



Recommended limits on radioactive contamination on surfaces in laboratories (1995)

RADIATION HEALTH SERIES No. 38



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National Health and Medical Research Council

NHMRC

**Recommended limits on
radioactive contamination
on surfaces in
laboratories (1995)**

Radiation Health Series No. 38

**Approved at the 119th session of the
National Health and Medical Research Council
Canberra, June 1995**

National Health and Medical Research Council

NHMRC

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ISBN 0644 36302 9

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Produced by the Australian Radiation Laboratory for the National Health and Medical Research Council.

Publications and Design (Public Affairs and International Branch)
Commonwealth Department of Health and Family Services

Produced by the Australian Government Publishing Service

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1. Introduction

This document establishes recommended limits for radioactive contamination on surfaces in laboratories. Guidelines for the evaluation of radioactive contamination in work areas where unsealed radioactive material is used are given as an annexe.

2. Scope

2.1 Types of areas

This document applies to radioactive contamination which may result from the use of unsealed radioactive material in industrial, scientific or medical laboratories, and includes contamination of designated radioisotope areas and of work areas which are not designated as radioisotope areas but which may inadvertently become contaminated with unsealed radioactive material. This document is not applicable to industrial plant nor in contexts which differ greatly from controlled laboratory conditions.

2.2 Types of surfaces

Limits are presented for surfaces in work areas which are designated for the use of radioisotopes; surfaces include protective clothing worn by workers. Modifying factors are presented for:

- the skin of workers;
- personal clothing;
- work areas not designated as ones in which unsealed radioactive material may be used; and
- the interiors of glove boxes and fume hoods.

2.3 Environmental contamination

This document does not cover environmental contamination in areas in which members of the public are likely to be exposed as a result of the release of unsealed radioactive material. The determination of appropriate limits for environmental contamination requires consideration of the circumstances surrounding such releases.

2.4 Related codes

The following topics are covered in other codes.

2.4.1 Design of laboratories

Areas to be used for operations involving unsealed sources should be properly designed and planned. Standards Australia has published a Standard which, inter alia, deals with the design requirements for laboratories in which unsealed radionuclides¹ are used. The design features required will depend upon the radiotoxicities and quantities of material likely to be used and upon the types of operations likely to be performed in the laboratory.

2.4.2 Working with radioactive materials

Any use of unsealed radioactive materials should be undertaken on the assumption that contamination may occur. Forethought and planning before operations commence will greatly facilitate clean up operations after any contamination occurs. Details of source containers, handling equipment, protective clothing, area monitoring and decontamination are given in the International Atomic Energy Agency publication 'Radiation protection procedures' chapters 13-17².

2.4.3 Radioactive waste disposal

Radioactive waste must be disposed of in accordance with the regulations of the appropriate statutory authority. National guidelines on waste disposal may be found in the NHMRC publication 'Code of practice for the disposal of radioactive wastes by the user (1985)³.

2.5 State and federal legislation

Attention is drawn to the legislation of the appropriate statutory authority (see Annexe A) that relates to:

- obtaining a licence/registration to possess, sell, purchase, dispose of or use radioactive materials;
- transporting radioactive materials by air, sea, rail or road;
- sending radioactive materials through the post (Australia Post currently prohibits the sending of radioactive materials through the post); and
- importing radioactive materials.

2.6 Guidelines for the evaluation of surface contamination

Guidelines for the evaluation of surface contamination are given in Annexe B.

3. Derived limits for surface contamination

3.1 Dose limits

The surface contamination limits in this document are based on the committed effective dose limit of 20 mSv per year recommended for workers by the NHMRC⁴.

3.2 Dosimetric model for the intake of radioactive materials

The dosimetric models used for the determination of equivalent dose per unit intake of radioactive material for inhalation and ingestion are based on the models prescribed in ICRP 30^{5,6,7,8,9} and modified in ICRP 60¹⁰ and ICRP 61¹¹. The limiting dose is considered to be the committed effective dose.

