PRIVY COUNCIL

MEDICAL RESEARCH COUNCIL

MEMORANDUM

No. 39

Introductory Manual on the Control of Health Hazards from Radioactive Materials

COMMITTEE ON PROTECTION AGAINST IONIZING RADIATIONS

Preface

IN 1945 the Council set up a Committee on the Medical and Biological Applications of Nuclear Physics to advise them in a field which appeared to be open to rapid and important developments. This committee appointed a Subcommittee of experts to consider the protective measures required to safeguard the health of individuals exposed to ionizing radiations. At the instance of the Subcommittee, notes were prepared by the Atomic Energy Research Establishment at Harwell (then of the Ministry of Supply) on the control of health hazards from radioactive materials, and these notes were circulated privately to persons known to be working with radioactive isotopes. In January, 1949, a revised issue (No. 2) of these notes was printed as 'Introductory Manual on the Control of Health Hazards from Radioactive Materials'. The demand for copies was heavy and the manual was reprinted six times between 1949 and 1954. Subsequently the Council's Committee on Protection Against Ionizing Radiations (successor to the above-mentioned Subcommittee) put in hand the preparation of the present extensively revised edition, which is largely the work of Mr. W. Binks and Dr. W. G. Marley. Owing to the continued and increasing demand for the manual, the new edition is now published in the Council's regular series of Memoranda.

It is essentially an introductory manual intended mainly for the guidance in outline of those concerned with the manipulation of radioactive materials in laboratories and elsewhere. Other official publications dealing in greater detail with various aspects of hazards from radiation are mentioned both in the text and in the bibliography.

The recommendations on maximum permissible doses of external and internal radiation, and on maximum permissible concentrations of radioisotopes in air and in water, are based on those of the International Commission on Radiological Protection, published in 1959, and of its Committee on Permissible Dose for Internal Radiation, published in 1960, as well as on those of the Council's Committee on Protection against Ionizing Radiations. As the views of these two bodies do not at present completely correspond in all respects, the Memorandum expresses the British views based on the most up-to-date information available. It is, however, to be expected that such recommendations will be subject to revision from time to time in the light of the new information that is constantly emerging in this rapidly developing field of research.

CONTENTS

INTRODUCTORY MANUAL ON THE CONTROL OF HEALTH HAZARDS FROM RADIOACTIVE MATERIALS

I. Introduction

IT is generally recognized that manipulation of radioactive materials may involve hazard to health unless adequate precautions are taken, and that scientific work can be spoiled and laboratories seriously contaminated by the careless handling of such materials. The purpose of this Introductory Manual is to indicate the nature of the hazards involved in working with radioactive materials, and the type of precautions which should be taken, so that a safe procedure may be established and followed from the outset.

Workers with no personal experience should adopt more stringent precautions than those which may be required of an experienced worker. Whatever isotope is to be handled ultimately, it is recommended that initial experience be gained with one of the less dangerous materials, such as P–32, very small quantities being used, certainly less than 100 microcuries. Experience of the control of contamination, and of handling and counting procedures, can readily be gained in this way with very little risk.

II. General Nature of the Hazards

MANY radioactive substances are dangerous in extremely minute quantities when inhaled or ingested, and are dangerous in somewhat larger quantities through the external effects of their radiations. When they are handled without proper precautions their radiations may cause burns or other permanent injury to the body, and, in certain circumstances, can be carcinogenic. There are two principal sources of danger, associated with internal and external radiation respectively.

Deposition of Radioactive Isotopes in the Body

This is probably the most important source of danger. It may result from ingestion or inhalation of the radioactive material, or from absorption through the intact or injured body surface. It usually arises either from ingestion of small amounts of radioactive material on contaminated hands, cigarettes, and other objects brought into contact with the mouth, or from inhalation of radioactive gas, vapour, spray, or dust. Ingestion of such material may lead to direct irradiation of the alimentary tract, or more commonly to chronic irradiation of the tissues or organs in which a particular radioactive element becomes concentrated—for example, the bones in the case of radiostrontium, and the thyroid gland in the case of radioiodine. Inhalation of spray or dust involves particular hazard because of the large fraction which may be retained in the lungs. Moreover, both ingestion and inhalation of radioactive material are specially dangerous because damage may be done before it is possible to demonstrate any accumulation of radioactive material in the lungs or any deposition in specific organs of the body. The toxicity of ingested or inhaled isotopes varies according to the type of radiation emitted, the half-life of the isotope, the way in which it is metabolized, the rate of elimination from the body, and other factors.

