acute effect if divided than if given in a single exposure.

iv) Area exposed

Ordinarily when reference is made to a level of exposure, it is assumed to be the mean whole body dose. The qualification of whole body radiation is important. Large doses of radiation can be applied to local areas (as in therapy) with little damage, but are lethal if applied to the whole body. For example, a person could expose a finger to 10Sv and experience little effect except localised injury to the finger, with subsequent healing and scar formations. If the same dosage were delivered to the entire body, it would prove fatal.

v) Species and individual variability

Different species show a wide variation in response to identical exposures of radiation. There is a considerable variation in response within species.

vi) Relative sensitivity of cells and tissues

In general the relative sensitivity of various

cells and tissues is the same in the various mammals. Under identical exposure conditions, the different types of cells and tissues exhibit marked differences in their response to firm radiation.

c) Types of effects

As mentioned previously the biological effects of radiation, except for exceedingly high doses, are delayed from hours to many years depending on the dose and type of radiation received. Over-exposure to ionising radiation may cause:-

- i) injury to superficial tissues;
- ii) general effects on the body, particularly blood and blood-forming organs, e.g., production of anaemia and leukaemia;
- iii) induction of malignant tissues;
- iv) other deleterious effects such as cataracts, impaired fertility and reduction of life span;
- v) genetic effects;
- vi) the probable early effects of acute whole body exposure. Table 6 summarises the effects and conditions of both early and late radiation effects.

1.4. PROTECTION AGAINST IONISING RADIATION

The hazards of radiation have received a great deal of attention since the International Commission on Radiological Protection (ICRP) was established. The ICRP issue recommendations and formulate practical guidelines which are generally accepted throughout the world. Most countries safety standards and regulations are based on ICRP guidelines/recommendations (34). Examples are:-

- the system of dose limitation and requirements of

- "As Low As Reasonably Achievable" (ALARA);
- publication number 26 defines radiological protection as "The Protection of Individuals, their progeny and Mankind as a whole"

Later on various national and international agencies who were established operated in this field and contributed effectively in promoting the standards for radiation protection. One of those agencies is the National Radiological Protection Board (NRPB) in the United Kingdom. NRPB have published formal advice on radiation protection. Their recommendations, advice and suggestions have been accepted as basic requirements necessary for radiation protection regulations or for radiation safety standards (28).

1.4.1. Radiation Protection

Radiation protection based on these general principles:-

- a) justification of the exposure;
- b) all exposures shall be kept As Low As Reasonably Achievable;
- c) radiation doses shall not exceed certain limits.

The protection against radiation in general can be applied to prevent or control the exposure of personnel to radiation hazards:-

- a) removing the hazards, if possible;
- b) eliminating the hazards, if possible;
- c) guard against hazards or enclose the hazards by isolating them from man;
- d) protect the workers.

To implement these principles there are certain

factors or techniques for protection:-

For external radiation protection

The main factors to be considered are:-

a) Time of exposure

Time is the most effective factor in reducing radiation exposure in many cases. A simple procedure, minimising exposure time should always be adopted. This means that the dose accumulated by the worker in an area having a particular dose rate will be minimised.

b) Distance

The use of distance is an effective means of reducing dose. Alpha and beta particles do not travel far in air, and distance is a most effective shielding for them. For X-rays and gamma-rays the intensity decreases very rapidly with the distance between the source and the point of interest (37). The relationship is expressed by the inverse square law which is written as:-

$$\frac{I_1}{I_2} = \frac{d_2^2}{d_1^2} \quad (7)$$

where I_2 is the original intensity:-

I_1 is the new intensity

d_2 is the original distance

d_1 is the new distance

c) Shielding

The use of shielding is often most important but expensive for protecting personnel. Shielding allows large sources to be used in working areas where personnel must remain for long periods of

time. The principle of shielding is straight forward and concepts have been introduced to make calculations of shielding requirements very simple. These are Half-Value Layer (HVL) and Tenth-Value Layer (TVL). It should be noted that the values of these vary as radiation penetrates a thick shield. This variation is caused by the build-up within the absorber, e.g., X-ray shielding.

There are two types of shielding (7) for protection against X-rays:-

- i) Source shielding which is usually supplied by the manufacturer of the equipment, i.e., lead shield in which the X-ray tube is housed.
- ii) Structural shielding which is usually designed to protect against the X-ray leakage and scattered radiation. This type encloses the X-ray tube, space in which it is located and the object being irradiated, i.e., a lead-lined box for the X-ray tube or shielding around a room in which a patient is undergoing treatment.

Internal radiation protection

Internal radiation occurs as a result of contamination by radioisotopes entering the human body by the following ways:-

- Absorption: through the skin or through wounds;
- Inhalation: by breathing radioactive dust or gas;
- Ingestion: by drinking or eating contaminated foods or water.

Therefore, the control of internal radiation hazards must start by justifying the need and minimising possible exposure (see legal aspects) and then the principles of control should be applied as follows:-

1. Basic methods of control;
 - following the correct procedures regarding monitoring facilities, analysing methods, working etc;
 - avoiding contamination;
 - cleanliness and good housekeeping.
2. Area classification (for more details, see legal aspects) e.g., follow the written "System of Work".
3. Local Rules (for more details see (36) and (9)).
4. Protective clothing/devices.
5. Design areas (working areas), for radioactive work, such as working surfaces, walls, floors, ceilings, etc.

1.4.2. Regulations and Safety Standards (Legal Aspects)

The legal aspects of ionising radiation/or safety standards can be defined as "the maximum permissible radiation dose a worker can receive in a given time". However, the specific function for both is to provide a challenge and impact for the radiation protection.

a) Objectives of legal aspects

The main objectives and purposes are:-

1. to provide guidelines for the protection of people from the risks of ionising radiation;
2. to reduce the risks resulting from ionising radiation exposure by minimising the affect;
3. to maintain this effect at an acceptable level

which is considerably below the threshold value, by keeping all exposures "As Low As Reasonably Achievable" (ALARA).

4. to formulate practical guidance for their application.

However, the legal aspect contains the fundamental requirements needed to control the ionising radiation exposure and plays a major role in minimising radiation doses which resulted from the following conditions:-

- the occurrence of exposure which can be foreseen limited by appropriate measures (normal condition);
- the source of exposure cannot be controlled, (abnormal condition) e.g., accidental exposure or emergency exposure.

b) The control systems of legal aspects

The main systems (20 and 36) are:-

1. system of notification, registration and licensing. This system is carried out by governmental agencies or official authorities;
2. system of dose limitation. This system consists of three complementary requirements:-

- i) Optimisation of radiation protection by keeping exposure ALARA

By keeping radiation doses as low as reasonably achievable, risks of harm are kept as low as possible.

- ii) Justification

Justification can be carried out by ensuring that radiological harm, which may be caused by the introduction of the

practice, is taken into account in the decision made.

iii) Individual dose limitation

Dose equivalent limits have been introduced to which no individual shall be exposed in excess. Different DEL's have been set for different organs (see Tables 7 and 8). For protection from non-stochastic effects, a dose equivalent limit of 500mSv/y has been set for all tissue groups except the lens of the eye, for which the limit is 150mSv/y (see Appendix 4).

The Annual Limit on Intake (ALI) used to control the occupational exposure, which is due to intake of radionuclides, i.e., the smaller value of intake of a given radionuclide which if it occurs every year, would deliver an effective dose to the body of 50mSv per year over 50 years or an average dose of 500mSv per year to any tissue group over a period of 50 years (20 and 36).

c) Duties and responsibilities

Usually the establishment or the company appointing any person concerned with any type of radiation sources and other work involving the use of ionising radiation do so in accordance with their country's standards and regulations. This means that the appointment of any person involved in the uses of radiation must be approved by the competent authority. This competent authority must establish authorised limits to apply to

individual persons, irrespective of the radiation source. (For more details see (36) Paragraphs 68-76).

Examples:- (36 and 9)

- Radiation Protection Adviser (RPA) must have sufficient technical knowledge to exercise special supervision with regard to the requirements of this procedure and to assist in enforcing its observance.
- Radiation Protection Supervisor (RPS) must have sufficient technical knowledge in respect of safe working techniques to attain the desired level of radiological protection in order to exercise "on-the-job" supervision with regard to the requirements of this procedure and the Local Rules/written System of Work (must be a Classified Person (CP)).
- Qualified Person (QP). A person who is authorised to carry out certain special duties and responsibilities relating to ionising radiations - always carries written evidence of such authority - (must be a classified person, his employment is involved in the use of ionising radiation/or whose work causes him to be in contact with ionising radiation to the extent that he might exceed an effective dose equivalent of 15mSv in any calendar year).
- Other persons are persons who may be exposed to ionising radiation as a result of working nearby but who are not directly involved with uses of ionising radiation (must be excluded from radiation areas and shall not exceed a whole body limit of 5mSv in any calendar

year). See Appendix (3).

d) Classification of working conditions

Internationally there are two classes of working conditions (20):-

- working condition "A",
where the annual exposure might exceed three-tenths (7.5 Sv/h) of the dose equivalent limit;
- working condition "B",
where it is most unlikely that the annual exposures will exceed three-tenths of the dose equivalent limit - see Appendix 3. The value of three-tenths represents a reasonable dividing line between conditions in which dose limits could be approached or exceeded, and conditions in which they are most unlikely even to be approached.

e) Classification of areas of work

All work areas where any type of ionising radiation is used or stored must be identified and classified according to the potential levels of exposure. However, two main areas were mentioned by international and national regulations and safety standards (36). These are:-

1. Controlled area

Where the radiation exposure may exceed three-tenths of the dose equivalent limit, i.e., 7.5 Sv/h, also where the access of workers is controlled and subject to operating procedures. These areas should be marked and warning signs must be fitted at the entrances and within the areas. Sometimes it is necessary to point out regions, within these

areas, where compliance with relevant limits can be achieved, by limiting the time the worker spends in this region or by recommending special protective clothing or devices during working time (see Appendix 3)

2. Supervised area

Where the dose rate does not generally exceed 7.5 Sv/h and hence where personnel will not exceed three-tenths of the dose limit, but monitoring of the environment should be carried out (see Appendix 3).

Generally speaking both these areas should be subject to the following requirements:-

- continuous radiation surveillance;
- clear and adequate working instructions;
- signs to be displayed indicating type of working area;
- appropriate instruments for identifying the risks resulting from these sources;
- provision of guidance notes relating to measures for restricting exposure.

f) Medical supervision

Medical examinations are required in order to provide medical surveillance of workers and to ensure that the work is carried out properly, e.g.,

- pre-employment medical;
- periodic medicals;
- special medicals.

These examinations are required without delay whenever a worker receives a radiation dose in excess of 100mSv (i.e., twice the annual dose limit), (36), or when there is reason to suppose

that any employee has been accidentally exposed to a higher than normal dose of radiation which might be due to the occurrence of some abnormal incident (see Appendix 3).

g) Record keeping

The keeping of up-to-date records of personal radiation doses is of great importance. These records must be kept for at least 50 years from the date of the last entry therein (36). These records which contain the results of monitoring of workers, work environment, medical examinations and maybe the surrounding environment, must be on forms acceptable to the competent authorities (see Appendix 3).

1.5. DETECTION OF IONISING RADIATION

As mentioned earlier in this chapter, ionising radiation - unlike light and heat - cannot be detected by our normal senses. Consequently it is necessary to have an instrument available that will detect it and determine its type and intensity.

1.5.1. Purpose of Measurement

Radiation measuring instruments can be classified into the following main categories:-

- a) laboratory instruments for measuring the activity of a sample in units related to the source strength, i.e., the number of becquerels (Bq);
- b) surveying instruments for measuring the rate of radiation in units, such as Sv/h, related to ionising and radiation damage to tissue;
- c) monitoring instruments for measuring total

cumulative exposure in units related to absorbed dose, e.g. grays (Gy).

1.5.2. Methods of Measurement

There are many techniques for the detection of radiation, the most important and commonly used are:-

a) Electrical Collection of Ions

The devices based on the principle of collection of ions formed in gas comprise the vast majority of instruments used. The most common of these are:-

1. Ionisation chamber

Modern ionisation chambers are usually cylindrical in shape. The current is too small to be measured directly by a millimeter and it is therefore amplified by a battery powered electronic circuit. Before using a radiation meter of this type certain precautions must be taken to make sure that the value indicated is the correct one. Firstly, it should be allowed to "warm-up", secondly, the meter should be adjusted to zero and then, before attempting to read radiation dose rates the scale selector position should be checked.

2. Geiger-Mueller counter

This counter is capable of detecting very small amounts of radiation. It does not give a uniform response for different energies and is accurate only for the type of radiation for which it is calibrated. For example, if it is calibrated for iridium-192, it will not be

reliable for cobalt-60. Also, an undesirable feature of the instrument is that it can become "saturated" in a field of high intensity radiation.

b) Photographic Detection

Darkening with photographic emulsion was the first method used to detect radiation. When radiation strikes photographic film it ionises the silver halide in the emulsion. The affect is so small that no visible change is produced in the undeveloped films, however, upon development the latent image is converted into a black deposit of metallic silver. This darkening is related to the type, energy and quantity of radiation to which the film has been exposed. This method is used to study the tracks of atomic particles. The most extensive use, however, is in X-ray diagnosis and autoradiography.

c) Scintillation of Crystals

Scintillation detectors have a number of advantages over the ionisation type instruments, their main features are:-

- ability to detect different types of radiation by changing the phosphor;
- high sensitivity, especially for gamma radiation;
- ability to measure high disintegration rates without losses due to dead time;
- the possibility of using them as spectrometers to determine the energy of the incident radiation.

Example: liquid scintillation counter
(see Point 1.5.7.b in the laboratory).

1.5.3. Other Methods of Detecting and Measuring Radiation (Table 9)

These are:-

- a) chemical decomposition;
- b) fluorescent and thermoluminescent detectors;
- c) calorimetric determination;
- d) recoil and nuclear reactions.

These methods are used for very specific situations only.

1.5.4. Calibration

Instruments are designed to read directly in radiation units, generally mR/h, R/h or CPS. However, for reasons given above, and since the characteristics of individual components can cause variations in instrument response, it becomes necessary to calibrate each instrument for the use intended. The "inverse square-law" provides a convenient approach for calibration. The dose rates from a source of known strength of the survey meter. (The calculated intensities and the meter readings should be approximately the same.) When calibrating an instrument, the reference point of the instrument is generally considered as the centre of the sensitive volume. For X-ray work the instrument must be calibrated for the energies in the region of interest. The amount of filtration and the type of X-ray generator must also be taken into consideration to obtain accurate calibration curves. A high degree of accuracy is required for measuring the output of an X-ray tube, however, for survey work where scatter intensities are of main interest, inaccuracies of the order of 10% may be tolerated.

a) Adjustment

Some survey meters have a calibration adjustment screw whereby the dial needle can be moved to read the dose rate calculated for that particular distance. If no calibration adjustment is available, the meter readings should be plotted against the calibrated intensities, on graph paper and this is used for correcting the readings obtained (Figure 2).

b) Calibration Curve

The calibration curve is used to determine the "true" radiation intensity and will indicate instrumental errors. So from 5 to 10 equally spaced scale readings should be taken and a graph of these values versus the calculated or "true" intensities at the corresponding point should be plotted on linear or log-log graph paper (Figure 2).

1.5.5. Maintenance and Care

Because instruments are very sensitive they should, therefore, be treated with care at all times. This can prevent unnecessary exposure of surveyors or operators only when in proper working conditions and if used correctly.

Before use these instruments should be checked to ensure that:-

- there are no physical defects;
- batteries are not weak;
- the instrument is in proper working condition in all respects.

1.5.6. Personal Monitoring Instruments

Personal monitoring instruments measure the accumulated radiation dose received by a person. These are different from the previous instruments, which normally measure the radiation exposure rate only. Various devices are used for personnel monitoring, the most common is the film badge, however, where daily and/or immediate exposure dose reading is required an ionisation-type dosimeter should be used in conjunction with the film monitor. However, there are other kinds of special dosimeters:-

- a) fluorescent glass dosimeters;
- b) thermoluminescent dosimeters (TLDs);
- c) scintillation dosimeters;
- d) calorimetric dosimeters;
- e) solid state detectors.

1.5.7. Instruments used in this Study

The instruments used in this study were similar to other radiation detection instruments in operation. Portable, sensitive simple in construction and reliable. There are:-

a) In the field (survey meters)

1. A Bertholt digital beta/gamma contamination monitor type LB1210D with a built-in xenon proportional counter tube was used.

Function

The function of this monitor is checked by means of a test source (approximately 100Bq of strontium-90 (Sr-90) which is built into the protection cover of the detector. When the protection cover is put on and key S-1 is pressed the monitor must show the same nominal

indication as the one inscribed in the protection cover.

Adjustment, Calibration, Battery Control and Background Compensation

See the instruction on the diagram (1).

Nuclide Pre-selection

Diagram (1) shows that the monitor has six keys for pre-selection of the nuclides. These are:-

- one key for the display in S^{-1} ;
- four keys with a fixed calibration factor;
- one key "FREECAL", where the user may adjust the factor corresponding to this key as he wishes.

The calibration factors corresponding to the four fixed nuclide pre-selection keys and other radionuclides (Table 10b). In case the radionuclide to be measured is unknown, key "I-125", i.e., the group of nuclides with the largest factor, must always be selected.

Optical and Acoustical Indication of the Single Pulses for Detecting Contamination

To detect contamination, the acoustical indication for single pulses is switched on via the key marked with the loud-speaker symbol. The audible change of the pulse rate facilitates detection significantly. Detection is also made easier when the green LED to the left of the display field is watched; this LED also flashes up according to the rhythm of the single pulses. These points have to be observed. The optical as well as the acoustical indication is reduced by the factor

2 compared with the actual single pulse sequence, resulting in an audible and visible range which can be evaluated much more easily.

Calibration of Contamination Monitor - Factors which influence the Measurement

1. Type of radionuclides:-

- decay pattern of the nuclide including type, energy and frequency of the emitted radiation;
- sensitivity of the detector for the various types of radiation and energies.

2. Area geometry of the calibration standard:-

- ratio of the window area of the detector and the area of the calibration standard.

Therefore, it is important to the user to know the nuclides to be measured otherwise the measurement may be inaccurate.

Advantages and Disadvantages

1. Advantages:-

- the display is easily understood by the inexperienced user;
- the display allows direct comparison with the limit values;
- the threshold adjustment on the monitor is clear and independent from the radionuclide which is already installed;
- the fixed calibration factors are known and may be verified at any time, contrary to the possibly "free" factors for the subsequent conversion of S^{-1}

into Bq.cm⁻²;

- regular checks of the monitor with area sources of known activity are very simple, standard values can be read off directly;
- for stationary monitors at least, and pre-selected nuclides the calibration factor valid for conversion can be documented together with the measuring value.

2. Disadvantages:-

- very sensitive (as mentioned in f)
- Ref: IR.1.

2. "Panoramic" Survey Meter

Function

This survey meter is an ionisation chamber meter used to detect beta, gamma and X-ray radiation. It can measure total exposure rates from 3 mR/h approximately (30 Sv/h) full scale for gamma and X-ray energies from 8.0keV to 2meV.

Adjustment

Since the instrument is susceptible to zero drift after initial turn on or when subjected to environmental extremes, zeroing is provided which may be accomplished in high radiation fields. Depress the zero set button adjacent to the zero adjust control on the instrument until the meter reads zero. Release the zero set button and the instrument is ready for operation.

Calibration Procedures

- Set the 470A to 1R/h range. Zero the 470A

- Pull out the Victoreen logo plate and look down through the opening at the circuit board. The calibration potentiometer, R7, is the lower one on the right hand side - subject the ion chamber to a low R/h field and adjust the pot for the correct reading. Use the equilibrium cap if the effective energy of the source is over 100keV. Be sure to correct for temperature, pressure and energy response. (see Factors to be considered below).

Factors to be considered

- Calibration. The 470A is calibrated at the factory. When field calibration is performed, correction factor procedures, as mentioned above, must be remembered.
- Energy dependence. Any ion chamber has a certain energy dependence that is holding the exposure rate constant, the chamber responds differently to different energy photons. (470A has been calibrated at an effective energy of 662KeV from Cs-137.
- Temperature and pressure. Air, at standard temperature and pressure is the ionised medium in the exposure rate definition. The density of the air determines directly the ionisation rate with all other factor held constant. The density is, in turn a function of barometric pressure and kelvin temperature. Since the ion chamber is not sealed, a small correction must be made for temperature and barometric pressures different from those during calibration. A standard temperature 0°C is rarely

encountered in practice. The 470A is calibrated and corrected to 22°C and 760mmHg.

- Angular dependence. The shape, well material, centre electrode design, and position of the ionisation chamber of the 470A results in an instrument response relatively independent from the direction of the incident radiation.
- Source distance. If a point source or a collimated beam is used, the 470A chamber must be far enough away from the source so the entire ion chamber is uniformly exposed. In practice this means any point source should be at least one meter from the ion chamber.

Ref: IR.2.

3. Mini Instruments 5-10EL (GM tube)

Function/Uses

This monitor is designed for use in teaching research, hospital and industrial laboratories. When fitted with a suitable probe it will measure contamination down to the lower contamination limits from C-14, S-35, Ca-45 and I-131 as well as the more penetrating beta emitters but not H-3 and indicate gamma or X-ray background intensity.

A thin end window GM tube of thickness 1.5-2.2mg cm² and area 6.4cm² is contained in a black anodised holder fitted with a stainless steel grille to protect the fragile window. The tube is sensitive to alpha particles and can estimate contamination level down to about 7Bq/cm².

Calibration

The calibration potentiometer is sited at the bottom centre of the printed circuit board. To re-calibrate, inject square pulses of a few volts via a capacitor of about 10pf into the input. The pulse repetition rate will need to be corrected to allow for the paralysis time correction incorporated in the scale. Input pulse rate =

Scale reading

$1 + \text{Scale reading} + \text{paralysis time}$

Adjustment

The adjustment depends upon the probe type and EHT supply. The potentiometer is sited on the circuit board at 2 o'clock from the transformer. First turn the set alarm control maximum clock-wise. Using a strong source to send the meter hard off scale, adjust the overload control to set off the alarm. Then reset the alarm to the desired position.

Ref: IR.3

3. Portable Air Sampler - Type L5-10

The above sampler is complete with battery pack and integral 60mm filter paper holder.

Function/Uses

The L5-10 air sampler can be used for any static air sampling application. A 40 litre sample of air is drawn through a 60mm Whatman No.2. filter paper at a convenient flow rate.

Specification

Flowrate: 5-10 litres/minute fully adjustable by needle valve within this range.

Flowrate indication: Floating ball; gauge calibrated 5 to 10 l/min.

Battery type: Ni-Cad rechargeable 6 x 1.2V,
2A/hr pack.

Technical Description

The pump used in the L5-10 is a sliding vane type containing four blades made of SRBP. This is driven by a 12 volt motor under-run at about 7V from 6 x 2 A/hr nickel cadmium cells with red in series. The pump inlet is connected to the 60mm filter holder through the floating ball flow gauge. The lower flow gauge mounting block incorporates the flow control, a restriction valve with a slotted head for ease of adjustment. A two-pin socket on the side of the sampler allows a battery charger to be connected without removal of the battery. Ref: IR.9.

b) In the Laboratory

1. Liquid scintillation counters
models numbered 1211 and 1212

Introduction

Liquid scintillation counting is the best method for counting weak beta emitters such as H-3, C-14 and S-35. Indeed the method may be used to count any radioisotope but it does involve expense and trouble of preparing a special solution for counting.

The radioactive substance to be measured is dissolved in a solvent which also contains an organic scintillator so the source is intimately mixed with the detector and effects due to the absorption of radiation are minimised. The solution is placed in a capped counting vial which is then placed, either manually or mechanically, into a light-tight

chamber where one or more photomultiplier tubes detect the scintillations and convert them into electrical pulses for counting (Diagram 3). The model used in this study was an LKV-Wallac Mini Beta. It is an automatic micro computer controlled four channel liquid scintillation counter. This model is intended for counting beta emission over the range 1keV to 2800 keV.

Programme Modes

There are three ways in which the Mini Beta may be used to count samples. The basic instrument uses single label with sample channels ratio method (SCR). Other options such as external standard option allows single and double label counting with external standard channels ratio method (ESCR). These are grouped into five programme modes with present count windows and printout for the most common counting situations. Ref: 21, 10 and IR.5.

1.5.8. Personal Monitoring Instruments Used for Workers who deal with Ionising Radiation as Alternative Method to Detect any Accumulated Radiation Dose

a) Film Monitor (film badge)

It is a piece of photographic film very much like dental film. The photographic emulsion is especially suited for ionising radiation. The film, when exposed to radiation, and subsequently processed shows blackening just like ordinary film exposed to light. The degree of blackening is related to the exposure. The situation is somewhat complicated because the degree of

blackening also depends on the quality of the radiation. In a personal monitor it is, therefore, necessary to have some method by which the quality of radiation can be found. In most countries, radiation protection authorities provide a national X-ray and gamma-ray film monitoring service in which many thousands of films are processed on a regular basis. (Here in Manchester, for example, the Radiation Protection Laboratory at Christie Hospital and Holt Radium Institute is responsible for the monitoring service.)

The dosimeter used consists of the following components:-

1. the film packet;
2. the film packet holder.

The holder can be assembled only with identical foils facing each other, then the film surface is divided into four areas:-

1. window area, open on both sides;
2. an area between lead foils;
3. an area between copper foils;
4. a narrow window open on one side only, on which the wearer's name is printed.

The degree of penetration of radiation through these foils depends on the quality of the radiation. It is, therefore, possible by measuring the ratios of blackening on the various portions of the film to get a fair idea of the quality of radiation to which the film has been exposed. Knowing this, it is simple to measure the radiation dose.

Calibration

By exposing films to a known amount and quality of radiation and then measuring the blackening in each area.

The films are very carefully processed, the blackening or the optical density is measured on a very accurate instrument and data processed on computing machines. The advantages of film badges are:-

1. they provide a permanent record of the radiation exposure received;
2. provide information about the quality of radiation the film was exposed to;
3. economical;
4. detects loose contamination;
5. can be used as an area monitor;
6. has a wide range from a few Sv to more than the lethal dose for energetic radiation.

The disadvantages of film badges are:-

1. they have to be treated with reasonable care and should not be roughly handled, or subjected to high temperatures;
2. they are not suitable for giving an immediate indication of the exposure received during an accident.

Thermoluminescent Dosimeters (TLDs)

Of the other types of personnel dosimeters, the (TLD), is the most useful for determining surface exposure rates. It can be used for measuring the possible doses of radiation received during the isotope handling operation, which might arise from the following sources:-

2. solutions contaminated in small plastic tubes;
3. labelled materials in small columns within centrifuge tubes;
4. extended sources, e.g., membrane, labelling solutions, either in hybridisation badge or in protein labelling plastic boxes;
5. small concentrated drops of contamination on skin or clothing.

TLDs can be used to evaluate short exposures for any particular manipulations. It can then be quickly decided whether to modify, reduce or eliminate some handling operation, or to decide that the work in its present form cannot be permitted to continue, (21).

Also TLDs are used in clinical work, accident analysis and research, in order to make workers aware of the magnitude of the risk involved in using sources.

The main advantages of TLDs are that they can be made in different shapes and sizes, and are thus very suitable for monitoring doses (to the fingers for example), and in other conditions where film badges are not always so adaptable.

The phosphors commonly used are suitably activated, LiF , CaF_2 and CaSO_4 . A definite small weight of phosphors is enclosed in a sachet in a suitable holder that is worn in the manner of a film badge.

The phosphor is heated under precise conditions and the dose automatically read and recorded.

TABLE 1

**Average Annual Effective Dose Equivalent
for Radiation of Natural Origin**

<u>Source</u>	Dose (<u>μSv/year-1</u>)
Cosmic	250
Terrestrial (earth gamma rays)	350
Radon decay products	1,200
Thoron decay products	100
Other internal radiation	300

Source: Ref. 29.

TABLE 2

COUNTRIES WITH NUCLEAR POWER REACTORS IN OPERATION (1984)

COUNTRY	NUMBER OF UNITS	TOTAL CAPACITY (MW)
United States	85	68,867
France	41	32,993
USSR	46	22,997
Japan	31	21,751
Germany (F.R.)	19	16,133
United Kingdom	37	9,564
Canada	16	9,521
Sweden	10	7,355
Spain	7	4,690
Belgium	6	3,474
Switzerland	5	2,882
Finland	4	2,310
Korea (Rep.OF)	3	1,790
German (D.R.)	5	1,694
Bulgaria	4	1,632
Italy	3	1,273
Czechoslovakia	3	1,194
India	5	1,020
Argentina	2	935
South Africa	1	921
Hungary	2	820
Yugoslavia	1	632
Brazil	1	626
Netherlands	2	508
Pakistan	1	125

Source: Ref.37.

TABLE 3

SUMMARY OF DOSES FROM NUCLEAR REACTOR EXPOSURE IN THE UK

No.	TYPE OF PROCESS	NUMBER OF WORKERS IN DOSE RANGE mSv				TOTAL NO. OF WORKERS	ANNUAL COLLECTIVE DOSE man.Sv	AVERAGE ANNUAL DOSE mSv
		0-5	5-15	15-50	>50			
1	Fuel fabrication	2865	468	71	0	B.404	9.7	2.8
2	Fuel enrichment	988	0	0	0	988	0.2	0.2
3	Fuel reprocessing	6799	1975	632	1	9407	39.1	4.2
4.	Power stations	22208	701	62	0	22971	18.1	0.8
5.	Research establishment	8223	820	149	3	9195	24.6	2.7
All Nuclear Industry		211083	3969	914	4	45965	91.8	2.0

Source: Ref.16.

* Includes contractors, visiting employees, and site reactor staff.