3.3 Classification of compounds

In ICRP 30, various compounds of radionuclides are considered when determining doses to workers. The fraction of a compound reaching body fluids after its entry into the gastrointestinal tract is denoted by f_1 and, for inhalation, three solubility classes, D, W and Y, denote residence times in the lungs of days, weeks and years respectively. Although the various alternatives were considered in the determination of surface contamination levels, they did not result in different levels for different compounds.

3.4 Assumptions for the determination of limits for inhalation

For the calculation of the contamination limit for work surfaces in designated areas via the inhalation pathway, a resuspension factor of $5 \times 10^{-5} \text{ m}^{-1}$ is assumed for all materials¹². It is also assumed that a worker will breathe at a rate of 1.2 m^3 per hour and will work 2000 hours per year.

3.5 Assumptions for the determination of limits for ingestion

For the calculation of the derived contamination limits for work surfaces in designated areas via the ingestion pathway, it is assumed that a worker may ingest the entire contents of 10 cm^2 of a contaminated surface each working day of the year and that there are 250 working days in a year^{13,14}.

3.6 External irradiation of the skin

Equivalent dose rates for external irradiation of the skin were taken from NRPB DL-2¹⁴. The equivalent dose rate for uniform surface contamination is averaged between tissue depths of 50-100 μm . For the calculation of the derived contamination limits for work surfaces in designated areas it is assumed that the skin is in continuous contact with the surface for 200 h/y; for the derived limits for the skin of radiation workers it is assumed that the contamination is on the skin for one tenth of a year (ie 876 h/y).

3.7 Recommended limits for surface contamination

When calculating the limits for surface contamination, the ingestion, inhalation and external irradiation pathways described above were all considered and the most restrictive pathway was used. In most operational and minor accident situations, the inhalation pathway is the most restrictive and also the most difficult to control, but for some

nuclides the ingestion pathway is the most restrictive. In a few instances only, the external irradiation pathway is the most limiting.

For some radionuclides of low radiotoxicity, the calculated surface contamination limit based on dose considerations yielded a limit in excess of 10^3 Bq/cm². In these cases, an upper limit of 10^3 Bq/cm² has been adopted, based on the principles that doses be kept as low as reasonably achievable and that it is not unreasonable to restrict contamination levels to 10^3 Bq/cm².

Most commonly used radionuclides are listed in the Table, and the surface contamination limit for each nuclide is given in Bq/cm². For convenience, the surface contamination limits are rounded to an order of magnitude. This reflects the broad assumptions made in the determination of the levels and the practical difficulties of making measurements of surface contamination.

3.8 Mixtures of radionuclides

If a surface is contaminated with a mixture of radionuclides and it is not possible to determine the relative activity of the contaminants, the limit of the most restrictive nuclide shall apply.

Where the relative activity is known, the limit may be calculated for a mixture of nuclides a, b, c, etc. by using the equation

$$S_m = 1/(F_a/S_a + F_b/S_b + F_c/S_c + \dots)$$

where S_m is the surface contamination limit of the mixture,

S_a is the surface contamination limit for nuclide a,

S_b is the surface contamination limit for nuclide b, and

S_c is the surface contamination limit for nuclide c.

F_a , F_b , F_c , etc are the activities for nuclides a, b, c, etc. expressed as a fraction of the total activity.

3.9 Application of limits to different surfaces

Surface contamination shall at all times be kept as low as reasonably achievable, and shall not exceed the following limits:

- for all exposed surfaces in designated areas, including protective clothing and the skin of workers: the limits in the Table;
- for the interiors of glove boxes and fume cupboards: ten times the limits in the Table; and
- for areas which are not designated radioisotope areas and for personal clothing: one twentieth of the limits in the Table.