Exposure of the Body to External Beta and Gamma Radiation

The other main source of danger is the exposure of the whole body, or parts of it (such as the hands), to beta or gamma radiation from radioactive material outside the body. Experience with X-rays and gamma rays has enabled a maximum permissible exposure to such radiations to be assessed, and, through the use of monitoring instruments which measure the dose or dose-rate of local radiation, the hazard of external radiation can readily be controlled. The important factors here are the nature of the radiations and the quantity of radioactive material involved. Reference is made to these factors in Section V (p. 9), where acceptable and hazardous quantities of material are considered.

III. Maximum Permissible Dose of Radiation

DEFINITIONS

Types of Ionizing Radiation

Several different kinds of ionizing radiation are known, of which the following are the common types:—

Alpha particles (*alpha rays*). These are nuclei of helium atoms usually arising as the radiation emitted by naturally occurring radioactive atoms, but sometimes otherwise. Alpha particles have little penetrating power; they pass into soft tissues for only small fractions of a millimetre. Consequently they are much more hazardous when they arise from radioactive elements within the body than when they occur as external sources.

Beta particles (*beta rays*). These are high-speed particles having the same mass and charge as the electron. Beta particles are the most common type of radiation emitted by radioactive isotopes, especially those artificially produced. In general, they are more penetrating than alpha particles and can traverse distances up to about a centimetre in tissue. Heavy doses of beta particles from outside the body can damage superficial tissues and if beta-emitting substances are deposited within the body they may cause damage there.

Gamma rays. These are high-energy electromagnetic radiations which originate within the nucleus of the atom. They have great penetrating powers in comparison with alpha and beta particles, the more energetic being able to traverse the whole body. Consequently, even when the gamma-ray emitter is external to the body, all body tissues may be irradiated.

X-rays. These are electromagnetic radiations which originate from the field outside the nucleus and are usually produced artificially by electrical machines. They vary considerably in penetrating power, depending on the amount of energy they have acquired in their production. The properties of X-rays and gamma rays of comparable energy are similar.

Neutrons. These are nuclear particles similar in mass to the proton but having no electric charge. They interact with the nuclei of atoms, thus producing ionization and inducing radioactivity. Since neutrons are not normally emitted by radioactive materials, protection against them is outside the scope of this manual.

Units of Dosage

The units commonly used in expressing doses of ionizing radiations are the röntgen, the rad and the rem.

Röntgen (r). This is the unit of exposure dose of X- or γ-rays, but not of other ionizing radiations. It is the quantity of X- or γ-radiation such that the associated corpuscular emission per 0·001293 gramme of air produces, in air, ions carrying 1 electrostatic unit of quantity of electricity of either sign. 1000 milliröntgens (mr) are equal to 1 röntgen.

Rad. This is the unit of absorbed dose of any ionizing radiation, and corresponds to the absorption of 100 ergs per gramme of the absorbing medium. The röntgen and the rad (in soft tissue) are approximately equivalent in magnitude. 1000 millirads (mrad) are equal to 1 rad.

Rem. Equal doses (expressed in rads) of different types of radiation have different degrees of biological effectiveness. Consequently it is necessary to introduce a unit—the rem—to express the quantity of any ionizing radiation such that the energy imparted to a biological system per gramme of living matter by the ionizing particles present in the locus of interest has the same biological effectiveness as 1 rad of 200–250 kV X-rays. 1000 millirems (mrem) are equal to 1 rem.

PUBLICATIONS ON MAXIMUM PERMISSIBLE LEVELS OF RADIATION

Present evidence indicates that a person may be exposed to certain levels of ionizing radiations at which risk is negligible. These levels have been evaluated by the International Commission on Radiological Protection, and, in Great Britain, by a committee appointed by the Medical Research Council. Detailed recommendations are contained in the following publications: *Recommendations of the International Commission on Radiological Protection* (Pergamon Press, 1959; *British Journal of Radiology*, 1960, **33**, 189), *The Hazards to Man of Nuclear and Allied Radiations* (A Second Report to the Medical Research Council, Cmnd. 1225, H.M. Stationery Office, London, 1960), and *Code of Practice for the Protection of Persons Exposed to Ionizing Radiation* (prepared by the Standing Advisory Committee set up under the Radioactive Substances Act, H.M. Stationery Office, London, 1957). Attention is also drawn to the *Factories (Ionizing Radiations) Special Regulations; Second Preliminary Draft of Regulations*, 1960. When these Special Regulations become effective, it will be necessary to comply with them in premises coming within the scope of the Factories Acts.

