Monitoring of Radioactive Contamination on Surfaces
MONITORING
OF RADIOACTIVE CONTAMINATION
ON SURFACES
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MONITORING
OF RADIOACTIVE CONTAMINATION
ON SURFACES

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1970
FOREWORD

The assessment of radioactive surface contamination forms an important part of the application of safety standards to work involving the use of unsealed radiation sources.

This manual is intended to help those concerned with the implementation of these standards to select and apply suitable procedures and techniques. It has been prepared on behalf of the Agency by Mr. R. F. Clayton of the Health Physics and Medical Division, Atomic Energy Research Establishment, United Kingdom Atomic Energy Authority, Harwell, Berks.

The manual outlines the objectives of surface contamination monitoring and discusses the relative advantages and disadvantages of various available methods. Examples of derived working limits of surface contamination at present in use are quoted. The factors to be considered in selecting contamination monitoring instruments are also discussed and a few instruments commonly used in the United Kingdom are illustrated by way of example.

In a manual of this type it is difficult to give a balanced exposition of practices adopted by different countries throughout the world. An attempt to do so would result in a text of bewildering complexity. It is acknowledged that the present text is largely based on the approach adopted in the United Kingdom Atomic Energy Authority. A bibliography is provided, however, which may to some extent counteract this bias by directing attention to publications dealing with practices adopted in other countries.
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1. GENERAL CONSIDERATIONS

1.1. Purpose and scope

The manual is intended as a practical handbook on methods of monitoring the working environment, for health physicists and other persons using radioactive materials. Section 2 deals briefly with the derivation of working limits of contamination.

The applications, advantages and disadvantages of direct and indirect monitoring methods are discussed, and useful supplementary techniques to assist the health physicist in his interpretation of measurements are described.

The manual does not discuss monitoring of surface contamination in the environment of nuclear installations. This aspect of monitoring has already been dealt with in two IAEA manuals, one covering normal operations and the other emergency situations [1, 2].

Although the manual is not primarily concerned with the detection of contamination on humans, permissible levels of skin contamination are quoted. Many of the methods described for surface contamination monitoring can be applied to measuring the amounts of radioactive contamination on skin, but internal personnel contamination monitoring requires special techniques not within the scope of this manual.

The surface monitoring techniques described are more applicable to situations in which one is concerned with preventing or controlling a radiological hazard rather than to those in which experimental or operational inconvenience can arise. In these latter cases, permitted levels may be lower and greater precision in monitoring assessments may be required than in the case of radiological protection.

1.2. Definitions

Monitoring. Committee 4 of the International Commission of Radiological Protection has defined monitoring as 'the measurement of radiation or radioactivity for reasons related to the assessment or control of exposure to radiation or radioactive material' and quotes the principal objects of a surface contamination monitoring program [3, 4].

Radioactive surface contamination [5] is unwanted radioactive material deposited in an uncontrolled manner in or on animate or inanimate objects, irrespective of their situations, in such concentrations that either operational inconvenience or radiological hazard is caused.

Classification of radioactive contamination. Several ways are used to classify radioactive contamination: by the type of radiation emitted, by the availability for or ease of transfer to other objects, or by the physical form of the contaminant.

(a) Classification by emission is primarily into alpha, beta and low-energy beta emitters. For surface monitoring techniques, X- and gamma-ray emissions are of secondary importance, although the radiation hazard due to their presence must never be ignored.

(b) Contamination is further classified as being 'fixed' or 'loose'. 'Fixed' contamination is that which is not transferred from a contaminated
surface to an uncontaminated surface when the two surfaces accidentally touch; conversely, 'loose' contamination is that which may be readily transferred under these circumstances.

(c) Contamination of surfaces by solid material may occur by spillage of powders, by contact between the surface and radioactive material, by the drying of radioactive liquids and solutions on the surface of the material, or by deposition from airborne radioactive material. Surface contamination may also occur by sorption of radioactive gas such as tritium, or vapour such as tritiated water.

Active areas. There are areas in which persons may be exposed to radioactive contamination, radiation, or the risk of inhaling or ingesting radioactive material from airborne or surface radioactive contamination at levels in excess of those recommended by the International Commission on Radiological Protection or the International Atomic Energy Agency; these may include change rooms and offices as well as laboratories and process areas.

Inactive areas are all areas other than those classified as active areas as defined above.

1.3. The undesirability of surface contamination

A potential radiological hazard arises from the presence of radioactive surface contamination. It can become airborne and subsequently may be inhaled, or it may be transferred by contact to the hands and subsequently to food and ingested, or it may penetrate the intact skin or enter an open wound giving rise to an internal radiological hazard. In the case of beta and gamma emitters an external radiation hazard may also exist.

If the contaminated article is portable, it might be moved to an inactive area where, as the presence of radioactive materials is not expected, it would be handled without the precautions normally taken in active areas.

The presence of radioactive contamination at levels which may not be a health hazard may interfere with experimental work, leading to erroneous low-level counting results, or cross-contamination of radiochemical experiments.

Because of the undesirability of radioactive contamination the risk of its occurring should be minimized by careful design of laboratories and radioactive plants. The choice of proper equipment for handling radioactive materials and the selection of correct operating procedures together with the strict management and disposal of radioactive waste all serve to reduce this risk.

1.4. Derived working limits of surface contamination

Derived working limits (DWL) have been set as an indication of the level of surface contamination which can be tolerated. These levels are such that the risk of exposure to radiation from contamination within or without the body in excess of the maximum permissible level is minimal.

In this manual derived working limits of surface contamination (which are discussed in greater detail in Session 2) are based on radiological
protection considerations only. Interference with sensitive measurements, or the prevention of cross-contamination between experiments may impose more stringent limits. It is not possible in a manual such as this to attempt to give figures for these cases as each must be individually assessed. Methods of measurement are too specialized, involving the use of low background counting equipment in properly equipped laboratories.

1.5. Monitoring techniques

Monitoring techniques may be broadly divided into 'direct' and 'indirect' methods. Direct methods are those in which a radiation detector is presented directly to the surface under examination or vice versa. When direct methods are inapplicable because of unfavourable geometry, or because of interference by other radiations, or when it is necessary to determine whether or not contamination is 'fixed', indirect methods are used. These usually involve taking samples of the surface contamination, e.g. on smears, which are then examined for radioactivity. In many circumstances the two methods are complementary and both must be used to attain a complete picture of the state of a surface under examination.

The points to be considered which govern the choice of technique to be employed, and the relative advantages and limitations of the methods are described in Section 3.

1.6. Record keeping

Records of monitoring provide a check that monitoring is being done correctly and at the required frequency; they enable the responsible organization to maintain a close surveillance of hazardous operations so that the effectiveness of control measures can be assessed. They also form the basis from which a health physicist may make recommendations for altering control procedures. In the event of litigation, records of conditions during operations may be related to reported or alleged exposures to radiological hazard.

The type and extent of records of surface contamination monitoring and their period of retention must depend largely on local conditions and relevant administrative and legal requirements.

2. DERIVED WORKING LIMITS

2.1. Health considerations

Radiological safety controls must always be related to the maximum permissible exposure of workers to radiation whether arising from radioactive materials outside or inside the body.

To restrict the dose to the person from internally deposited radionuclides, the concept of the maximum permissible body burden [6] is used. Mathematical models [6, 7] to describe the behaviour of radionuclides in the body following an intake have been proposed and from these data the maximum permissible concentrations of radionuclides in air and water have
been calculated \[6, 8\]. From these primary levels it is possible to derive levels of surface contamination which should result in these primary levels not being exceeded \[9\].

Calculations on the basis of the maximum permissible airborne concentrations of individual radionuclides result in a range of derived working limits. Additionally the amount of activity removed from a surface depends upon the type of surface, the operations being performed and the physical form of the contaminant. It would not be realistic to attempt to tabulate DWLs to cover every contingency. To arrive at a rational solution, the worst conditions likely to be encountered must be assumed, i.e. that the most hazardous radionuclide likely to be present is spread over a wide area in a condition in which it will become readily available for inhalation or ingestion.