** Excludes reactor staff at reprocessing site and UKAFA site.

TABLE 4

DOSES TO WORKERS IN GENERAL INDUSTRY IN 1987

GROUP	NUMBER OF WORKERS IN DOSE RANGE mSv				TOTAL NUMBER OR WORKERS	ANNUAL COLLECTIVE DOSE man.Sv	AVERAGE ANNUAL DOSE mSV
	0-5	5-15	15-50	>50			
Industrial radiographics	3050	79	29	4	3162	3.60	1.1
Radiological protection	442	1	5	0	448	0.23	0.5
Servicing equipment	3065	7	2	0	3074	0.74	0.2
Manipulating materials	1802	5	1	0	1808	0.56	0.3
Miscellaneous industry	2144	31	5	0	2180	1.06	0.5

Sources: Ref.16

TABLE 5

TIME FRAME FOR EFFECTS OF IONISING RADIATION

TIME	EVENTS
<u>Physical Stage</u> $\leq 10^{-15}\text{Sec}$	Formation of H_2O^+ , H_2O and subexcitation electrons, e^- , in local track regions ($\leq 0.1, \mu\text{m}$).
<u>Prechemical Stage</u> $\sim 10^{-15}\text{Sec. to } 10^{-11}\text{Sec.}$	Three initial species replaced by H_3O^+ , OH , e^-_{aq} , H , H_2 and O .
<u>Chemical Stage</u> $\sim 10^{-11}\text{Sec. to } 10^{-6}\text{Sec.}$	The four species H_3O^+ , OH , e^-_{aq} and H diffuse and either react with one another or become widely separated. Intratrack reaction essentially complete by $\sim 10^{-6}\text{Sec.}$
<u>Biological Stages</u> $\leq 10^{-3}\text{Sec}$ $\leq 1 \text{ Sec}$ Hours Days Weeks Years	Radical reaction with biological molecules complete Biochemical changes Cell division affected Gastrointestinal and central nervous system changes Lung fibrosis develops Cataracts and cancer may appear, Genetic effects in offspring

Source: Ref.21

TABLE 6

**PRINCIPAL HARMFUL RADIATION CONDITION
FOR OCCURRENCE AND SOURCE OF INFORMATION**

STAGE	EFFECT	CONDITION	INFORMATION
E A R L Y	Death	Very high dose and dose rate to much of body to area of skin to testes and ovaries	Human data from various sources
	Erythema		
	Sterility		
L	Malignant Diseases	Any dose rate, probability depends on dose manifested years later	Risk data for human by linear extrapolation from high doses and dose rates. Various sensitivities of organs
A T	Hereditary Defects	Any dose or dose rate probability depends on dose manifested in descendants	Risk data for human by infestence from mouse data. Upper limit from human dataA
E	Non-Malignant Changes	Very high dose various time to manifestation	Human data from various sources
	Developmental Change	Irradation of embryo Manifested after birth	Limited human data

Sources: Ref.29

TABLE 7

DOSE EQUIVALENT LIMITS (DEL) IN mSv IN A YEAR GIVEN OR IMPLIED
BY ICRP PUBLICATION 26 WITH COMPARATIVE LIMITS IN ICRP PUBLICATION 9

Tissue/organ	Worker			Member of the public		
	Stochastic	Non-stochastic	ICRP Pub.9	Stochastic	Non-stochastic	ICRP Pub.9
Whole Body	50	-	50	5	-	5
Tissue/organs irradiated singly:						
gonads	200	500	50	20	50	5
breast	330	500	150	33	50	15
red bone marrow	417	500	50	42	50	5
lungs	417	500	150	42	50	15
thyroid	1670	500	300	167	50	30
bone surfaces	1670	500	-	167	50	-
lens	-	300	150	-	50	15
other single organ	633	500	150	83	50	15
bone	-	-	300	-	-	30
skin	-	500	300	-	50	30
hands and forearms	-	-	750	-	-	75
feet and ankles	-	-	750	-	-	75
Planned special exposure						
single		2xDEL	2xDEL			
lifetime		5xDEL	5xDEL			
Pregnant women						
after diagnosis of pregnancy	0.3xDEL pro rata		10			

Source Ref.18.

TABLE 8

STATUTORY DOSE LIMITS

(ADULT EMPLOYEES AGED 18 YEARS AND OVER)

ORGAN OR TISSUE DOSE LIMIT	PREVIOUS NUCLEAR SITE LICENCE REQUIREMENT (mSv)	NEW IONISING RADIATIONS REGULATIONS REQUIREMENT (mSv)
Annual Dose Limits		
Whole body	50	50
Lens of the eye	150	150
Hands, forearms feet and ankles	750	500
Bone and skin	300	500
Gonads and Red bone marrow	50	500
Any other organ	50	500
Other Dose Limits for the Abdomen		
Women of productive Capacity	13 per calendar quarter	13 per consecutive 3 calendar months
Pregnant women	10 during the declared term of pregnancy	10 during the declared term of pregnancy

Source: Ref. 36

1. Received dose from both external radiation in the year and internal radiation in the year arising from intake in that year and in previous years.
2. Committed effective dose from both external radiation and internal radiation arising from intake in the year.
3. Committed dose from both external radiation and internal radiation arising from intake in the year: the values given are the non-stochastic limits. In some cases (dependent on the organ and nature of the exposure) the requirement to add a contribution of dose to the whole-body committed effective dose may be more limiting.
4. Received dose from external radiation.

TABLE 2

DETECTION AND MEASUREMENT OF RADIATION

EFFECT	TYPE OF INSTRUMENT	DETECTOR
Electrical	1. Ionisation chamber	1. Gas
	2. Proportional counter	2. Gas
	3. Geiger counter	3. Gas
	4. Solid state	4. Semi-conductor
Chemical	1. Film	1. Photographic emulsion
	2. Chemical dosimeter	2. Solid or liquid
Light	1. Scintillation counter	1. Crystal or liquid
	2. Cerenkov counter	2. Crystal or liquid
Thermolumi- nescence	Thermoluminescent dosimeter	Crystal
Heat	Calorimeter	Solid or liquid

Source: Ref.7

TABLE 10

A STATISTICAL FLUCTUATION OF THE BACKGROUND INDICATION WITH NORM
AMBIENT RADIATION OF APPROX. $8-10s^{-1}$ AND PROPER BACKGROUND
COMPENSATION

NUCLIDES OR SETTING	TIME CONSTANT	
	2S	20S
S ⁻¹	± 4.00	± 1.50
125-I	± 0.99	± 0.30
137-Cs	± 0.10	± 0.03
14-C	± 0.60	± 0.20
90-Sr	± 0.05	± 0.02

"B" Group formation of Calibration factors, probe BZ 100
(window area 110m x 110mm, net area when taking into account
the protection grating 100cm², thickness of foil mg cm⁻²,
xenon filling).

NUCLIDE	CALIBRATING FACTOR Bqcm ⁻² S	MEAN VALUE OF THE GROUP	MAXIMUM ERROR
125-I	0.285	0.275	± 4%
99-Tc	0.265	0.275	± 4%
14-C	0.195	0.190	± 3%
57-Co	0.85	0.190	± 3%
131-I	0.038	0.190	± 3%
137-Cs	0.040	0.040	± 7%
204-Tl	0.043	0.040	± 7%
36-Cl	0.039	0.040	± 7%
32-P	0.026	0.027	± 3%
90-Sr/90-Y	0.028*	0.027	± 3%

Source: Ref. related to the total activity of the
"double nuclide" 90-Sr/90-Y.

**Graph 1. Sources of UK population
radiation exposure 1989 (%)**

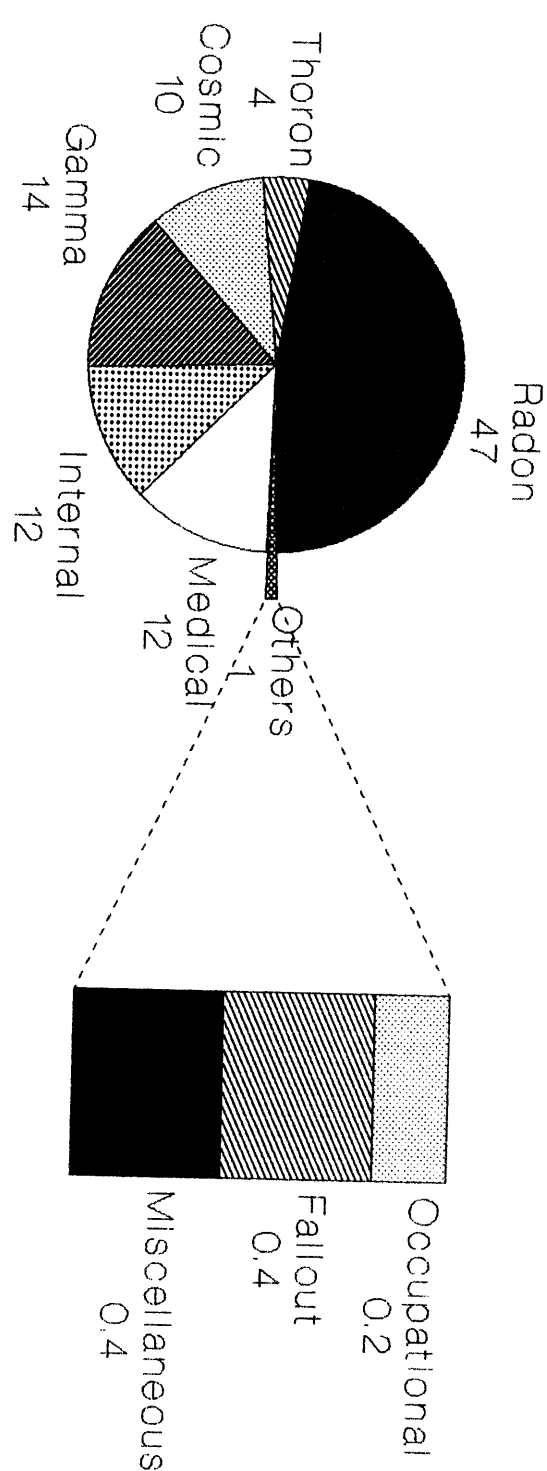


Diagram 1. Contamination Survey Meter

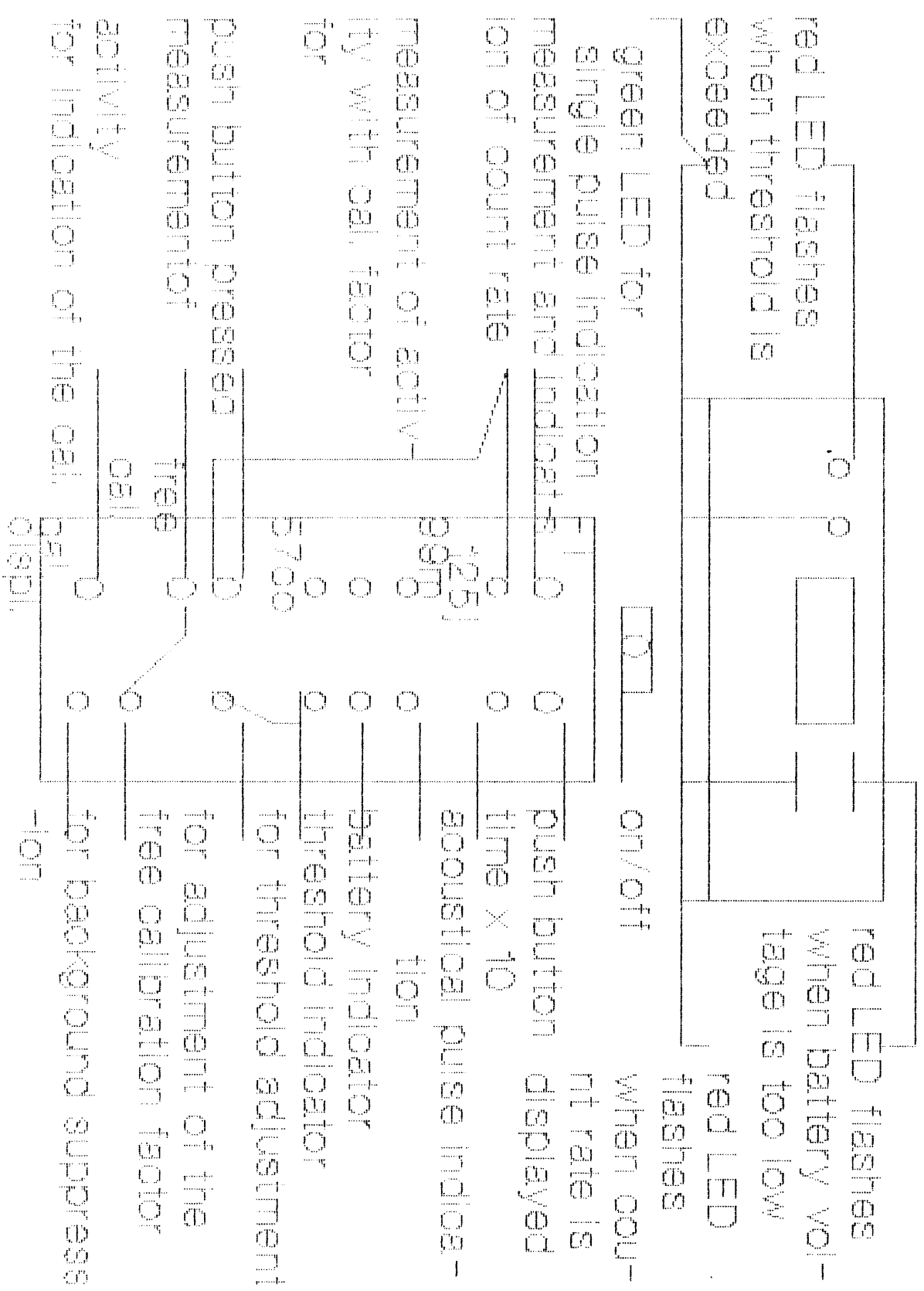


Diagram 2.

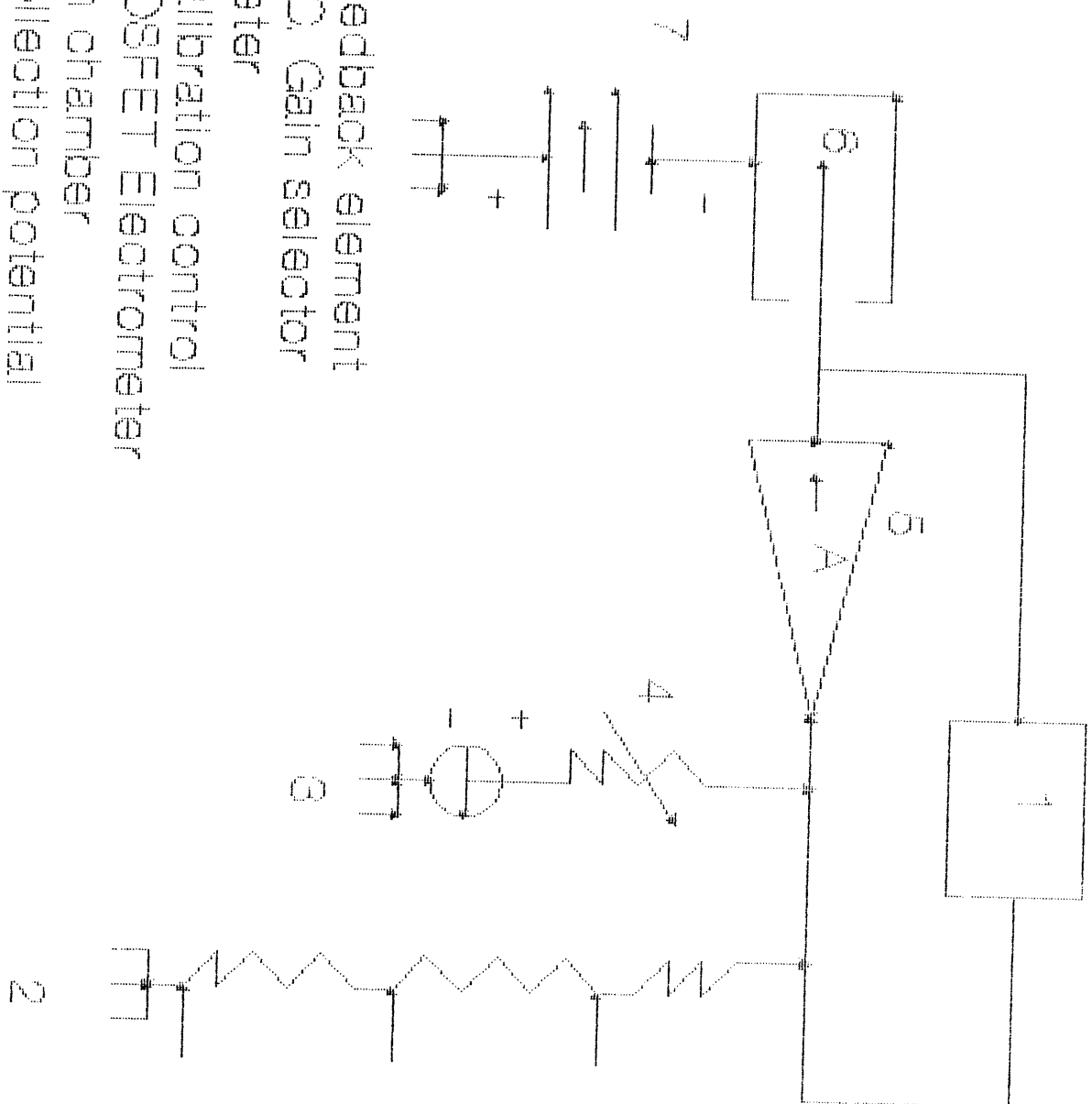


Diagram 3 -A block diagram of a simple liquid scintillation counter

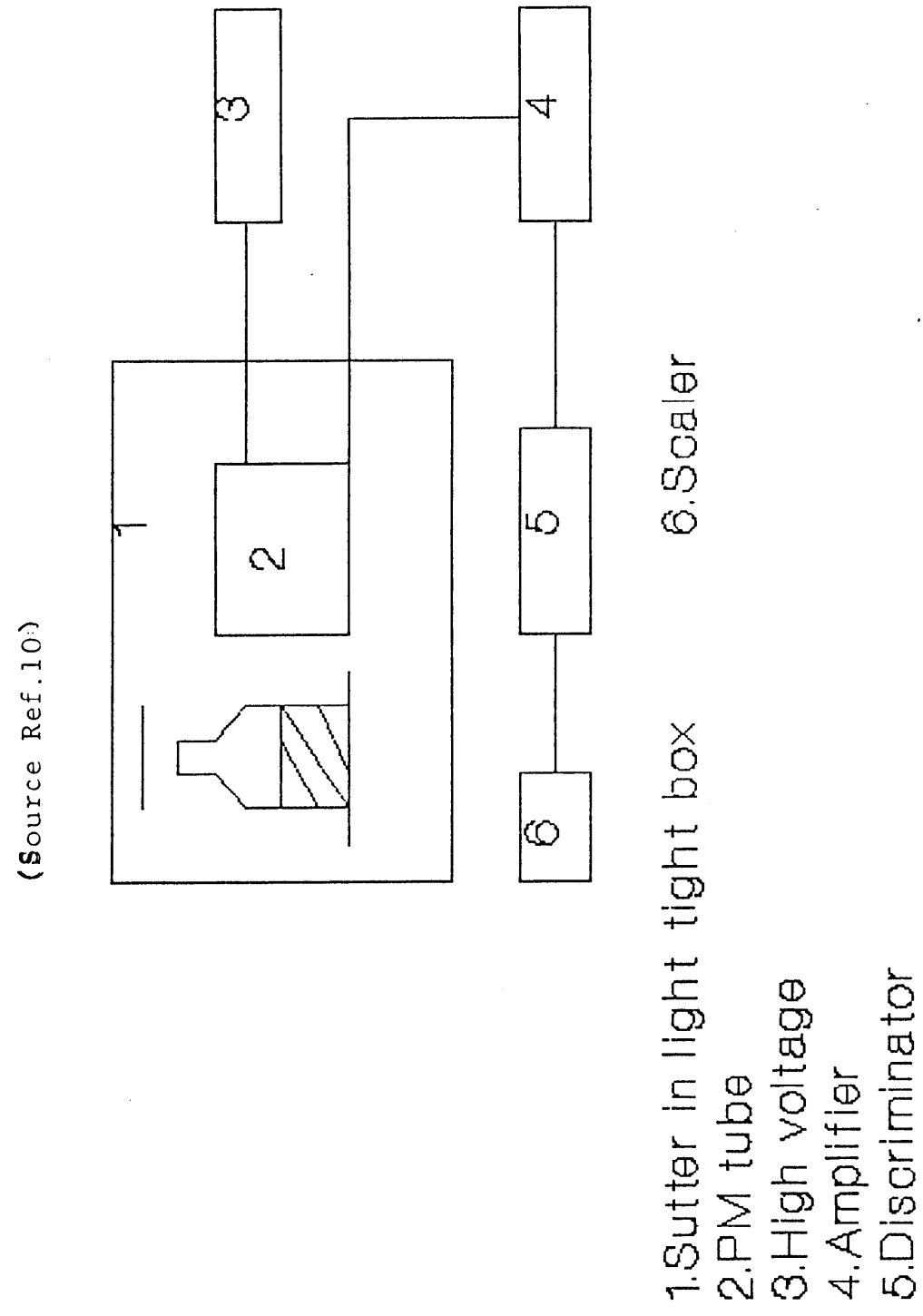


Diagram 4- Mini-Beta (control panel)
(source: Mini-Beta manual)

1	2	3	0	START (a)
4	5	6	.(d)	STOP (b)
7	8	9	F (e)	EDIT (c)

- a)starts automatic counting(with group No. and F
- b)stop counting and parameter setting
- c)allows parameter setting
- d)separator in window setting and print selection
- e)enters intructions into instrument

Fig.1 Dose-response relation

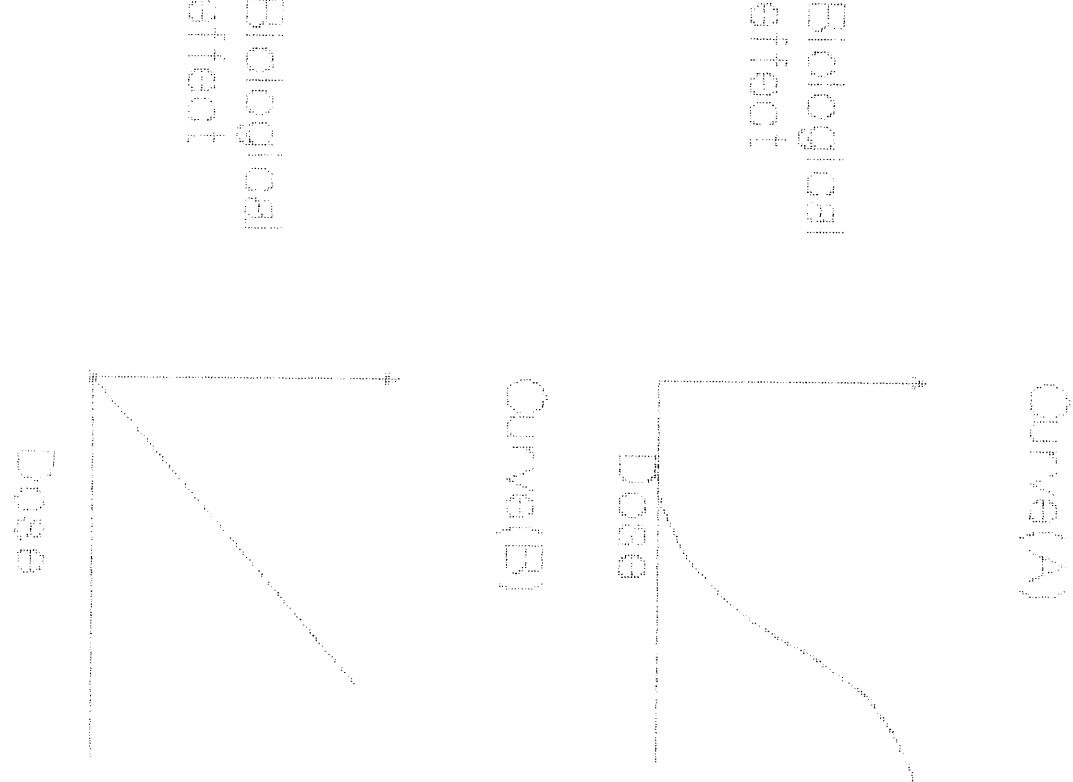
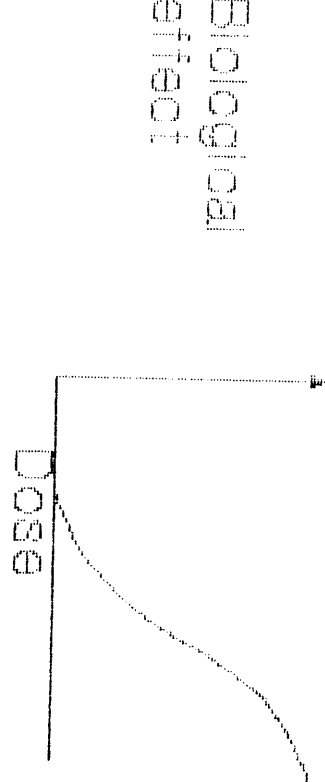


Fig.1.Dose-response relation

Curve(A)



Curve(B)

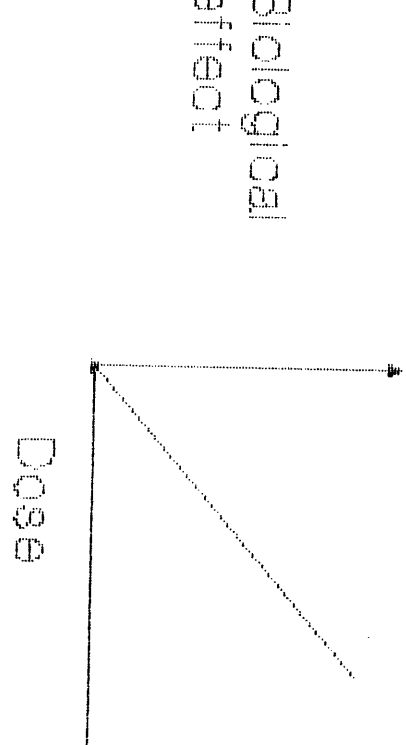
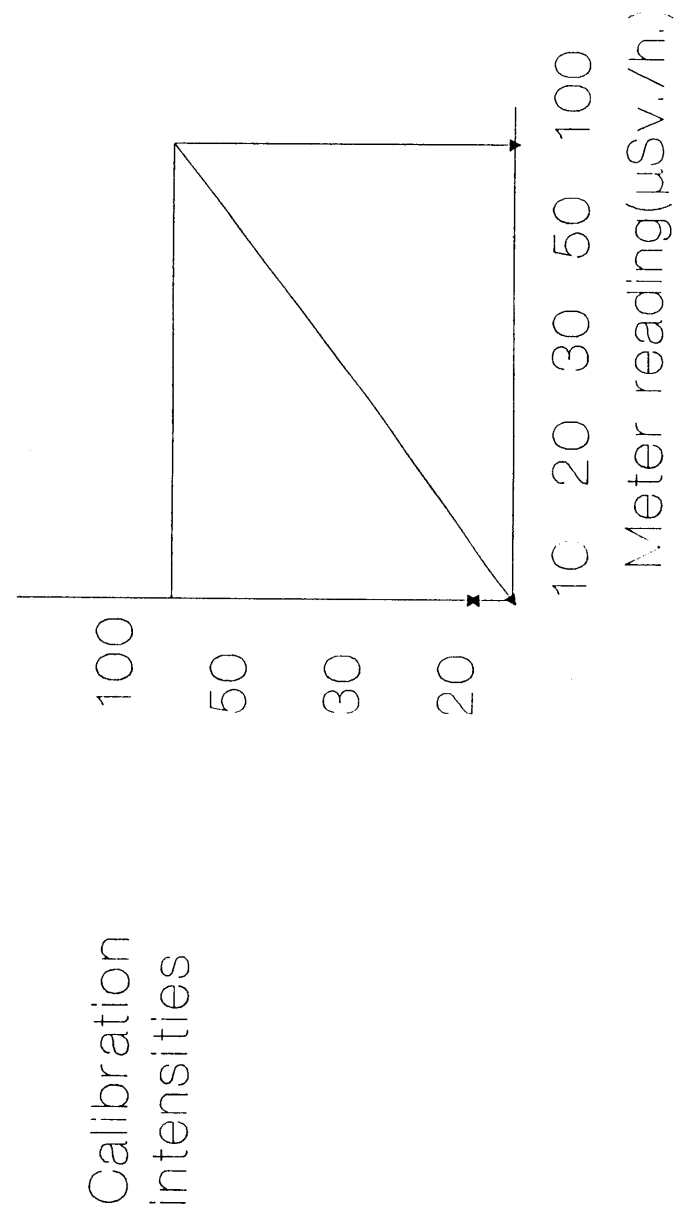


Fig 2. Calibration Curve (detrmination of true radiation intensity)



As shown above,a Meter reading of 100 μSv./h indicated on the horizontal axis,gives a TRUE intensity of 70 μSv./h. as read on the vertical axis.

RADIATION DOSES FROM RESEARCH LABORATORIES

2.1. INTRODUCTION

2.1.1. Uses

The practical applications of radioactive material are extremely widespread, for example, from medicine to industry and research. It is used in unsealed or open sources to trace chemicals participating in various reactions. For example, in medicine, radiotracers are used as radiochemicals to study the metabolism of potential new drugs. Whilst in biological research, structural studies on macroscopic and microscopic biological materials can be carried out by incorporation of a suitable precursor followed by autoradiography, a method whereby the position of the radiochemical is detected by the interaction of its emission with photographic film (Ref.30 and 11).

Examples:-

- a) the localisation of receptor sites on cell surfaces by the attachment of labelled steroids;
- b) phosphorus-32 (P-32) is particularly useful for studies on Ribo Nucleic Acid (RNA) and Deoxy Ribo Nucleic Acid (DNA). It has proven an excellent marker for invivo DNA (labelling and for phosphorus metabolism studies in plants and animals, (4 and 25).

2.1.2. Occupational Hazards (Radiation Hazards)

Contamination occurs when a radionuclide spreads beyond the normal place of confinement. The radionuclide thus released may spread through the

work's environment (air, water, floor, benches and surfaces in general), and become partially fixed for some time. It may eventually affect the worker and become fixed on the inside and outside of the worker's body. This external contamination may involve the worker personally, his clothes, work's equipment/tools, working surfaces (benches, sinks, floors, etc.) and other surfaces in the working rooms. Therefore, the main occupational hazards are:-

a) The direct effect on the workers

Contamination of the worker is usually the result of an accident. It can affect workers who handle radionuclides or who deal with or use the radionuclides. It takes the form of contamination of the hands or other areas of the skin. The seriousness of this contamination depends mainly on the dose delivered at the site where the radionuclide settles. Internal contamination occurs either through penetration of the skin or through ingestion.

b) Clothing

In any working areas, working clothes may become contaminated but major contamination is almost always the result of a handling incident or mishap. Contamination of clothing carries the risk of irradiation of skin and the danger of internal exposure by the inhalation of radioactive suspensions in air.

c) Equipment/tools/apparatus

The contamination of working equipment, such as glassware, trays, handling and laboratory tools in general is obviously undesirable as it may lead to contamination of the workers and could also cause

errors in analysis and measurements.