OCCUPATIONAL EXPOSURE

The following levels of exposure are recommended as the 'maximum permissible' levels for persons who are occupationally exposed to radiation and who are under medical supervision. Nevertheless it is stressed that exposure to radiation and to radioactive material should be reduced to the lowest practicable level.

In any organ or tissue, the total dose due to occupational exposure shall comprise the dose contributed by external sources during working hours and the dose contributed by internal sources taken into the body during working hours.

External Radiation

Exposure of the Whole Body, Gonads, Blood-forming Organs, or Lenses of the Eyes

(i) The maximum permissible total dose accumulated in the gonads, the blood-forming organs, the lenses of the eyes or the whole body at any age over 18 years shall be governed by the relation

$$D = 5\,(N - 18)$$

where D is the tissue dose in rems and N is the age in years.

This relation sets the average occupational exposure at 5 rems per year. It also permits a maximum dose to the gonads of 60 rems by the age of 30 years, which dose is regarded as acceptable, provided that the contribution from this source to the genetic dose for the whole population does not exceed 1 rem per head of population.

(ii) Those persons between the ages of 16 and 18 years who are in 'occupational' contact with radiation shall not thereby be allowed to receive doses in excess of 1·5 rems per year. For such persons, subsequent exposure shall be controlled so that the dose accumulated to age 30 years shall not exceed 60 rems.

(iii) To the extent that the above relation permits, an occupationally exposed person may accumulate the maximum permissible dose at a rate not in excess of 3 rems during any period of 13 consecutive weeks. If there is no reason to suppose that doses are being accumulated at grossly irregular rates, a calendar 13-week period may be used instead of a period of 13 consecutive weeks.

(iv) Where work involves exposure to β-rays of $E_{max} > 2{\cdot}5$ MeV, eye shields or other suitable shielding may be necessary to keep the dose within the permissible limits stated in (i) above. In the case of exposure to β-rays of lower energy, if the provision of shielding is impracticable, the small additional dose in the lens over the dose already permitted for more penetrating radiations, such as γ-rays or neutrons, is permissible, provided the dose in the skin is limited to the level recommended below.

(v) In the event of an accidental high exposure, any exposure in excess of that permissible in the light of the subject's age should be included in further calculations of the subject's accumulated dose and should, if possible, be 'worked off' during the following 5 years under conditions of reduced exposure. Accidental exposure to doses higher than 25 rems must be regarded as potentially serious, and shall be referred to competent medical authorities for appropriate remedial action and recommendations on subsequent exposure.

(vi) Emergency work involving exposure above permissible limits shall be planned on the basis that the individual will not receive a dose in excess of 12 rems. If the total accumulated dose including the emergency exposure exceeds that value permitted at the age of the subject, the excess shall be 'worked off', within a period not exceeding 5 years, by reducing the subsequent exposure rate.

Exposure Limited to Other Parts of the Body

	Maximum permissible dose	
	In any 13-week period	In one year
Skin Thyroid	8 rems	30 rems
Hands and forearms Feet and ankles	20 rems	75 rems

Internal Radiation

The maximum permissible doses for radioisotopes deposited within the body are consistent, as far as possible, with those given above for external radiation. In general the maximum permissible body burden for a particular isotope has been assessed by calculation of the amount of that isotope which would produce

TABLE 1

Maximum permissible body burdens and maximum permissible concentrations in air and water for occupational exposure (40-*hour week*) *for selected isotopes*