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Table. Surface contamination limits

NUCLIDE	LIMIT Bq/cm ²	NUCLIDE	LIMIT Bq/cm ²	NUCLIDE	LIMIT Bq/cm ²
³ H	10 ³	⁹⁹ Mo	10 ³	¹⁸¹ Hf	10 ³
¹⁴ C	10 ³	^{99m} Tc	10 ³	¹⁸⁵ W	10 ³
²² Na	10 ²	⁹⁹ Tc	10 ³	¹⁸⁶ Re	10 ³
²⁴ Na	10 ³	¹⁰³ Ru	10 ³	¹⁹² Ir	10 ³
³² P	10 ²	¹⁰⁶ Ru	10 ²	¹⁹⁸ Au	10 ³
³⁵ S	10 ³	^{110m} Ag	10 ²	¹⁹⁷ Hg	10 ³
³⁶ Cl	10 ³	¹¹¹ Ag	10 ³	²⁰³ Hg	10 ³
⁴⁵ Ca	10 ³	¹⁰⁹ Cd	10 ²	²⁰¹ Tl	10 ³
⁴⁷ Ca	10 ³	^{115m} Cd	10 ²	²⁰⁴ Tl	10 ³
⁴⁶ Sc	10 ³	¹¹¹ In	10 ³	²¹⁰ Pb	10 ⁰
⁴⁷ Sc	10 ³	^{113m} In	10 ²	²¹⁰ Bi	10 ²
⁵¹ Cr	10 ³	¹¹³ Sn	10 ³	²¹⁰ Po	10 ⁰
⁵⁴ Mn	10 ³	¹²⁴ Sb	10 ²	²²³ Ra	10 ¹
⁵⁵ Fe	10 ³	¹²⁵ Sb	10 ³	²²⁴ Ra	10 ¹
⁵⁹ Fe	10 ³	¹²³ I	10 ³	²²⁶ Ra	10 ⁰
⁵⁶ Co	10 ²	¹²⁵ I	10 ²	²²⁷ Th	10 ⁰
⁵⁷ Co	10 ³	¹³¹ I	10 ²	²²⁸ Th	10 ⁰
⁵⁸ Co	10 ³	¹²⁹ Cs	10 ³	²³⁰ Th	10 ⁻¹
⁶⁰ Co	10 ²	¹³¹ Cs	10 ³	²³² Th	10 ⁻¹
⁶³ Ni	10 ³	¹³⁴ Cs	10 ²	²³¹ Pa	10 ⁻¹
⁶⁴ Cu	10 ²	¹³⁷ Cs	10 ²	²³² U	10 ⁻¹
⁶⁷ Cu	10 ²	¹³³ Ba	10 ³	²³⁴ U	10 ⁰
⁶⁵ Zn	10 ²	¹⁴⁰ La	10 ²	²³⁵ U	10 ⁰
⁶⁷ Ga	10 ³	¹³⁹ Ce	10 ³	²³⁶ U	10 ⁰
⁶⁸ Ga	10 ²	¹⁴¹ Ce	10 ³	²³⁸ U	10 ⁰
⁶⁸ Ge	10 ³	¹⁴⁷ Nd	10 ³	²³⁸ Pu	10 ⁻¹
⁷⁵ Se	10 ²	¹⁴⁷ Pm	10 ²	²³⁹ Pu	10 ⁻¹
⁷⁷ Br	10 ³	¹⁴⁷ Sm	10 ⁰	²⁴¹ Am	10 ⁻¹
⁸¹ Rb	10 ³	¹⁵³ Sm	10 ⁰	²⁴⁴ Cm	10 ⁻¹
⁸⁶ Rb	10 ²	¹⁵² Eu	10 ²		
⁸⁵ Sr	10 ³	¹⁵⁴ Eu	10 ²	All other alpha	
^{87m} Sr	10 ³	¹⁵³ Gd	10 ³	emitters with a half	
⁸⁹ Sr	10 ²	¹⁶⁰ Tb	10 ³	life > 3 months	10 ⁻¹
⁹⁰ Sr	10 ¹	¹⁶⁹ Er	10 ³		
⁸⁷ Y	10 ³	¹⁷⁰ Tm	10 ³	All other non-	
⁸⁸ Y	10 ³	¹⁶⁹ Yb	10 ³	alpha emitting	
⁹⁰ Y	10 ²	¹⁷⁷ Lu	10 ³	nuclides	10 ²