2.1.3. Contamination Measurement in the Workplace

Contamination measurements are used as a basis for detection of radioactive material released from working areas, and for determination of the level of radiation exposure or radiation doses which may affect the worker. Generally speaking the aims are:-

- a) to control operations and to provide information for the prevention of spread of contamination;
- b) to provide general knowledge of hazards in the working environment and to protect the workers from these hazards;
- c) to serve as an indicator of deteriorating conditions or as a warning indicator to warn before the hazards occur (31).

Contamination of the workplace/working surfaces, such as floors, sinks, walls and benches may originate from limited spills, the settling of aerosols present in the air and the transfer of contamination by footwear. It may also result from a contamination accident such as the spillage of radioactive solution or other substance. The result usually is the exposure of workers in their skin or clothes.

2.1.4. Type of Isotope Used in this Study

Phosphorus-32 has been used during this survey in five biochemistry laboratories; at Manchester University Medical School and the University of Manchester Institute of Science and Technology (UMIST). In the above laboratories P-32 is used for three labelling techniques, by researchers undertaking studies involving genetic manipulations, cloning,

hybridisation and recognition of complex patterns of DNA sequences. The physical properties of P-32 are summarised in Table 11.

2.1.5. The Techniques Used in the Two Laboratories

- a) Estimation of the sizes of DNA molecules by analysis of DNA/RNA hybrids with a single-strand specific nucleus. This is carried out by examining the RNA isolated from bacteria at different times to look at the expression of a particular gene.

Processing

1. Isolation of RNA.
2. S1 mapping (liquid hybridisation of a specific DNA species with total cellular RNA).
3. Agarose gel electrophoresis to separate RNA/DNA hybrids generated (in 2 above), according to the size.
4. "Southern Blotting" - transfer of the RNA/DNA hybrids from the agarose gel onto a nylon membrane.
5. Labelling of the specific DNA species (used in 2 above) with P-32 Deoxycytidine-triphosphate to make a probe.
6. Using DNA from 5 to probe the membrane.
7. Wash away DNA that has not bound to the membrane.
9. Exposure to X-ray film to obtain an autoradiographic image. (If the gene is expressed we will see a band on the gel at each time point - Table 12a).

b) NICK Translation

This technique refers to the activity of DNA polymerase. Most purified samples of DNA contain

some nicked molecules. The reaction requires a supply of nuclides, if one of these is labelled with a radioactive species then the DNA molecule will itself become labelled.

NICK translation can be used to label any DNA molecule but may, under some circumstances, also cause DNA cleavage processing.

1. NICK translation per becquerel quantities of P-32 per probe (one probe for each filter).
2. Hybridisation of filters with labelled DNA (adding labelled DNA to filters and incubate at 42°C).
3. Washing the filters.
4. Exposing the filter to X-ray film to obtain an autoradiographic image (Table 14b).

c) Random Primed DNA Labelling

This technique is used to modify P-32 present in the reaction into the ready synthesized complimentary DNA stand.

Processing

1. Random primed DNA labelling using Bq quantities of P-32.
2. Drying the label down and collecting it from the dryer after 30 minutes.
3. Labelling reaction (adding labelled DNA to filters) - mixing it and incubating at 37°C.
4. Stopping the reaction by adding 2ml EDTA 0.2mol/l and heating it to 65°C for ten minutes.
5. Hybridisation of filters.
6. Washing the filters.
7. Exposing the filters to X-ray film to obtain an autoradiographic image (Table 15a).

2.2. METHODS OF MEASUREMENT

Three methods/procedures were used to assess the radiation doses in five biochemistry laboratories (Manchester University and UMIST). These methods were:-

1. Surface contamination measurement

A survey meter (digital contamination monitor LB1210D) was used to measure radioactive surface contamination.

2. Monitoring of airborne radioactivity

Two pieces of equipment were used to take measurements of air contamination in both locations:-

- a) air sampler (L5-10 portable);
- b) liquid scintillation models 1211 and 1212.

Both the above were used in the following procedures:-

a) Sampling procedures

- Air samples were collected by using filters for ten minutes.
- Samples were collected once every ten minutes in each work site in the laboratory for a period of four consecutive weeks.
- Sampling filters were removed for analysis on a daily basis.
- The blank (unexposed filters) were used for background counting.

b) Analytical procedures

- Putting the filter paper in a glass bottle.
- Adding 20ml of Ecoscint (counting solution).
- Doing the same with one blank filter paper.
- Counting for 600 seconds for each sample by using a liquid scintillation counter.
- Adding 10ml of standard to each sample.
- Re-counting.

c) Calculation

The air volume sampled was known and the mineral

activity was compared to a standard. Hence the airborne activity could be calculated.

3. Dosimetric measurement

Two types of dosimetry were used to measure the accumulated radiation dose during the uses of the radioactive isotopes.

- a) TLDs were used to measure worker's finger doses over two weeks. TLDs were chosen since hand exposure was considered to be of greatest importance for this type of procedure. Each worker wore a TLD on the fingers of both hands.
- b) Film badges were used to measure the whole body dose, for a period of six months being changed at monthly intervals.

2.3. RESULTS

2.3.1. Surface Contamination Measurements

The programme was implemented using the following methods:-

- a) Direct measurements were made in the following sites:-
 - controlled areas, where experimental staff carried out DNA sequencing experiments;
 - supervised areas, where experimental staff moved throughout the areas for purposes such as collecting and washing the experimental tools.
- b) check-lists or inspection forms have been used to check laboratory design, handling devices, monitoring devices, ventilation, etc. (see Lab 2.382 - Form 1 as an example).

c) Random measurements

Contamination measurements were taken from different sites within the laboratories. Floors,

benches and sinks were monitored. Measurements were also taken after the experiments were finished and the sinks had been washed.

I. UMIST Laboratories

The contamination measurements were carried out in four laboratories, one of these (F.23) is used for washing membrane filters for Lab.G.20 and F.7. The other laboratories are used as the main isotope laboratories. Phosphorus-32 work had been carried out in all laboratories.

Lab.No.G.20

a) Direct measurements were taken in the following areas:-

- 7 measurements in the controlled area;
- 12 measurements in the supervised area;
- 9 measurements taken at random.

See Tables 12a and 12b.

The average surface contamination measurement result is shown in Table 17 and Graph 2.

b) Check-list/inspection results shown in Table 13.

Lab.No.F.7

a) Direct measurements were taken in the following areas:-

- 9 measurements in the controlled area;
- 5 measurements in the supervised area;
- 7 measurements taken at random.

See Tables 14a and 14b.

Average measurements are shown in Table 17 and Graph 2.

b) Check-list or inspection results shown in Table 13.

Lab.No.F.28

a) Direct measurements were taken in the following areas:-

- 5 measurements in the controlled area;
- 1 measurement in the supervised area;
- 6 measurements taken at random.

See Tables 15a and 15b.

Average measurements as shown in Tables 17 and Graph 2.

b) check-list or inspection results shown in Table 13.

Lab.No.23

a) Two direct measurements were taken in controlled areas. See Table 17 and Graph 2 (average).

b) check-list or inspection results in Table 13.

II. University of Manchester Laboratory

Surface contamination measurements were taken from this multi-user laboratory which used the same isotope (P-32) and similar techniques to those adopted in UMIST laboratories.

Lab.No.2.382

a) Surface contamination measurements were taken in the following areas:-

- 19 measurements in the controlled area;
- 7 measurements in the supervised area;
- 7 measurements taken at random.

See Tables 16a and 16b.

Average results as shown in Table 17 and Graph 2).

b) check-list or inspection results shown in Table 13.

2.3.2. Air Monitoring

The programme of air monitoring was carried out in previous laboratories by collecting air samples over a period of ten minutes at a height of one metre from the floor (bench height), by using an air sampler which was placed at each of the locations (as shown in the attached diagrams) and the concentration of P-32 was calculated as described previously.

The following areas were selected for monitoring according to the distance from the controlled areas where radioactive material (P-32) was being handled:-

- a) controlled area;
- b) supervised area;
- c) random measurements.

A. UMIST Laboratories

Lab.No.6.20

Air samples were taken from the following areas:--

- 2 air samples from the controlled area;
- 3 air samples from the supervised area.

Results shown in Table 18 and Graph 3.

Lab.No.23

- One air sample from the controlled area;
- One air sample from the supervised area.

Results shown in Table 19 and Graph 3.

Lab.No.28

- One air sample from the controlled area;
- One air sample from the supervised area.

See Table 20 and Graph 3.

Lab.No.F.7

- One air sample from the controlled area;
- One air sample from the supervised area.

Results as shown in Table 21 and Graph 3.

B. Manchester University Laboratory

Lab.No.2.382

Air samples were taken from the following areas:--

3 air samples from the controlled area;

- 4 air samples from the supervised area.

The average results are shown in Table 22 and Graph 3.

NOTE: Air sampling sites are shown in the diagram form one as an example.

2.3.3. Dosimetric Measurements

a) TLD Results

Tables 23 and 24 give a summary of TLD results after analysis by Christie Hospital & Holt Radium Institute, Radiation Protection Laboratory. (See Graphs 4 and 5).

b) Film Badge Results

Details of film badge results are shown in Tables 25, 26 and 27 after analysis by the same service as the TLDs.

2.4. RESULTS DISCUSSION AND RECOMMENDATIONS

The findings presented in this part of the study are based on surface contamination measurements, air monitoring, dosimetric measurements and check-list inspections, taken in Manchester University and UMIST Biochemistry Laboratories which are used for research and teaching.

All sites in the five laboratories were surveyed and the results of measurements are listed in the following graphs and tables.

1. Graph 2 shows the average surface contamination measurement in the open source laboratory.
2. Graph 3 shows the average radioactive air contamination in the open source laboratory.

3. Graph 4 shows the dosimetric measurement (TLDs) for the first period.
4. Graph 5 shows the dosimetric measurement (TLDs) for the second period.
5. Table 13 shows the check-list results.
6. Tables 25, 26 and 27 show the dosimetric measurement results (film badge).

From the above mentioned graphs and tables all results indicated the following:-

- a) The level of measurements of surface contamination and air monitoring in all five laboratories is much lower than the Ionising Radiations Regulations 1985 (UK) and the ICRP recommendations. For example, the Ionising Radiations Regulations 1985 recommend that the level for a controlled area = $2 \times 10^3 \text{Bq/m}^3$ for air concentration, and $2 \times 10^3 \text{Bq/cm}^2$ for surface contamination.
- b) TLD dosimeter measurements have indicated that the dose to the finger tips of the five workers engaged in labelling and processing in the laboratory are of the order of:-

(1) In the first period

0.0-0.70 Sv/h in accordance with 0.37-2.96MBq P-32 used, as shown in Tables 23 and 24 and Graph 4.

(2) In the second period

0.0-0.10 Sv/h in accordance with 0.37-1.85MBq P-32 used, as shown in Tables 23 and 24 and Graph 5.

The measurements assume that the workers to whom the measurements relate were consistent in their protection procedures and that whilst manually restraining the radiation source (P-32), they wore protective gloves (rubber gloves) and ensured that their hands were not directly on the source.

In the case of worker No.4, as shown in Tables 23 and 24 and Graph 4, the highest reading recorded was 0.70 Sv/h, still below the limit. The reason for this reading is that worker No.4. arbitrarily removed 2.96MBq of P-32 from the container which originally contained 9.25MBq of P-32.

- c) Out of five laboratories, only four issued film badge dosimeters to their staff, there were two workers at the last laboratory (worker No.4 and worker No.5) who should also have worn dosimeters but did not. However, the doses reported were zero.

Finally, through the thorough investigation (check-list and inspection) which was carried out as part of this study, it has been found that there are some regulation offences, faults and errors that must be avoided, such as:-

i) Laboratory No.2.382

- a) The controlled area is located between two offices and there is no demarcation for the controlled area.
- b) There is no written "system of work".
- c) The floor and benches of the laboratory are not clean enough in accordance with radiation protection procedures.
- d) There are no warning signs on the radioisotope refrigerator.
- e) Solid radioactive waste (emptied radioactive containers) were located on the controlled area's shelf.
- f) No warning signs on the outer door of the laboratory.
- g) No changing room for the workers.
- h) No "local rules" for the laboratory.

- j) Some workers in the controlled area were not wearing radiation dosimeters.

However, based upon the above errors and faults found and, in accordance with good radiological working practice, which requires a high standard of protection, the following recommendations should be implemented.

1. The controlled area should be redesigned and the two offices should be moved to the outside of the laboratory (any area designated as controlled or supervised will remain as such for most of the time - "Regulation 8(1)40-IRR"). Alternatively, this area should be cordoned-off (the far side of the laboratory is cordoned off thus creating a controlled area) and must not include the offices to either side of the controlled area demarcation. Controlled area warning signs must be posted to either side of the cordoned-off area, or a sign must be permanently fixed at a central position to the area (see Appendix 5).
2. A written "system of work" must be made available for the controlled area.
3. The floor and benches of the laboratory should be clean to avoid contamination.
4. The refrigerator should have an appropriate warning sign attached.
5. Suitable waste containers or large covered metal drums should be provided for collection of solid radioactive waste.
6. A "supervised area" sign should be attached to the outer door.
7. A special changing room for the workers should be provided.

8. The laboratory or Biochemistry Department "local rules" regarding the handling of radioactive materials must incorporate the "system of work" (as recommended by Regulation 11-UK), which recommends "local rules" for the purpose of enabling the work to be carried out in compliance with the Regulations.
9. All persons working in controlled areas should wear a dosimeter. It is a requirement of the 1985 Regulations-UK) that all workers working within a controlled area have their radiation monitored and recorded.
10. An adequate exhaust ventilation system should be operative in a controlled area, to direct airborne contamination - arising from this area - to flow lines which are directed into main fume hood which is located in the supervised area.

ii) Laboratory No.G.20

The offences, errors and faults are:-

- a) An office is located in this laboratory to the nearside of the controlled area.
- b) The radioactive work was carried out in the laboratory (most of the processing steps were carried out in Lab.G.20, while the process of adding and washing the filters was carried out in Lab.F.23. A worker carried the radio-isotope filter in a plastic bag down to Lab.F.23. without any protection.
- c) There was no adequate fume hood or exhaust ventilation system in the laboratory.
- d) There was no changing room for the workers.
- e) The housekeeping was inadequate.
- f) The washing of radioisotope filters was

carried out (which contained isotopes) without any protector or screen.

The recommendations are:-

1. The office must be moved outside the laboratory and the controlled area should be re-designed in order to carry out all processing steps including adding and washing processes, to protect the worker and the environment.
2. An adequate fume hood or exhaust ventilation system should be made available.
3. Good general housekeeping in accordance with working practices in relation to radiation is required.
4. It is advisable to place the radioisotope filters in a perspex screen (shield) for the washing operation, to shield the front of the body of the worker from any radiation emanating from the plastic bag which contained the radioisotope filters, and to avoid a radiation dose to the hands. Also this would be useful to use during the cutting of the membrane filter operation. Further-more, I would like to recommend for those processing (washing and cutting the filters) that the screen, which is used in Lab.No.2.382 (see diagram 5) which allows the workers face to get close to the work activity, at the same time it can shield the front of the body and the face from any radiation emanating during the operation or processing.

iii) Laboratory No.F.23

This is a small laboratory used as a controlled area only. The errors and faults found were:-

- a) The ventilation system (fume cupboard) does not operate well;
- b) The laboratory is too crowded, and

- c) is not clean enough to carry out radioactive work.

It is, therefore, recommended that:-

1. An adequate ventilation system or fume cupboard should be provided because operations in such a small laboratory should be confined to good ventilation in order to avoid aerosols or contaminated fumes to be formed or accumulated on the laboratory floor, benches and on analytical tools.
2. It is advisable to use a screen (shield) during the washing operation as recommended for Lab.G.20.

iv) Laboratory No.F.7.

This is a multi-user laboratory. The errors and faults were:-

- a) The main problem with this laboratory was the floor covering (tile joints). If a spill of radioactive materials occurred in this laboratory, it could prove very difficult to decontaminate the floor.
- b) Two offices are located in the laboratory.
- c) Bench surfaces are not clean enough for the purpose of carrying out radiation operations.
- d) The ventilation system extract was very low.

The recommendations are:-

1. The laboratory floor should be maintained by sealing the gaps in the floor tile joints. This will make it easier to remove any accumulated radioactive dust/spillages and also for ease of decontamination.
2. The offices should be moved to the outside of the laboratory.
3. The bench surfaces should be cleaned.

4. The ventilation system should be re-designed in order to maintain adequate air flow.

v) Laboratory No.F.28

This is a multi-user laboratory and the errors and faults are:-

- a) the grouting between the floor tiles is exposed and could easily absorb contamination and may be difficult to decontaminate;
- b) a small office is located near the controlled area;
- c) the fume cupboard does not function adequately enough to carry out radiation work;
- d) general cleanliness was inadequate.

It is recommended that:-

1. The laboratory floor should be fully maintained by sealing the gap in the floor tile joints which will make it easier to remove any accumulated radioactive dust and enable ease of decontamination.
2. The office should be moved to the outside of the laboratory.
3. The fume cupboard should be adequately maintained in order to carry out radioactive working practices.
4. Cleaning of the laboratory (floor, benches and walls), should be carried out on a daily basis after all radioactive work has been completed. This procedure should be maintained, the laboratory should be kept neat and tidy, all glassware should be washed regularly and waste materials should not be accumulated, otherwise this could contaminate other materials.

2.5. CONCLUSIONS

From the overall results of measurements and the investigation (check-lists and inspections), the basic conclusion to be drawn is that all results of measurements in the five laboratories are insignificant and much lower than the recommended levels (British and International). This means that the radiation protection procedures in these laboratories are being applied very carefully. However, on the other hand the investigation indicated some contravention to the regulations and standards, with many errors and faults which must be avoided. Contraventions against the regulations were:-

1. in some laboratories there was no written "system of work" and no "local rules" which contravenes regulation 11;
2. the controlled areas in all laboratories were located between or near to the offices. This is an offence against regulation 8(1)40;
3. some workers did not wear dosimeters which is an offence against regulation (8)54.

The errors and faults were:-

- a) designing errors, e.g., offices should not be located in laboratories;
- b) in all laboratories the ventilation system was inadequate to enable radioactive operations to continue in accordance with good radiological working practices;
- c) general housekeeping in most of the laboratories was inadequate, and not in accordance with good radiological working practices, which is essential.

SURVEY REPORT

Site/Location: Department of Biochemistry,
Manchester University, Lab.No.2.382
Isotope Used: P-32
Survey Equipment: LB1210D Digital Contamination Monitor

Area Background	Area Designation	Contamination Bq/cm ²	Comments
0.17	controlled	1.607	average measurement results
0.17	supervised	0.368	average measurement results
0.17	supervised	0.532	average of random measurement results

LABORATORY SURVEY

Site/Location: Adequate Inadequate Must re-design
 Lab.No.2.382 ✓ * +

1. Floor covering

☒ smooth	☐ non-porous
☐ non-absorbent	☐ easily removable
☐ protective under layer	☒ floor tiles

2. Walls and ceiling

☒ smooth	☐ non-porous	☐ washable
☐ coating	☐ paint	

3. Bench top material

☒ smooth	☐ non-absorbent
☐ sealed coating	☐ removable covering

4. Ventilation

☒ no re-circulated air
☐ absolute filters on exhaust air

5. Hoods

☐ singly ducted	☐ absolute filters on exhaust air
☒ flow rate	☐ external control

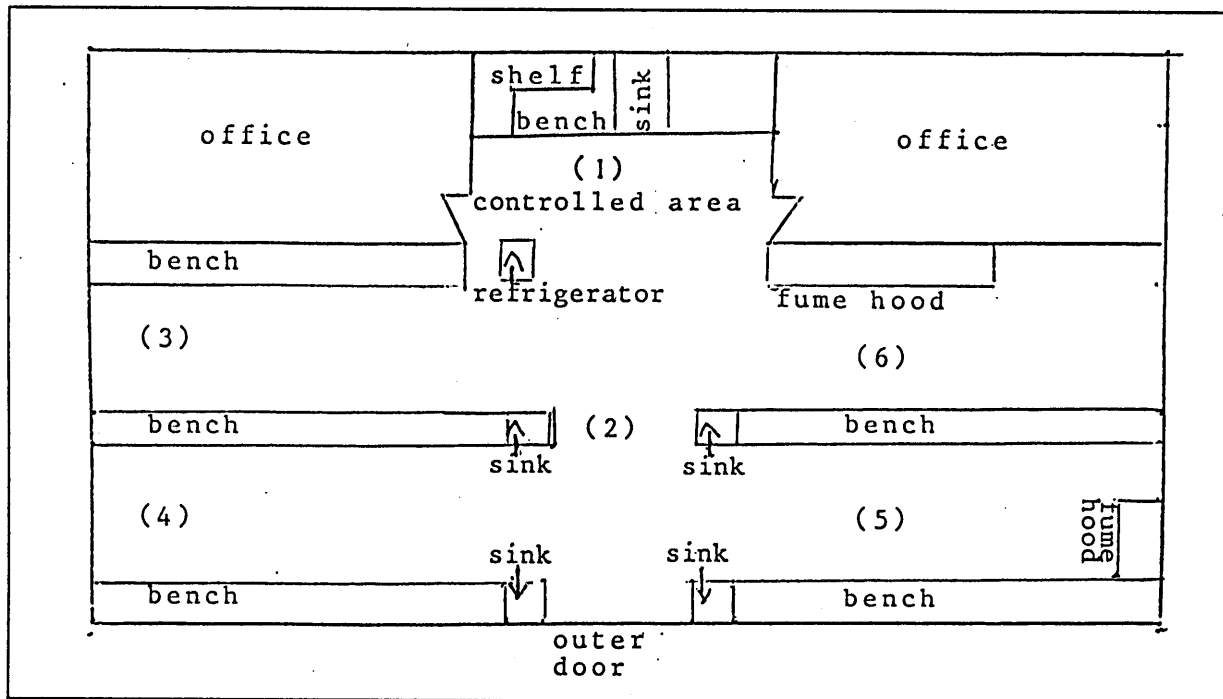
6. Consider other design criteria

☒ shielding	☒ portable; localised
☐ special handling devices	☒ glove boxes

7. Monitoring devices

<u>Type</u>	<u>Range cps</u>
1. Contamination Monitor (M.Monitor) Type 271	
2. B1411 BQW	

Plan of the Survey Location



Remarks

1. The "controlled" area is located between two offices and there is no demarcation for the "controlled" area.
2. No written "system of work".
3. The floor of the laboratory is not clean.
4. There are no warning signs on the isotope refrigerator.
5. Empty radioactive containers (cans) were located on the "controlled" area shelf.
6. There were no warning signs on the outer door of the laboratory.
7. There was no changing room for the workers.
8. Some workers in the "controlled" area were not wearing radiation dosimeters.
9. The fume hood is located in the "supervised" area and not working well; also the exhaust ventilation system is not working well.
10. Benches are not clean enough.

TABLE 11

PHYSICAL PROPERTIES OF P.32

HALF-LIFE	BETA ENERGY (MeV) (Max) (mean)		SPECIFIC ACTIVITY (max)	COMMON VALUES FOR COMPOUNDS	DAUGHTER NUCLIDE (STABLE)
14.3 DAYS	1.709	0.69	9.13kg/matom 338TBq/matom	0.01-10 ³ Ci/mmol 370MBq-37TBq/ mmol	Sulphur -32

* A milli atom is the atomic weight of the element in milligrams

** One thousandth part of a mole

Source: Ref.1

TABLE 12(a)

PROCESSING STEPS AND SURFACE CONTAMINATION MEASUREMENTS IN UMIST
LAB. NO. G.20 (BIOCHEMISTRY DEPARTMENT)

S No.	PROCESSING STEPS	TIME IN MIN.	SITE NO.	A R E A	CONTAMINATION IN Bq/cm ²		REMARKS
					BACK- GROUND	CONTAM- INATION	
1	Collecting the radio- activity (0.37 MBq P-32)	5	1	*A	0.20	1.30	while processing screen is used
2	Drying the radio- activity in the fume cupboard	15	5	**B	0.20	0.35	measurement was taken inside the cupboard
					0.20	0.20	measurement was taken outside the cupboard
3	Adding and Reaction of the components	5	1	A	0.20	2.05	while processing with screen sink fume cupboard
			2	B	0.20	0.27	
			5	B	0.20	0.23	
			4	B	0.20	0.23	
			6	B	0.20	0.22	
			7	B	0.20	0.21	

*A = Controlled area

**B = Supervised area

CONTINUED.....

CONTINUED.....

TABLE 12(a)

PROCESSING STEPS AND SURFACE CONTAMINATION MEASUREMENTS IN UMIST

LAB. NO. G.20 (BIOCHEMISTRY DEPARTMENT)

S No.	PROCESSING STEPS	TIME IN MIN.	SITE NO.	A R E A	CONTAMINATION IN Bq/cm ²		REMARKS
					BACK- GROUND	CONTAM- INATION	
4	Mixing and making sure that all the isotopes in the components	5	3	B	0.20	0.31	during processing
5	Putting the mixture in the incubator (making DNA labelling process)	45	3	B	0.20	0.45	37°C
6	Adding DNA to the membrane filter and putting these membranes into plastic bags	10	1	A	0.20	2.50	the process has been handled without any protector shield
7	Transferring the plastic bags to the incubator in lab. No.7	5	4 in lab.7	A	0.25	2.50	carrying the plastic bags from lab.G.20 to lab.F.7 area (4) without a protector
8	Washing the filters	25	2	A	0.33	1.67	washing the filters in lab No. F.23 without any protector
	Re-washing the filters	25	2	A		1.49	
	Final washing	25	2	A		1.26	
9	Applying in the filter to X-ray film 5 obtain an autoradiographic image	5	in dark room	B	0.16	0.16	

*A = Controlled area

**B = Supervised area

TABLE 12(b)

*RANDOM SUFACE MEASUREMENTS IN UMIST LAB. G.20

SITE	CONTAMINATION IN Bq/cm ²
3	0.40
4	0.35
5	0.22
6	0.30
7	2.29
2	0.44, 0.49

* Random measurement considered as from supervised area. Biochemistry Department

TABLE 13

CHECK-LIST/INSPECTION RESULTS FOR ALL LABORATORIES

LAB NO.	FLOOR COVERING	WALLS AND CEILING	BENCH TOP MATERIAL	VENTILATION	HOOD	OTHER DEVICES CRITERIA	MONITORING DEVICES	REMARKS
G.20	smooth floor tiles	smooth washable painted	non-absorbent	no-recirculated air	flow-rate	gloves boxes no special handling devices shielding	mini-monitor s.no.900 range CPS	personnel office in lab. house-keeping
F.23 Consider as controlled area	smooth floor tiles painted	smooth washable	non-absorbent	no-recirculated	flow-rate	gloves boxes	m.monitor type 5.900 range CPS	floor not clean enough too crowded
F.28	smooth floor tiles	smooth painted	non-absorbent	no-recirculated	flow-rate	gloves shielding	m.monitor type 5.900 range CPS	floor tiles personnel office
F.7	smooth floor tiles	smooth painted washable	non-absorbent	no-recirculated	flow-rate	gloves shielding	m.monitor type 510 range CPS	personnel office floor tiles
2.382	smooth floor tile	smooth	non-absorbent benches	no-recirculated	flow-rate	gloves shielding	m.monitor type 271 B1411 B9W	personnel offices cleanliness benches not clean empty radioactive can located on the shelf in controlled area

TABLE 14(a)

PROCESSING STOPS AND SURFACE CONTAMINATION MEASUREMENTS IN UMIST

LAB. NO. F.7 (BIOCHEMISTRY DEPARTMENT)

S No.	PROCESSING STEPS	TIME IN MIN.	SITE NO.	A R E A	CONTAMINATION IN Bq/cm ²		REMARKS
					BACK- GROUND	CONTAM- INATION	
1	Collecting the radio- activity (1.85 MBq P-32)	5	1	*A	0.25	1.87	while process- ing (shield used bench sink fume hood
			2	**B	0.25	0.29	
			2		0.25	0.31	
			2		0.25	0.25	
2	Drying the radio- activity and collecting it from dryer	32	2	**B	0.25	0.35	
3	Labelling the reactions (adding the DNA)	10	1	A	0.25	0.35	behind the screen (shield)
4	Mixing and making in incubator (making DNA labelling process)	5	1	A	0.25	0.30	behind the (shield)
5	Putting the mixture in incubator (making DNA labelling process)	45	3	B	0.25	0.26	37°C

*A = Controlled area

**B = Supervised area

CONTINUED.....

CONTINUED....

TABLE 14(a)

PROCESSING STOPS AND SURFACE CONTAMINATION MEASUREMENTS IN UMIST

LAB. NO. F.7 (BIOCHEMISTRY DEPARTMENT)

S No.	PROCESSING STEPS	TIME IN MIN.	SITE NO.	A R E A	CONTAMINATION IN Bq/cm ²		REMARKS
					BACK- GROUND	CONTAM- INATION	
6	Stopping the reactions and putting the DNA in the callium	8	1	A	0.25	0.25	
7	Hybridization of the filter, with labelled DNA	18	1	A	0.25	1.45	behind the shield
8	Washing the filter (3 times)	24	2	A	0.33	2.70) 1.18) 1.80)	washing the filter in lab. F.23 without any protector 1.11MBq 0.185MBq 0.555MBq
9	Exposed the filter to X-ray film to obtain an autoradiographic image	5	dark room	B	0.16	0.16	

*A = Controlled area

**B = Supervised area

TABLE 14(b)

RANDOM SURFACE CONTAMINATION MEASUREMENTS
IN UMIST LAB. NO. F.7

SITE	CONTAMINATION IN Bq/cm ²
3	0.30
4	0.25
5	0.25
6	0.23
7	2.29
2	0.45 and 0.51

* Random measurements considered as from supervised area. Biochemistry Department.