Isotope	Critical organ*	Maximum permissible total body burden (μc)	Maximum permissible concentration (40-hour week) In air (μc/ml)	In water (μc/ml)
H–3				
(as HTO or $H_2{}^3O$) (sol.)	Body tissue	10^3	5×10^{-6}	0·1
(as $H_2{}^3$) submersion	Skin		2×10^{-3}	
C–14				
(as CO_2) (sol.)	Fat	300	4×10^{-6}	0·02
submersion	Whole body		5×10^{-5}	
Na–24 (sol.)	GI(SI)		10^{-6}	6×10^{-8}
(insol.)	GI(LLI)		10^{-7}	8×10^{-4}
P–32 (sol.)	Bone	6	7×10^{-8}	5×10^{-4}
(insol.)	Lung		8×10^{-8}	
	GI(LLI)			7×10^{-4}
K–42 (sol.)	GI(S)		2×10^{-6}	9×10^{-3}
(insol.)	GI(LLI)		10^{-7}	6×10^{-4}
Fe–59 (sol.)	GI(LLI)			2×10^{-3}
	Spleen	20	10^{-7}	
(insol.)	Lung		5×10^{-8}	
	GI(LLI)			2×10^{-3}
Co–60 (sol.)	GI(LLI)		3×10^{-7}	10^{-3}
(insol.)	Lung		9×10^{-9}	
	GI(LLI)			10^{-3}
Cu–64 (sol.)	GI(LLI)		2×10^{-6}	0·01
(insol.)	GI(LLI)		10^{-6}	6×10^{-3}
Br–82 (sol.)	Whole body	10	10^{-6}	8×10^{-3}
	GI(SI)			8×10^{-3}
(insol.)	GI(LLI)		2×10^{-7}	10^{-3}

(*cont.*)

*The various sections of the gastrointestinal tract referred to are:

GI(S) Stomach
GI(SI) Small intestine
GI(ULI) Upper large intestine
GI(LLI) Lower large intestine

TABLE I—*continued*

Maximum permissible body burdens and maximum permissible concentrations in air and water for occupational exposure (40-hour week) for selected isotopes

Isotope	Critical organ*	Maximum permissible total body burden (μc)	Maximum permissible concentration (40-hour week)	
			In air (μc/ml)	In water (μc/ml)
Sr–89 (sol.)	Bone	4	3×10^{-8}	3×10^{-4}
(insol.)	Lung		4×10^{-8}	
	GI(LLI)			8×10^{-4}
Sr–90 (sol.)	Bone	2	3×10^{-10}	4×10^{-6}
(insol.)	Lung		5×10^{-9}	
	GI(LLI)			10^{-3}
I–131 (sol.)	Thyroid	0·7	9×10^{-9}	6×10^{-5}
(insol.)	GI(LLI)		3×10^{-7}	2×10^{-3}
	Lung		3×10^{-7}	
I–132 (sol.)	Thyroid	0·3	2×10^{-7}	2×10^{-3}
(insol.)	GI(ULI)		9×10^{-7}	5×10^{-3}
Cs–137 (sol.)	Whole body	30	6×10^{-8}	4×10^{-4}
(insol.)	Lung		10^{-8}	
	GI(LLI)			10^{-3}
Tm–170 (sol.)	GI(LLI)			10^{-3}
	Bone	9	4×10^{-8}	
(insol.)	Lung		3×10^{-8}	
	GI(LLI)			10^{-3}
Ta–182 (sol.)	GI(LLI)			10^{-3}
	Liver	7	4×10^{-8}	
(insol.)	Lung		2×10^{-8}	
	GI(LLI)			10^{-3}
Ir–192 (sol.)	GI(LLI)			10^{-3}
	Kidney	6	10^{-7}	
(insol.)	Lung		3×10^{-8}	
	GI(LLI)			10^{-3}
Au–198 (sol.)	GI(LLI)		3×10^{-7}	2×10^{-3}
(insol.)	GI(LLI)		2×10^{-7}	10^{-3}
Po–210 (sol.)	Spleen	0·03	5×10^{-10}	2×10^{-5}
(insol.)	Lung		2×10^{-10}	
	GI(LLI)			8×10^{-4}
Ra–226 (sol.)	Bone	0·1	3×10^{-11}	4×10^{-7}
(insol.)	GI(LLI)		2×10^{-7}	9×10^{-4}

*The various sections of the gastrointestinal tract referred to are:

GI(S) Stomach
GI(SI) Small intestine
GI(ULI) Upper large intestine
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an energy absorption biologically equivalent to the level permissible for the 'critical organ' in which the maximum effective concentration occurs. However, in certain cases, for example, Ra-226 plus its daughters, the values of the maximum permissible body burdens are assessed direct in microcuries on the basis of clinical evidence. The figures derived by either method for the maximum permissible body burdens can then be used to calculate the maximum permissible concentrations of radioactive isotopes in air and in water.

Actual values of the maximum permissible body burdens and maximum permissible concentrations in air and in water are contained in *Recommendations of the International Commission on Radiological Protection; International Commission on Radiological Protection Publication 2—Report of Committee II on Permissible Dose for Internal Radiation* (Pergamon Press, 1959). A few examples are given in Table 1.

