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safety series
No. 48

PROCEDURES AND DATA

Manual on Decontamination of Surfaces

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1979

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MANUAL ON DECONTAMINATION OF SURFACES

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FOREWORD

Radioactive contamination of the working areas, equipment, protective clothing and skin may result from normal operations involving unsealed radioactive materials, or from accidental releases. Decontamination, therefore, forms an essential part of a radiation protection programme, serving to ensure clean and safe working conditions as well as maintaining proper hygiene in the handling of radioactive materials. The subject of decontamination was covered briefly in the Agency's Safety Series No.38, "Radiation Protection Procedures", published in 1973, but the information therein was only general. With the rapid development and application of atomic energy for peaceful purposes, the work with unsealed radioactive materials has been increasing. The Agency therefore considered it important to prepare a guide on methods of decontamination.

The present manual is intended for those persons or authorities in Member States, particularly developing countries, who are responsible for the organization and implementation of decontamination programmes for facilities where radioactive materials are handled mainly on a laboratory scale. It contains information and guidelines on practical methods for decontaminating working spaces, equipment, laboratory benches and protective clothing. Useful information is also provided on the removal of loose skin contamination from personnel by mild, non-medical processes. Methods of removing skin contamination needing medical supervision, or of internal decontamination, which is entirely a medical process, are not covered in this manual. Large-scale decontamination of big nuclear facilities is also considered as outside its scope.

The manual has been prepared with the help of two consultants, J.H. Clarke, Chemical Technology Division of AERE, Harwell, United Kingdom, and T. Dippel, Department of Treatment of Radioactive Wastes, Gesellschaft für Kernforschung mbH, Karlsruhe, Federal Republic of Germany. The final draft of the manual was also reviewed by R.E. Linnemann, President, Radiation Management Corporation, Philadelphia, USA. The staff members of the Agency involved in its preparation were J.U. Ahmed and J.P. Labarthe of the Division of Nuclear Safety and Environmental Protection. The final compilation of the material was the responsibility of J.U. Ahmed.

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1. INTRODUCTION

In the nuclear industry standards of safety for personnel are very similar in most respects to ordinary industrial regulations, and if these are adhered to then the problems of contamination can be kept to a minimum.

Personnel engaged in modern industry are familiar with measures designed to ensure that contamination and cross-contamination of their products does not occur and recognize that scrupulous cleanliness is essential for efficient working. This is particularly true in the pharmaceutical industry and in hospitals whose work is carried out on pathogenic bacteria.

The essential difference between these examples and the problems of people engaged in handling radioactive substances is the fact that radiation-emitting materials cannot be neutralized or destroyed. It is therefore necessary for plants and laboratories to be designed for adequate containment of radioactivity and that materials and surfaces should be chosen that will permit effective decontamination if the containment becomes inadequate. The basic principle should always be that if contamination is prevented by good planning and practices then decontamination is not a problem.

Radioactive contamination results basically from contact between radioactive materials and any surface and occurs to some extent whenever radioactive isotopes are handled. Frequently the presence of contamination is an indication of the inadequacy of the programme of containment of unwanted sources of radioactivity. Therefore it is always most useful to evaluate the basic and proximate causes of contamination so as to prevent similar contamination later.

Decontamination is loosely described as any process that will either reduce the level of, or completely remove, any radionuclides from a contaminated surface. Decontamination is necessary for a variety of reasons, some of which are:

(1) Health hazard – levels must be reduced to ensure staff are not subjected to radiation above a stipulated level
(2) Interference with accurate counting equipment
(3) To allow routine or other maintenance to take place
(4) So that the articles can be safely disposed of or repaired
(5) In order that the contamination level is low enough for the article to be returned for re-use.

With respect to the health hazard it should be borne in mind that internal contamination is the potential hazard from the airborne contaminants or dormant contaminants that are resuspended in the air. Ingestion, absorption and skin penetration are relatively minor hazards. The next most significant hazard is contact exposure to skin from direct contact with contaminants. Whole-body exposure from contaminants is seldom a dominant hazard.

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Decontamination can only be effective if it is backed up by efficient inspection and monitoring procedures.