TABLE 15(a)

PROCESSING STEPS AND SURFACE CONTAMINATION MEASUREMENTS IN UMIST

LAB. NO. F.28 (BIOCHEMISTRY DEPARTMENT)

S No.	PROCESSING STEPS	TIME IN MIN.	SITE NO.	A R E A	CONTAMINATION IN Bq/cm ²		REMARKS
					BACK- GROUND	CONTAM- INATION	
1	Collecting the radio-activity 1.11MBq P-32 and its into ice in 3MBq probe each probe for each filter contained 0.37 MBq P-32	10	1	*A	0.27	0.78	without issuing screen
2	Hybridization of the filter with labelled DNA (adding labelled DNA at 42°C)	10	1	A	0.27	0.55	behind screen
3	Washing the filter (3 times)	30	1	A	0.27	0.45 0.40 0.34	behind screen
4	Exposing the filter to X-ray film 5 obtain an autoradio-graphic image	5	D. Room	**B	0.16	0.66	

*A = Controlled area

**B = Supervised area

TABLE 15(b)

RANDOM SURFACE CONTAMINATION MEASUREMENTS

IN UMIST LAB. NO. F.28

SITE	CONTAMINATION IN Bq/cm ²
3	0.34
4	0.30
5	0.29
6	0.29
7	2.27
2	0.30

* Random measurements considered as from supervised
area. Biochemistry Department.

TABLE 16(a)

PROCESSING STEPS AND SURFACE CONTAMINATION MEASUREMENT IN
MANCHESTER UNIVERSITY LAB. NO.2-382 (BIOCHEMISTRY DEPARTMENT)

FIRST DAY

S No.	PROCESSING STEPS	TIME IN MIN.	SITE NO.	A R E A	CONTAMINATION IN Bq/cm ²		REMARKS
					BACK- GROUND	CONTAM- INATION	
1	Collecting the radio- activity (2.96 MBq P-32 from store room	5	-	-	-	5.47	while the worker was taking out 2.96MBq P-32 out of the container which originally contained 9.25MBq P-32
2	Adding P-32 on the enzyme solution	10	1	*A	0.17	1.85	behind screen in "b" position
			1	A	0.17	1.45	behind screen in "a" position
3	Mixing and isotope with enzyme, DNA and primer (Labelling)	5	1	A	0.17	2.31	behind screen in "b" position
						1.40	behind screen in "a" position
4	Separating the mixture	5	1	A	0.17	3.44	the reading which has been taking during this process, when the worker is not using a pro- tector or screen

*A = Controlled area
 **B = Supervised area
 "a" and "b" see Diagram 5

CONTINUED.....

CONTINUED....

TABLE 16(a)

PROCESSING STEPS AND SURFACE CONTAMINATION MEASUREMENT IN
MANCHESTER UNIVERSITY LAB. NO.2-382 (BIOCHEMISTRY DEPARTMENT)

FIRST DAY

S No.	PROCESSING STEPS	TIME IN MIN.	SITE NO.	A R E A	CONTAMINATION IN Bq/cm ²		REMARKS
					BACK- GROUND	CONTAM- INATION	
5	Incubating and boiling the mixture	7	2	**B	0.17	0.63	37°C
6	GIET electrophoresis processing (sequencing - Loading the mixture)	20	1	A	0.17	1.87	during injection the mixture in the GIET electrophoresis system
7	Putting the filter in 10% acetic acid	15	1	A	0.17	2.15	without using screen
8	Washing the filters (3 times)	15	1	A	0.17	2.05	without using screen
9	Drying filters by water	5	2	B	0.17	0.61	without using screen
10	Exposed the filter to the X-ray film to obtain an autoradiographic image	5	-	B	0.19	0.19	

*A = Controlled area
 **B = Supervised area

CONTINUED.....

CONTINUED.....

TABLE 16(a)

PROCESSING STEPS AND SURFACE CONTAMINATION MEASUREMENT IN
MANCHESTER UNIVERSITY LAB. NO.2-382 (BIOCHEMISTRY DEPARTMENT)

SECOND DAY

S No.	PROCESSING STEPS	TIME IN MIN.	SITE NO.	A R E A	CONTAMINATION IN Bq/cm ²		REMARKS
					BACK- GROUND	CONTAM- INATION	
1	Adding P-32 to the enzyme solution (0.74MBq P-32)	6	1	A	0.17	0.58	behind screen in"a"position
						0.95	behind screen in"b"position
2	Mixing the components	5	1	A	0.17	0.28	
3	Collecting the mixture	2	1	A	0.17	3.80	while collect- ing the mixture
4	Incubation of the labelling reaction	5	2	B	0.17	0.78	behind screen in"b"position
5	Stopping the reaction	2	1	A	0.17	0.78	behind screen in"b"position
						0.54	behind screen in"a"position
6	Mixing the component	5	2	B	0.17	0.27	
	Boiling the sample (mixture)	2	2	B	0.17	1.19	

CONTINUED.....

TABLE 16(a)

PROCESSING STEPS AND SURFACE CONTAMINATION MEASUREMENT IN
MANCHESTER UNIVERSITY LAB. NO.2-382 (BIOCHEMISTRY DEPARTMENT)

SECOND DAY

S No.	PROCESSING STEPS	TIME IN MIN.	SITE NO.	A R E A	CONTAMINATION IN Bq/cm ²		REMARKS
					BACK- GROUND	CONTAM- INATION	
7	GIET electro-phosresis processing (sequencing-loading the mixture	20	2	A	0.17	0.35 2.15	while the worker is injecting the sample in the electro-phosresis system in "b" position
						0.58	while the worker is injecting the sample in the electro-phosresis system in A position
8	Putting the filter in the 10% acetic acid	5	1	A	0.17	2.20	
9	Washing the filter by water 3 times	15	1	A	0.17	1.80	
10	Exposing the filter to X-ray film to obtain an autoradiographic image	5	D. Room	B	0.19	0.19	

TABLE 16(b)

RANDOM SURFACE CONTAMINATION MEASUREMENTS IN MANCHESTER UNIVERSITY

LAB. NO. 2-382

SITE NUMBER	CONTAMINATION IN Bq/cm ²
3	0.28
6	0.31
4	0.20
5	0.23
Measurements were taken after washing the sink in controlled area	0.83, 0.79 and 0.81

* Random measurement considered as from supervised area.
Biochemistry Department.

TABLE 17

AVERAGE SURFACE CONTAMINATION IN OPEN SOURCE LABORATORIES IN
BIO-CHEMISTRY DEPARTMENT (IN UNIST AND MANCHESTER UNIVERSITY)

No. OF MEASUREMENTS	LAB NO.	LOCATION	CONTAMINATION Bq/cm ²		RANDOM * MEASUREMENT
			CONTROLLED AREA	SUPERVISED AREA	
28	G.20	UMIST	1.63	0.25	0.388
2	F.23	UMIST	0.935	-	-
12	F.28	UMIST	0.504	0.161	0.299
21	F.7	UMIST	1.161	0.272	0.372
33	2.382	MANCHESTER UNIVERSITY	1.607	0.368	0.532

* Measurements considered from supervised area.

TABLE 18

RADIOACTIVE AIR CONTAMINATION MEASUREMENTSUMIST - LAB - NO.G.20 (BIOCHEMISTRY DEPARTMENT)

SITE NUMBER	TIME IN MINUTES	AREA	RESULTS Bq/m ³	AVERAGE RESULT Bq/m ³	REMARKS
1	10	Controlled	1.82	0.995	
1	10	Controlled	0.18		0.18 after finishing the processing
3	10	Supervised	0.55		sites 4 and 6 were measured as random measurement.
4	10	Supervised	0.60	0.675	
6	10	Supervised	0.92		
2	10	Supervised	0.63		

TABLE 19

RADIOACTIVE AIR CONTAMINATION MEASUREMENTS IN UMIST

LAB F.23 (BIOCHEMISTRY DEPARTMENT)

SITE NUMBER	TIME IN MINUTES	AREA	RESULTS Bq/m ³	REMARKS
1	10	Controlled	0.77	
4	10	Supervised	0.72	

TABLE 20

RADIOACTIVE AIR CONTAMINATION MEASUREMENTS IN UMIST
LAB. NUMBER F.28 (BIOCHEMISTRY DEPARTMENT)

SITE NUMBER	TIME IN MINUTES	AREA	RESULTS IN Bq/m ³	AVERAGE RESULT Bq/m ³	REMARKS
1	10	Controlled	0.71	0.71	One Measurement
4	10	Supervised	*1.01	0.05	* more radio- active work was carried on during this measurement. Site, 6, 7, and 8 were taken as random measurements.
6	10	Supervised	0.35		
7	10	Supervised	0.215		
8	10	Supervised	0.76		

TABLE 21

RADIOACTIVE AIR CONTAMINATION MEASUREMENTS IN UMIST - LAB. NO. F.7
(BIOCHEMISTRY DEPARTMENT)

SITE NUMBER	TIME IN MINUTES	AREA	RESULTS IN Bq/m ³	AVERAGE RESULT IN Bq/m ³	REMARKS
1	10	Controlled	0.94	0.94	One Measurement
4	10	Supervised	0.69	0.62	
5	10	Supervised	0.55		

TABLE 22

RADIOACTIVE AIR CONTAMINATION MEASUREMENTS IN MANCHESTER UNIVERSITY
LAB. NO. 2-382 (BIOCHEMISTRY DEPARTMENT)

SITE NUMBER	TIME IN MINUTES	AREA	RESULTS IN Bq/m ³	AVERAGE RESULT IN Bq/m ³	REMARKS
1	10	Controlled	0.75		
1	10	Controlled	0.29*	0.52	* after finished the processing.
1	10	Controlled	0.52		
2	10	Supervised	1.53		
3	10	Supervised	0.40	0.337	
5	10	Supervised	0.19		
6	10	Supervised	0.23		

TABLE 23

DOSIMETRIC MEASUREMENTS (TLDs) IN UMIST LABORATORIES
(BIOCHEMISTRY DEPARTMENT)

WEARER	ACTIVITY OF P-32	DATES WORN	POSITION WORN	TLDs SERIAL NUMBER	DOSE RECORDED (mSv)	REMARKS
Worker No. 1	0.37MBq	22/1/90 to 23/1/90	Left Finger Right Finger	U.159 U.160	0 0	First Period
Worker No. 2	0.37MBq	23/1/90 to 24/1/90	Left Finger Right Finger	U.161 U.164	0 0	First Period
Worker No. 3	1.85MBq	25/1/90 to 26/1/90	Left Finger Right Finger	U.162 U.163	0 0.10	First Period
Worker No. 4	1.665MBq	30/1/90 to 2/2/90	Left Finger Right Finger	U.165 U.166	0.10 0	Second Period
Worker No. 3	0.37MBq	2/2/90 to 5/2/90	Left Finger Right Finger	U.184 U.185	0 0	Second Period
Worker No. 2	1.85MBq	2/2/90 to 5/2/90	Left Finger Right Finger	U.187 U.186	0.10 0	Second Period

TABLE 24

DOSIMETRIC MEASUREMENTS (TLDs) IN MANCHESTER UNIVERSITY LABORATORY
(BIOCHEMISTRY DEPARTMENT)

WEARER	ACTIVITY OF P-32	DATES WORN	POSITION WORN	TLDs SERIAL NUMBER	DOSE RECORDED (mSv)	REMARKS
Worker No. 4	2.96MBq	30/1/90 to 2/2/90	Left Finger Right Finger	U.167 U.168	0.70* 0	*The reason behind this high reading was that the worker no.4 has arbitrar- ly removed 2.9MBq of P-32 out of the container which originally contained 9.25MBq of P-32. (First Period)
Worker No. 5	1.11MBq	1/2/90 to 2/2/90	Left Finger Right Finger	U.169 U.170	0.10 0.10	First Period
Worker No. 5	1.11MBq	15/2/90 to 22/2/90	Left Finger Right Finger	U.240 U.182	0 0.10	Second Period
Worker No.5	1.11MBq	22/2/90	Left Finger Right Finger	U.189 U.139	0 0	Second Period

TABLE 25

DOSIMETRIC MEASUREMENTS (FILM BADGE) IN UMIST LABORATORIES
(BIOCHEMISTRY DEPARTMENT)

WEARER	TYPE OF ISOTOPE USE	DATES WORN	P E R I O D	POSITION WORN	FILM BADGE SERIAL NO.	DOSE RECORDED (mSv)	REMARKS
Worker No. 1	P-32	15/12/88 to 12/1/89	4	Body	454	0	
Worker No. 1	P-32	12/1/89 to 9/2/89	4	Body	409	0	
Worker No. 1	P-32	9/2/89 to 9/3/89	4	Body	449	0	
Worker No. 1	P-32	9/3/89 to 6/4/89	4	Body	424	0	
Worker No. 1	P-32	6/4/89 to 4/5/89	4	Body	431	0.05	
Worker No. 1	P-32	4/5/89 to 1/6/89	4	Body	437	0	
Worker No. 1	P-32	1/6/89 to 29/6/89	4	Body	459	0	
Worker No. 1	P-32	29/6/89 to 27/7/89	4	Body	446	0	

TABLE 26

DOSIMETRIC MEASUREMENTS (FILM BADGE) IN UMIST LABORATORIES
(BIOCHEMISTRY DEPARTMENT)

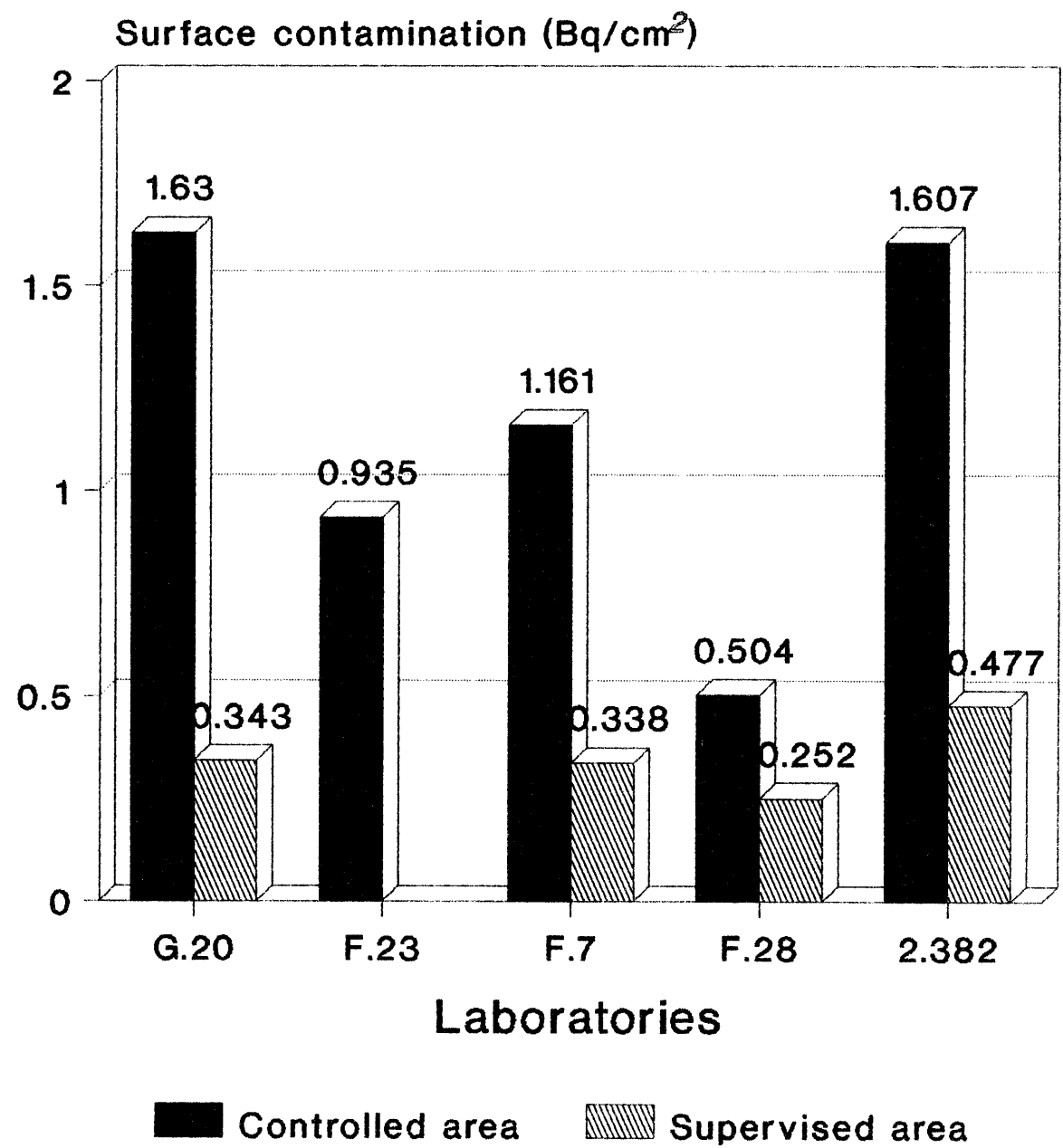
WEARER	TYPE OF ISOTOPE USE	DATES WORN	P E R E I E C E D	POSITION WORN	FILM BADGE SERIAL NO.	DOSE RECORDED (mSv)	REMARKS
Worker No. 2	P-32	15/12/88 to 12/1/89	4	Body	457	0	
Worker No. 2	P-32	12/1/89 to 9/2/89	4	Body	419	0	
Worker No. 2	P-32	9/2/89 to 9/3/89	4	Body	427	0	
Worker No. 2	P-32	9/3/89 to 6/4/89	4	Body	449	0	
Worker No. 2	P-32	6/4/89 to 4/5/89	4	Body	448	0	
Worker No. 2	P-32	4/5/89 to 1/6/89	4	Body	437	0	
Worker No. 2	P-32	1/6/89 to 29/7/89	4	Body	455	0	

TABLE 27

DOSIMETRIC MEASUREMENTS (FILM BADGE) IN UMIST LABORATORIES
(BIOCHEMISTRY DEPARTMENT)

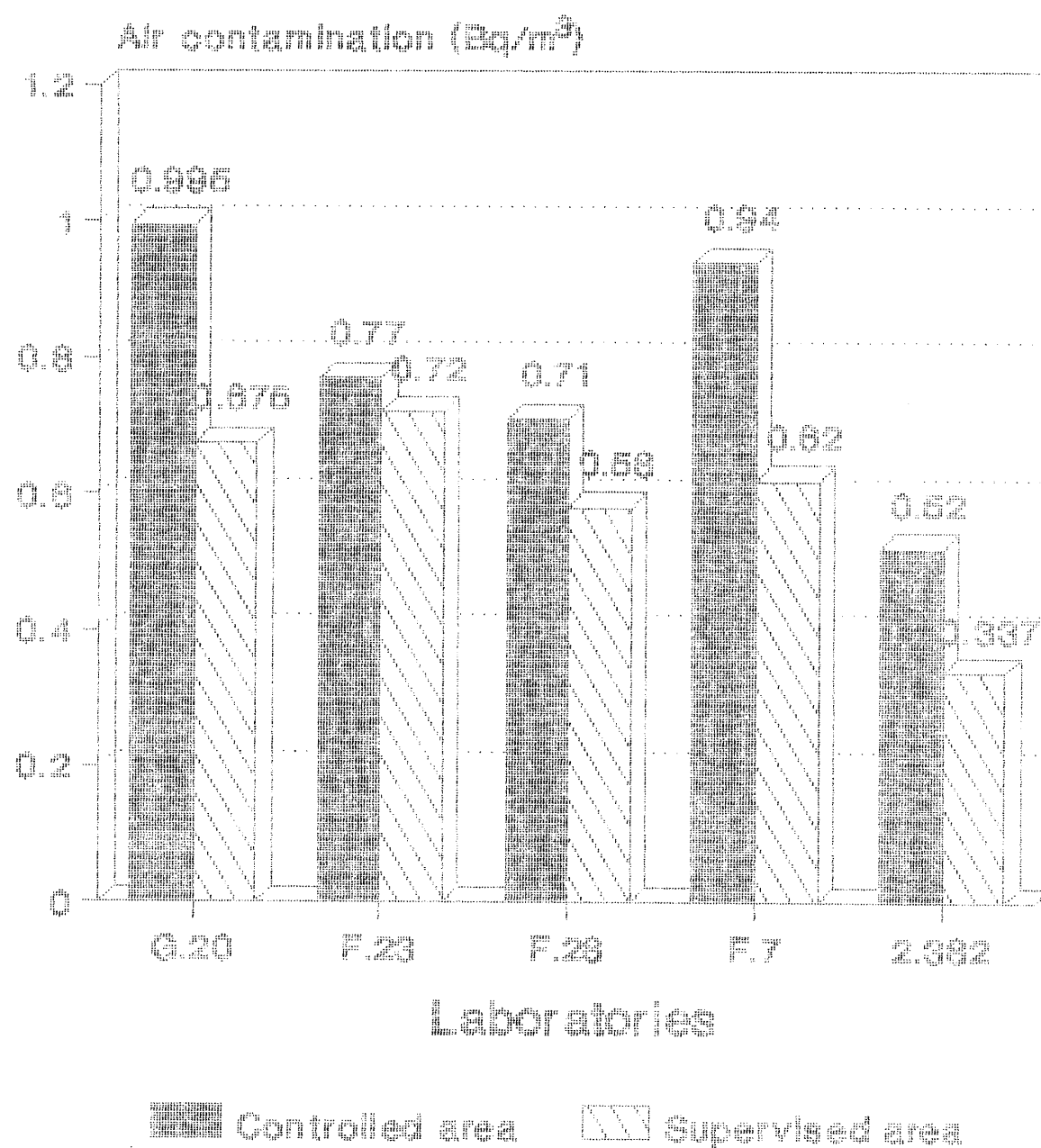
WEARER	TYPE OF ISOTOPE USE	DATES WORN	P E W R E I E O K D	POSITION WORN	FILM BADGE SERIAL NO.	DOSE RECORDED (mSv)	REMARKS
Worker No. 3	P-32	15/12/88 to 12/1/89	4	Body	452	0	
Worker No. 3	P-32	12/1/89 to 9/2/89	4	Body	408	0	
Worker No. 3	P-32	9/2/89 to 9/3/89	4	Body	430	0	
Worker No. 3	P-32	9/3/89 to 6/4/89	4	Body	447	0	
Worker No. 3	P-32	6/4/89 to 4/5/89	4	Body	428	0	
Worker No. 3	P-32	4/5/89 to 1/6/89	4	Body	431	0	
Worker No. 3	P-32	1/6/89 to 29/6/89	4	Body	455	0	
Worker No. 3	P-32	29/6/89 to 27/7/89	4	Body	458	0	

Graph 2. Average surface contamination
in open source laboratories in
Bio-chemistry Department



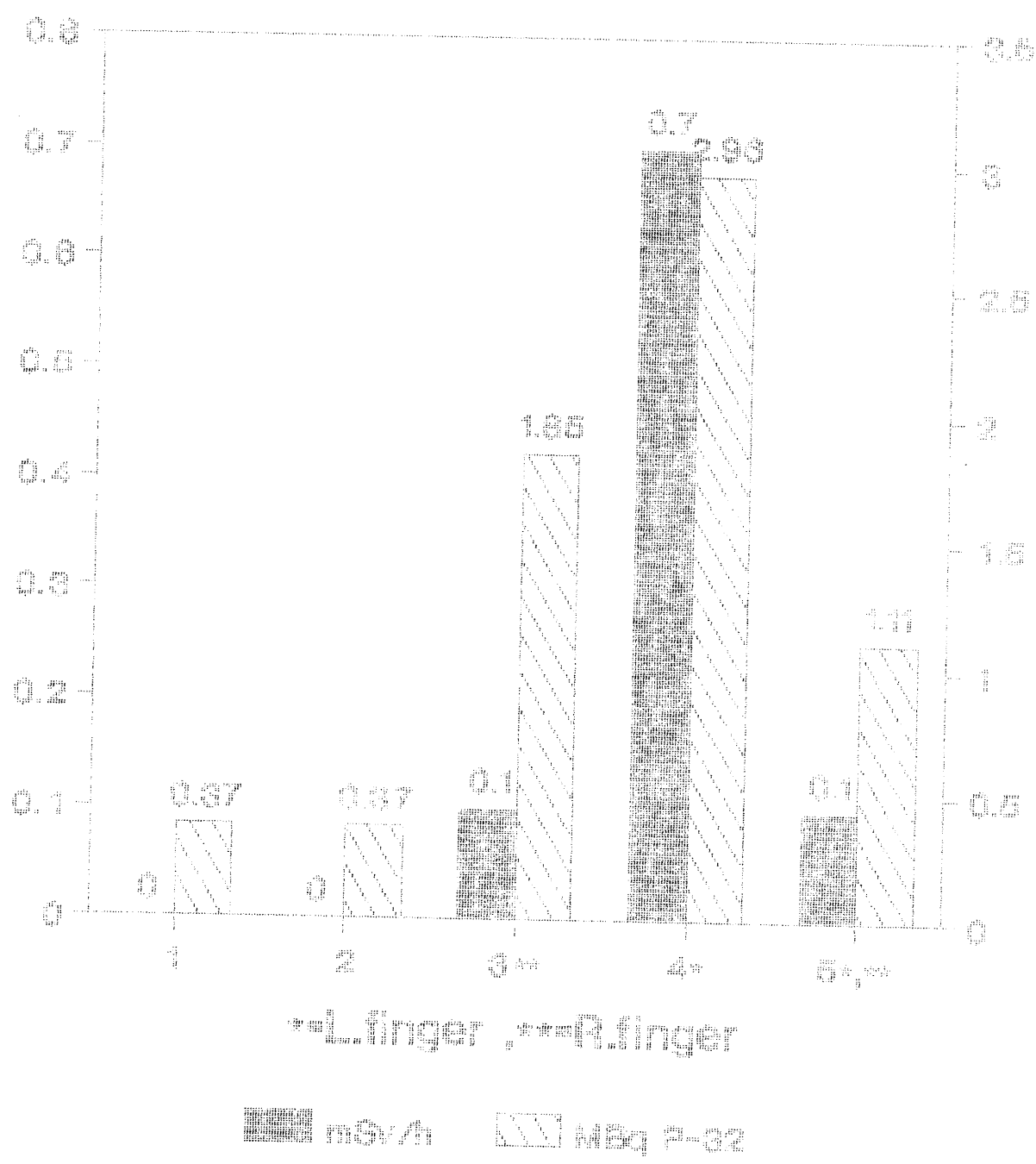
UMIST and Manchester University

Graph 3. Average radioactive air contamination in open source laboratories in Biochemistry Departments



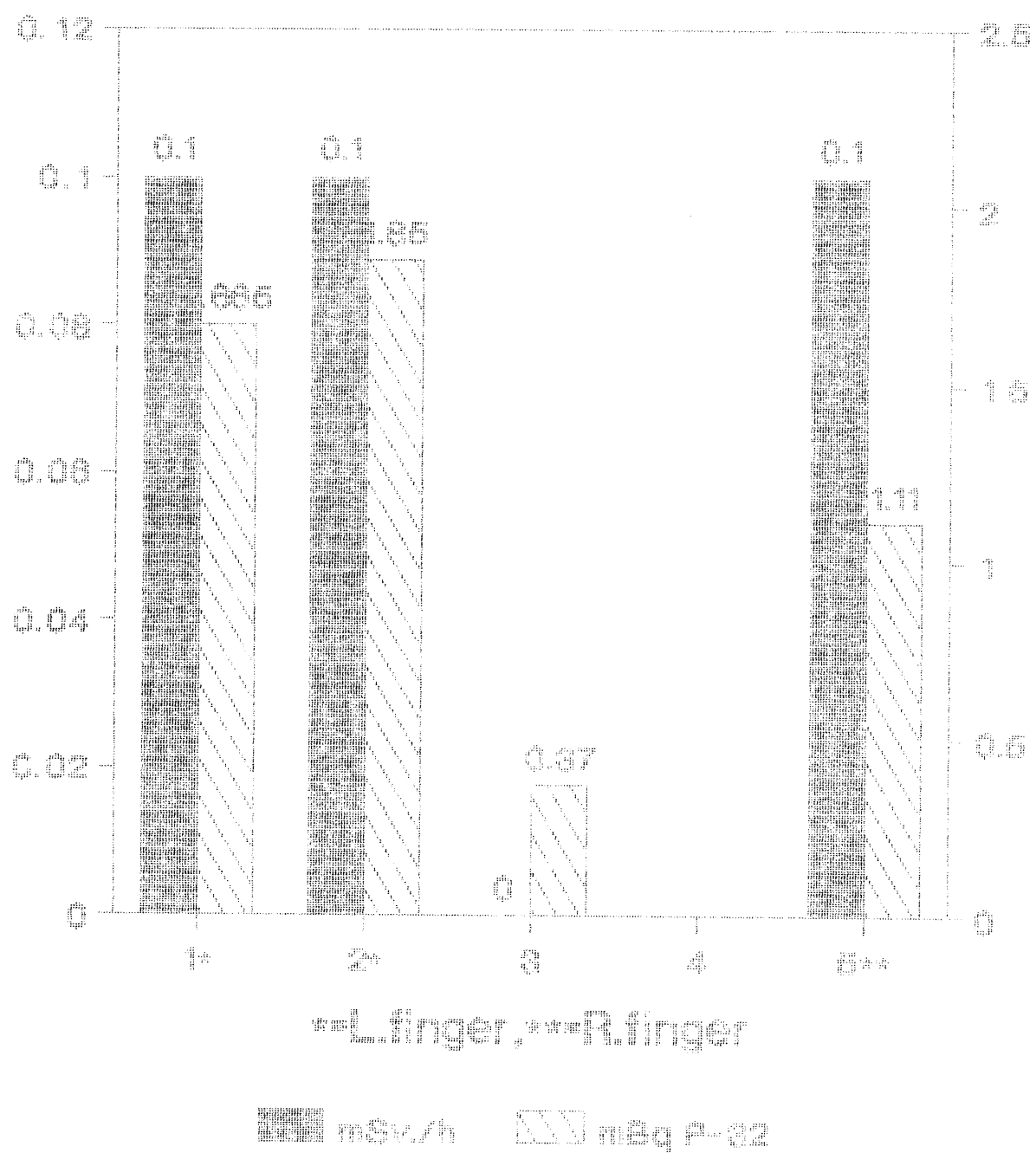
UMIST and Manchester University

Graph 4.Dosimetric measurements (TLDs)
First period



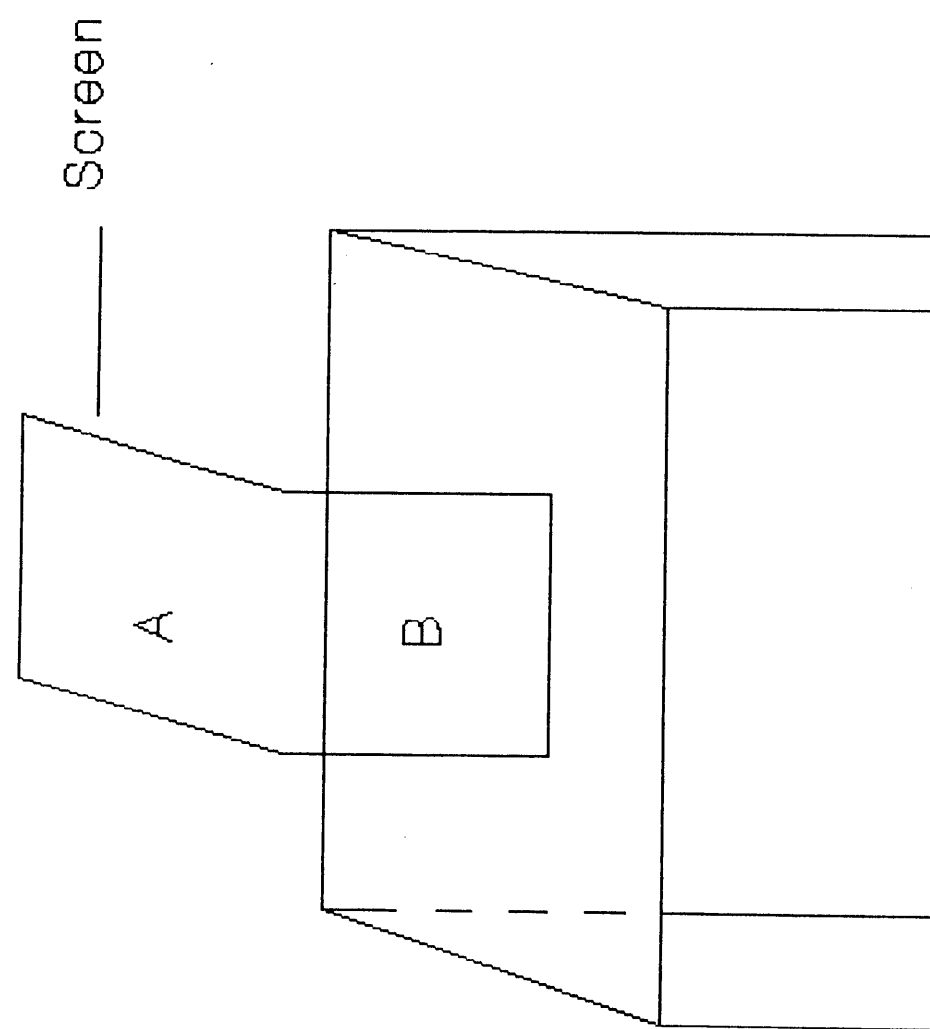
UMIST and Manchester University

Graph 5. Dosimetric measurements (TLDs)
Second period



Unlabeled and Manchester University

Diagram 5 -Protection screen



RADIATION DOSES FROM X-RAY EMITTING EQUIPMENT

3.1. INTRODUCTION

3.1.1. Uses

At the present time X-rays generally constitute the most widely used type of ionising radiation. There are thousands of X-ray machines used in medicine for radiography, fluoroscopy and therapy. In industry, as mentioned in Chapter I, X-rays are used for radiography, fluoroscopy, crystallography. They are used in gauges etc. to analyse or study the elements/structure of materials or for checking quality, etc.