EXPOSURE OF SPECIAL GROUPS

Adults who work in the vicinity of areas where ionizing radiations are used but who are not themselves employed on work causing exposure to such radiation, and adults who are not regarded as radiation workers but who, in the course of their duties, occasionally enter areas where ionizing radiations are used, constitute special groups. For these persons the total annual dose, including contributions from external and internal sources, to the gonads, the blood-forming organs, the lenses of the eyes, and the whole body should not exceed 1·5 rems. Similarly, the total annual dose from a mixture of isotopes whose combined exposure constitutes essentially whole body exposure should not exceed 1·5 rems. In the case of the thyroid and skin, the total annual dose should not exceed 3 rems.

If no external irradiation results from operations within the area where ionizing radiations are used, the corresponding maximum permissible concentrations of radioisotopes in air and in water for the special groups referred to are three-tenths of the occupational values given in Table 1, when the 'critical organs' are the gonads, the blood-forming organs, the lenses of the eyes, or the whole body, and one-tenth of the occupational values in the case of the skin and thyroid.

IV. The Measurement of Radiation Dose and Dose-rate

In general, the biological effect of ionizing radiation is closely related to the ionization produced in tissue. The quantity of such radiation arising outside the body can be measured, for purposes of health control, by the amount of ionization produced in an air-filled ionization chamber. As the blackening on a photographic plate depends upon the ionization produced, this too may be used as a measure of the dose of ionizing radiation. It is possible also to use a Geiger counter in conjunction with a suitable counting-rate meter, but the use of scaling equipment with the Geiger counter employed for counting is not in general desirable, since it may well become contaminated. Moreover, Geiger counters used for monitoring are liable to give false readings on account of 'blockage' of the counter at high radiation levels.

Film Dosemeters

All workers handling radioactive materials should be required to wear at all times, on the front of the body, film dosemeters consisting of suitable holders containing pieces of sensitive photographic film, for the purpose of recording integrated doses of gamma and beta radiation. As the sensitivity of photographic emulsions is dependent upon the type and energy of such radiations, it is necessary to know the type and energy involved before any observed blackening can be interpreted in terms of dose. To this end, part of the holder is provided with an open window while other parts are fitted with suitable absorbers which, by giving rise to areas of different blackening, enable exposure to beta rays to be distinguished from exposure to gamma rays. This type of film holder can also be used to record exposure to slow neutrons, but these are not encountered in the normal handling of radioactive isotopes; protection from, and monitoring of, neutrons are outside the scope of this manual.

The films or film dosemeters should be collected at regular intervals and sent for development and measurement; at the same time a new dosemeter containing unexposed film should be issued. Film dosemeters may also be mounted in various places in the laboratory where measurement of the exposure is desirable; for certain operations they may conveniently be worn on a wrist strap, or attached to a finger ring.

The doses indicated by film dosemeters form valuable permanent records of the exposure of individual employees and such records should be kept by every institution where employees are exposed to radiation hazard. Care should be taken that members of the special groups mentioned above and non-technical employees, such as cleaners, do not have access to radiation areas without appropriate monitoring provision.

Pocket Ionization Chambers

In new or unusual procedures involving the use of appreciable quantities (e.g. millicuries) of radioactive substances that emit gamma radiation, workers should carry, in addition to film dosemeters, pocket ionization chambers which can be used to give an immediate reading of the gamma-ray dose received. Chambers of this type are also invaluable for indicating the gamma-ray dose (but not the beta-ray dose) near the operator's hands during work. The ionization chambers should be carried until the results read from films over several weeks have shown that the possibility of over-exposure is remote. It is preferable for chambers to be carried in pairs, so that any undue leakage in one chamber may be detected immediately. The laboratory supervisor should arrange for daily records to be kept of the doses measured by these chambers.

Radiation Monitors

For all work involving millicuries or greater quantities, the laboratory should be provided with an electronic dosemeter; this usually comprises an ionization chamber and valve electrometer. The instrument should be beta-sensitive; this is usually effected by the provision in the ion chamber of a thin window which can be closed for the assay of the gamma-radiation component. For many applications a mains-operated monitor can be used; this contains a Geiger counter probe which operates a counting-rate meter, and is provided with a loudspeaker or earphones. Such an instrument is invaluable for bench and apparatus monitoring.*

In the event of a serious spill of radioactive material, the monitoring of radioactivity in air at the breathing level is very desirable during any subsequent remedial procedures; for this purpose, air may be sucked through a filter continuously and the concentration measured to ensure that it does not exceed the maximum permissible level. In the event of any doubt on this matter, respirators should be worn.