Annexe A. Statutory authorities

Advice and assistance from the relevant statutory authority may be sought by contacting the following offices:

Australian Capital Territory

ACT Department of Health
Radiation Safety Section
GPO Box 825
CANBERRA ACT 2601

Tel: (06) 247 2899

Fax: (06) 257 3503

South Australia

South Australian Health Commission
Radiation Protection Branch
PO Box 6 Rundle Mall
ADELAIDE SA 5000

Tel: (08) 226 6520

Fax: (08) 226 6255

New South Wales

Environment Protection Authority
Radiation Control Section
PO Box 136
REGENTS PARK NSW 2143

Tel: (02) 795 5014

Fax: (02) 649 4470

Tasmania

Department of Community and Health Services
Health Physics Branch
GPO Box 125B
HOBART TAS 7001

Tel: (002) 33 6421

Fax: (002) 310735

Northern Territory

Department of Health & Community Services
Radiation Health Branch
GPO Box 40596
CASUARINA NT 0811

Tel: (089) 99 2983

Fax: (089) 99 2700

Victoria

Department of Health and Community
Radiation Safety Section
GPO Box 4057
MELBOURNE VIC 3001

Tel: (03) 9412 7560

Fax: (03) 9412 7568

Queensland

Department of Health
Radiation Health
450 Gregory Terrace
FORTITUDE VALLEY QLD 4006

Tel: (07) 3252 5446

Fax: (07) 3252 9021

Western Australia

Health Department of Western Australia
Radiation Health Section
Locked Bag 2006
NEDLANDS WA 6009

Tel: (09) 346 2261

Fax: (09) 381 1423

Commonwealth

Department of Health and Family Services
Australian Radiation Laboratory
Lower Plenty Road
YALLAMBIE VIC 3085

Tel: (03) 9433 2211

Fax: (03) 9432 1835

Annexe B. Guidelines for the evaluation of surface contamination

B.1 Types of radionuclide decay

Surface contamination can be evaluated by monitoring the radiations emitted during the nuclear decay process. In order to select appropriate monitoring equipment, it is necessary to know the types of radiations being emitted. Most of the commonly used radionuclides undergo nuclear transformation by one of the following processes:

- alpha particle emission
- beta particle emission
- electron capture
- isomeric transition

These decay processes lead to the emission of one or more of the following types of radiations: alpha particles (helium nuclei), electrons (beta particles, auger electrons or internal conversion electrons) and photons (gamma rays or X-rays).

B.2 Types of monitoring equipment

Monitoring equipment must be suitable for measuring the particular type and energy of the principal radiations emitted by the radionuclide being monitored. The radiation detectors in the probes of most commercially available surface contamination monitors are one of three types: scintillation detectors, gaseous ionization detectors or solid state detectors.

Scintillation detectors comprise a sensitive material, which converts ionizing radiation into light photons, and a light detector (usually a photomultiplier tube). Typical scintillation materials used include zinc sulphide (ZnS), plastic scintillator and organic and inorganic crystals such as anthracene and thallium-activated sodium iodide (NaI(Tl)).

Gaseous ionization detectors comprise an electrode within a chamber or a sealed glass tube, the most common being ionization chambers and geiger tubes.

Solid state detectors are those in which ionization of a solid detection medium results in pulses of electric charge and include detectors made from germanium (Ge) and silicon (Si).

B.3 Detection of alpha particles

Alpha particles lose energy when travelling through matter by colliding with outer shell electrons. As their mass is 7200 times that of an electron, they tend to travel in straight lines losing small amounts of energy at each collision. Alpha particles are emitted with energies ranging from 4 to 10 MeV and lose approximately 1 MeV for every 1 mg/cm² of matter traversed (for example, about 1 cm of air). Consequently, the thickness of any material enclosing scintillation or ionization media should be no more than approximately 1 mg/cm² in order that the alpha particles may be detected at a distance of a few centimetres in air. A layer of ZnS powder screened by a light-tight aluminised mylar window and a geiger tube with a thin mica window are the most common types of alpha particle detectors. These detectors also have some sensitivity to high energy electrons and photons.