2.2. Limits derived from inhalation risk

To estimate the amount of surface contamination which may become airborne under a variety of conditions, resuspension factors, defined as the ratio of the air contamination (μCi/m³) to the surface contamination (μCi/m²), have been determined \[10-14\]. Values quoted vary from \(3 \times 10^{-3}/m\) to \(2 \times 10^{-6}/m\); a mean value of \(5 \times 10^{-5}/m\) appears to be appropriate for general conditions. From this figure and the occupational mpcaf for plutonium-239 \((2 \times 10^{-12} \muCi/cm^{3})\), the most toxic alpha emitter normally encountered which is likely to be inhaled, the derived working limit for contamination by this radionuclide is calculated to be \(4 \times 10^{-6} \muCi/cm^{2}\).

Widespread uniform contamination is not usually found in practice, the resuspension factor can be reduced by careful selection of suitable surfaces and footwear, and all the resuspended material is not of respirable size. Because of these mitigating factors, a relaxation to \(10^{-5} \muCi/cm^{2}\) is recommended. Under some circumstances, when large areas of surface contamination at this level occur, the permitted air concentration may be exceeded.

By applying similar criteria, the derived working limit for contamination by strontium-90, the most toxic beta emitter normally encountered, is calculated to be \(2 \times 10^{-3} \muCi/cm^{2}\).

2.3. Limits derived from external radiation hazard

All beta emitters are a source of external radiation. The dose-rate at a planar source of beta particles of maximum energy in the range 0.5 to 3.0 MeV is about 7 rad/h per μCi/cm² \[15\]. Back-scattering from a contaminated surface may increase this figure by a factor of 1.5. The hands are the most likely part of the body to be exposed to contaminated surfaces and the maximum permissible dose to these extremities is 75 rem/yr or 1.5 rem/week. Since it is desirable to restrict the dose due to contamination alone to 1/10th of this, and assuming continuous exposure during a 40-hour working week, the derived working level for beta contamination should not exceed \(4 \times 10^{-4} \muCi/cm^{2}\) (i.e. \(\sim 3 \text{ mrad/h}\)).

A relaxation factor of 10 can be applied for some low-energy beta emitters (0.2 MeV max.).
2.4. Limits derived from ingestion risk

As safety regulations governing procedures in active areas, e.g., banning the consumption of food, drink, and tobacco therein, and good supervision should reduce the risk of direct ingestion to negligible proportions, derived working limits can be based on indirect ingestion risks. The most likely route for indirect ingestion is via contaminated hands.

No quantitative data are available for relating skin contamination levels to the rate of ingestion but it has been assumed that a person may ingest all the contamination from 10 cm$^2$ of skin every day. From this assumption, combined with the maximum permissible daily intake for radiation workers of radium-226, which is more hazardous than plutonium-239 when ingested ($\text{mpc}_{\text{water}}^{226}\text{Ra} = 4 \times 10^{-7} \mu\text{Ci/cm}^3$; $\text{mpc}_{\text{water}}^{239}\text{Pu} = 10^{-4} \mu\text{Ci/cm}^3$), and of strontium-90 and lead-210, the most hazardous beta emitters likely to be ingested ($\text{mpc}_{\text{water}}^{90}\text{Sr} = 10^{-5} \mu\text{Ci/cm}^3$; $\text{mpc}_{\text{water}}^{210}\text{Pb} = 4 \times 10^{-6} \mu\text{Ci/cm}^3$), the derived working limits for skin contamination have been set at $10^{-5} \mu\text{Ci/cm}^2$ and $10^{-4} \mu\text{Ci/cm}^2$ for alpha and beta contamination, respectively. At these levels, the intake should be about 1/10th of the maximum permissible concentration recommended by ICRP. Because of the additional risks of irradiating the basal layer of the skin and percutaneous absorption into the blood stream [16], careful consideration must be given before allowing any relaxation of these levels. In addition, the sociological and dietary habits of workers must be considered when determining derived working levels of hand contamination [17].

2.5. Examples of derived working limits currently in use

The above sections show that the greatest risk from alpha contamination is inhaling resuspended radioactive material, and for beta activity the limiting factor is the external radiation hazard. If the relevant derived working limits are applied, then the risk due to ingestion of radioactive material from surface contamination is virtually eliminated. The levels for skin contamination coincide with those derived for the inhalation and external radiation risks. Tables I and II give examples of derived working levels at present in use in the United Kingdom and the United States of America, respectively. Other examples appear in ICRP Publication 5 [19] and in IAEA Safety Series No. 1 [20]. Tables III and IV compare the permissible levels of surface contamination in use in different atomic energy establishments [17-24].

It is recommended by the International Atomic Energy Agency [25] that radioactive contamination on the outside surfaces of containers used for transporting radioactive material should not exceed the levels quoted in Table V.

Other national codes of practice require that the radioactive contamination on the outside of sealed therapeutic or industrial sources should not exceed 0.5 $\mu\text{Ci}$.

The contamination on the inside surfaces of respirator face-pieces, air hoods, pressurized suit helmets or other types of breathing apparatus should never exceed the derived working limit for skin. At these levels, and with intermittent use, the maximum permissible inhaled daily intake for plutonium-239 and strontium-90 should not be exceeded. For long-term and regular use it may be advisable to work to a lower level.
<table>
<thead>
<tr>
<th>Type of area</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Principal alpha</td>
<td>Low-toxicity</td>
<td>Beta emitters</td>
<td>Low-energy</td>
</tr>
<tr>
<td></td>
<td>emitters b</td>
<td>alpha emitters</td>
<td></td>
<td>beta emitters</td>
</tr>
<tr>
<td></td>
<td>(μCi/cm²)</td>
<td>(μCi/cm²)</td>
<td>(μCi/cm²)</td>
<td>(μCi/cm²)</td>
</tr>
<tr>
<td>Inactive and low activity areas</td>
<td>10⁻⁵</td>
<td>10⁻⁶</td>
<td>10⁻⁴</td>
<td>10⁻³</td>
</tr>
<tr>
<td>Active areas</td>
<td>10⁻⁴</td>
<td>10⁻³</td>
<td>10⁻⁴</td>
<td>10⁻³</td>
</tr>
<tr>
<td>Personal clothing</td>
<td>10⁻⁴</td>
<td>10⁻³</td>
<td>10⁻⁴</td>
<td>10⁻²</td>
</tr>
<tr>
<td>Clothing not normally worn in</td>
<td>10⁻⁴</td>
<td>10⁻³</td>
<td>10⁻⁴</td>
<td>10⁻²</td>
</tr>
<tr>
<td>inactive areas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skin</td>
<td>10⁻⁴</td>
<td>10⁻⁵</td>
<td>10⁻⁴</td>
<td>10⁻³</td>
</tr>
</tbody>
</table>

a Averaging is permitted over inanimate areas of up to 300 cm² or, for floors, walls and ceiling, 100 cm². Averaging is permitted over 100 cm² for skin or, for the hands, over the whole area of the hand, nominally 300 cm².

b All alpha emitters other than those listed under c.

c Uranium isotopes (except separated isotopes of mass numbers 230, 232 or 233); natural, enriched and depleted uranium; natural thorium; thorium-233; thorium-228 and thorium-230 when diluted to a specific activity of the same order as that of natural uranium and natural thorium; short-lived nuclides, such as astatine-211, radium-224 and daughters of the isotopes of radon.

d The relaxation for low-energy beta emitters does not apply to beta-emitting plutonium isotopes.

The resuspension factor of radioactive material from contaminated clothing during changing has been determined to be 10⁻⁴/m to 10⁻³/m [12]. The greatest inhalation risk to personnel from contaminated clothing occurs during removal of the clothing and during the processing of clothing at a laundry before it has been washed. Contaminated clothing should be laundered before being re-worn, when any residual contamination may be considered to be fixed. The contamination levels on clothing should not exceed those permitted for skin contamination. A relaxation factor of 10 may be applied to coveralls and laboratory coats worn only in active areas.