Long-range Protection of Health

In every institution a competent person, who must be selected from among its full-time employees, should be appointed as 'Radiological Safety Officer' to ensure that the protection measures laid down for each department are carried out. There should, in addition, be appointed an appropriately qualified physicist to act as 'Radiological Protection Adviser'. He should advise the head of each department on the protection measures to be adopted and should regularly visit the institution to which he has been appointed to review, in consultation with the heads of the departments concerned, the protection measures laid down. This adviser should work in close association with a qualified medical adviser.

No person should be 'occupationally exposed' to ionizing radiations unless, within a period of 4 months immediately preceding first employment in such work, he has been subjected to a general medical examination, including a *full blood count*. Furthermore, any occupationally exposed person should, so long as his employment in the work continues, be medically examined at a frequency depending upon the conditions of the occupational exposure and at the discretion of the supervisory medical officer. During any medical examination, the supervisory medical officer may, at his discretion, require a full blood count or any other special examination (including an X-ray examination, ophthalmological examination and examinations of skin and nails).

Although blood counts are a part of a medical examination, and may be particularly desirable where a person has been exposed to a heavy overdose of external radiation or has assimilated a significant amount of an internally deposited isotope, they are not to be considered as a method of radiation monitoring. They are important in establishing, for an individual, a base-line for clinical evaluation in the event of over-exposure.

Where it is suspected that a person has assimilated a significant amount of radioactivity into the body, it is important that samples of urine or faeces as appropriate are obtained for accurate radiochemical assay, and that the whole situation be reviewed by the supervisory medical officer.

V. Acceptable and Hazardous Amounts of Radioactive Material

In this section some indication is given of the degree of hazard associated with the handling of specific quantities of various isotopes. The hazards arise from the two causes set out in Section II: deposition of radioactive isotopes in the body, and exposure of the body to external beta and gamma radiation.

*Brief specifications of available radiation monitors are given in the brochure *British Nucleonic Instruments*, published in 1957 by the Scientific Instrument Manufacturers Association of Great Britain Ltd., Queen Anne Street, London, W.1.

TABLE 2

Classification of isotopes according to relative radio-toxicity per unit amount

(The isotopes in each class are listed in order of increasing atomic number. 'm' indicates metastable state.)

Class 1. Very high toxicity

Pb–210, Po–210, Ra–223, Ra–226, Ra–228, Ac–227, Th–227, Th–228, Th–230, Pa–231, U–230, U–232, U–233, U–236, Np–237, Pu–238, Pu–239, Pu–240, Pu–241, Pu–242, Am–241, Am–243, Cm–242, Cm–243, Cm–244, Cm–245, Cm–246, Cf–249, Cf–250, Cf–252.

Class 2. High toxicity

Na–22, Co–60, Sr–90, Ru–106, Ag–110m, I–126, I–129, I–131, Ce–144, Sm–147 (in natural Sm), Eu–152 (13 years), Eu–154, Bi–210, At–211, Ra–224, Th–232, Nat-Th, Pa–230, U–234, U–235, U–238, Nat–U, Bk–249.

Class 3. Moderate toxicity

Na–24, Si–31, P–32, S–35, Cl–36, K–42, Ca–45, Ca–47, Sc–46, Sc–47, Sc–48, V–48, Mn–52, Mn–54, Mn–56, Fe–55, Fe–59, Co–57, Co–58, Ni–59, Ni–63, Ni–65, Zn–65, Zn–69m, Ga–72, As–73, As–74, As–76, As–77, Se–75, Br–82, Kr–87, Rb–86, Rb–87, Sr–85, Sr–89, Sr–91, Sr–92, Y–90, Y–91, Y–92, Y–93, Zr–93, Zr–95, Zr–97, Nb–93m, Nb–95, Mo–99, Tc–96, Tc–97m, Tc–97, Tc–99, Ru–103, Ru–105, Rh–105, Pd–103, Pd–109, Ag–105, Ag–111, Cd–109, Cd–115m, Cd–115, In–114m, In–115, Sn–113, Sn–125, Sb–122, Sb–124, Sb–125, Te–125m, Te–127m, Te–127, Te–129m, Te–131m, Te–132, I–132, I–133, I–134, I–135, Cs–134, Cs–135, Cs–136, Cs–137, Ba–131, Ba–140, La–140, Ce–141, Ce–143, Pr–142, Pr–143, Nd–147, Pm–147, Pm–149, Sm–151, Sm–153, Eu–152 (9·2 hrs), Eu–155, Gd–153, Gd–159, Tb–160, Dy–166, Ho–166, Er–169, Er–171, Tm–170, Tm–171, Yb–175, Lu–177, Hf–181, Ta–182, W–181, W–185, W–187, Re–183, Re–186, Re–187, Re–188, Os–185, Os–191, Os–193, Ir–190, Ir–192, Ir–194, Pt–191, Pt–193, Pt–197, Au–196, Au–198, Au–199, Hg–197m, Hg–203, Tl–201, Tl–202, Tl–204, Pb–212, Bi–206, Bi–207, Bi–212, Rn–220, Rn–222, Ac–228, Th–234, Pa–233, Np–239.