However, X-ray analytical work comprises various types of X-ray units for either X-ray spectrographic work using a known crystal structure or diffraction studies on a crystal of unknown structure (Ref.3). For example, it is used, (Ref.9 and 3), to analyse the elemental composition of samples (as mentioned above) by studying the fluorescence, X-rays emitted by the sample.

Irrespective of the type of apparatus employed and the application, X-rays are almost always produced by decelerating electrons and always consist of:-

- a) an X-ray tube in which electrons are produced, accelerated to a high speed, and then suddenly stopped by collision with the target;
- b) an assembly of electrical devices for the controlling tube;
- c) accessories that depend on both the type and use of the equipment.

3.1.2. Factors Affecting the X-ray Beam

An X-ray beam can be altered before and after it leaves the tube.

- a) The quality, or the penetrating ability, of the beam can be controlled by voltage applied to the tube, and the average quality can be improved by the use of filters (Ref.25).
- b) The intensity of an X-ray beam may be altered by manipulating four factors:-
 - 1. tube current (milliamperes);
 - 2. tube potential (kilovoltage);
 - 3. filtration;
 - 4. distance.

3.1.3. The Continuous Spectrum Beam Radiation or Braking Radiation

The production of the energy emitted as X-rays is not subject to simple theoretical treatment (Ref.29). As the electrons enter the surface layers of the target, they are slowed down by collision with the orbital electrons in the atoms of the target material and are deflected from their original direction of motion, (Ref.21) with collision energy in the form of X-rays being given off. The energy of the emitted photon depends upon the deceleration that occurs. If the electron is stopped in a single collision, all its energy appears as one photon of X-radiation with a wavelength corresponding to the shortest wavelength limit. If the electron suffers a less drastic collision, a longer wavelength (i.e., lower energy photon will be produced).

3.1.4. Characteristic Radiation

In addition to the heterogeneous (continuous) radiation, an X-ray beam may contain one or more strong, nearly homogenous components, within a very narrow wavelength range. The higher the atomic number of the target, the shorter the wavelength of this narrow region. These are called characteristic radiations, and are produced when an electron with a sufficient maximum kinetic energy, collides with an inner orbital electron of the target atom, ejecting it from its shell. A vacancy is left in the shell and the excess energy is emitted in the form of an X-ray photon (Ref.21 and 7).

The intensity of the characteristic radiation is negligible compared to the intensity of the continuous spectrum and is, therefore, of little consequence in radiography for example, and most other applications of X-rays. It is, however, of importance in the study of crystal structure (as mentioned earlier).

3.1.5. Other Factors to be Considered

A. Attenuation of X-ray radiation

When a narrow beam of X-ray radiation passes through matter, absorption and scattering processes decrease the original number of photons in the beam (the same happens with gamma radiation). This decrease is proportional to the thickness of the absorber and is expressed mathematically as:-

$$I = I_0 e^{-\mu X} \quad (\text{Ref.21 and 7})$$

where (I_0) is the initial intensity and (I) the intensity after penetrating a distance (X) is the

medium. The constant () is known as the linear attenuation or absorption coefficient, and implies that there is a constant fractional decrease of intensity per unit thickness of absorber. The value of () is different for different materials and depends greatly on density.

B. Shielding calculation

To calculate shielding requirements, it is usually sufficient to use the so-called half-value layers (HVL) and tenth-value layers (TVL). For a particular material and radiation these are the thickness of absorber required to attenuate a beam to one-half and one-tenth of its initial intensity respectively; these can be mathematically expressed as:-

$$I = \frac{I_0}{2^n} \quad \text{for half-value layer}$$

$$I = \frac{I_0}{10^n} \quad \text{for tenth-value layer}$$

where (n) is the number of HVL or TVL respectively.

C. Important details concerning scattered radiation

1. Scattered rays are emitted in all directions with maximum intensity in the forward direction, the shorter the wavelength the greater the scatter in the forward direction.
2. Scattered radiation delivers a lower dose rate than the incident beam, this varies with the angle of scattering and the atomic number of the scatterer.

D. Secondary radiation

Whenever X-rays or gamma-rays are incident on matter, secondary radiation is emitted in all

directions, and keeping away from the primary beam by no means ensures protection, for an individual may be bathed in secondary rays from objects that the primary beam strikes.

There are two kinds of secondary radiation:-

1. scattered rays, which consists of two components, one with the same wavelength as the primary beam and the other whose wavelength is longer;
2. characteristic fluorescence, which is identical with the characteristic X-rays emitted by the material, if it were used as the target in an X-ray tube.

3.1.6. Radiation Hazards

X-ray emitting equipment is usually designed in such a way that, under normal operating conditions, the main beam does not come into contact with the operators. But due to equipment errors or accident faults, radiation hazards may be associated with the uses of these machines. However, there are three possible sources of radiation exposure:-

- a) from main beam exposure;
- b) leakage radiation;
- c) scattered radiation.

Of these possible sources, main beam exposure presents by far the greatest hazard. The most likely equipment where an exposure could occur is a diffraction set where the main beam is available before the specimen is irradiated. Dose rates after the specimen are very much reduced.

Leakage of radiation gives rise to narrow beams of fairly intensive radiation which may pose a hazard to the irradiated part of the body (Ref.32). This is particularly so where the eyes are concerned.

Leakage with microscopes often leads to loss of performance and is, therefore, rapidly detected. For more details see Chapter I Section 1.3. The Effects of Ionising Radiation.

3.2. METHODS AND PROCEDURES OF MEASUREMENT

In this area of the study three methods were implemented to monitor X-ray diffraction sets. These methods were:-

3.2.1. Direct Measurements

Direct measurements were taken in the University of Manchester and UMIST departments, where the X-ray diffraction sets were used for research and teaching.

Three types of surveying equipment were used to record dose rate measurements, i.e.,

- a) Mini - Instrument (5-10E GM tube);
- b) Mini - Instrument (5-42A scintillation probe);
- c) Victoreen 470A (ion chamber)

3.2.2. Fixed Film Badges

This method was used as an alternative method to detect any leakage or scatter from X-ray diffraction equipment.

3.2.3. Investigation Method

This method was executed in these departments by using a questionnaire, which asked for information about the uses of ionising radiation, the kind of radiation,

numbers of the machines and radiation protection methods adopted in the department (see Form 2 as an example).

3.3. RESULTS

3.3.1. Direct Measurements

Surveys were carried out in the following departments:-

A. University of Manchester,
Department of Geology - Room No.14.

In this department the X-ray emitting equipment was used to analyse the elemental composition of the sample by studying the fluorescent X-rays emitted by the sample.

Room B.14 contains three Philips X-ray diffraction sets, these are:-

Set 1. Serial Number PW 1730

This set was monitored under operating conditions of 40kV and 20mA. The shutter warning lights and interlock systems were found to function correctly. Leakage was detected from a gap at the top of the X-ray tube housing. The leakage was from the left hand side equipment port, when the apparatus was viewed from the control panel (see Diagram 6). A dose rate of 1.0 Sv/h was measured from the above area.

Set 2. Serial Number PW 1010/77

This set was monitored under operating conditions of 40kV and 20mA. The interlock system is not automatic. The shutter lights were functioning. No leakage was detected. However, the

present arrangement of holding the shutter micro-switch closed with tape, and the equipment port open with a plastic clip, is not fail safe.

Set 3. Serial Number PW 1130/00

This set was monitored under operating conditions of 40kV and 20mA. The set is fully enclosed, except for the cable entrance point at the rear of the casing (see Photograph 1). The shutter lights and interlock system were found to be functioning correctly. Leakage was detected from the middle of the X-ray tube housing and was possibly due to a defective blanking plate. A dose rate of 2.0 Sv/h was measured at the above area of leakage (see Diagram 6 and Table 31).

B. University of Manchester,
Department of Chemistry - Room No.7-20.

The X-ray emitting equipment was used in this department for identifying unknown elements in research and teaching.

Room 7-20 houses three X-ray diffraction sets. Two of the sets were manufactured by Philips and the third set was manufactured by Enraf.

Set 1. Philips PW 1120/90 (Serial Number DY924)

This set was surveyed whilst operating at its normal parameters of 50kV and 20mA with the shutter closed, X-rays were detected from the right-hand side port (see Diagram 7). The dose rate measurements are shown in Table 28. The set incorporated a shutter and generator

warning light, however, the warning light indicating that the generator is switched on could be improved if the lights incorporated a "worded" warning (e.g., GENERATOR ON). It was noted that only at the initial set-up stage (i.e., placing beam stops, etc.) were the shutter micro-switches open, causing the shutters to be closed. However, due to the nature of the crystallography work that this set is used for, operators of the equipment are required to be in close proximity to the X-ray head to install and align crystals. It is, therefore, possible for operators of this set to be exposed to the useful beam and scattered radiation. There is no written system of work in force for this set.

Set 2. Philips PW 1008/80 (Serial Number 4DY846)

This set was tested under operating conditions of 40kV and 20mA. It is used by a demonstrator, who operates the set for students; the work involves the use of powder-cameras. There are no automatic interlock systems. There were no shutter lights. The safe use of this set depends on the demonstrator following a rigid written system of work. No leakage was detected.

Set 3. Enraf Nonius Delft (Serial Number 585-900)

This diffraction set is fully enclosed with the sliding panels interlocked to the shutter. The set also has the appropriate generator and shutter warning lights. It

was tested under operating conditions of 50kV and 20mA. A radiation survey was implemented around the outside of the enclosure. One area of leakage from the cabinet was detected. This was from the gap between the rear panels at approximately two thirds of the way up, when the enclosure is viewed from the control panel. A dose rate measurement was taken from the area of leakage and indicated a dose rate of 1.0 Sv/h. The enclosure/shutter interlock switches were tested to ensure that the shutter was closed when any of the cabinet panels were opened, by placing the meter inside the cabinet and noting the displayed count rate. The diffraction set was then operated and a count rate of 50cps was noted, as each entrance panel in turn was opened. The meter count rate fell back to normal background of 4cps, indicating that the fail safe micro-switch had operated the shutter mechanism. There were no local rules for the operation of this diffraction set.

C. University of Manchester,
Department of Medical Biophysics - Room No.6-43.

In this room there are two Philips X-ray diffraction sets which are used for research purposes, such as:-

- a) the study of biological calcium phosphates;
- b) the study of the structure and function of inter-spinal ligaments;
- c) the development of X-ray diffraction as an

invivo technique for determining bone composition.

Set 1. Philips type PW 1120/90
(Serial Number DY885)

This set has the potential to have four X-ray ports operating at the same time, but it is the practice of the department that only two are used. The two unused ports have been permanently blanked-off.

Metal casings are used to enclose the cameras and thus the useful X-ray beam. The casings from part of the fail safe mechanism are such that if these are moved away from the X-ray port the shutter mechanism micro-switch operates to close off the port. Each X-ray port had shutter warning lights based on a two light-bulk system and if both bulbs fail the shutter cannot be opened. There was no obvious warning light to show that the generator was switched on and functioning.

With the X-ray set operating at its normal settings of 36kV and 20mA, a leakage survey was carried out. The survey did not reveal any X-ray leakage from either of the two ports or equipment joints. There are no written local rules for the operation of this X-ray diffraction set.

Set 2. Philips type PW 1729 (Serial Number DY791)

This set was tested under operating conditions of 38kV and 20mA. No leakage was detected. It has a large warning light to show when the generator is

switched on. Each X-ray port had shutter warning lights based on a two light-bulb system and if both bulbs fail the shutter cannot be opened. There are no written local rules for the operation of this X-ray set (see Table 31).

D. University/UMIST
Material Sciences Building

In this building a survey was carried out on the X-ray sets and the electron microscopes which are used for research and teaching purposes, such as:-

- X-ray diffraction which is used for the study of the properties of materials;
- X-ray diffraction which is used for the study of polymer processing;
- X-ray diffraction which is used for the study of partitioning and deconvolution;
- X-ray diffraction which is used for the study of the characteristics of polyurethane;
- X-ray diffraction which is used for the study of the micro-structure of a $(Zr,Sn)TiO_4$;
- X-ray diffraction which is used for the study of dielectric ceramics;
- electron diffraction which is used for the study of Nigerite.

1. Room No.A23.

This room contains one Philips X-ray crystallography set. One window has a parkhill enclosure and one window has a camera in position. The set was tested under operating conditions of 40kV and 20mA. Both shutter lights and interlock systems functioned. No leakage or scatter was

detected. It was possible to move the camera aside and expose the beam but the camera must be adapted to prevent this happening. There was no supervised area sign.

2. Room No.A19.

This room contains one Philips (type 10-11) X-ray set. The left hand side (from the control panel) has an individual enclosure and the set as a whole is enclosed. The set was monitored under operating conditions of 40kV and 20mA. Scatter at a level of 200cps was detected at the opening on the right hand side in the top of the enclosure. This gave a dose rate of 1 Sv/h. No other leakage or scatter was detected.

3. Room No. 23.

This room contains a Hilton-Brooks X-ray crystallography set with four shutters. The set was monitored under operating conditions of 40kV and 20mA. The only scatter detected was from an opening in the top of the enclosure where a dose rate reading of 1 Sv/h was recorded.

The following surveys were carried out on electron microscopes and the scanning electron microscopes.

4. Room No.A9.

This room contains one set, a 400 T.A.E.M. The set was tested under normal operating conditions of 100kV and 40mA. No radiation levels above background were detected.

5. Room No.A10.

One Philips E.M. 300 set is housed in this room. The operating conditions were 100kV and 20mA. No levels above background were

detected.

6. Room No.A11.

This room houses one Philips E.M. 300. At the operating conditions of 100kV and 20mA there were no radiation levels detected.

7. Room No.F23.

A micromeritics - sedigraph 5000 ET instrument is kept in this room. It operates at a set kV of 13.8. The interlock system was checked and works correctly. No radiation levels above background were detected (see Table 31).

E. UMIST,
Department of Physics

This survey was carried out to check the Philips X-ray diffraction set in Room E.24. (PW 1120/00 Serial Number DY796). The set was tested under operating conditions of 40kV and 20mA. The shutter warning lights and interlock system functioned satisfactorily. The fail safe micro-switch operated the shutter mechanism, and leakage was detected from a gap at the top of the X-ray tube housing. This leakage was from the right hand side equipment port (looking from the control panel). A count rate of 20cps was recorded from the area of leakage (see Table 31).

3.3.2. Fixed Film Badge Results

It has been reported by Christie Hospital and Holt Radium Institute that all films indicated that no dose rate was recorded during the period of the tests (see Table 29).

3.3.3. Questionnaire Results

Information had been obtained from the questionnaires

which were filled in by a responsible person in each department (in both the University and UMIST). This information indicated that all the departments used the same kind of radiation for the same purposes, and that none of the departments have had medical check-ups carried out for their workers. Also none of the departments were keeping any records of monitoring of the X-ray machines (for more details see Table 30).

3.4. RESULTS DISCUSSION AND RECOMMENDATIONS

The results shown in this chapter were from direct measurements, fixed film badges and investigation methods carried out in Manchester University and UMIST departments. Five departments were surveyed by the above methods and the average results are shown in the following tables and diagrams:-

- a) direct measurement results are shown in Table 31 and Diagram 7;
- b) fixed film badge results are shown in Table 29;
- c) questionnaire results are shown in Table 30.

Based upon the direct measurement results discussed, it was determined that all measurements indicated that all doses recorded do not present a radiation hazard. However, from a radiation protection point of view, any radiation source is a potential source of hazard. Due to accident faults or human errors, risks may be associated with the uses of these sources. Thus, for these reasons and the questionnaire results, it is recommended that the following should be implemented in the departments mentioned.

(A) University of Manchester, Department of Geology

- 1. For both sets PW 1730 and 1130/00, the X-ray leakage should be reduced to background level.

2. Ideally diffraction sets PW 1730 and 1010/77 should be fully enclosed and the enclosure entrance interlocked to the shutter in order to create a fail safe environment (see Photograph 1).
3. If the room door is normally kept open during the operation of the diffraction sets, an additional warning sign should be placed on the inside face of the door (see Appendix 5).
4. A record of monitoring of the diffraction sets should be available and must be kept in accordance with the Ionising Radiations Regulations 1985. When leakage is not detected, an entry of "no leakage found" should be made.
5. Medical check-ups should be implemented. As required by Regulations 9(3) and 16 UK (Ref.34). Therefore, periodic medical examinations are required and radiation dose records should be made available whenever required.

Medical supervision may play an important role in protecting radiation workers against possible radiation damage. Amongst the main tasks of medical supervision is the proper placement of radiation workers and physical condition, and history of previous radiation exposure.

(B) University of Manchester, Department of Chemistry

1. In Diffraction set PW 1120/90 (Serial Number DY924) it was noted that only at the initial set-up stage (i.e., placing of the beam stops) were the shutter micro-switches open causing the shutters to be closed. However, due to the nature of the crystallography work that this set is used for, operators of the equipment are required to be in close proximity to the X-ray head to install and

align crystals. It is, therefore, possible for operators of this set to be exposed to the useful beam and scattered radiation. Thus this is not an ideal situation and, to comply with the Ionising Radiations Regulations 1985 (Part II) UK, it is recommended that this diffraction set must be fully enclosed (see Photograph 1).

2. There is no written system of work in force for set PW 1120/90 (Serial Number DY924). Therefore, according to the Ionising Radiations Regulations 1985 (UK), a system of work should be included in the department local rules and all operators of this set should be aware of its existence. All persons using this diffraction set must only do so under the system of work unless they are classified workers, since until the set is fully enclosed it is possible for persons to enter a controlled area when in close proximity to the beam. Once the set is fully enclosed and interlocked the system of work could then be modified such that only classified workers or service engineers working under the system of work could enter the enclosure when X-rays were being emitted. All other persons would not be able to enter the enclosure without operating the interlock system.
3. Diffraction set PW 1008/80 (Serial Number DY846) should be fully enclosed (see Photograph 1). Also the department should follow the above procedure for this set.
4. Diffraction set Enraf Nonius Delft (Serial Number 585-900). There are no local rules for the operation of this set. To comply with the Ionising Radiations Regulations 1985 (UK), local rules

covering the operations of this set must be drawn up.

5. With both diffraction sets PW 1120/90 (Serial Number DY924) and Enraf Nonius Delft (Serial Number 585-900) leakages should be reduced to background level.
6. All three diffraction sets must be included in the department local rules in order to comply with the Ionising Radiations Regulations 1985 (UK), and the local rules must be available to the radiation workers, and should include:-
 - instruction on how to use the equipment safely;
 - a system of work covering such operations as servicing, if servicing is carried out by a non-classified person;
 - beam alignment procedure and the name of the person responsible for this operation.
7. Medical check-ups should be implemented on a regular basis.
8. Records of monitoring of diffraction sets should be available whenever needed.

(C) University of Manchester,
Department of Medical Biophysics

1. Diffraction set PW 1120/90 (Serial Number DY885).
A clear warning light showing when the generator is switched on must be installed to ensure that this equipment complies with the requirements of the Ionising Radiations Regulations 1985 (UK).
2. There are no written local rules for the above set and local rules should be made available to all radiation operators.
3. The two diffraction sets should be ideally fully enclosed (see Photograph 1).

4. Medical check-ups should be implemented on a regular basis.
5. Records of monitoring of X-ray diffraction sets should be available for inspection.

(D) University of Manchester/UMIST
Material Sciences Building

1. With both the X-ray sets type 10-11 in Room No.A.19. and the Hilton-Brooks type X-ray crystallography set in Room No.A.23, all X-ray leakages should be reduced to the background level.
2. Supervised area signs provided for room should be removed as this room no longer contain X-ray emitting equipment.
3. Medical check-ups should be implemented on a regular basis.
4. Records of monitoring of the diffraction sets should be made available whenever needed.
5. The department has a set of local rules but these are kept in the office. To comply with the Ionising Radiations Regulations 1985 (UK) the local rules must be available to the radiation workers.

(E) UMIST, Department of Physics

1. Set PW 1120/00 (Serial Number DY796), leakage should be reduced to the background level.
2. Ideally the diffraction set should be fully enclosed (see Photograph 1).
3. Medical check-ups should be implemented on a regular basis.
4. Records of monitoring of this diffraction set should be available whenever required.

3.5. CONCLUSIONS

Firstly, all results of direct measurement are insignificantly low, therefore, no radiation hazard is presented to the workers or operators.

Secondly, the film badges showed no detectable radiation doses.

Finally, the investigation indicated that some contraventions of the Ionising Radiations Regulations 1985 (UK) were recorded in this survey and the following should be avoided:-

- a) none of these departments had consulted or arranged for medical check-ups for their employees. This means that none of the departments had even considered the possibility that individual members of their staff might be unfit or otherwise unsuitable for work with ionising radiation;
- b) most of these departments did not have local rules or did not have them available to their employees;
- c) none of these departments had kept radiation dose records, i.e., both personnel radiation dose records and diffraction monitoring records.

University of Manchester
M.Sc. in Occupational Hygiene 1989/1990

Questionnaire - Radiation Protection

Name of Establishment:

.....

Person Responsible:

Address:

.....

Telephone No:

Kindly furnish the following information:-
(Tick/X as applicable)

Are you using ionising radiation in your establishment? YES/NO
If yes, then please answer the following questions:-

1. Ionising radiation is used for:-

a) Diagnostic Therapeutic Research
Others

b) Kind of radiations:-

X-rays Gamma rays Alpha Beta

other particles, state:

.....

c) In case of X-rays:-

range of tube voltage

25 - 150 kV - diagnostic

10 - 15 kV - skin therapy

150 - 1 Mv - deep therapy

1Mv and above - higher energy therapy

d) Number of X-ray machines, maximum kV, mA output of each:-

	Manufacturer	Serial No.	Operating Voltage (kV)	Operating Current (mA)
1.				
2.				
3.				
4.				
5.				
6.				

e) Number of staff involved (designated persons):-

Specialist Doctor
Physicist
Qualified Technician
Student Technician
Darkroom Technician

2. Radioactive isotopes used are:-

Sealed	Unsealed	Not Used
<u>Type of Isotope</u>		<u>Max Quantity of Radioactivity (MBq)</u>
.....		
.....		
.....		
.....		

3. Average working hours/week
4. Number of procedures/week
5. Fluoroscopy used YES/NO
6. Image Intensifier (TV) YES/NO
7. Radiation Protection Adequate YES/NO
(please refer to last question)
8. Dosimeters (radiation detectors available) YES/NO
a) Do they work YES/NO
b) Are they the correct type YES/NO
c) Do people understand how they work YES/NO
9. Personnel monitoring done regularly YES/NO
10. Equipment YES/NO
11. Frequency of personnel monitoring
(state whether monthly/quarterly/half yearly or annually)
12. Is there an indicator light on each functional port ..YES/NO
13. Is there a "generator-on" warning light YES/NO
14. Are there records of monitoring of the machine YES/NO
15. Are the port interlocks "failsafe" YES/NO

16. Medical check-up
 (state whether annual/bi-annual/5 years/more than
 5 years/never)
- a) Physical examination YES/NO
- b) Eye examination YES/NO
- c) Skin examination YES/NO
- d) Full Blood Count YES/NO
- e) Other YES/NO

17. Is the equipment maintained by a service engineer ...YES/NO

18. Remarks

Give details of radiation protection methods adopted in your
 institution:-

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

REF: MK/672
 08/02/1990

TABLE 28

LEAKAGE FROM SET NO.1

PHILIPS SERIAL NO. DY924

X-RAY PORT	POSITION	DISTANCE	DOSE RATE IN mSv/h.
*RHS	Near side (a)	10 cm	5.0
RHS	Near side (b)	30 cm	1.0
RHS	Far side (c)	10 cm	1.0
RHS	Far side (d)	30 cm	Background

*RHS = Right hand side

Note: all positions shown above are viewed from the Control
Panel of the diffraction set.

TABLE 29

(FIXED FILM BADGE RESULTS)

DATES BETWEEN FILM BADGE FIXED	LOCATION	FILM BADGE SERIAL NUMBER	SITE NUMBER ROOM B14	TYPE OF WORK KILO VOLTAGE RANGE	RESULTS DOSE EQUIV- ALENT IN (mSv)
9/2/90- 23/2/90	Geology Department Manchester University	MO65543 MO65544 MO65542	PW1730 PW1010177 PW1130/00	40 kV and 20 mA	- 0 0
19/2/90- 9/3/90	Material Science Building Manchester University/ UMIST	MO65539 MO65540	Room A19 Room A23	40 kV and 20 mA	0 0
2/3/90- 30/3/90	Chemistry Department Manchester University	MO65541	Room 7.20	40 kV and 20 mA	0
5/3/90- 26/3/90	Physics Department UMIST	M145552	Room E.211	40 kV and 20 mA	0

TABLE 30 INFORMATION COLLECTING BY QUESTIONNAIRE (QUESTIONNAIRE RESULTS)

DEPARTMENT	IONISING RADIATION IS USED FOR	KIND OF RADIATION	RANGE OF TUBE OF X-RAYS	NO. OF X-RAYS	NO. OF STAFF INVOLVED	ISOTOPE USED	AVERAGE WORKING HOURS PER WEEK	DOSIMETER AVAILABLE	FREQUENCY OF PERSONNEL MONITORING	INDICATOR LIGHTS (FAIL SAFE)	INTER-LOCK (FAIL SAFE)	MEDICAL CHECK UP	RADIATION PROTECTION METHODS ADOPTED
Geology M/uni	Research	X-rays	25-150 kV diag-nostic	4	2	--	40	* F.B.	Every two months	Yes	Yes	Never	X-ray shielding film badges warning signs
Chemistry M/uni	Research Teaching	X-Rays	25-150 kV diag-nostic	3	1	--	>100	F.B.	Monthly	Yes	Yes	Never	Restricted room access (Keys) area access (barrier) set 1: Fully enclosed set 2: local screening set 3: scheme of work
Physics UMIST	Research	X-rays	25-150 kV diag-nostic	2	3	--	4	F.B.	Every two months	Yes	Yes	Never	X-ray shielding by lead cover film badge
Biophysics M/uni	Research	X-rays	25-150 kV diag-nostic	2	4	--	~160	F.B.	Monthly	Yes	Yes	Never	As advised by University RPS
Material Science Building Uni/UMIST	Teaching and Research	X-ray	25-150 kV diag-nostic	4	--	--	--	F.B.	Every 8 weeks	Yes	Yes	Never	All students using x-ray equipment must attend course run by RPS in M/Univ.