B.4 Detection of electrons and beta particles

Like alpha particles, electrons also collide with outer shell electrons but, because the colliding particles have the same mass, they undergo collisions involving much larger scattering angles than alpha particles and consequently tend to move with erratic paths through matter. It is possible to state only the range in matter of electrons of particular energies and not uniform losses of energy per unit distance travelled (eg 300 keV electrons will travel approximately 100 mg/cm² in low atomic number materials). Auger electrons and conversion electrons are monoenergetic, while beta particles are emitted with a range of energies from zero to an end point energy, with the distribution being biased toward the lower energies. Thin plastic scintillators, anthracene crystals, geiger tubes and proportional counters are common detectors for electrons and beta particles.

B.5 Detection of X-rays and gamma rays

X-rays and gamma rays lose energy in matter through photoelectric absorption, Compton scattering and, if the energy is above 1022 keV, through pair production. These electromagnetic radiations are very penetrating and require thick dense detecting materials to achieve a satisfactory detection efficiency. NaI(Tl) is commonly used in detectors because of its high efficiency and good energy resolution. Photons below 100 keV will be stopped completely by 3 mm NaI(Tl), whereas only 15% of 1 MeV photons will stop in 25 mm NaI(Tl). Thick plastic scintillators, geiger tubes and ionization chambers are sensitive to photons, but have low intrinsic efficiencies.

B.6 Selection of monitoring equipment

In order to select the most suitable radiation monitor for a particular radionuclide, it is first necessary to study the nuclear decay scheme, noting the type and energies of all the principal radiations including any conversion electrons and X-rays.

For those nuclides emitting both particles and photons, it is preferable to detect alpha particles and electrons than to detect X-rays and gamma rays, as the lower penetration of these particles means that contamination is easier to localise. Furthermore, detectors which are sensitive to charged particles usually have high intrinsic efficiencies and low background rates. Energy discrimination can also be used to advantage in the determination of alpha particle contamination as alpha particles usually deposit much more energy in the sensitive volume of the detector than other radiations.

When detecting photons, the selection of the detector is important as its efficiency will vary greatly with the energy of the photons being detected. The background count rate of the probe should be noted in the area to be monitored as a high photon background count rate can make detection of surface contamination difficult. Energy discrimination may also be used when detecting photons, and is particularly desirable when measurements are being attempted in regions of high background. Very few radionuclides emit photons only and a better evaluation of surface contamination can often be made by monitoring for the associated alpha or beta particles or for conversion electrons.

B.7 Monitoring techniques

The sensitive area of a probe should preferably be 50-100 cm² so that large areas may be monitored in a reasonable time.

The monitor should be held over each area for at least 1 or 2 seconds so that it has time to respond to count rates which may be as low as several counts per second.

The probe should be held as close as practical to the surface being monitored to increase the geometrical efficiency of the count and to obtain the best delineation of the contaminated area.

It is important to avoid contaminating the probe by actually touching the surface with it. For photon and electron monitoring, taping a thin plastic cover over the probe is recommended; this can easily be replaced if it becomes contaminated by accidentally touching the surface.

If the monitor does not have an energy discrimination device, alpha particles may be distinguished from beta particles by placing a thin sheet of paper over the sensitive area of the probe; the paper will block the passage of alpha particles but have little effect on the beta particles. Similarly, beta particles may be distinguished from photons by placing a thin metal sheet between the detector and the contaminated surface.

Monitors should be checked in a low background area before use, in order to verify their satisfactory operation. Ideally, the monitor should be calibrated using a source of the same radionuclide as that to be detected. This process need not be rigorous as surface contamination monitoring is unlikely to result in the level of surface contamination being determined to better than 30%.