Class 4. Slight toxicity

H–3, Be–7, C–14, F–18, Cl–38, A–37, A–41, Cr–51, Co–58m, Cu–64, Zn–69, Ge–71, Kr–85m, Kr–85, Sr–85m, Y–91m, Nb–97, Tc–96m, Tc–99m, Ru–97, Rh–103m, In–113m, In–115m, Te–129, Xe–131m, Xe–133, Xe–135, Cs–131, Cs–134m, Nd–149, Dy–165, Os–191m, Pt–193m, Pt–197m, Hg–197, Tl–200, Pb–203, Th–231.

In considering protection against external radiation from either sealed or unsealed sources of radioactive isotopes, the merits of three factors—shielding, distance, and time—should be examined. Where unsealed isotopes are concerned, two additional factors—containment and cleanliness—must be considered in attempting to reduce internal radiation hazards.

TABLE 3

*Gamma-ray dose-rate at one metre from a curie source of various isotopes**

Isotope	Half-life	Gamma-ray energy (MeV) and approximate percentage of gamma photons per disintegration	Dose-rate† (röntgens per hour at 1 metre from 1 curie‡)
Na–22	2·6 years	1·28 (100%)	1·18
Na–24	15·0 hours	1·37 (100%), 2·76 (100%)	1·84 [1·87]
K–42	12·5 hours	1·53 (18%)	0·14 [0·14]
Cr–51	27·8 days	0·32 (8%)	0·015
Mn–52	5·6 days	0·73 (100%), 0·94 (100%) 1·45 (100%)	1·85
Mn–54	300 days	0·84 (100%)	0·46
Fe–59	45 days	0·19 (2·5%), 1·10 (56%) 1·29 (44%)	0·62 [0·68]
Co–58	72 days	0·81 (100%), 1·62 (0·5%)	0·54
Co–60	5·25 years	1·17 (100%), 1·33 (100%)	1·30 [1·31]
Zn–65	245 days	1·11 (45%), β+ (2%)	0·27
As–76	26·5 hours	0·55–2·05 0·55 (41%), 0·64 (8%), 1·20 (9%)	0·24
Br–82	36 hours	0·55–1·48	1·47 [1·48]
I–131	8·05 days	0·08–0·72 0·36 (80%), 0·64 (9%)	0·218 [0·223]
I–132	2·33 hours	0·53–2·20	1·17 [1·20]
Cs–137	30 years	0·66 (82%)	0·31
Tm–170	127 days	0·084 (3%) and Bremsstrahlung	0·004§
Ta–182	112 days	Gammas of various energies up to 1·23	0·58 [0·61]
Ir–192	74·5 days	Gammas of various energies up to 0·61	[0·50]
Au–198	2·7 days	0·41 (96%)	0·23 [0·232]
Ra (B + C)	Filtered through 0·5 mm Pt.		0·825

*Dose-rates in milliröntgens per millicurie-hour at 1 foot may be obtained by multiplying the values in column 4 by 10·8.

†These figures are calculated on the assumption that 34 eV of energy are lost in the formation of each ion pair. For positron emitters, it is assumed that all positrons are annihilated in the source and its container. Figures in square brackets are experimental determinations.

‡For protection purposes, 1 röntgen per hour may be taken as equivalent to 1 rad per hour.

§A calculated figure for an unshielded source (gamma rays and X-rays); in practice the dose-rate will be increased considerably by Bremsstrahlung.