2.6: Relaxation of derived working limits

Some relaxations of these basic derived working limits may be allowed. In addition to the mitigating factors described in Section 2.2 (second paragraph), others may be considered. The inhalation risks from surface contamination so far considered assume loose contamination uniformly distributed over at least several square metres. In practice this rarely occurs; even in cases of widespread contamination it is usually patchy with a few limited areas or discrete spots per square metre. If limited areas are defined as those which do not exceed 100 cm²/m², the risk for this type of contamination is far less than general contamination [9, 18].
If a relaxation factor of 10 is applied in these circumstances, no appreciable increase in risk to personnel should occur. Such general relaxations are only applied in active areas; in other circumstances, each case requires individual assessment.

If the contamination is present as discrete particles which may have a high specific activity resulting in high surface dose rates, further consideration is necessary before permitting relaxation of the derived working limits, especially in the cases of skin or clothing contamination. Typical dose rates to 1 cm² of skin from particulate contamination on clothing [26] are approximately 2.5 rad/h from 1.0 μCi strontium/yttrium-90, and 4 rad/h from about 1.0 μCi of two-year-old fission products. Because of the unfavourable geometry a contamination monitor may indicate that the activity of a spot of contamination is lower than it actually is.

### TABLE II. PRESCRIBED VALUES OF SURFACE CONTAMINATION [18] (Oak Ridge National Laboratory)

<table>
<thead>
<tr>
<th>Site</th>
<th>Method</th>
<th>Contamination value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin — hands</td>
<td>Direct reading</td>
<td>α 150 dpm/100 cm², or 6.7 x 10⁻⁷ μCi/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>β-γ 0.3 mrad/h</td>
</tr>
<tr>
<td>Skin — general body</td>
<td>Direct reading</td>
<td>α 150 dpm/100 cm², or 6.7 x 10⁻⁷ μCi/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>β-γ 0.66 mrad/h</td>
</tr>
<tr>
<td>Clothing (other than contaminated zone)</td>
<td>Direct reading</td>
<td>α 150 dpm/100 cm², or 6.7 x 10⁻⁷ μCi/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>β-γ 0.25 mrad/h</td>
</tr>
<tr>
<td>Clothing (contaminated zone)</td>
<td>Direct reading</td>
<td>α 150 dpm/100 cm², or 6.7 x 10⁻⁷ μCi/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>β-γ 0.75 mrad/h</td>
</tr>
<tr>
<td>Non-contamination zone areas</td>
<td>Direct reading</td>
<td>α 300 dpm/100 cm², or 1.3 x 10⁻⁶ μCi/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>β-γ 0.25 mrad/h</td>
</tr>
<tr>
<td></td>
<td>Transferable (smear survey)</td>
<td>α 30 dpm/100 cm², or 1.3 x 10⁻⁷ μCi/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>β-γ 1000 dpm/100 cm², or 4.5 x 10⁻⁷ μCi/cm²</td>
</tr>
<tr>
<td>Tools and equipment for re-issue</td>
<td>Direct reading</td>
<td>α 300 dpm/100 cm², or 1.3 x 10⁻⁶ μCi/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>β-γ 0.05 mrad/h</td>
</tr>
<tr>
<td></td>
<td>Transferable (smear survey)</td>
<td>α 30 dpm/100 cm², or 1.3 x 10⁻⁷ μCi/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>β-γ 200 dpm/100 cm², or 9 x 10⁻⁷ μCi/cm²</td>
</tr>
</tbody>
</table>
TABLE III. COMPARATIVE DATA ON MAXIMUM PERMISSIBLE LEVELS OF SURFACE CONTAMINATION USED IN DIFFERENT ATOMIC ENERGY ESTABLISHMENTS [17]

<table>
<thead>
<tr>
<th>Location</th>
<th>Level for alpha emitters (dpm/100 cm²)</th>
<th>Level for beta-gamma emitters (mrad/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic Energy Establishment, Trombay</td>
<td>600</td>
<td>0.3</td>
</tr>
<tr>
<td>Atomic Energy Research Establishment, Harwell (active areas)</td>
<td>20000</td>
<td>7.5</td>
</tr>
<tr>
<td>Oak Ridge National Laboratory [20]</td>
<td>300</td>
<td>0.25</td>
</tr>
<tr>
<td>Los Alamos Scientific Laboratory [21]</td>
<td>100</td>
<td>0.05</td>
</tr>
<tr>
<td>Brookhaven National Laboratory [22]</td>
<td>100</td>
<td>0.1</td>
</tr>
<tr>
<td>USSR [23]</td>
<td>133</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Following a skin contamination incident it may be necessary to consider at which stage decontamination should stop, further decontamination possibly being more injurious than the radiation dose from the residual activity. The possibility of percutaneous absorption into the blood stream, and irradiation of the basal layers of the skin as well as the surface dose rate and possibility of transference by ingestion or inhalation into the body must also be considered.

Although certain derived working levels and relaxations to these levels have been quoted, it is often possible to work to lower levels without too much additional expenditure of funds and time. The aim should be to reduce exposure of personnel to the minimum, therefore radioactive contamination should be removed at the earliest opportunity. The derived working levels are guide lines to which to work, and should be used as such, rather than as hard and fast rules which must be adhered to at all costs.

3. SURFACE MONITORING TECHNIQUES

3.1. General

The aim of all radiological protection operations is to prevent persons being needlessly exposed to harmful radiation, and surface contamination monitoring must be planned with this aim in mind. Indiscriminate monitoring is meaningless and therefore a waste of time and manpower.

The International Commission on Radiological Protection in ICRP Publication 12 has subdivided monitoring of the working place into three distinct types, environmental monitoring, operational monitoring and special monitoring. The functions of each type respectively are: to show that conditions in the working environment are satisfactory; to keep a check on a particular operation and form a basis for immediate decisions on the conduct of the operation; to provide more detailed information about a situation or operation to define problems and to form a basis on which to plan future procedures.[4].
### TABLE IV. EXAMPLES OF PRESCRIBED VALUES OF SURFACE CONTAMINATION [18]

<table>
<thead>
<tr>
<th>Site</th>
<th>NCRP Handbook 48</th>
<th>British Codes of Practice ($\mu$Ci/cm²)</th>
<th>Atomic Energy of Canada Ltd. ($\mu$Ci/cm²)</th>
<th>France, CEA ($\mu$Ci/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Hands and other parts</td>
<td>0.1 mrem/h&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$\alpha 10^{-3}$</td>
<td>$\alpha 5 \times 10^{-3}$&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$\alpha 5 \times 10^{-3}$&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>1.0 mrem/h&lt;sup&gt;b&lt;/sup&gt;</td>
<td>$\beta 10^{-4}$</td>
<td>$\beta 10^{-4}$</td>
<td>$\beta 5 \times 10^{-5}$&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2. Personal clothing</td>
<td>Same as above</td>
<td>$\alpha 10^{-5}$</td>
<td>$\alpha 10^{-5}$&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$\alpha 10^{-5}$&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha 10^{-4}$&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$\beta 5 \times 10^{-6}$</td>
<td>$\beta 10^{-4}$&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\beta 10^{-4}$&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td>$\beta 10^{-4}$&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>3. Protective clothing, glassware, tools, objects to be handled with bare hands</td>
<td>Same as above</td>
<td>$\alpha 10^{-4}$</td>
<td>$\alpha 10^{-4}$&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$\alpha 10^{-4}$&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha 10^{-3}$&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$\beta 10^{-3}$</td>
<td>$\beta 10^{-3}$&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\beta 10^{-3}$&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td>$\beta 10^{-3}$&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>4. Active areas</td>
<td>Same as above</td>
<td>Same as above</td>
<td>$\alpha 10^{-3}$</td>
<td>Same as above</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\beta$ 'clean on swipe', Less than 2 mR/h on contact</td>
<td></td>
</tr>
<tr>
<td>5. 'Inactive' areas</td>
<td>Same as above</td>
<td>$\alpha 10^{-5}$</td>
<td>$\alpha 10^{-5}$&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$\alpha 10^{-5}$&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\alpha 10^{-4}$&lt;sup&gt;a&lt;/sup&gt;</td>
<td>$\beta 10^{-4}$</td>
<td>$\beta 10^{-4}$&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\beta 10^{-4}$&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td>$\beta 10^{-4}$&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Very hazardous radionuclides
<sup>b</sup> Other radionuclides

In NCRP Handbook 92, the level for radionuclides corresponding to groups 1 and 2 of Table I is given as 0.1 mrad/h whilst that for radionuclides corresponding to groups 3 and 4 of Table I is given as 1.0 mrad/h.