In some instances, where unsuitable geometry or interference from other radiations prevents direct measurement, indirect methods of surface contamination monitoring may be used. These methods are also useful in determining whether the contamination is loose or fixed. A wipe or smear sample may be taken from the surface using a tissue or filter paper which may be wet or dry. A smear test could remove any fraction up to 100% of the contamination present but generally a removal factor of 10-20% may be assumed if no other information is available. Wetting the smear with water or a solvent is likely to increase the fraction removed. The smear should be taken to a lower radiation area or to a sensitive radiation detector to be analysed. There is always a large uncertainty in relating the activity on the smear to the activity on the contaminated surface but the taking of subsequent smears from the same area can help to establish how easily removable the contamination is and thus give a more accurate picture of the degree of the contamination hazard.

B.8 Background levels and detection limits

Alpha particles are usually detected with ZnS screens covered with $1\text{mg}/\text{cm}^2$ aluminised mylar light tight windows. Such detectors usually have a background count rate of a fraction of a count per second. For geiger tubes, proportional counters and ionization chambers with appropriately thin entrance windows, background count rates of several counts per second are likely as these detectors are also sensitive to beta and gamma background radiations.

All the above devices have high intrinsic efficiencies for alpha particles so that, when such probes are held close to a surface, overall detection efficiencies of 10-20% are achievable. (Detection efficiency is the detector count rate divided by the activity on an area of the surface equal to the area of the probe).

Beta particles and electrons are most commonly detected with thin plastic scintillators, organic crystal scintillators such as anthracene or with ionization detectors operating in the geiger or proportional regions. Even with an entrance window as thin as $1\text{mg}/\text{cm}^2$, most commonly available detectors are not sensitive to electrons with energies less than 30 keV and are therefore not suitable for measuring tritium contamination; however, they will have some sensitivity to ^{14}C beta particles. Background count rates for most detectors lie between a few counts per second and several tens of counts per second and efficiencies vary from a few percent to more than 25%; efficiencies depend upon the type of detector, the window thickness and the energy of the particles being measured.

When it is necessary to measure X-rays and gamma rays, probes using an inorganic scintillator such as a NaI(Tl) crystal are preferred to plastic scintillators, ionization chambers, proportional counters and geiger tubes. Probes using NaI(Tl) have an intrinsic efficiency of a few percent for the more energetic photons and have backgrounds in an uncontaminated environment of the order of 100 counts per second. Energy discrimination can sometimes be used to improve the signal to noise ratio if the monitor has inbuilt electronic discrimination. Location and spatial definition of the contamination is more difficult when monitoring for gamma rays because of their penetrating nature. Plastic scintillator detectors, large area proportional counters and ionization tubes are sensitive to low energy photons (ie tens of keV and less) and are often more sensitive to beta particles, conversion electrons or auger electrons, which are produced by many gamma emitting radionuclides.

B.9 Determination of instrumental efficiency

For detailed information on the calibration of surface contamination monitors the reader should refer to NCRP Report No. 112¹, IAEA Technical Report Series No. 120² and ISO reports ISO 7503-1³ and ISO 8769⁴.

Calibration of a surface contamination monitor to within 30% is quite adequate as the derived limits presented are based on very conservative assumptions and are also rounded down to one decimal place for convenience.

Ideally, a surface contamination detector should be calibrated with a large area uniformly-deposited source made from a radionuclide which has emissions similar to the radionuclide being measured. An efficiency factor can then be determined which enables the count rate of the monitor to be converted to Bq/cm².

If only a small area source is available, it is still possible to perform a calibration with acceptable accuracy. If such a source is placed close to the centre of the surface of the probe, the error in the calibration will not be large in view of the accuracy acceptable for surface contamination measurements. The accuracy of a calibration using a single source may be improved by making a template of the sensitive area of the probe and dividing it into equal areas. By making measurements with the source placed in each area in turn and summing the count rates, any non-uniformity in the response of the probe is allowed for.

Calibration sources should produce count rates of at least 100 counts per second in the monitor and should be at least ten times the background count rate so that the response of the monitor can be quickly checked.

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