In respect of the hazards from deposition, radioisotopes may be grouped into four classes according to their relative radiotoxicity. This classification is given in Table 2.

When the hazards arising from ingestion and inhalation are small, the risk incurred in handling radioactive materials will depend essentially upon the effects of external beta and gamma radiation. In view of the small range of the beta rays (generally less than 1 g/cm^2 of material or air interposed), it is usually a simple matter to absorb these rays completely. It should be appreciated, however, that considerable Bremsstrahlung (or X-rays generated when β-particles are arrested) may arise from intense β-ray sources. Apart from such Brems strahlung, the main external radiation hazard from radioactive materials is determined by the gamma radiation experienced at normal handling distances. The gamma-ray dose-rate received at a distance of 1 metre from a one-curie source of various isotopes is shown in Table 3.

VI. Laboratory Facilities

It is desirable to set aside a special laboratory for radioactive work, especially where this involves manipulation of open (unsealed) radioactive material, and to have it clearly marked for this purpose. The grade of laboratory (A, B or C) required to deal with radioisotopes depends on the types and quantities of the isotopes to be used. Guidance on this matter is given in Table 4.

TABLE 4

Grades of laboratory required for radioisotopes in relation to levels of activity

Relative radio-toxicity of isotope	Classification of toxicity	Levels of activity of unsealed isotopes: Lab. grade C required	Lab. grade B required	Lab. grade A required
Very high	1	< 10 μc	10 μc — 1 mc	> 1 mc
High	2	< 1 mc	1 mc — 100 mc	> 100 mc
Moderate	3	< 100 mc	100 mc — 10 c	> 10 c
Slight	4	< 10 c	10 c — 1000 c	> 1000 c

Modifying factors to be applied to the above quantities, according to the nature and complexity of the procedures to be followed:

Procedure	*Modifying factor*
Storage (stock solutions)	× 100
Very simple wet operations	× 10
Normal chemical operations	× 1
Complex wet operations with risk of spills	× 0·1
Simple dry operations	× 0·1
Dry and dusty operations	× 0·01

The three grades of laboratory should meet the following requirements:

Grade C Laboratory

Few modifications are needed to any modern conventional chemical laboratory having floors covered with linoleum. Work-benches should be provided with non-absorbent tops or with disposable covers. There should be at least one good fume cupboard with induced draught. The exhaust air should be carried outside the building but need not be filtered.

All working surfaces, including fume cupboards, should be strong enough to carry any necessary shielding against gamma rays.

Grade B Laboratory

A high-grade laboratory should be provided for work involving the use of isotopes in quantities of the order shown in column 4 of Table 4 above. Great care in design is necessary to facilitate the control of contamination.

In addition to fume cupboards, it may be necessary to use glove boxes; these considerably reduce the risk of inhalation or ingestion of radioactive materials, and help to minimize the spread of contamination into the working environment. However, it should be appreciated that, in some circumstances, the advantage gained from using glove boxes is offset, partly by increased exposure to external radiation resulting from longer handling times, and partly by a tendency for workers to exercise less care in maintaining cleanliness.

Once material or equipment has entered an 'active' area, it should not normally be removed for use in an 'inactive' area; if it should prove necessary to do this, the equipment must be considered as contaminated unless proved otherwise. The laboratory should be so constructed and equipped that thorough cleaning is not difficult, it should be kept clean, and the cleaning process should not give rise to dust. Scrupulous care and cleanliness in the laboratory are the best precautions against the spread of contamination; a standard comparable to that required for handling highly virulent pathogenic bacteria is recommended.

To facilitate cleaning, floors should preferably have an easily removable surface. Waxed linoleum is a good floor surface; wooden floors with cracks and crevices are unsuitable. The seats in the laboratory should be smooth and they should be frequently cleaned.

Wood, concrete, and metal are good constructional materials for benches, walls, ceilings, and fume cupboards, provided that they are painted with a hard smooth paint. Where the quantities of activity handled are high, it is important to ensure that the risk of fire is minimized both in the design of the laboratory and in the conduct of the work. Working surfaces should be protected when necessary by disposable covers, plastic coated paper, plastic sheets or similar materials.

Fume cupboards should be tested by means of a smoke generator before they are put into use, and care should be taken to ensure that the exhaust cannot re-enter the building through nearby windows.

Grade A Laboratory

For the higher levels of activity, a specially-designed laboratory will be required.