The fundamental test is that the surface must be 'clean on swipe', and 'swipe' tests cannot be expressed as $\mu$Ci/cm². The background in the active areas is such that $10^{-4} \mu$Ci/cm² could not be measured with the instruments available. With these provisos, the nearest values that could be indicated to conform with the others listed are those shown in this column.
TABLE V. MAXIMUM PERMISSIBLE LEVELS OF RADIOACTIVE CONTAMINATION ON OUTSIDE SURFACES OF TRANSPORT CONTAINERS [25]

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Maximum permissible level (μCi/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta or gamma emitters</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>Alpha emitters</td>
<td>$10^{-5}$</td>
</tr>
</tbody>
</table>

Note: The above levels are permissible when averaged over any area of 300 cm² of any part of the surface.

A surface decontamination program should be planned with certain primary objects in view, and the limitations of such a program in the general field of radiological protection should be realized. The program should be designed so that surface contamination does not exceed levels at which personnel might be exposed to radiation doses approaching the limits recommended by the ICRP. It should be able to detect failures of radioactive material containment and departures from correct operating procedures, and should provide information from which it is possible to plan personnel monitoring and air monitoring programs.

In practice it is difficult to correlate surface contamination in a working place with the exposure of workers, therefore surface contamination monitoring alone is inadequate. Additional radiation, air and individual monitoring programs are required.

In addition to monitoring surfaces and articles in radioactive working areas, neighbouring areas such as change rooms, offices and rooms in which food and drink are consumed should be monitored routinely. Presence of radioactive material in these areas indicates a break-down in the control systems.

For routine monitoring programs of large areas of floor, benches, tables, etc., direct monitoring techniques are normally used. Indirect monitoring may be required in certain circumstances, and if direct monitoring shows the presence of contamination then indirect methods are used to ascertain whether or not the contamination is fixed.

To calibrate instruments so that meter readings can be converted into activity levels by applying the correct conversion factor, the energy of the radiation being measured, the geometry of the radioactive source/detector assembly, counter characteristics and amount of self-absorption in the source must be considered.

Laboratories designed for radioactive work have, or should have, relatively impervious surfaces making the quantitative estimation of the amount of activity present from direct measurements fairly easy. Away from a laboratory or process area the problem is more difficult. Contamination on porous surfaces such as roadways, footpaths (tarmacadam, concrete), brickwork, soil or grassed areas, will penetrate below the surface and some of the radiations from the contamination will be fully attenuated. In these circumstances quantitative estimation of surface contamination from direct measurements made with routine surface monitoring instruments is impossible.
All indirect methods rely upon measuring the amount of radioactivity removed from a surface. The greatest disadvantage of indirect monitoring lies in the uncertainty as to the fraction of surface contamination removed. The removal factor is affected by the type of surface, physical form of the contaminant, and in the case of smear monitoring, personal variations in sampling technique affecting the size of area smeared and pressure applied to the smear. Indirect monitoring will detect the presence of only removable radioactive contamination. Calibration of instruments to measure the sample activity is necessary as in the case of direct monitoring.

3.2. Selection of method

Several points must be considered before a choice between direct or indirect methods of monitoring is made. Most important is the type of contamination which may be present, whether alpha emitters, beta emitters or low-energy beta emitters, and whether they are present individually or collectively, so that the appropriate detector is used. In laboratories or process areas handling only one specific radionuclide, it will only be necessary to monitor for one type of contamination unless it is suspected that other radionuclides have been spread from other areas. In some places such as decontamination or waste disposal areas, the presence of any radionuclide used in the establishment must always be suspected.

Although alpha, beta and some low-energy beta emitters can all be detected by direct monitoring methods, certain interfering factors may make direct monitoring impossible. There is, generally speaking, little problem in monitoring smooth surfaces such as floors, bench tops and the outside of some apparatus, except that moisture or dirt may interfere with direct monitoring for alpha emitters. A general high gamma background, or even a high beta background emanating from inside thin-walled vessels, will make it difficult to detect low levels of beta contamination by direct monitoring.

It may be geometrically impossible to monitor directly. Indentations in the surface of an article may be so deep that the distance from the bottom of the indentation to the detector is greater than the range of the particles emitted, and the inside of a vessel or tube may be inaccessible to the probe. In these circumstances indirect techniques must be employed.

Indirect monitoring will not detect the presence of fixed contamination, nor will direct monitoring show whether the contamination detected is fixed or loose. The two methods should be used, one to complement the other to obtain a complete assessment of the state of a surface being examined.

4. DIRECT METHODS OF SURFACE MONITORING

4.1. Alpha contamination monitoring

Alpha monitoring raises special problems because of the short range of alpha particles in air and their complete attenuation by thin films of liquids or solids; 5-MeV alpha particles are completely attenuated in material with a thickness of about 5 mg/cm².

The transient response of a probe passing over a source is considerably less than the response with the probe stationary above the same
source [27]. The time constant of the ratemeter is often longer than the transit time of the probe past the source, therefore the meter may not indicate the presence of the contamination. Although a loudspeaker has a quicker response, the ear may not detect small variations in the loudspeaker sound pulse-rate.

To ensure detection of alpha contamination by direct monitoring methods, the probe should not be more than about 0.5 cm from the surface under examination and the probe transit velocity across the surface should not exceed about 15 cm/s.

Although a variety of detectors is available for alpha monitoring, the technique for using them is always similar.

4.2. Beta contamination monitoring - general techniques

The detection of all but the lowest-energy beta radiation is easier than that of alpha contamination because of its longer range and greater penetration, but attention must be paid to several points.

The response of a beta probe is dependent on the energy of the beta radiation. Because all radionuclides do not emit beta radiation of the same energy, probes should be calibrated so that the count-rate from contamination by the relevant radionuclide at its derived working level is known.

During routine monitoring the area under examination is usually 'swept' by the probe, rather than a number of measurements made with a stationary probe over different parts of the area. The response of the probe varies with the distance between the surface and the probe but the effect is less than the change in response due to variable transit velocities. The response of a Geiger tube with a 30 mg/cm² envelope varies by only a factor of about 2 at distances between 2.5 and 10 cm from the surface with a probe transit velocity of about 15 cm/s. For these reasons and those outlined in Section 2.1 (second paragraph), the transit velocity of the probe should not exceed about 10 to 15 cm/s at a distance of between 2.5 and 5 cm from the surface [27].

When high levels of contamination are being monitored the dead time of the detector will affect the count-rate and may lead to underestimation of the activity present.

Radiation from very high levels of contamination may 'saturate' a Geiger tube, resulting in an erroneous nil reading being obtained on the ratemeter. Most modern instruments are designed to maintain full-scale deflection on the ratemeter, and if fitted with a loudspeaker a distinctive note is heard should the tube be saturated.

Some probes are fitted with a shield, which when closed prevents beta radiation from reaching the detector, enabling a gamma-only measurement to be made. Using this facility to identify whether the radiation detected is beta or gamma may help to determine whether or not the emitting source is above or below a shielding surface, e.g. whether the radiation detected is from contamination on a bench or from a source in a drawer under the bench. Similarly, by taking measurements at varying distances from a source and comparing the rate of change in count-rate it may be possible to determine whether or not the radiations are beta or gamma. Use of this method over a porous surface may indicate the approximate depth of the contamination below the surface.
4.3. Beta contamination monitoring — low-energy emitters

Because of the short range of low-energy beta radiations special problems similar to those encountered in alpha monitoring are raised. Geiger tubes or scintillators with thin windows (about 2 mg/cm$^2$) or gas-flow or air-filled proportional counters are most suitable. Indirect methods are usually employed to monitor for tritium [28] and plutonium-241.