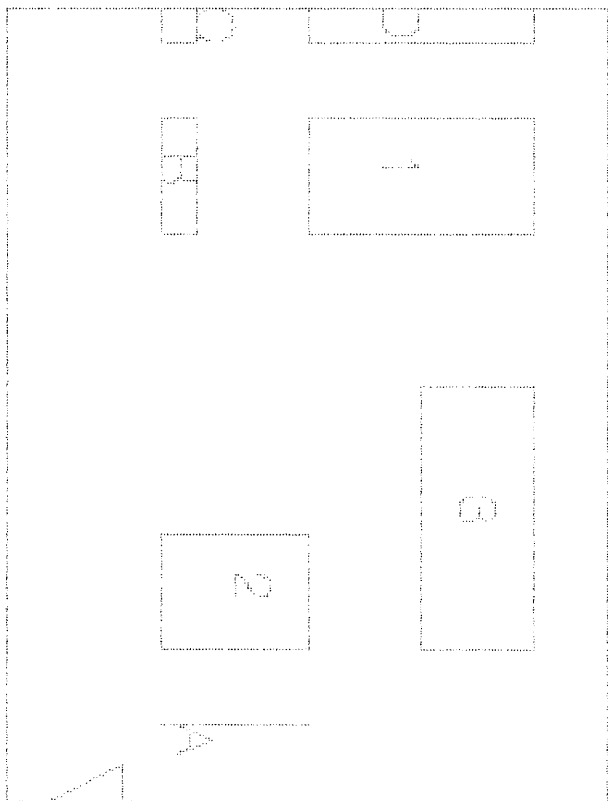
* Film Badge

TABLE 11

X-RAY EMITTING EQUIPMENT RESULTS

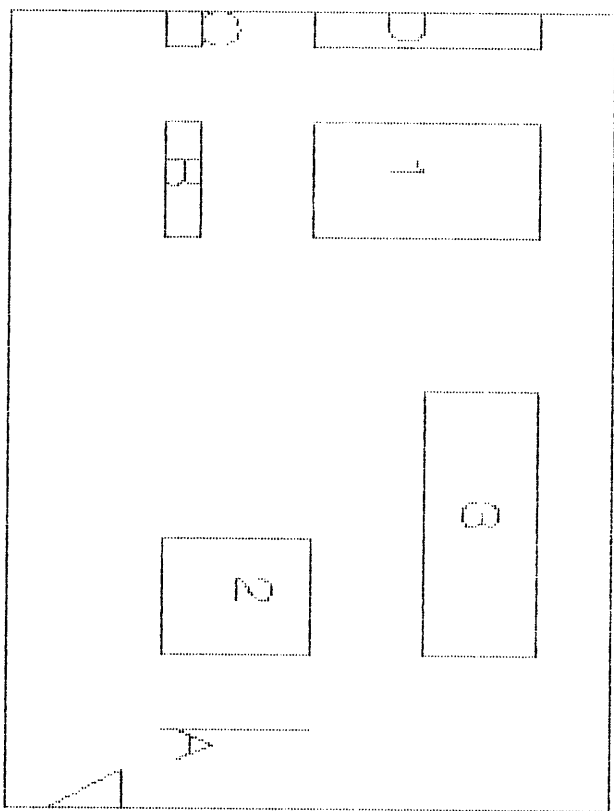
LOCATION	DEPARTMENT	KIND OF RADIATION USED	MANUFACTURER	SERIAL NO.	RANGE OF TUBE VOLTAGE		DOSE RATE RECORD $\mu\text{Sv/h}$
					OPERATING VOLTAGE (kV)	OPERATING CURRENT (mA)	
Manchester University	Geology Room 14	X-Rays	Philips Philips Philips	PW1730	40	20	1
				PW1010172	40	20	0
				PW1130100	40	20	2
Manchester University	Chemistry Room 7-20	X-Rays	ENRAF Philips	FR.585	50	20	1
				PW1120190	50	20	see Table 2
				PW1008	40	20	0
Manchester University	Medical Bio-Physics Room G.443	X-Rays	Philips Philips	PW1120190	38	20	0
				PW1120190	38	20	0
Manchester University and UMIST	Material Science Building Rooms - A12 - A23 - A9 - A10 - A11 - F23	X-Rays					
		X-Rays	Philips	crypt.	40	20	0
		X-Rays	Philips	10-11	40	20	200cps
		X-Rays	Hilton-Brooks	crypt.	40	20	1
		X-Rays	400T	A.E.M.	100	40	0
		X-Rays	Philips	E.M.301	10	20	0
		Elec- tronic	Philips	W.M.300	100	20	0
		Micro-Scope	Sedgraph	5000 ET	13.8	—	0
UMIST	Physics Room E-24	X-Rays	Philips	PW1120/00 Dy796	40	20	200cps

Diagram 6. Geology Department



- 1.Set type No.pw 1730
- 2.Set type No.pw1010/77
- 3.Set type No.pw130/00
- A.Protection shield
- D.Table
- B.Table
- C.Sink

Diagram 6. Geology Department.



- 1.Set type No.pw 1730
- 2.Set type No.pw1010/77
- 3.Set type No.pw130/00
- A,Protection shield
- B,Table
- C,Sink
- D,Table

Organic Chemistry Department

(c)

Philips Type PW120/90
S. No DY924

X-ray tube
housing

(c)

(a)

Survey positions shown

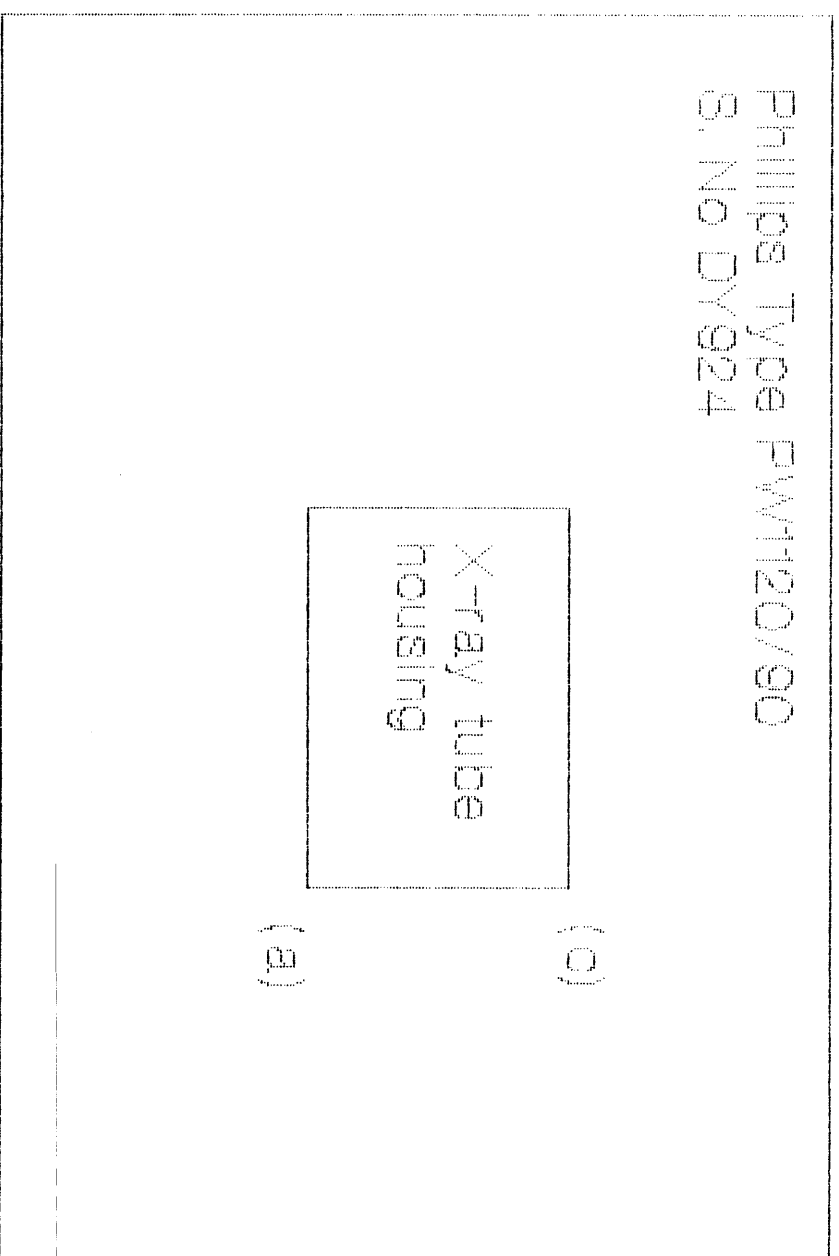
(b)

- a) = 10 cm doserate = 5.0 $\mu\text{Sv/h}$
- b) = 30 cm doserate = 1.0 $\mu\text{Sv/h}$
- c) = 10 cm doserate = 1/0 $\mu\text{Sv/h}$

d) = 30 cm

doserate = bgnd

Diagram 7 Chemistry Department (d)

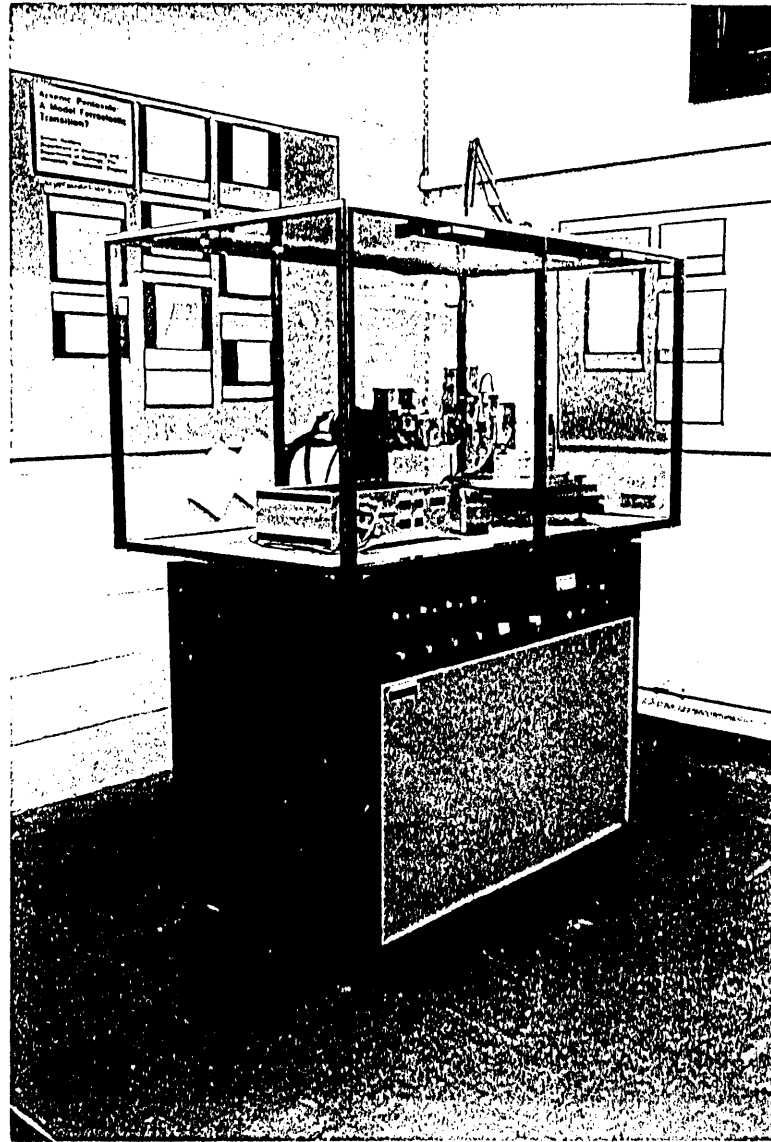


Survey positions shown

- a) = 10 cm doserate = 5.0 $\mu\text{Sv/h}$
- b) = 30 cm doserate = 1.0 $\mu\text{Sv/h}$
- c) = 10 cm doserate = 1/0 $\mu\text{Sv/h}$

(b)

- d) = 30 cm doserate = bgnd



As shown in the above photograph, the diffraction set is fully enclosed, except for the cable entrance point at rear to cabinet. The entrance panels are not however, interlocked to the shutter mechanisms. For an ideal "Fail Safe" situation the following recommendations can be made:-

1. The cable entrance point should be made as small as possible to prevent unnecessary or accidental entrance.
2. The enclosure panels should be interlocked to shutter mechanisms, such that, if any panels are opened or removed the open shutter is automatically closed to blank-off the x-ray exit port.

RADIATION DOSES FROM INDUSTRIAL SOURCES

4.1. INTRODUCTION

4.1.1. Uses

The use of radioisotopes has become an important element in all fields of manufacturing and production processes, as mentioned previously. They are used for industrial techniques such as irradiation purposes, non-destructive testing of metals, researching techniques, thickness measurement, etc. Also, there are a number of miscellaneous industrial uses of radioactive material as for example the calibration of instruments, e.g., Geiger counters, fluorescent tubular, lamp starter switches. These uses, however, are intended to:-

- i) examine and improve the quality and quantity of industrial products;
- ii) increase the efficiency of industrial uses;
- iii) speed the industrial operations.

4.1.2. Type of Radioisotopes

Among these radioisotopes, wide industrial use is made of the X-ray and the gamma emitters, iridium-192, (Ir-182) cobalt-60, caesium-137 and thallium-170. These radioactive isotopes chosen according to the X-ray and gamma ray energy required for the industrial purposes or use and the activity of the radioisotope itself. This means that the choice of radioisotope will depend on the type of work needed, and the energy of this radioisotope, for example, iridium-192 (half-life 74 days), is usually chosen for testing welds,

while cobalt-60 (half-life 5.3 years), is chosen for work which needs more energy and short exposure times such as under water weld testing. Another example is that of medical and surgical sterilization which needs a high energy X, gamma or beta radiation. Nevertheless, the types of radiation emitters surveyed during this study were:-

- i) X-ray emitting equipment (see chapter III for more details);
- ii) sealed isotopes (gamma-ray emitting radioactive isotopes).

A sealed source is composed of radiation materials and made in such a way that, under normal working conditions, the radioactive materials do not come into contact with the surrounding atmosphere. Usually the sealed source consists of a small sealed metal capsule inside which the radioactive material is completely contained and which is enclosed in a source holder. But, due to any accidental faults or leakage, these radioactive isotopes become a source of hazard or danger to the worker and their environment. For example, an accident or leakage may occur, in case of: (see the avoidance procedures - section 4.5. in this chapter).

1. In industrial radiography on the working site, e.g., while welding test operations are carried out.

a) Blockage of the remote control during the source returning procedure

In this case the fault may be caused by either:-

- a fault in the coupling of the gear remote control wire; or

- the wire not being able to run in its sheath due to crushing, bending, dirt, breakage, etc.

This may be recognized by the fact that the control handle for the internal wire will no longer turn, and from the audible warning signals emitted by the monitor.

- b) Breakage of the internal remote control wire at point of attachment with the isotope container

This fault may be identified by the alarm signals emitted by the measuring equipment.

- c) Breakage of the isotope container's lead

The fault in this case may be noticed when one turns the controls for the source to be extracted and the control handle exceeds the normal number of turns expected for this to be accomplished.

- d) Breakage of the isotope container

This fault may be identified by audible signals emitted by the monitor.

- e) Leakage from the sealed isotope capsule

Source capsules can develop leaks due to corrosion, defective construction, or damage suffered by incidents. However, in this case the fault may be identified by the alarm signals which are emitted by the surveying monitor.

2. In radiography enclosures X and gamma ray emitting radioactivity equipment. Because, the protection system in some cases of X and gamma ray emitting equipment depends on the ray contact (or X-ray contact or coil) to release the contact. Therefore if the contacts jam mechanically or

become welded together, the rays (X-rays) interlock chain becomes inoperative and the X-rays in this case will be generated.

- 3, In case of a source jammed outside a radioactive camera. The jamming might occur due to malfunction of a cranking device, or sometimes due to a fault in a coupling deformation of source tube or malfunction of the pneumatic system. So, the protection of industrial radiation workers (e.g., industrial radiographers) has become an important issue. It is important (in case of an accident) to assess the length of time the employees are exposed to radiation, the intensity of the exposure, and the areas of the body exposed - for more details see Chapters I and V.

4.1.3. Radiation Hazards

As mentioned above, accidents and leakage mean hazards and dangers to the workers, their environment and to the public. Therefore, penetrating radiation can irradiate all the regions of the body causing internal radiation hazards which will affect the blood cells and can cause, for example, leukaemia (see chapter I for more details). It may cause bad skin burns which are difficult to heal, particularly to the fingers. For example, there has been two accidents involving exposure to high doses of iridium-192 (Ref.38). In the first accident an untrained worker released an iridium-192 capsule containing 162.8×10^{10} Bq from a shield and re-inserted it into the container with the fingers of his left hand in direct contact. The fingers subsequently became tender and discoloured. Finger exposure was assessed to be between 5.5 to 26.1 Grays (Gy).

In the second accident also, an untrained worker was exposed to 129.5×10^{10} Bq of unshielded Ir-192 for two hours during which time he repeatedly handled the capsule with his fingers. His fingers became sore after 10 days. His fingers has received an estimated absorbed dose of up to 50 Gy. Also, radiation may present (Ref.21) toxicological as well as radiological hazards to persons who have inhaled or ingested them.

4.1.4. Categories of Industrial Radiation Workers/Radiographers

There are four categories of industrial radiation workers:-

1. those who are involved in shielded room operations in a fully enclosed chamber;
(For examples see sections 4.3.2 and 4.3.3 in this chapter)
2. those who are involved in shielded room operations;
(For example see section 4.3.2)
3. those who are involved in a portable self-contained protection system;
(For example see section 4.3.2)
4. finally those involved in open field operations.
(For example see section 4.3.2).

4.2. METHODS OF MEASUREMENT

In this part of the study, practical surveys were carried out with four techniques which used sealed isotopes/gamma ray emitters.

Measurements were taken to establish the level of radiation doses or, the level of occupational radiation exposure. Also, general investigations were carried out to check the

work conditions in any application of these techniques, as well as to determine whether the radiation protection is maintained at acceptable level. The method or procedure used for these techniques was direct measurement, involving the following instruments:-

- a) Mini Instrument 5-10E;
 - b) Victoreen 470A (ion chambers).
- (see Instrumentation in chapter I)

4.3. RESULTS

4.3.1. Doses Monitored During the Measurement of Paper Thickness Techniques

A radioactive source - krypton-85 (1480 MBq) - was used for continuous measurement (weight of paper, grams square meter), in the Paper Technology Laboratory at UMIST. This source is controlled automatically by an industrial gauging system. The safety shutter over the radioactive source is operated by a pneumatic switch. Thus when the instrument is switched to zero or measure, the source shutter is opened. The shutter position is shown as open at all times, except when it is fully closed. Beta radiation was detected from the measuring gap. Dose rates were recorded as follows:-

- i) when the source shutter was opened, with no material (paper) in the measuring gap:-
 - behind the chamber = 2 Sv/h;
 - at the front of the chamber = 2 Sv/h.
- ii) when the source shutter was opened with the material (paper) in the measuring gap, (or when paper was placed between the source and the chamber):-
 - behind the chamber = 2 Sv/h;

- at the front of the chamber = 7 Sv/h.

4.3.2. Doses Monitored from Gamma-Ray Emitting Radioisotope Sources, Used for Industrial Radiography in Petro Spec Company Limited

In this company, the industrial radiography technique is carried out in two ways:-

1. in the company a permanent installation (pit) is used for testing the samples by utilising gamma ray emitters (gamma-radiography) under controlled procedures;
2. on the working site, radioactive sources are used for radiographic welding tests (sealed isotopes in exposure containers).

The standards of control, supervision and protection were different in these two ways.

In the first, the radiography pit (installation) was designed under the special requirements for radiography operations according to the British Regulations and standards, which require that the industrial radiography shall be carried out in a walled enclosure). There is sufficient shielding used to keep the radiation area (exposure area, operation area and the field around this area) below safe levels. For example, there are very thick walls built around the exposure area and well shielded doors (lead used). The interlock system functions automatically, i.e., the interlock door to the exposure pit is connected with the shutter mechanism. When the source is exposed, the door is automatically locked, so that it is impossible for any person to enter the testing pit during the exposure time. Also, there is a warning system (alarm and signals) which are placed in the

control room to indicate the exposure time, whilst warning signs are located around the testing pit. It was found that both interlock and warning systems functioned satisfactorily, and no leakage or scatter was detected.

In the second technique, a radioactive source - iridium-192 ($55.5 \times 10^{10}\text{Bq}$) was used for welding tests (examination of welds) to check for faults. The procedures used for radiation protection in this condition in the company are mainly by:-

- a) a safe working distance. This procedure is based on the maximum allowable dose rate for unclassified personnel of 7.5 Sv/h;
- b) a suitably marked area and encircling by a barrier with high visibility (bunting) set up at 7.5 Sv/h. dose rate distance from the source and the exclusion of all except classified persons. Notices bearing a warning message were placed at intervals near the barrier;
- c) warning signs and signals in conjunction with fencing the area of operation. Adequate warning to all persons by a flashing light (from a rechargeable battery) when the radioactive source is about to be exposed and whilst the radioactive source is exposed.

All these procedures have been found in this company to be applied satisfactorily, and no leakage or scatter was recorded.

4.3.3. Doses Monitored from a Radioactive Source in a Closed Installation

A radioactive source of cobalt-60 ($740 \times 10^{10}\text{Bq}$) is used for chemical analysis and researching purposes in

the Department of Chemistry at Manchester University as a fixed installation in a fully enclosed room. The safety procedures worked automatically, i.e., the door to the exposure room has a shutter mechanism connected with an interlock system switch which is mounted on the door of the enclosure, so that if the door is open the radiation exposure will stop automatically. On the other hand the door automatically closes, so that it is impossible for anyone to enter the room while the source is exposed. This operation is controlled and carried on by a special switch which is mounted on the control panel outside the exposure room. A warning bell with light signals (alarm) is placed in the control room to indicate that the source is in the exposed position.

Generally, both interlock and warning systems function satisfactorily. The fail safe interlock timer also worked well. No leakage was detected during the surveying in either the exposure or control room.

4.3.4. Doses Monitored from Large Radioactive Sources

A radioactive source of cobalt-60 (925×10^{10} Bq) is used as fixed installation in a fully enclosed exposure room. The safety procedures worked automatically, as before with the safety system in the chemistry department (see section 4.3.3). A measurement survey was carried out and the dose rate readings recorded in the following areas:-

- i) exposure room (inner chamber of the irradiation facility);
- ii) control room (outer chamber of the irradiation facility).

Table 32 shows the dose rate readings recorded from the cable hole cover which is shielded by lead, and which normally reduces the radiation level between the inner and outer area of the irradiation facility or between the exposure room and control room when the winding key is being turned or when winding key is moving to different locations (see number 6 in Diagram 8). As shown in Graph 6, the radiation level increased to the maximum (2500 Sv/h) in turns or locations, numbers 3 and 4, when the cable hole cover was closed, and (10,000 and 9,000 Sv/h) in the same locations, when the cable hole cover was opened and decreased as the source moved into the final locations - numbers 1 and 8, (see Graph 6 and Diagram 8).

Other measurements were taken at 40cm from the central cable or cable hole cover near the wooden table (see number 5 in Diagram 8. Results are shown in Table 33.

iii) outside the building (outside of the irradiation facility).

Also, whilst the source was in the fully exposed position radiation measurements were taken outside the building. A dose rate was detected from the surface of the ventilation stack. The measurement results are recorded as follows:- (see Diagram 8)

- a) from the surface of the ventilation stack (at 5cm above the bending point) = 11 Sv/h;
- b) from the surface of the ventilation stack (at the bending point) = 14 Sv/h;
- c) from the surface of the ventilation stack (at 5cm below the bending point) = 7 Sv/h;
- e) 50cm from the ventilation stack = 0.6 Sv/h;
- f) 100cm from the ventilation stack = 2.3 Sv/h.

4.4. RESULTS DISCUSSION AND RECOMMENDATIONS

Survey investigations were carried out by direct measurements in four techniques using sealed isotopes. Different dose rates were determined from these techniques and are described below:-

A. in the Paper Technology Laboratory, the radiation scatter does not form a radiation hazards as:-

1. the workers do not normally approach the measurement gap when it is in operation;
2. since the source is automatically controlled;
3. does not operate regularly.

Thus notices bearing the radiation warning should be placed at or near the working operation. Also, adequate warning signals with flashing lights should be operated at or near the measurement gap and these should be clearly recognisable.

B. In Petro Spec Company Limited, all protection aspects of preventative measures were applied and formed a useful background for ICRP and British Standards and Regulations in their present revision of the recommendations on protection against external exposure. There were no leakages recorded during the surveying period. However, the following are brief examples of their protection methods:-

1. special emphasis is put upon the interlock devices (working automatically);
2. sufficient shielding is used in the exposure room (pit);
3. collimation of source and direction of beam within the shielded radiation pit;
4. always at the end of exposure the radioisotope source is returned to a well shielded container;

5. an automatic warning system is used to indicate the exposure time;
6. a safe working distance method is used for workers protection;
7. marking the operation area, fencing the area, signs and signals are used for protection.

For more details see section 4.3.2. in this chapter.

C. In the chemistry department, ideal control of radiation generation for personnel protection is implemented and radiological protection consideration in the design of the facility and in the preparation of the operation procedures has proved very effective. Linkage arrangements and practical interlocks with the control system are discussed above (section 4.3.3).

D. In the pharmacy department, measurement results are recorded in Tables 32 and 33, and shown in Graph 6, giving an indication of higher dose rates than background levels which will present a radiation danger to the workers carrying out work in the control room, and possibly to anyone moving near the ventilation stack during irradiation operations, if the correct procedures not carried out. However, as a result of these measurements, according to the investigation carried out in this irradiation facility, under the present regulation (the Ionising Radiation Regulations 1985), and as per the principle of ALARA (As Low As Reasonably Achievable), the dose rate levels and leakages should be reduced to the background level. Thus, the following recommendations should be executed:-

1. the cable hole should be re-designed and moved from the centre of the control room to an area which is not facing the operator. Or, an extra lead layer or

lead shield should be fitted around the hole cover to blank-off the cable port, and to be an extra safety guard;

2. the ventilation stack should be re-covered with a lead shield which would reduce the dose rate to the background level;
3. also, the ventilation duct within the irradiation chamber should be shielded;
4. as it was noted, when the source was wound at a slow speed, the source exposed warning bell did not activate, it was active only when the source was wound out at the normal. Therefore, the warning bell must be changed to ensure that the mechanism operates at all potential winding speeds;
5. it is essential to provide fixed radiation monitors at various locations in this irradiation facility, so that, in the case of failure of the shutter (interlock system) mechanism or if the source can not be retracted to its safe position, no person will inadvertently enter the high radiation field (exposure area or inner chamber).

**4.5. TO AVOID ACCIDENTS OR FAULTS WHICH MIGHT OCCUR
(AS MENTIONED PREVIOUSLY IN SECTION 4.1.2.)**

a) It is therefore, necessary in case (1a) to:-

- i) measure the radiation;
- ii) grasp the wire and pull until the isotope container goes back into the machine. This manoeuvre must be carried out in the shortest time possible in order to limit the time of exposure.

If the above procedures do not have a satisfactory result it is necessary to cover the extension lead at the point of the source with one or more lead sheets in

order to be able to approach the source. Grasping and pulling the wire in order to return the source to its protected position.

b) In cases (1b), (1c) and (1d), it is necessary to:-

- i) measure the radiation;
- ii) plan the action to be taken and prepare a screen which will completely protect the operator while he carries out the procedure of inclining the machine to an angle of approximately 45°;
- iii) grip the extension lead with the pliers and raise it until the isotope container is returned to the machine.

c) To avoid case 1e:-

If a sealed source is found to be leaking in the course of routine checking or maintenance of the equipment or even in the course of operation, the following steps should be taken:-

- i) a film badge should be worn;
- ii) all crevices and openings through which contamination may spread should be taped;
- iii) the environment (operation area) should be surveyed or measured for radiation contamination.

d) To avoid case 2, see chapter 3.

e) To avoid case 3, the following steps should be taken:-

- i) the source should be pulled with long handled tongs and it should be placed in the emergency container; or
- ii) the source should be drawn back inside the camera.

f) Finally, all above operations should be carried out in the shortest possible time in order to limit the exposure.

4.6. CONCLUSIONS

Based upon the survey results and investigations discussed in this chapter, it was determined that the irradiation facility in the pharmacy department was the only technique which gave high dose rates, which originated from points A and B, as can be seen in Diagram 8, and Graph 6, in the condition of the cable hole cover closed (as normal) or, in the condition when it is opened. Therefore, it is necessary for the re-designing of the cable hole or fitting of a lead shield around the cable hole cover. This should be done in a way that reduces the exposure as much as possible in order to ensure that the operators or any person who enters the facility for any reason during the irradiation operation will be safe from radiation exposure hazards. Also, it is necessary to provide additional shielding around the actual ventilation stack to prevent the workers or public, moving near this stack, from exposure.

Finally, it can be concluded in general that the potential for high or even low exposure to radiation can be eliminated through proper design of irradiation and industrial facilities.