5. INDIRECT METHODS OF SURFACE MONITORING

5.1. General

Indirect methods of surface contamination monitoring are used when unsuitable geometry or interference from other radiations prevent direct monitoring and as a complementary method when direct monitoring has shown the presence of radioactive contamination. A wide range of techniques is available, but all depend upon the removal of radioactive material from the surface being examined. It may be necessary to take samples from the area being monitored to another area for counting.

The fraction of material removed during routine indirect monitoring is not known accurately. A smear test may remove anything from 0 to 100% of the contamination present, but generally a removal factor of about 10 to 20% is assumed. The variations in the removal factor make quantitative estimation of the amount of contamination present on the surface uncertain. The removal factor is affected by varying the pressure applied during smearing, by the type of surface or smear, and by the form of the contamination. Devices to ensure uniformity in pressures applied and area sampled have been described [29] and usually include some form of spring loading of a pad to which the smear paper is attached.

When a smear paper is used manually, most of the contamination picked up on the paper is concentrated in an area of about 5 cm$^2$ coincident with the area of the finger tips [29]. Because this area may be small compared to the area of the detector used to measure the smear activity, erroneous results may be obtained unless the probe is specially calibrated.

Most surfaces in radioactive laboratories and process areas can be smear-tested satisfactorily. Outside these areas where rough brickwork, tarmacadom roadways, concrete paths and hardstandings, areas of gravel, soil or grassland may be encountered, the ability to obtain a satisfactory smear sample varies from the difficult to the almost impossible.

If successive smears show decreasing amounts of activity, but it is suspected that some radioactive contamination is left on the surface being examined, further tests should be made after 24 h. Experience has shown that where direct and indirect monitoring has indicated that fixed contamination only is left after some decontamination procedure, after such a period loose contamination again may be detected. In certain cases the amount of removable activity detected on smears has reached a level approaching that originally found [29].

The validity of indirect methods in which the amount of activity transferred to rinse solutions or wash-down liquors is estimated depends upon the solubility of the contaminant in the liquid in question, or on the homogeneity of particles dispersed in the liquor.
An article may be declared free from radioactive contamination with respect to indirect monitoring, but fixed contamination may still be present. Although adhering to the surface firmly enough not to have been removed and thus detected by the indirect method employed, it may become dislodged if the surface is more vigorously attacked during work upon it, e.g. by grinding, filing or polishing.

5.2. Dry smears

The technique of smear monitoring usually involves rubbing a circle of dry filter paper over about 100 cm\(^2\) of the suspected surface and then measuring the amount of activity transferred to the smear. This is repeated until the whole of the suspected area has been monitored. By applying a removal factor, the approximate amount of loose radioactive contamination on the suspected surface can be estimated. This method obviously cannot be applied operationally and routinely when large surface areas or large pieces of equipment are to be examined.

When taking smear samples from sealed sources or highly active surfaces the smear paper must be held by tongs or forceps. In this case, it is necessary to mount the smear paper on a pad such as a rubber bottle stopper which can be more readily held by the remote handling equipment.

Dry smearing is a most inefficient way of removing radioactive material from a surface and serves only to indicate the presence or absence of material which may be transferred from the contaminated surface to a clean surface by casual contact or rubbing.

5.3. Wet smears

The techniques of wet smearing are similar to those of dry smearing. The liquid chosen to moisten the smear papers should not attack the surface to be monitored but should be effective in removing the radioactive material involved. A low-toxicity organic degreasing agent such as trichloro-ethane, which is non-inflammable, is a good general solvent for this purpose. The commercially available solvent, sold under various trade names, usually contains some corrosion inhibitors.

Wet smears must be dried before monitoring for alpha activity or low-energy beta activity. Attenuation of the radiations in the smear paper, due to the radioactive material having been carried down into the paper by the wetting liquid, may result in underestimation of the activity.

The techniques described in this section do not apply to monitoring for tritium (see Section 5.9 in which more appropriate methods are described).

5.4. Large area swabs

In many circumstances the use of small smears is uneconomic of time and labour, or operational commitments may demand that large areas or articles must be examined quickly, e.g. following suspected spills or large airborne releases of radioactive material. It is acceptable practice in these circumstances to use large area smears or swabs. A pad of cotton waste or similar material is moistened with a suitable liquid and
an area up to 2 or 3 m² is wiped. The pad is then monitored. Floor mops or similar cleaning equipment can be used successfully in this type of monitoring. This method is not satisfactory for alpha monitoring, unless a smooth pad or cloth of fairly impervious, easily dried material is used.

No attempt at quantitative estimation of the amount of activity present on surfaces should be made from large area swab results; direct monitoring, if possible, or more detailed smear testing must be done if quantitative estimates are required.

5.5. Adhesive tape samples

A piece of impact adhesive tape (1 or 2 cm²) pressed against a surface will collect a sample of removable contamination. The contamination is firmly held on the tape and can be examined without the risk of losing it or cross-contaminating monitoring instruments. This is a particularly useful method of obtaining samples from inside areas where access is restricted, such as hot cells.

As in the case of conventional smear monitoring, removal factors depend upon the type of surface and physical form of the contamination, and the same reservations must be applied to results calculated from measurements made in this way.

5.6. 'Smair' sampling [30]

The smair sampling procedure employs air impingement to redisperse loose contamination from the surface under examination.

A smair sampler is a conventional air sampler fitted with a special sampling head. Through the head is a series of small holes, drilled at angles and so arranged that jets of air will be directed at the surface to be examined. When the open end of the sampler is pressed against the surface, air intake is restricted to the series of holes. Contamination, resuspended by the air jets, is collected on the sample filter paper and counted like an ordinary air sample.

The smair technique shows a relatively constant removal factor from all types of surface and minimizes the inaccuracies introduced by variations in personal techniques during smear testing. Variation in the air velocity through the impingement holes leads to associated variations in the resuspension factors.

5.7. 'Sniffing' techniques

These are closely allied to the smair techniques, but are limited to the evaluation of radioactive gases or vapours sorbed on surfaces. The sample head of a portable tritium-in-air or similar type of monitor is passed over the suspected surface, at about 1-2 mm distance. The evolved radioactive gases or vapours pass through a detachable filter and electrostatic ion trap into a compensated ionization chamber for counting.

Thoron and radon gases will decay inside the ion chamber contaminating it with their radioactive daughters, making the instrument unserviceable until they have decayed.
5.8. Examination of rinsing and washing solutions

Estimation of the amount of radioactivity in the rinse solutions from articles being decontaminated and from the washing machines in radioactive laundries will show whether or not radioactive contamination is still being removed. This method does not show the presence of fixed or insoluble contamination which may be on the articles being cleaned.

Activity measured in a solution in which a radioactive source has been immersed will indicate either the presence of contamination on the source or leakage or leaching of radioactive material from the source [18, 24].

5.9. Tritium smears

Metal foils or discs will remove tritium from surfaces. A filter paper, moistened with glycerol, has proved to be a better smearing medium having a better transfer ratio, probably due to chemical exchange and better contact with the surface as it conforms more readily to the surface geometry. The activity on the smear can be counted in a gas-flow proportional counter. A more accurate method is to seal the smear sample immediately into a phial containing water and a liquid scintillator; the sample can then be counted later in any suitable counter.

Experiments [29] have shown that up to 50% of the tritium transferred from a contaminated surface to the sampling material is lost by evaporation during the first 20 minutes after sampling.

5.10. Skin and wound monitoring

Although skin and wounds can usually be monitored directly, estimation of the activity on surgical swabs will check the efficiency of the decontamination methods being used.

As a first-aid check for radioactivity, samples of blood from open wounds may be dried on glass or metal trays and counted. The blood should not be absorbed into swabs or filter paper because alpha and low-energy beta particles may be fully attenuated. For detailed examination samples should be sent to a bioassay laboratory.

5.11. Instruments used for indirect methods

Since the estimation of the amount of activity on a sample is a direct monitoring procedure, any portable monitor or installed counting equipment which fulfils the general characteristics described in Section 8 may be used for this purpose during the application of overall indirect methods of surface contamination monitoring.

6. SUPPLEMENTARY TECHNIQUES

Some supplementary specialized techniques available to assist in the evaluation of risk or dose to persons exposed to radioactive surface contamination are outlined in this section.
6.1. Autoradiography

An autoradiograph will locate the position of small sources or areas of beta and gamma radioactive contamination on skin or inanimate surfaces. The simplest method is to place an X-ray plate in contact with the contaminated surface for a period determined by the dose rate from the contamination. For beta activity good correlation between spot size and activity is obtained. In the case of alpha contamination it is necessary to remove the wrappings from the X-ray plate, therefore the operation must be done in a dark room. In this case the spot obtained on the X-ray plate is more a measure of the range of the alpha emission than the activity or size of the particle.

A more suitable method of autoradiography for alpha activity is first to convert the alpha particle energy into visible light by a scintillator and then to record the light emission on a light-sensitive photographic plate [31, 32].

6.2. Thermoluminescent dosimetry

The surface dose from some contaminated surfaces may be measured by exposing a thermoluminescent dosimeter in contact with it. There will be some under-reading with respect to low-energy beta particles due to their absorption in the sachet containing a thermoluminescent powder, therefore correction factors must be applied.

The distribution of the powder in a thermoluminescent powder sachet will affect the dose estimation. When approximately 26 mg of LiF powder are loose in a packet the powder thickness may vary between 20 mg/cm² and ~130 mg/cm². Taking a sachet window thickness of 14 mg/cm² the mean depth will be 24 to 79 mg/cm². Even for the relatively energetic beta particles from yttrium-90 the response of the dosimeter in the latter condition is only about 0.65 of a similar dosimeter having uniform powder distribution. The use of lithium-fluoride-impregnated teflon discs would reduce this error as the thermoluminescent powder is kept homogeneously distributed in the dosimeter. Some estimate of the dose to subcutaneous tissue from beta contamination on skin is obtained by introducing appropriate filters between the contamination and the dosimeter.

6.3. Radiation spectrometry

Alpha, beta and gamma radiation spectrometry [33] identify radio-nuclides by the characteristic energy of their radiation. Such techniques may be extended to make quantitative measurements of radioactive mixtures. This information assists in determining the nature and degree of hazard arising from contamination and may also help to identify its source.

Gamma-ray spectrometry is particularly valuable because the penetrating nature of gamma radiation precludes the need for sample preparation and it is usually possible to do measurements on samples in the form in which they are received. The samples may be smears from contaminated surfaces, bottled liquids, clothing, soil, grass, gravel, tools or small pieces of apparatus. Similar measurements may be made on contaminated humans or animals. Currently, two methods of gamma-ray
spectrometry are commonly used, by lithium-drifted germanium solid-state detectors [34] and sodium iodide crystal scintillation detectors. The solid-state detectors are capable of resolving gamma-ray energies differing by 2 or 3 keV, but have the disadvantage that they operate at liquid nitrogen temperatures only. Because of their small size, they have low sensitivity and samples should be not less than about a microcurie to obtain satisfactory results. The sodium iodide detectors have poorer resolution (by normal techniques, energies differing by less than about 50 keV cannot be resolved), but their ease of operation and ability to detect about a picocurie make them an attractive tool.

Since the energy spectrum of beta radiation is continuous, high resolution spectrometry is not possible. Scintillation spectrometry using a sufficiently large plastic phosphor may be used although better resolution is obtained with a lithium-drifted silicon solid-state detector in conjunction with a multi-channel pulse-height analyser. Variable distortion of the beta spectrum due to scattering of the radiation from the detector housing, self-absorption in thick sources, and interference by scattered gamma rays add to the problems of this form of spectrometry. Although not a very attractive form of spectrometry, when beta radiation only is being measured it is vastly superior to the use of aluminium absorbers.

Gridded ion chambers, scintillation detectors and solid-state detectors are used for alpha spectrometry. Because of the short range of alpha particles the type of sample which may be examined is limited. Ideally, samples should be thin sources mounted on stainless-steel discs. Operatio nal smears can be examined although the spectrum obtained is usually degraded.

Spectrometric methods are used for in-vivo measurements in cases of either external or internal contamination of personnel.

Aluminium absorbers are commonly used to determine maximum beta energy. Aluminium absorbers of increasing thicknesses are interposed between the source and the counter window. The degree of absorption is determined by counting the beta particles penetrating each absorber. The observed count-rate, modified as necessary by counter dead-time corrections, counter window thickness and air absorption factors are plotted against the absorber thickness (in mg/cm²) on semi-logarithmic paper. The maximum range is read by visual inspection. The maximum beta energy is obtained by reference to tables or graphs.

The visual estimation of the maximum range is much less precise when the beta radiation is accompanied by gamma radiation, since the latter produces a long 'tail' to the curve, hiding the end point of the beta radiation absorption curve. In these cases, the Feather method of analysis gives a more accurate estimation of the range [35]. The long tail of the curve is ignored, and the first 70-80% of the beta absorption curve are compared with the corresponding portion of the absorption curve of a pure beta emitter. Originally Feather used RaE (210Bi), but phosphorus-32 is equally suitable.

The absorption curve for the reference source is plotted and the maximum range observed. The abscissa is then divided into ten equal fractions of the range. The activities corresponding to these fractions, excluding the 9/10 and 10/10, are marked in the ordinate. These marks, corresponding to the various fractions of the range are transferred to a 'Feather analyser', which may simply be a strip of card, but can be made
from more durable material. The Feather analyser may now be used to
determine the maximum range of beta particles from another radionuclide.
The same experimental conditions must be used to obtain the absorption
curve for identification and the results plotted with the same ordinate scale.
The Feather analyser is placed by the side of the graph, with the zero
mark opposite the point corresponding to the count-rate for zero absorber.
The values of absorber thickness corresponding to the various fractions
are read off the graph and divided by the corresponding fractions of the
range. Each is now an estimate of the total range. These estimated values
are plotted against their corresponding fraction, and the curve is extra-
polated to the full range. The energy corresponding to the full range is
then obtained from reference tables or graphs.

In areas where low-energy as well as higher-energy beta emitters can
occur, all samples may be examined routinely as follows [36]. The activity
on the smear is measured by a thin window (2 mg/cm²) detector, with and
without an aluminium absorber thick enough to absorb the low-energy betas
between the sample and the detector. The difference between the two count-
rates will be that due to the low-energy component. If alpha activity is
supposed also to be present, a further count with tissue paper between the
sample and the counter should be made. The relative amounts of each type
of radiation present can then be calculated.

6.4. Air monitoring

Widespread contamination at derived working levels may lead to air-
borne contamination at or above maximum permissible concentrations when
movements associated with normal work in an area are made. If air samples
at this level are obtained, the possibility of widespread surface contamina-
tion should be considered, as well as the more obvious and usual con-
clusion that airborne radioactivity is being released from an operation or
process in the area.

Surface contamination monitoring should be started when high air
samples following a release of airborne activity from some accident or
process are measured, because surfaces may have become contaminated
by radioactivity deposited from the airborne radioactivity.

6.5. Deposition trays

The presence of a slow, long-term build-up of surface contamination
in areas not readily accessible for direct or indirect monitoring, such as
building rafters, service ducts, etc., can be detected by placing deposition
trays in these areas and counting the activity on them at intervals of a
few months.

6.6. Overshoe and cleaning material monitoring

Routine monitoring of overshoes and shoes worn in radioactive areas
often provides the first indication that radioactive contamination of the
floor has occurred.

Mops, cleaning rags and vacuum cleaners used in radioactive areas
should be checked frequently for two reasons. First, the presence of
radioactive material on them will indicate the presence of radioactive
surface contamination in the area. Second, the undetected presence of radioactive contamination on cleaning appliances can result in the spread of contamination to hitherto clean areas.

6.7. Personnel dosimetry

An unusual density pattern on a developed personal film badge dosimeter may be due to contamination on the badge. Alternatively, it may be due to unshielded radiation from surface contamination in the working area, or radiation from contaminated clothing.

The occurrence of doses higher than planned or expected on finger or wrist dosimeters can be due to contaminated personal gloves or installed gloves, as in glove boxes at which the operator has worked.

6.8. Biological monitoring

In-vivo measurements in whole-body counting equipment and examination for radioactivity in excreta will confirm the effectiveness or otherwise of contamination control procedures.