Measurements taken in the University Department of Pharmacy

Table 32

Turn No. or winding No. of source position	D o s e R a t e	
	When the cable hole cover was closed $\mu\text{Sv/h.}$	When the cable hole cover was opened $\mu\text{Sv/h.}$
1	200	1,000
2	1,000	4,000
3	2,500	10,000
4	2,500	9,000
5	1,000	5,000
6	950	3,000
7	150	6,000
8	0	0

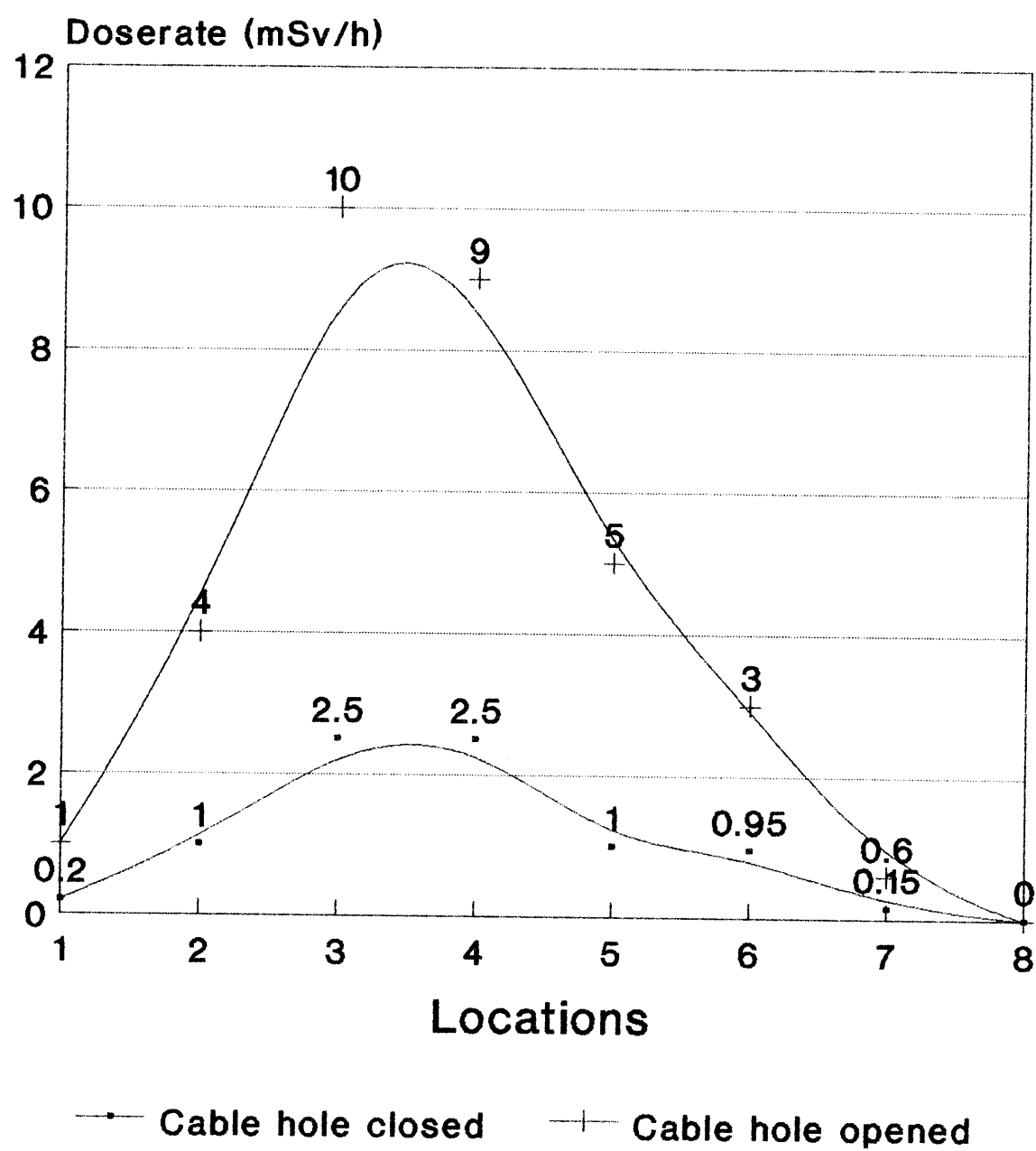
Note: Readings were taken from a close position to the central cable port (cable hole cover)

Table 33

D o s e R a t e	
With the source at position Nos. 1 and 2	With the source at position Nos. 3 and 4
15 $\mu\text{Sv/h.}$	70 $\mu\text{Sv/h.}$

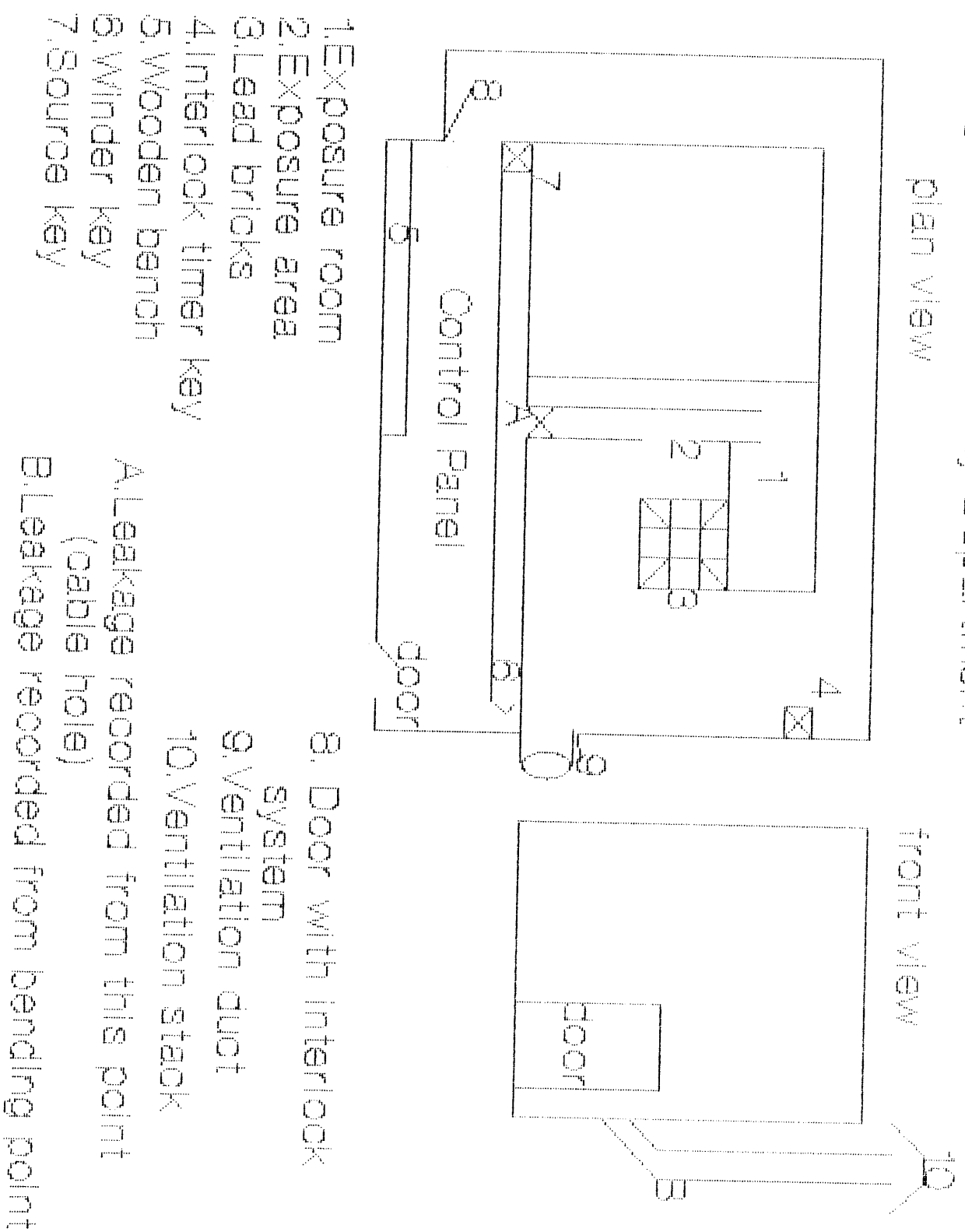
Note: Readings were taken 40cm from the central cable port (in the control room)

Graph 6. Effect of opening cable hole on the doserate from the cobalt-60 source in Pharmacy Department.



Manchester University

Diagram 8. Pharmacy Department



GENERAL DISCUSSION

5.1. GENERAL CONCLUSIONS

The preceding chapters have described various methods for determining the ionising radiation exposure or doses at different cases of handling (three types of ionising radiation sources:- open sources, sealed sources and X-ray sources), in order to assess the effect of the various methods of handling for radiation protection, to compare between similar uses of these sources, to study dose accumulation patterns of workers and to demonstrate compliance with occupational exposure limits. However, each of these sources are used in a similar way (researching and teaching). Therefore, there are recommendations in each chapter, with general recommendations summarised late in this chapter.

It is important to avoid offending the regulations (local rules, medical check-ups, monitoring records or record keeping, written systems of work, etc.) and it is necessary to give careful consideration to each handling procedure at its design stage, concerning the need for management supervision in the practices, training and designation of these procedures which I think will play a major role for ionising radiation protection, and will avoid the exposure of the personnel involved without imposing unbalanced instructions.

5.2. GENERAL RECOMMENDATIONS

In the light of the conclusions drawn from this study, and in addition to the previous recommendations, it is

recommended that protection measures should be considered when handling the following cases.

5.2.1. In Case of Handling of Open Sources

According to this study, there are two main hazards in handling unsealed sources of radioactivity:-

- a) skin contamination and deposition of an isotope in the body;
- b) spread of contamination.

a) To avoid skin contamination and deposition, the following procedures should be implemented:-

1. laboratory coats must always be worn in the laboratory;
2. eating, drinking, smoking and the application of cosmetics should be strictly forbidden;
3. extreme care must be taken to avoid cuts or puncture wounds;
4. cracked or chipped vessels should not be used. Any small wound should be covered by a suitable water-proof dressing during working hours;
5. if there is a risk of splashing (operations with syringes and vials can give rise to a spray) the face should be protected by working behind a transparent sheet or screen (see Diagram 5), or eye protector shields should be worn;
6. disposable gloves must be worn for all procedures involving solutions with radioactive substances;
7. gloves should be rinsed over a designated sink. Make sure that the hands do not touch the outside of the gloves during removal, (and

do not touch objects such as pencils, telephones, etc when wearing gloves);

8. in the event of any drips or splashes getting onto the gloves they should be immediately washed and monitored or should be disposed of as radioactive waste;
9. hands should be washed and monitored immediately after handling any radioactive substances;
10. all personnel who have been manipulating unsealed sources of any activity should monitor their hands and clothing before going home or eating.

b) To avoid the spread of contamination, the

following procedures should be implemented:-

1. all operations should be carried out over a drip tray which should be covered with absorbent paper;
2. wherever it is possible disposable containers and instruments should be used;
3. glassware and plastic-ware which is not disposable should be rinsed out immediately after use and then set aside for washing;
4. it is advisable, always to use disposable syringes - contaminated syringes should be rinsed out before the needle is removed. The needle should then be placed in an appropriate box (and labelled), so that there is no possibility of the needles pricking anyone, and the syringes should then be placed in the radioactive waste bin;
5. no contaminated material of any description must be left lying about on benches or

draining boards;

6. if radioactive material has to be stored in containers, it should be carefully labelled and stored in a designated area, where there is no possibility of accidental breakage or spillage;
7. any tools which have been used, (e.g. bottle openers, etc.) must be checked for contamination and decontaminated if necessary before being put away;
8. containers should be segregated into groups which have contained similar concentrations of activity before being carefully washed. The possibility of residual activity in containers in which high specific activity solutions have been kept should always be considered and, if necessary, these containers should be kept solely for such solutions.

c) In addition to the above recommendations, the following should be strictly implemented:-

1. Work surfaces. All work areas (bench tops, hoods, floors, etc) as well as storage areas adjacent to sinks should be covered at all times with stainless steel or plastic trays, or other impervious materials. For some purposes a plastic-backed absorbent paper will be satisfactory. However, if such paper is used it should be discarded frequently to prevent spread of contamination.
2. Use of caution signs and labels (see Appendix 5). Laboratory personnel are responsible for

the labelling of containers and other laboratory apparatus in which radioactive materials are used in the laboratory.

3. Procedures involving aerosols, dusts, and gaseous products (airborne contamination. These procedures or any other procedures which might produce airborne contamination should be conducted in a hood, glove box or other suitable closed system. All releases from such systems should not exceed the Derived Air Concentration in air (DAC). However, where practical, traps should be incorporated in the experimental step-up to ensure that environmental releases are as low as possible.
4. Every person using sources of ionising radiation must wear a film monitor and/or a TLD dosimeter (if appropriate) whenever radioactive materials used.
5. A radiation survey meter should be provided, and should be used frequently during radioactive material uses. All these monitors should be properly maintained and calibrated.
6. Decontamination. The decontamination of radioactivity workers, materials and equipment may be necessary in order to lower the radiation level or intensity to extend working time (in case of contamination presented), to reduce the radiation background or to minimise the spread of contamination.

a) Decontamination of persons.

- i) Persons working with radioactive

substances should wash their hands thoroughly with soap and water before leaving working areas, and especially before eating, drinking smoking, or the application of cosmetics. Particular attention should be paid to cleaning the finger nails. After washing, the hands should be checked with a radiation monitoring meter or instrument.

- ii) When contamination of parts the body, other than the hands, is suspected or when the procedures (described above) are ineffective, special care needs to be taken in the decontamination of area near eyes and in preventing the spread of contamination to other parts of the body. Showers or baths should be taken after the major areas of contamination have been cleaned.
- iii) In case of broken skin or a wound where there is a risk of radioactive contamination, the injury should be irrigated with tap water.
- b) Floor covering. Floor covering should be cleaned with detergent and water. If the floor is covered by plastic, then dilute nitric acid can be used to clean plastic.
- c) Glassware. Glassware should be cleaned immediately after use (usually an alkaline detergent is used). If the contamination has been allowed to dry,

the glassware should be marked and segregated for special attention when cleaning.

- d) Metal tools, trays, sinks and equipment.
All metal tools, trays, sinks and equipment should be monitored to detect possible contamination. They may be cleaned by washing with heavy-duty detergent of the type used for laundering and followed (if necessary) by acid (e.g., dilute sulphuric acid).
- e) Clothes. Clothes (if contaminated) should be placed in a specially labelled container. For short-lived radio-nuclides, storage should be until the activity has fallen below an acceptable level. Washing can be carried out in a designated washing machine. Clothing which cannot be laundered satisfactorily or stored should be regarded as radio-active waste.

5.2.2. In Case of Handling of Sealed Sources

Handling of gamma-emitting sources or sealed sources create a radiation hazard to personnel and other persons in the vicinity depending on a number of factors. However, such operations can be quite safe if carried out by trained personnel using the equipment designed for this purpose. Finally these operations followed the operating procedures or local rules, which keep it within the frame-work of the standards and the protection regulations, and give each radiation worker guidance and understanding of his duties and responsibilities.

However, in the case of handling of sealed sources there are different situations, such as:-

A. Handling in a closed installation/dealing with a source in a closed facility

Examples:- Chemistry and pharmacy departments (see Chapter IV sections 4.3.3 and 4.3.4).

These installations or facilities are designed where large sources are used as fixed sources, additional safety features must be incorporated.

Some of these are:-

1. all doors to the exposure area or chamber should be interlocked with the shutter mechanism so that it is impossible for any person to enter this area or chamber while the source is exposed;
2. in addition to the interlocks there should be a warning sign. These signs should be around the facility at the entrance and in the control room (see Appendix 5). For more details see Chapter IV;

B. Handling the source/dealing with the Source in a pit designed for testing

Example:- Sampling testing pit in Petro Spec Company Limited (see Chapter IV section 4.3.2).

1. for protection of personnel, such a facility or room should be well designed (and well shielded) to ensure that the level of exposure outside the room is as low as reasonably achievable and not greater than 7.5 Sv/h;
2. the location should be in an isolated area, where only radiation workers are likely to be present (for more details see Chapter IV section 4.3.2);

C. Working on Site

Example;- Petro Spec Company Limited see section 4.4.2. in Chapter IV.

1. Ideally the radiography should be carried out in a fenced enclosure with a lockable gate which must be kept locked for all except classified persons whilst radiography is in progress. Otherwise radiography should be carried out in a suitably marked area with warning signals when a radioactive source is about to be exposed or whilst the radioactive source is exposed.
2. All radiographic devices should be conspicuously and permanently marked with the radiation warning signs (see Appendix 5).
3. The source capsules should be permanently identified with the type and original strength of the radioisotope contained in them.
4. Source capsules should be checked for leakage of radioactive material periodically (for more information see Chapter IV).

D. Transportation Procedures

The reason for mentioning these procedures as handling procedures is to describe the safety methods which may provide an acceptable level of control of radiation hazards to person's property and the environment that is associated during loading and unloading of radioactive materials. However, the transport of radioactive sources is generally governed and guided by International and National regulations and standards. For example:-

- i) internationally by the International Atomic Energy Agency (IAEA);
- ii) locally in the UK for example, it should comply generally with BS 5650.

The exposure rate from the container when the source is properly stored should not exceed 2mSv/h. at the surface of the container. In the driving compartment the dose should not exceed 7.5 Sv/h.

1. A placard in the form prescribed must be securely attached to each side and to the rear of any vehicle carrying radioactive materials. This is for warning fire services, public security and others in case of a vehicle accident. Also, care should be taken to remove the placard when no radio-graphic consignment is being carried.
4. A fire-proof notice should be carried in the vehicle conspicuously displayed in the driver's cab. This notice must state that the vehicle is carrying radioactive materials and the names, addresses and telephone numbers of users, qualified person or the responsible person to be contacted in case the vehicle should be involved in an accident. Also notices should be removed when the vehicle is not carrying radioactive materials. (see Appendix 5).

E. Other notices for handling sealed sources

1. Every person using the above sources must wear a film monitor (film badge) and/or pocket dosimeter whenever high radiation fields are likely to be encountered.

2. A radiation survey meter should be used frequently during each operation.
3. Whilst working with radiographic devices, the following steps should be considered:-
 - a) reduce as far as possible the radiation exposure of all personnel by suitable choice of:-
 - i) shielding;
 - ii) distance;
 - iii) working time;(for more information see Chapter I section 1.4.1).
 - b) test the camera before it is used for proper mechanical function and where applicable, special attention should be given to:-
 - i) the shutter mechanism;
 - ii) source coupling;
 - iii) source positioning plungers;
 - iv) cranking devices;
 - v) locking mechanisms;
 - vi) the cleanliness of the hose or tube through which the source moves.
4. Sufficient shielding should be used to ensure that the radiation is below safe level in place around the area used for radiography.
5. Appropriate shields should be used for every exposure to limit the radiation beam to the size of the area being radiographed.
6. Radiographic operations should be performed whenever possible during that time of day when a minimum number of people are in the vicinity.

7. Checking should be carried out after each exposure by a survey meter to see if the radioactive source has returned to its proper shielded position in the camera.

5.2.3. In Case of Handling of X-ray Emitting Equipment

There are many specifications which might cover aspects of handling or uses of X-ray sources or emitting equipment. These are:-

A) Equipment specifications

1. The control panel should be marked with a suitable warning sign. For example, caution X-rays or this equipment will produce X-rays when energized see Appendix 5 figures 9 and 10.
2. Effective means should be provided to prevent any unauthorized use of the equipment. For example, local rules and written systems of work.
3. There should be some easily discernible device on the control panel to give positive information as to whether or not the X-ray tube is energized.
4. The tube housing should provide adequate protection to personnel.
5. Any X-ray tube which can be continuously energized should be provided with lead shutters. The protection afforded by these devices should be at least equal to the tube housing and arranged so that it can be opened and closed from the control panel.

B) Diffraction set enclosure specifications

The diffraction set enclosure should provide

adequate protection for the operator for all positions of the X-ray tube. Thus the X-ray control circuit/key should be fitted or mounted on the enclosure doors with interlock switches, so when the door is open for any reason, the X-ray contact coil will de-energized and the radiation exposure will be automatically stopped (see Photograph 1 and chapter III).

C) Open installation specifications

1. The control panel should be placed and operated from behind a fixed or temporary barrier of adequate protective thickness (see Diagram 6 point A).
2. During X-ray exposure, all persons other than the control operator should be:-
 - i) shielded from direct and/or scattered radiation by a barrier of adequate protective thickness; or
 - ii) excluded from the area around the radiographic place.
3. The area as determined by the above procedure should be demarcated by roping off or by other suitable means (this should be carried in case of working on the site see Chapter IV).
4. Audible signals should be provided and operated immediately prior to radiation exposure.
5. Visible warning signs should be provided and operated during radiation exposure.
6. Whenever practicable, the useful beam should be directed away from occupied spaces and the beam cross-section should be limited to the

smallest area necessary for the work.

D) Other specifications

1. All examinations should be done as soon as possible and with the smallest practicable beam intensities and tube apertures.
2. As far as practicable, objects for examination should be positioned before the X-ray tube is energized.
3. Articles for examination should be inserted into the useful beam or moved during exposure by the use of tongs, conveyors, turntables, sliding trays, dial feeds or other suitable mechanism operated from behind a protective barrier.
4. Whenever necessary, operators working from behind protective barriers should wear gloves and aprons if needed or in the case of high exposure, which may offer adequate protection.
5. The use of a warning light will indicate when the tube is energized or a shutter is open.
6. It is pointed out that the primary on/off switch for each tube should include a visual indication of the tube status.
7. It is required that all work should be supervised by a person responsible for radiation safety.
8. Every worker/person using sources of ionising radiation must wear a film monitor whenever radioactive material is used. A proper radiation survey meter (maintained and calibrated) should be used frequently during

each operation.

5.2.4. Emergency Procedures in Case of a Radiation Accident

Accidents involving a radioactive source can vary according to the type of device, its location, the mode of use and the radioactive material involved. Therefore, emergency procedures applicable to one incident may be quite inadequate in another situation. Detailed procedures to be followed in a particular situation are to be decided by the responsible user and according to the official standards and regulations of that company, establishment or country. So, it is necessary to **THINK** about a radiation accident **BEFORE IT HAPPENS**. This is why detailed emergency procedures should be prepared in advance and a copy should be available at the place or site of every radiation operation.

In handling any emergency situation the **FIRST RULE** is never to attempt to correct it unless a radiation detector (monitor) in proper operating condition is available. If a suitable radiation detector is not available, a restricted area should be set up and warning signs should be posted. The extent of this will depend upon the strength of the source and other factors such as type of the source, is there a shield available, etc. No further action should be taken until proper instruments become available.

The **SECOND RULE** is "**THINK**" about the steps which must be taken to remedy the trouble which should result in the minimum personnel radiation exposure. For this the following factors must be used to the best advantages:-

- a) TIME;
- b) DISTANCE;
- c) SHIELDING.

For more details see Chapter I section 1.4.1.

However, it is imperative that simple comprehensive procedures anticipating various possible modes of accidents should be laid down to:-

1. ensure that external exposure to members of the public and emergency people or crew are kept to the lowest practical amount;
2. ensure that during emergency operations, there is no possibility of ingestion of radioactive material by any person;
3. be specific in relation to the equipment, radioactive substance in use and possible mode of accident.

Also, the person responsible must ensure that:-

- a) copies of the emergency procedures are distributed and explained to the radiation workers;
- b) all groups who use or store potentially hazardous amounts of radioactive substances should periodically meet to review the emergency procedures and modify them in the light of experience gained;
- c) emergency equipment is readily accessible to all concerned;
- d) names and telephone numbers of concerned authorities (e.g. Health, Safety, Fire, Police, etc.) are available to operating personnel;
- e) emergency measures taken in each accident are documented for judgment, for recording all persons who might have been exposed or may be for further study.

5.3. SUGGESTION FOR FURTHER STUDY

This study has focused on measuring and investigating the external exposure or doses of radiation resulting from the usage of unsealed and sealed isotopes and X-ray emitting equipment, and no measurements exceeded the recommended levels endorsed by the International and British Regulations in this respect.

Therefore, I should like to suggest a further study which deals with the internal exposure or doses of radiation which were not covered by this investigation.

Internal Exposure

Internal radiation, means internal source radiation or radiation emitted by a source which is inside the human body, such radiation implies that a source has entered the body through absorption through skin, ingestion or inhalation. Two methods could be used for measuring the internal exposure or doses of radiation. These are directly by total body counting (used in the cases of gamma and beta emitting radio-nuclides or directly by bioassay, (Ref.17 and 19).

5.3.1. Other Suggestions

It has been shown from the results that the doses which were received by radiation workers would not present a radiation hazard for the time being. It would be worthwhile to carry out the study over a longer period of time in order to see if the results obtained were truly representative. So, I would like to suggest the following methods to find out the small doses. These methods are:-

Method 1: Statistical Methods for Estimating the Mean and Variance from Radionuclide Data Sets Containing Negative, Unreported or Less-Than Values.

Method 2: Statistical Analysis of Low-Level Radioactivity (Ref. 13 and 22).

APPENDIX 1

Part (A): The State of Bahrain

The state of Bahrain is relatively industrialised in comparison with its reasonably rich natural resources and population. It is composed of three major islands of which Manama is the capital. Manama (the main island in which most of the commercial, economic and industrial activities exist) is about 50km long and 13-35km wide. The state has a population of 457,600 (estimate 1987) - thirty-two percent of the population consists of expatriates who are mainly workers participating in the nations building and construction industry (Ref.8). This number of foreign workers has contributed tremendously to the development projects which took place during the past five decades.

The crude birth-rate in Bahrain is 29.4/1000 (Ref.8). In the light of this rate the population is expected to increase dramatically in the future. The great majority of inhabitants (approximately 78%) exist in the urban areas. The rate of literacy is approximately 87%(Ref.). Arabic is the mother tongue of the state of Bahrain, the English language is widely spoken at private and public sector level. The climate is characterised by high temperatures, irregular winter rainfall and relatively high humidity. Bahrain was the first country in the Arabian Gulf to discover oil (1931). Therefore, its national economy is largely dependent on industrialised development based on oil production and marketing, and oil related industries, such as petroleum refining, petrochemical industries, aluminium smelting and aluminium manufacturing, iron ore pelletising, ship repairing and maintenance yards, banking (76 offshore banks Ref.8), and agriculture.

This rapid industrial development, and relatively legal

control of industrial hazards, such as ionising radiation, has led to a growing interest and awareness and has been a matter of great concern to the Bahrain Government (still in the process of preparing radiation protection regulations).

In Bahrain most of ionising radiation uses involve sealed, unsealed and X-ray sources. Sealed radioactive and X-ray sources are used under less sophisticated conditions on constructions sites and in installations, and other sites, such as industrial radiography. As in the developed countries unsealed radiation and X-ray sources are used in Bahrain's hospitals, universities, laboratories and research centres.

At the present time there are no specific statutory regulations in respect of ionising radiation carried out in the State of Bahrain, but there are requirements and Governmental instructions issued by the Ministry of Health, on the health and safety conditions to be followed when using radioactive materials and processes for industrial purposes only. These requirements are more or less similar to those applied in the United Kingdom, and broadly follow the purpose and intent of the British statutory instrument 1985 item 1333 Health and Safety the Ionising Radiations Regulations 1985.

The most important item of these requirements is dealing with radioactive waste which requires that, decayed isotopes must be returned to the supplier, after use. Thus, radioactive waste is exported for disposal or reprocessing outside the State of Bahrain. The Occupational Health Department enforces the suppliers and companies using any type of radioactive isotopes for any purposes, to export or return the radioactive wastes such as decayed isotopes, containers, etc, to the manufacturers. Only medical wastes

such as surgical and clinical are incinerated together with low level radioactive wastes following their storage until the level of radioactivity has fallen below a given threshold.

Part (B): Suggestion to establish a Radiological Protection Committee in the State of Bahrain

As it has been mentioned in the Part A of this appendix, the Government of Bahrain is in process of setting up rules and regulations in connection with radiation uses and protection, I believe that, it would be a good idea if the Official Authorities in Bahrain first thought of establishing a committee to carry out or to assist radiation protection functions to be more effective and successful, and to be responsible for authorising and approving all procedures concerned with the use and disposal of radioactive wastes, until regulations are issued. Then the committee will be the place where any radiation users or establishments seek advice or assistance to ensure that all work with ionising radiation is carried out safely.

Also, information, instruction and training should be provided by this committee, so that radioactive materials will be used in the correct way with minimum exposure to staff and members of the public.

Moreover, the formation of such a committee has proven successful in many countries. For instance countries like the UK and USA etc, have adopted such committees, boards, or organisations a long time ago.

For example, the National Radiological Protection Board (NRPB) in the UK and the National Council on Radiation Protection and Measurements (NCRP) in the USA, help to support the operation of radiological protection in their respective countries.

The Radiological Protection Committee (RPC) Structure. The membership of the suggested RPC shall consist of:-

1. The Vice-Rector:

to ensure a very strong and powerful committee, The Vice-Rector should be a minister or under-secretary.

2. Chairman (executive committee):

Chairmanship of this committee needs to be allocated to a highly qualified person who possesses both, the knowledge and expertise in management and administration.

3. Other members:

Special knowledge and expertise in the field of radiation, such as:-

- a) head of radiology department in the Central Governmental Hospital;
- b) heads of radiology department the in medical college and Physics departments in the Bahrain Universities;
- c) a clinical representative from the clinical department (hospitals);
- d) a representative from Occupational Health (radiation inspector/occupational hygienist/occupational physician or radiation specialist);
- e) a representative from Bahrain Research Centre;
- f) a representative from the environmental protection committee;
- g) any other member of staff with knowledge or expertise may be invited to attend committee meetings.

APPENDIX 2

CHERNOBYL ACCIDENT

Date of Accident : 26.04.1986.
Place of Accident : Chernobyl-USSR
Type of the Reactor : Boiling water
(graphite moderated design)
Accident end date : 07.05.1986.

1. Causes of accident (Ref.33)

An experiment was being carried out on the reactor, which resulted in safety systems being over-ridden and also many movements of the control rods. Control was lost and, therefore, it was decided to abort the experiment and close down the reactor, however, this decision was made literally seconds too late. The design was faulty in that there was a positive void coefficient at low power. This resulted in a surge of from 7% to 10,000% of rated power. A steam explosion was caused resulting in core material being thrown out of the reactor. As a consequence of this, fires started in neighbouring buildings. An attempt was then made to put out the fires by dropping material into the burning reactor by helicopter. 40 tonnes of boron carbide was dropped as a neutron absorber, 800 tonnes of dolomitic limestone as a heat sink, 2,400 tonnes of lead as a heat sink and shield, and 1,800 tonnes of sand and clay as absorbing filter mediums.

2. The developments

Airborne activity was carried with an air mass circulated over European Countries until 3rd May 1986, when air concentration started decreasing as the cloud

moved into the Atlantic (Ref.6). On the 7th May 1986, there was a smaller increase in activity as the air mass recirculated from the west, and later on in May 1986, there was another slight increase in air concentration of the airborne activity in the northern hemisphere (Ref.6).

About one third of fission product activity released consisted of the **Radiologically Significant** radionuclides caesium-137, caesium-134 and iodine-131. The concentrations of caesium-137 in the second and third passages of the cloud were two orders of magnitude less than in the first (Ref.6).

Total activity released was estimated as 1.85×10^{18} Bq with the release ending nine days after the incident had started (Ref.23). This represents 3.5% of the radioactive core material with a mass of 6-7 tonnes. 0.6-1 tonne was distributed in the immediate vicinity of the plant, 3-4 tonnes in a 20km zone and the rest at greater distances. Examples of nuclides released in this accident (Ref.33):-

Nuclide	Released (expressed as % of the reactor radioactivity inventory)
I-131	100
Cs-137	40
Cs-134	13
Sr-90	10
Ru-isotopes	40
Pu-isotopes	3

3. The effects (Ref.33)

The Russian Authorities found that bone marrow transplants were of little use and in fact felt that

they may have been detrimental. Two additional deaths were caused by thermal or beta burns and the latest USSR figures indicated one additional radiation death.

a) Local radiation doses

Dose Gy	No. of people exposed	Deaths
6-16	22	21
4-6	23	7
2-4	53	1
1-2	105	0

b) The radiation doses estimated to the local inhabitants

Total doses throughout Russia are estimated at 0.2mSv. (this would be expected to cause $2 \times 10^6 \times 3 \times 10^{-7}$ deaths) Ref.29.