6.9. Pinhole cameras

Mapping areas of beta [37] and gamma [38] contamination and the distribution of activity on sources [39] can sometimes be done more effectively by a pin-hole camera than by autoradiography. Some of the problems of exposure to radiation and contamination associated with the latter method are eliminated because shielding and remote operation facilities can be built into the camera.

A conventional picture and a 'radiation' picture [38] can be obtained if a light-sensitive and a radiation-sensitive film pinned together are exposed simultaneously. By superimposing one negative on the other the radiation sources can be located.

Disadvantages of the system lie in the long exposure times and in the weight of the shielding which may be required to prevent interference from extraneous sources of radiation.

7. CALIBRATION AND PERFORMANCE CHECKING OF SURFACE MONITORING EQUIPMENT

Surface contamination monitoring instruments as well as all health physics instruments should be calibrated and their performance checked at certain times so that their readings may be correctly interpreted. The frequency of calibration and its extent depend on the type of instrument and its usage but may be broadly divided into three categories.

(a) When a new instrument is first put into service, after an instrument has been repaired, and after predetermined periods in service it should be calibrated against standard radioactive sources and its performance at such a test recorded. The testing should be done by a person qualified to make simple adjustments to the instrument to make it serviceable. In many countries this sort of testing and recording is a statutory requirement.
(b) Routine checking on a daily or weekly basis of the instruments' response to sources in a simple calibration jig [40, 41] may be done by any person competent to use the instrument, interpret the results and make simple adjustments.

(c) Performance checking in the field is necessary to confirm that the instrument continues to work correctly. A small uranium disc is usually adequate for this purpose.

The accuracy of calibration can be identified at four levels: primary, secondary, laboratory and field standards.

(a) Primary standards are those nationally or internationally established to ensure consistency in interpretation and measurement within the country or group of countries.

(b) Secondary standards are those established for use by laboratories to provide calibration facilities for their own field and laboratory instrumentation.

(c) Laboratory standards are those applied in precision radiochemistry and physics work and in radiological protection laboratories supporting operational radiological protection teams.

(d) Field standards are those applied to the performance required in routine operational monitoring programs.

It may be necessary also to determine the response of the monitor to special circumstances. An instrument will respond to small smear samples (see Section 5.1, third paragraph) and discrete spots of radioactive contamination [29] differently from the way in which it will respond to an extended source. To calibrate an instrument for this work, standard small area sources in simple jigs designed to reproduce the geometry of the smear/detector assembly are adequate.

The response of beta detectors varies with beta energy. For measurements more precise than those for simple routine surface contamination monitoring where the detection of the presence of contamination is all that may be required, and in areas where a number of different radionuclides is used, the detectors must be calibrated against standard sources of differing beta energies.

Whenever possible, points at the lower, middle and higher ends of the instruments' range should be checked. This is most important if switch-range instruments are being used.

In the case of contamination monitoring instruments in which the probe is not integral with the ratemeter, the latter may be calibrated electronically by a pulse generator, after the detector probe has been disconnected.

Internationally agreed performance specifications for radioactivity detecting instruments are in preparation. The standard specifications will apply to the electronic reliability and the radiation detection efficiency.

To satisfy the calibration requirements outlined above, a number of calibration standards may be used. Most commonly these are calibrated radionuclide sources or specially calibrated instruments [42]. In the first case the response of the instrument is checked against the response it should give theoretically when exposed to the radioactive source. In the second case the response of the instrument under test to a radioactive source is compared with that of the primary instrument to the same source.

FIG. 1b. Calibration jig with standard beta probe (30 mg/cm² glass envelope Geiger-Müller tube).
A simple jig, suitable for daily checking of instruments is illustrated in Fig. 1. Four americium-241 sources to check alpha detectors and three strontium/yttrium-90 sources to check beta detectors are mounted in a wooden box which forms the jig. The strength of each source in $\mu$Ci, and the expected count-rate in counts per second (cps) is given on a card attached to the inside of the lid of the jig. The jig is designed so that the standard beta probe and the end-window probe are held in fixed positions with respect to the beta sources. Alpha probes may be moved freely so that any non-uniformity in response over the detector area will be indicated.

Suitable calibration sources for beta contamination monitors are strontium-90 or natural uranium in equilibrium with their respective daughters or phosphorus-32. Carbon-14 obtainable as thin sheets or discs of colourless poly(methyl-$^{14}$C) methacrylate may be used as solid reference sources for calibrating low-energy beta detectors. Plutonium-239, americium-241 or natural uranium in equilibrium with its daughters make suitable alpha calibration sources.

8. INSTRUMENTATION

8.1. Criteria for selection of instruments

A wide range of contamination monitoring instruments is available, varying in versatility and cost, from the cheap single-purpose instrument to the more expensive general-purpose monitor capable of being used with a variety of probes to detect the presence of most radionuclides. Figure 2
FIG. 2. Portable universal contamination monitor,
(a) Battery/mains operated contamination monitor mounted on mains power unit.
(b) Battery/mains operated contamination monitor showing monitor section containing batteries separated
from mains power pack.

The contamination monitor T1828 is a small self-contained instrument which may be used with a wide
range of detector probes to monitor most types of radiation. Its transistorized printed circuits are powered
either by internal batteries or a clip-on mains unit. Separate input sockets are provided for connecting semi-
conductor, Geiger-Müller and scintillation detectors, the latter being either single or dual phosphor types.
The high-voltage supply for the Geiger and scintillation/semi-conductor circuits is separately adjustable.
The instrument has visual indication by means of a four-decade logarithmic ratemeter (0–10,000 cps battery
check and E, H, T. Indication) and its own internal loudspeaker. The latter emits two tones, a normal
'crackle', and a distinctive 'sheep' for alpha particles detected by dual phosphor scintillators. A continuous
high-pitched tone from the loudspeaker indicates excessive counts recorded by a Geiger probe.
illustrates such an instrument. Great care should be exercised to select the most appropriate instrument for the monitoring program to be undertaken. The criteria to be considered are summarized as follows:

(a) General criteria which should be considered when selecting instruments for surface contamination monitoring are:

(i) They must be reliable and give reproduceable data;
(ii) The initial cost, and the costs of operating and maintaining the instruments must not be excessive with regard to other costs in the work to be controlled and the risks associated with that operation.

(b) For contamination monitoring all instruments should fulfil the following requirements:

(i) They should have adequate range;
(ii) They should respond quickly to the presence of radiations;
(iii) When exposed to levels of radiation in excess of their full range, their meters must maintain full-scale deflection;
(iv) There should be an audible output either via a loudspeaker or an earphone system;
(v) Battery, low and high voltage checking systems should be incorporated in the circuitry;
(vi) They should be robust enough to withstand a limited amount of rough treatment.

8.2. Detailed assessment for choice of instruments

The detailed assessment of an instrument may be made under three main headings: its mechanical, electrical and radiological performance [43].

8.2.1. Mechanical performance

(a) The instrument should be rugged enough to withstand operational use in the field. Special shock-proofing is not usually required especially in the case of printed circuit, transistorised instruments, although a metal rather than a thin plastic case is often specified. The indicating meter movement is usually the most shock-sensitive instrument component.

(b) The instrument components should be arranged so that they may be easily repaired or replaced. Meter scales and range change switches should be clearly marked to minimize the risk of an operator making an erroneous reading.

(c) Instruments should be sufficiently water-tight to meet the requirements of the conditions under which they will be used. In some climatic conditions it may be necessary to keep the instrument in a desiccated, water-tight box, removing it only when measurements are actually being made.

(d) Especially in the case of instruments operating at mains voltage, the design and construction should be such that electrical shock hazards are avoided.

(e) Controls should be easily manipulated and have position checks in each switch position so that operators wearing heavy protective clothing and breathing apparatus experience no difficulty in operating them.
(f) The batteries of battery-powered instruments should be readily accessible for quick and easy change. Instruments should be designed so that only one type of battery is required to provide the operating power, and a battery check point should be incorporated to check the condition of the instrument batteries.

8.2.2. Electrical performance

(a) A mains electricity supply to instruments should have sufficient stability to avoid fluctuations in the instrument readings. Transient effects should be minimized so that steady readings are obtained when the instrument is operating in a uniform non-varying radiation field.

(b) Batteries should be capable of providing at least a hundred hours of continuous instrument use.

(c) Switching transients should be minimized, so that when range changing or when switching on the instrument the meter settles quickly to a stable reading.

(d) Instruments should be screened so that they are not affected by magnetic or radio frequency fields. Meter readings and changes in readings should result only from ionizing radiations entering the detector and not from irradiation of the electronic circuitry or components.

(e) Electronic circuitry and components used should be stable in their response over the temperature range in which the instrument is to be used.

(f) The instrument should have a fast response time to ensure good performance when monitoring non-uniformly contaminated surfaces.

8.2.3. Radiological performance

(a) The instrument should have an adequate range and a sufficiently low detection limit to meet the needs for which it is to be used. The lower detection limit required depends on the value of the derived working limit of surface contamination to be used in the areas in question. The range depends upon whether one has to measure the amount of radioactive contamination present, or whether one only wants to know whether or not it exceeds some predetermined acceptable action level.

(b) The degree of accuracy should be determined; for operational field work ± 20% may be adequate, but for more detailed laboratory study ± 5% or less may be required.

(c) The instrument should have good reproducibility within its accuracy range, so that when properly calibrated, meaningful estimates of the amount of surface contamination present can be made.

(d) Meters should always be driven off scale at the high range whenever they are exposed to radiation fields exceeding their maximum range.

(e) The response of the instrument to radiations of different energies must be known, and correction factors calculated as necessary.

(f) The effect of temperature and atmospheric pressure changes and humidity on the instrument detector should be known and correction factors established if necessary.

(g) The response of the instrument to radiations other than those which it is designed to measure should be minimized.
(h) The instrument should be easily calibrated and when adjusted to give a determined response should be sufficiently stable to maintain the response, without drift, during its period of use from one calibration to the next.

8.3. Examples of instruments in use

An outline is given in this section of the types of detectors and monitors suitable for various surface monitoring programs.

For detection of alpha emitters, scintillators, proportional counters or semi-conductor detectors are normally used. Gas-flow and air-filled proportional counters are more readily affected by climatic conditions than scintillators or semi-conductors but are usually more robust and less likely to become light-sensitive. Thin window Geiger tubes can be used, but their detection efficiency is rather low, and the presence of beta or gamma radiation will interfere.

A Geiger tube with a window thickness of about 30 mg/cm$^2$ is adequate to detect beta radiation with a maximum energy above about 200 keV, but the response varies with the energy of the beta radiation [44]. For lower-energy beta radiation, either Geiger tubes with a thinner window (e.g., 2 mg/cm$^2$), proportional counters or plastic organic scintillators behind a thin light-tight shield are suitable. The first and last will not detect the low-energy beta radiation from plutonium-241 or tritium. Gamma radiation will interfere with all beta detectors and alpha radiations will also interfere with 2-mg/cm$^2$ window Geiger-Müller detectors. Shielded Geiger tubes may be used in areas where the gamma background is likely to interfere with measurements, but they are heavy and are only really suitable for monitoring floor or ground areas.

Alpha and beta detectors in a range of sizes are available, from small area (2.5 cm$^2$) semi-conductor detectors through detectors with 100 cm$^2$ detection areas to the large area probes (~500 cm$^2$) suitable for floor monitoring. For routine monitoring, alpha probes with a sensitive area of 50 cm$^2$, and standard beta probes with sensitive areas of 30 cm$^2$ or end window beta probes with 5 cm$^2$ detectors are suitable.

Because of their small size, semi-conductor detectors are more suitable for monitoring spots of contamination on apparatus or skin previously indicated by general monitoring.

For monitoring of high levels of alpha contamination which may be found in glove boxes, fume hoods and pressurized suit areas, either general purpose probes or specially developed probes incorporating small, thin-walled ion chambers may be used. The probe is connected to the rate-meter, which is kept outside the area, via a special bulkhead fitting mounted in the side of the box or the wall of the pressurized suit area.

Special hand and clothing monitors and foot monitors may be installed at the exits from radioactive areas or at strategic places within the areas. Doorpost monitors, which monitor personnel and their clothing, reduce the number of personal variables which arise during self-monitoring with standard probes [45] (Figs 3 and 4).

Automatic monitors which detect alpha and beta contamination on clothing may be installed in laundries serving radioactive establishments [46]. Devices may be incorporated which will allow the clothing to be sorted according to the degree of contamination.
FIG. 3. Doorpost monitor in use.

The detector system comprises twelve thin-walled Geiger-Müller tubes, eleven mounted vertically behind a thin protective cover, and one mounted horizontally in a foot plinth. The tubes are grouped in threes, and the output from each group is fed to its own alarm circuit. Counting is started when the user interrupts a light-beam/photo-electric cell assembly as he mounts the plinth. During the counting period of ten seconds, the user must rotate himself to present the whole of his clothing surfaces to the detectors. If the pre-set output level is not exceeded, a green "NOT CONTAMINATED" sign is illuminated. If the level from any group of detectors is exceeded, an audible warning sounds, and a light indicates which group has triggered the alarm. The instrument will detect > 0.04 μCi $^{90}Sr/^{90}Y$ over 100 cm² in a gamma background of 50 μR/h.
The fully transistorized hand and clothing monitor, type H. C. M. 3, monitors both hands of personnel for alpha and beta contamination simultaneously. A pair of dual phosphor probes are used for each hand, and automatic compensation against gamma backgrounds up to 1.5 mR/h is provided by an additional counter. The monitor provides meter indication of up to two derived working limits (DWL) for both alpha and beta contamination on each hand. If one DWL is exceeded, a red 'Wash again' light comes on, and an alarm bell rings at the end of the monitoring period which can be preset to any time between 2 and 20 s. If contamination does not exceed one DWL a green 'Safe' lamp lights and a two-tone chime sounds. A photoelectric cell interlock rings the alarm bell and lights a 'Recheck' lamp if the hands are withdrawn before the monitoring cycle is completed. Two separate single phosphor clothing probes are provided, one normally for alpha and the other for beta monitoring.

For monitoring alpha contamination on installed glove-box gloves a specially designed probe will give quicker and more reliable measurements than a general purpose instrument.

For measurement of high beta dose rates (up to 10^5 rad/h) a simple detector [47] incorporating a thin plastic scintillator (about 25 mg/cm^2) and a simple photodiode gives very good results. The gamma-ray response is small, below 100 R/h, and is a linear function of dose-rate above this level.

Some gamma radiation monitors [48] have detachable beta shields which when removed expose a thin window of the ion chamber. These monitors can be used to detect the presence of high levels of beta radiation, but, because of their large variation in response to beta particles of differing energies, the dose-rate measurement indicated on the meter is inaccurate. The instruments must be calibrated over a range of beta energies and source areas, at varying distances from the source.

Instruments are available which will only record the presence of radiations in specific energy bands peculiar to a specific radionuclide, e.g., one which will identify the presence of the plutonium-239 by its 17-keV X-ray emission. Portable gamma-ray spectrometers are available which may be used to identify radionuclides present in contamination in situ.
Care must always be exercised when using radiation detectors. Glass-walled Geiger tubes will implode when broken, causing glass fragments to fly some considerable distance. Injuries have been sustained from this type of accident, and it is recommended that eye protection is worn when replacing a tube in the detector holder. A protective mesh screen may be used over the tube while in use; a medical-gauze sleeve on the tube has proved effective, and it does not reduce the tube efficiency significantly.

The short range of alpha particles means that any probe used for alpha monitoring must have a very thin window. Alpha scintillation probes in general use have a light-tight foil of thickness about 1 mg/cm² which, if damaged, will allow light to penetrate to the photomultiplier and give spurious counts. Because of the necessity to monitor close to the surface, alpha scintillation detector foils can easily be damaged, e.g. by small pieces of glass, wire or gravel and even hair stubble. Probes must not touch contaminated surfaces as spurious results will be obtained should they become contaminated. When preparing the instruments for use, excessive voltages must not be applied as this will either damage the detectors or lead to spurious counts being registered.

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