Notes:

- i) world wide deaths including the USSR were estimated at 12,000 (Ref.33);
- ii) the latest death was the helicopter pilot who dropped materials to extinguish the fire (he died in the USA, where he was receiving treatment) as announced in the British News Media - July 1990.

4. Eastern european doses (Ref.33)

a) First year:-

Country	Estimated dose (mSv)
Poland (NE)	0.6 - 0.8
Warsaw	0.1
Prague	0.1
Hungary	0.1
Romania	0.1

Iodine-132, found in the milk (milk figures) in the following countries:-

Country	Peak I-131 concentration (Bq ⁻¹)
Yugoslavia	50 - 150
Poland	30 - 2000
Czechoslovakia	100 - 500
Hungary	200 - 2600

5. Doses and effects in the UK (as the second example of the effects), (Ref.30)

The fission activity (cloud) approached the UK from the South East, and the increased in airborne activity was first detected at the South Coast of England on the 2nd May 1986 and subsequently over the whole of the UK as the cloud moved northwards. The deposition in the UK was mainly due to rainfall. However, the mechanisms of the exposure were by:-

- a) Immersions;
- b) Inhalation;
- c) Irradation;
- d) Ingestion.

The average figures for the UK in general and in wet areas are as follows:

1.	Source	UK(in general)	Wet Area
	I-131	120	160
	Cs-137	20	20
	Cs-134	10	10
	Gamma	0.1	0.5

Bq/h.m⁻²
mSv/h

2.	Material	UK(in general)	Wet area (Bq.kg ⁻¹)
	Rain	300	2000
	Milk	50	200
	Lamb	240	600

Note: Out of 34 million sheep in the UK, three million were at one time restricted (Ref.33).

The concentration of the above types of nuclides gave rise to such doses as: (Ref.16 and 33).

Location	Thyroid (infants)	Doses (mSv) (adults)	Effective at (1st year)	Dose Equivalent (all years)
England	1000	160	25	30
Wales	1200	240	75	100
Scotland	1500	290	90	160
N.Ireland	1900	360	100	180
UK	1100	190	35	50
Wet Areas	3800	640	200	2800

**SUMMARY OF RADIATION PROTECTION LEGISLATION
IN THE UNITED KINGDOM**

There are two types of legislation in the UK dealing with radiation protection. The Radioactive Substance Act 1960 and the Ionising Radiations Regulations 1985. These Regulations and the Act impose a system of radiological protection which is more or less the same in all premises using radioactive materials or radiation emitting equipment.

1. The Radioactive Substance Act 1960 (Ref.33 and 36)

This act controls the following stages:-

1.1. Acquisition

The regulations under this act, specify both the radionuclides or class of radionuclides and the total activities allowed.

1.2. Storage

Radioactive materials must be stored under certain conditions as outlined in this act. This will always mean a lockable store sufficiently shielded, normally to reduce the radiation dose to below 7.5 Sv/h. on the outside of the store.

1.3. Radioactive Waste

The disposal of any type of waste is often very difficult, (especially in solid form). However, liquid radioactive waste can be disposed directly to the drainage or sewer systems. Gaseous radioactive waste is rarely permitted directly from a site. Finally solid waste disposal is as follows:-

- a) low levels can go to the local waste dumps, where the radioactive material is immediately

buried under normal refuse;

- b) high levels must be taken to the National Disposal Services, where special arrangements can be made for temporary or permanent storage.

2. The Ionising Radiations Regulations 1985, (Ref.14, 33 and 36).

These regulations are divided into the following parts or sections:-

2.1. Interpretation and General

The main features of these particular sections are that all work involving radiation must be **NOTIFIED** to the Health and Safety Executive, so that the premises can be inspected appropriately and that there should be close co-operation between different employers, (it is important to know when a worker may spend time in more than one establishment and to record all radiation doses he receives).

2.2. Dose Limitation

All radiation doses should be kept **AS LOW AS REASONABLY PRACTICABLE**, which means that it is not merely necessary to keep within the dose limits, but to keep as far below these limits as is practicable. Also, priority must be given to keep individual doses to as low as reasonably practicable.

2.3. Regulation of Work with Ionising Radiation

This section of the regulation commences by dealing with the definition of types of radiation areas, which are:-

- a) **"Controlled Area"** wherever considerable risk of exposure exists. In this area only a special category of worker is allowed, other

than by a written and approved "SYSTEM OF WORK". Such special workers are designated as "CLASSIFIED" and special records of radiation exposure and health must kept. This section also, calls for the appointment of a **Radiation Protection Adviser (RPA)** and **Radiation Protection Supervisor (RPS)**.

An RPA is a professional in the subject and should be consulted on all matters concerned with radiation protection.

An RPS is in control of protection within his department, and acts for the head of the department. He should also draw-up Local Rules for work with ionising radiation within his particular department consulting the adviser where necessary. Furthermore, this section deals with training, instruction and information which should be given to all workers before they commence work with ionising radiation.

2.4. Dosimetry and Medical Surveillance of Radiation Workers

This section accepts any approved and appropriate means of dose assessment but such assessment must be closely monitored to confirm the accuracy of the results obtained. An annual medical examination should be carried out to check the worker's health and his condition. Records must be kept of all dosimetric results and medical examinations.

2.5. Monitoring of Ionising Radiation

This section deals with monitoring of radiation in the two important areas, (controlled and

supervised). Equipment must be of the correct type and regularly checked by approved laboratories. The monitoring results must be recorded.

2.6. Arrangements for the Control Radioactive Substances

The whereabouts of sources should be known at all times and careful records of receipts and disposals should be kept. Special equipment and methods may be required for the movement of sources and special radiation areas declared during transport operations. Adequate washing and changing facilities as well as protective clothing for radiation workers must be provided.

2.7. Assessments and Notification

Special investigations and reports require to be submitted to the Health and Safety Executive in the case of over-exposure of radiation or any particular radiation hazard suspected or confirmed. Also, major spills or losses of radiation sources should be notified. Plans should be drawn-up in order to cover any likely incident that could occur with the particular sources that one possesses.

2.8. Safety of Articles and Equipment

All the equipment and articles should be checked regularly to ensure that users are not receiving excessive doses of radiation. This will be the responsibility of manufacturers and individuals.

2.9. Miscellaneous and General

Finally this section mainly deals with the timetable of implementation of the regulations.

DOSE LIMITING RECOMMENDATIONS

The main responsibility for providing guidance in matters of radiation protection has been assumed by the International Commission on Radiological protection (ICRP). Therefore, its recommendations are considered the basis for all international standards. The principles of the ICRP system of radiological limits are:-

1. no practice shall be adopted unless its introduction produces a positive net benefit;
2. all exposures shall be kept As Low As Reasonably Achievable (ALARA), with consideration of social and economic factors;
3. The dose equivalent to individuals shall not exceed the ICRP limit. The effective dose equivalent from external radiation and the committed effective dose equivalent from that year's intake of radionuclides is as follows (Ref.17 and 18):-

1. Dose limits for the whole body

- | | |
|--|------------|
| A. For employees aged 18 years or over | 50mSv/year |
| B. For trainees aged under 18 years | 15mSv/year |
| C. For any other person | 5mSv/year |

2. Dose limits for individual organs and tissues

- | | |
|--|-------------|
| A. For employees aged 18 years or over | 500mSv/year |
| B. For trainees aged under 18 years | 150mSv/year |
| C. For any other person | 50mSv/year |

3. Dose limits for the lens of the eye

- | | |
|--|-------------|
| A. For employees aged 18 years or over | 150mSv/year |
| B. For trainees aged under 18 years | 45mSv/year |
| C. For any other person | 15mSv/year |

4. Dose limits for the abdomen of a woman
of reproductive capacity shall be 13mSv in any
consecutive three month period.
5. Dose limits for the abdomen of a pregnant woman
shall be 10mSv during the declared term of
pregnancy.

APPENDIX 5

RADIATION WARNING SIGNS

For the purposes of radiation protection, the attached radiation warning signs are approved by British Standards Institution (BSI) and Safety Signs Regulation 1980.

Appropriate wording should be used in association with these radiation signs or symbols to indicate the nature of the source of radiation, type of radiation and limits of occupancy. Also, warning signs or symbols should be as prominent as is practicable and of a size consistent with the size of the equipment or material to which it is affixed or attached, and should be of such size as to permit the warning sign to be read from a safe distance.

According to British Standards the specifications of radiation signs are as follows, (Ref.27):-

1. BS.3510, specified basic symbols to denote the actual or potential presence of ionising radiation and to identify objects, devices or substances which emit radiation. (see Figure 3). (Note: the standard does not specify any radiation levels at which the symbol is used).
2. The background should be **YELLOW** in colour approximately to colour No.309 of BS.381c. The symbol should be on a **WHITE** background as is required for labels on some packages containing radioactive substances, and placards on certain vehicles transporting radioactive material or on a storage cabinet/storage container (see Figure 4).
3. BS.5378, Part 1. specifies various types of safety signs including a warning sign indicating "**Caution, Risk of Ionising Radiation**". This sign as shown in the figures (attached), it is triangular in shape, has a **YELLOW**

background and **BLACK** border, and the radiation symbol is placed centrally on the background. It is specified that at least 50% of the area of the safety sign shall be **YELLOW**, consequently the relative sizes of the triangular and symbol satisfy the following conditions:-

$$L \quad 27 \quad R$$

The warning sign and radiation symbol should be sufficiently large to be distinctive and the sign should be fixed in a prominent position (see Figure 5).

4. BS.5378 specifies that the supplementary signs shall be oblong or square with the text in **BLACK** on a background which is either **WHITE** or the same colour as the safety sign (i.e., yellow in the case of warning signs). The following wording is used to identify a "**CONTROLLED or SUPERVISED AREA**" to give information about access, to indicate the nature of the source of radiation or the type of radiation, to draw attention to special precautions (see Figures 6, 7, 8, 9 and 10).
5. A warning sign and its supplementary sign may, if desired be mounted on a common, **WHITE** background. (see Figures 8, 9 and 10).
6. The preferred sizes for overall height of safety signs and letter signs on signs are given in BS.5378, Part 2.
7. All safety signs give Health or Safety Information or Instruction to persons at work " apart from the exceptions referred to in 8 and 9 below". These requirements apply in particular to radiation warning signs. They apply not only when display of a sign is required by a particular regulation, or an approved code of practice, but also when displayed voluntarily. It is the employer's responsibility to see that the safety Signs Regulations are complied with. Signs specified in the British Standard may be displayed only to provide the Health or Safety Information or Instruction

indicated by that sign. Therefore, they should be taken down when not required.

8. The labels include the radiation symbol "Carriage By Road" - Great Britain Regulation 1974 - but not the radiation warning sign. This exclusion is not restricted to transport and it is acceptable to label a bottle in a laboratory. The door of a cupboard in which the bottle is kept should also be labelled with the triangular radiation warning sign (see Figure 11).
9. Apart from the radiation warning sign, other safety signs may be needed for protection against ionising radiations (see Figure 12). These signs should conform with BS.5378, Part 1, except where they relate to fire fighting or rescue equipment or emergency exits.

FIG.3. BASIC IONIZING RADIATION WARNING DESIGN

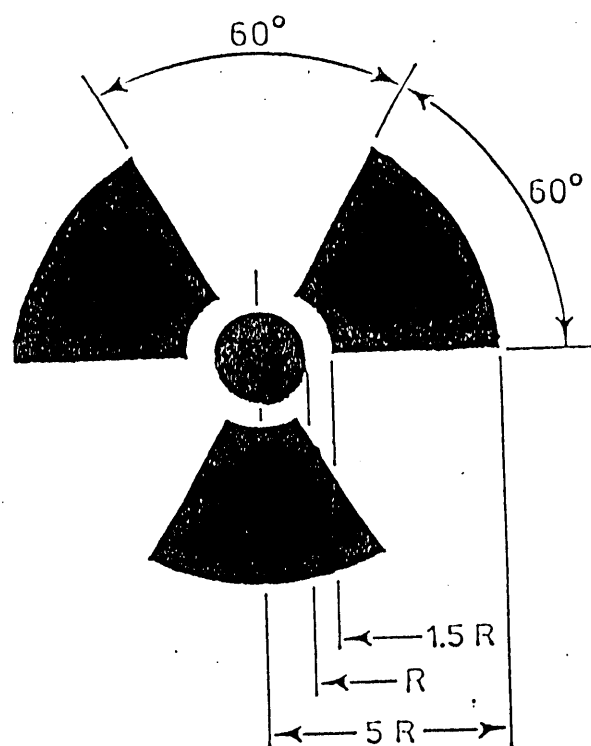
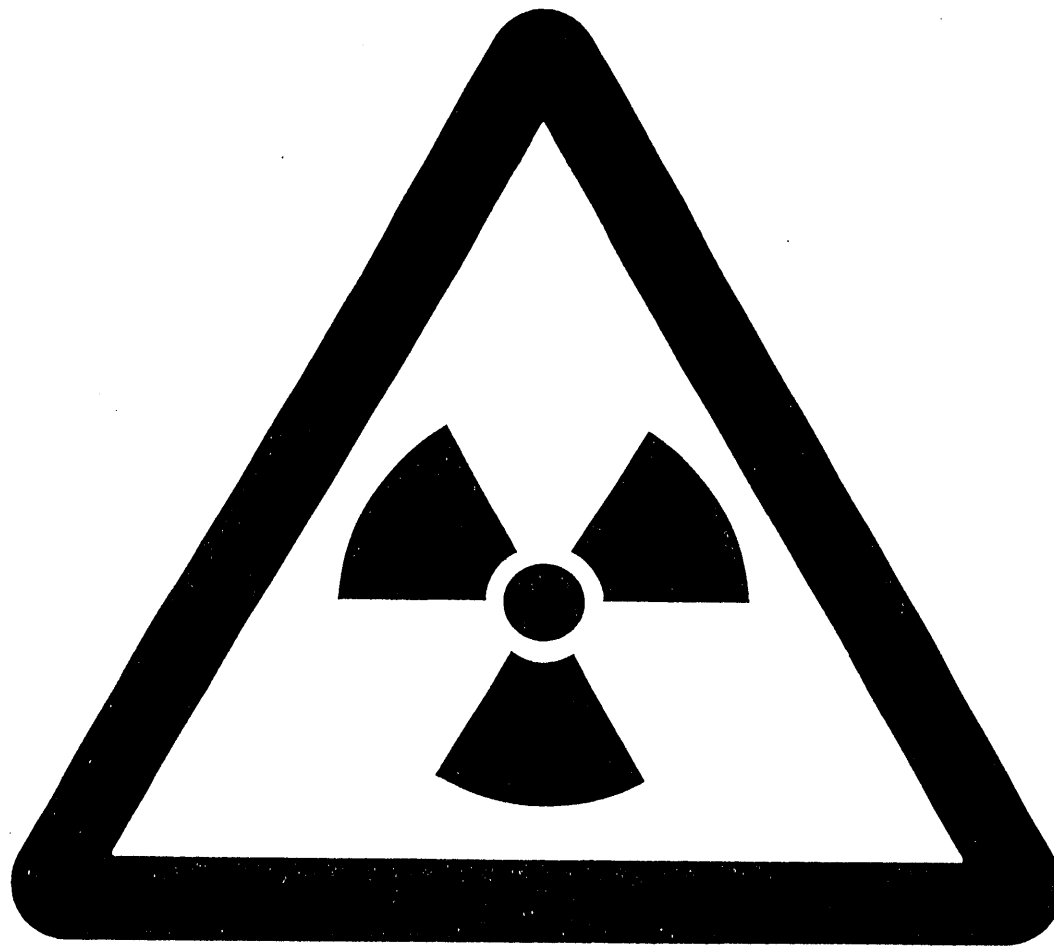
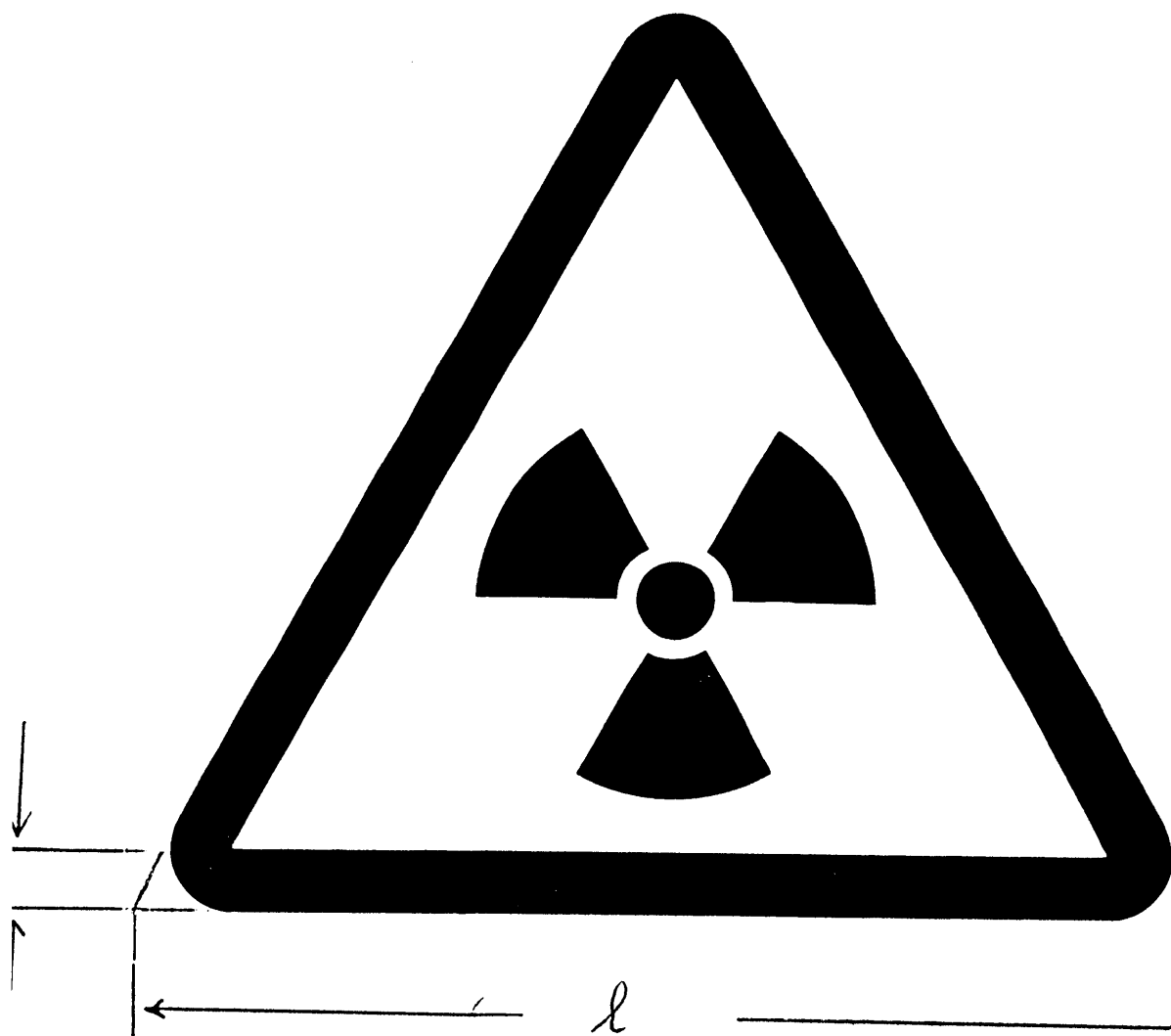


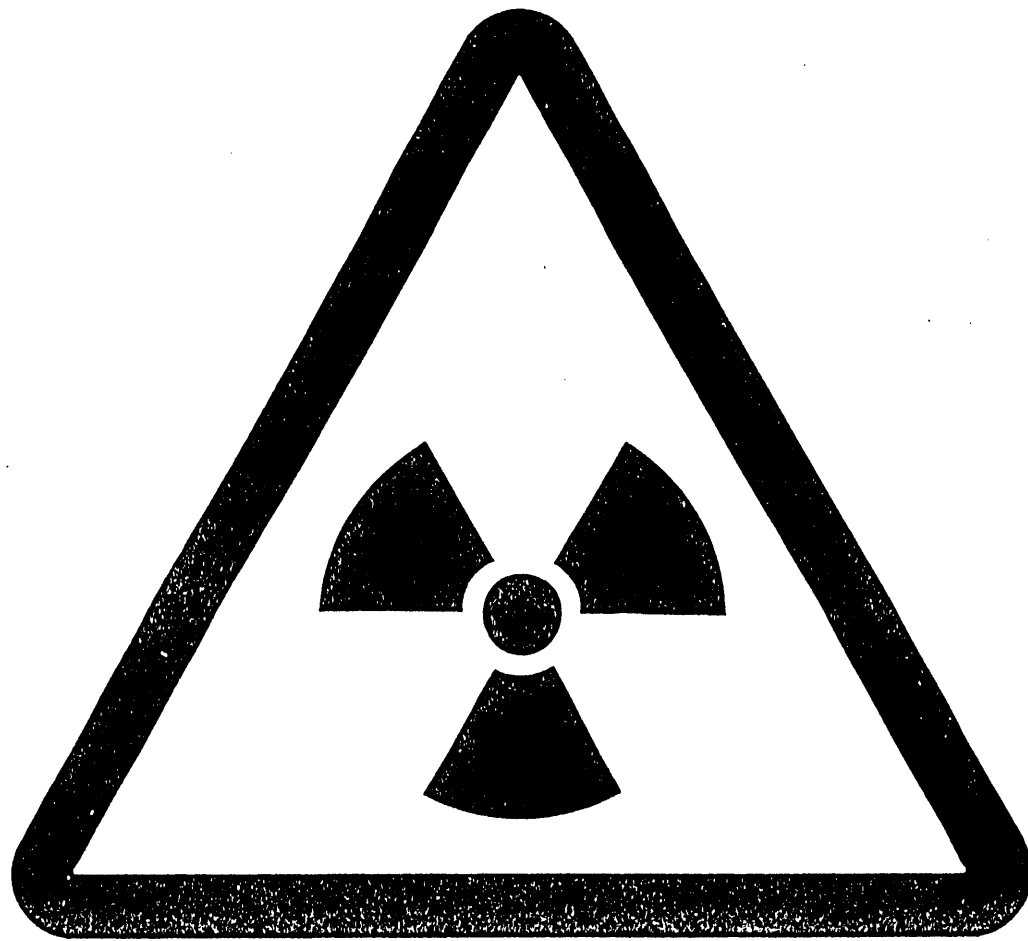
FIGURE 4. Sign on a storage cabinet/storage container
for radioactive materials



**RADIOACTIVE
MATERIALS**

FIGURE 5. Warning Sign - Ionising Radiations





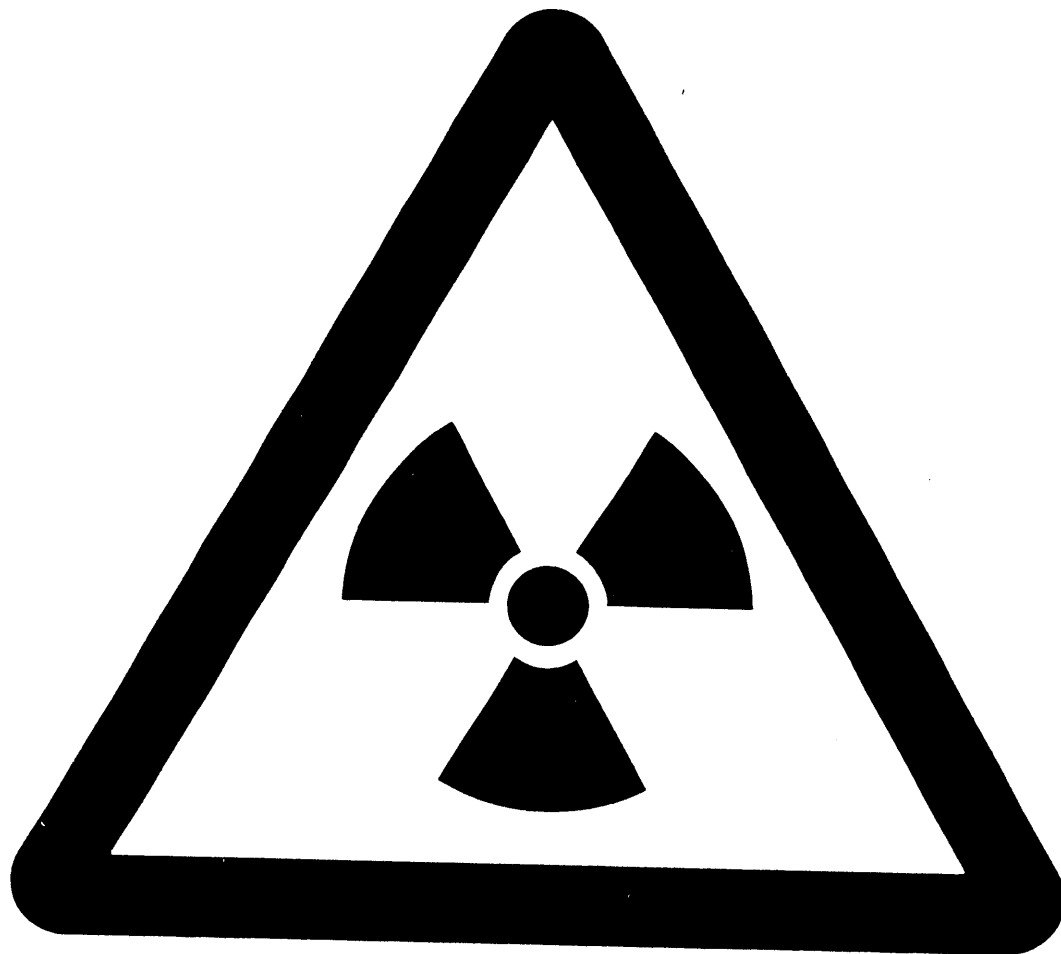
**Controlled
area**

FIGURE 7. Sign at the entry of supervised area

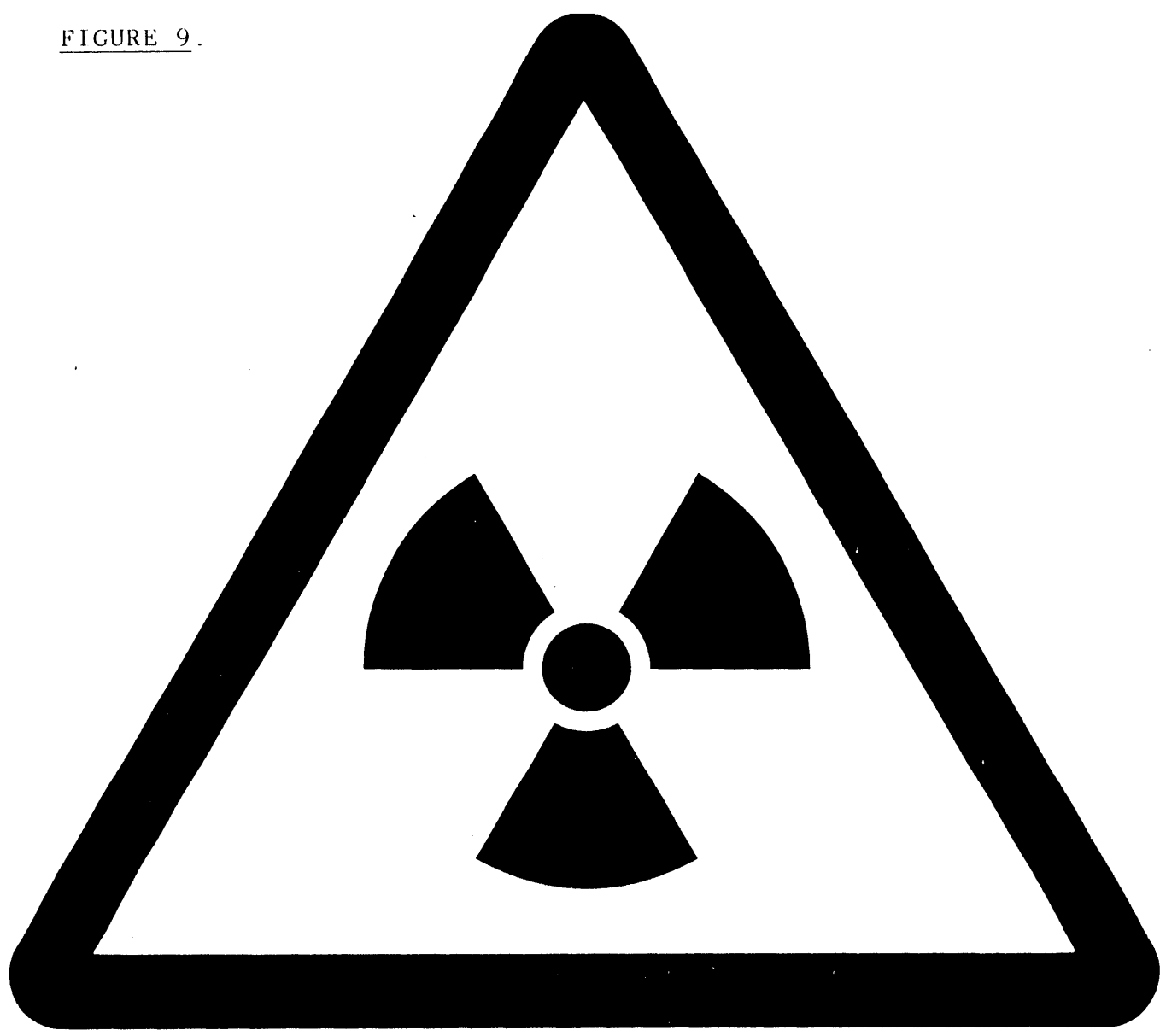


**SUPERVISED
AREA**

FIGURE 8. Sign on or close to sink which is used for purposes involving radioactive materials



**Designated
sink**



**Controlled
area
x-radiation**

FIGURE 11. Label on the bottle containing radioactive solution



FIGURE 12.



RADIOACTIVE
MATERIALS

RESTRICTED AREA
Authorized Entrance Only

LABORATORY COATS REQUIRED

EATING, DRINKING AND SMOKING PROHIBITED

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