Arisings from decontamination processes will produce radioactive effluents to be disposed of, and in many cases the efficiency of activity removal may be influenced by the presence of 'difficult' decontaminants in these radioactive effluents. It is obvious therefore that contamination, and by implication decontamination, should be kept to an absolute minimum. This means that it is necessary to study certain factors such as the nature of contamination, the mechanism of contamination and the nature of decontaminating reagents.

2. MAXIMUM PERMISSIBLE SURFACE CONTAMINATION

Radioactive nuclides distributed on any type of surface may be hazardous to man due to the external radiation field or to intake of radionuclides, particularly alpha emitters. The maximum permissible concentration values are derived from the dose-equivalent limits.

The figures currently used in practice are 10^{-5} μCi/cm^2 for α-emitters and 10^{-4} μCi/cm^2 for β, γ-emitters and should be regarded as maxima. These limits are for articles that may be removed from the controlled areas. However, other maximum permissible limits for surface contamination for materials within the controlled areas may be established, depending on the conditions of work. Depending on the origin and the models of derivation, these figures differ as demonstrated in detail in Ref. [1]. Besides normal practice, situations may occur that ask for a further reduction of these figures, as quoted in the following paragraph taken from the above reference:

> "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."

Within the controlled areas the maximum permissible limits for fixed contamination may be higher than that for grossly removable contamination. For articles to be released to the general public areas the level of fixed contamination must be within the maximum permissible limits mentioned above.

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3. INSPECTION AND MONITORING

Any facility or installation in which radioactive materials are handled must be inspected by monitoring as a routine procedure. Such procedures are effective if they are capable of detecting radioactive materials exactly at the position of the contamination, enabling one to locate its origin. Normally these results give a local background level in the area, thus it becomes easier to detect contamination when it does occur.

In practice these procedures consist of direct monitoring of surfaces and taking smear tests. It is most important to realize that careful control by personnel leaving a radioactive area is essential to minimize the spread of contamination. The careful observation of conventional safety aspects and sound interpretation of deviations from normal work as a possible source of contamination are also essential to protect personnel and equipment against contamination.

Hand monitors and foot monitors should be positioned at the exits to appropriate radioactive areas for use by the personnel working there. Direct monitoring for α-emitters is a difficult procedure and very careful interpretation of the results is necessary, while low-energy β-emitters like tritium and carbon-14 require special techniques.

There are two methods of monitoring for contamination, direct and indirect, and either or both may be used as the conditions require. Direct monitoring is the positioning of the instrument probe directly over the area of contamination, while in the indirect method smears are taken which can be monitored outside the affected area. The direct method has the disadvantage that it is difficult to carry out in areas that are not very accessible and where an external radiation background exists, but is good for a general survey of an area and also for personnel monitoring. With the smear method all areas are accessible but good estimation must be made as to how much of the total radioactivity has been picked up on the smear.

Details of monitoring procedures depend strongly on the type of radioactive material in question, e.g. fission products, nuclear fuels and others, therefore proper selection must be made with respect to monitoring equipment. To examine the possibilities and come to an optimum choice the IAEA Technical Report "Monitoring of Radioactive Contamination on Surfaces" [2] may be used as a guide.

4. CONTAMINATION

4.1. Type of contamination

Radioactive contamination may occur in the solid state, in solution or carried by a gas or vapour. Contamination under the second heading is probably the most common form but the others must still be considered.

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Contamination can be due to minute quantities of any radioactive substance, and as virtually every known element has at least one radioactive isotope, there are more than 100 elements capable of causing contamination.

The problem of decontamination is made complex because of this large number of possible contaminants, and also the fact that although they all decay in time, many produce a variety of daughter products, which are sometimes isotopes of different elements.

Two factors stand out as affecting decontamination:

(1) The chemical, physical and radiochemical nature of the contaminant
(2) The material and surface finish of the substrate.

4.2. Nature of contamination

The principal mechanisms by which radioactive materials are held on a surface do not differ from those of their non-active counterparts. The features that differentiate radioactive contamination from other contamination are the very small quantities involved (e.g. 1 mCi ^{32}P weighs 3.5×10^{-9} g) and that radioactivity cannot be destroyed. Contamination is often associated with the greasy soiling normally found on surfaces exposed to atmospheric conditions and the protective oxide layer on the surfaces of metals, e.g. stainless steel.

In most cases the contaminants are difficult to remove. They can be classed under three headings, soluble (ionic), particulate and colloidal. Soluble (ionic) contaminants are normally associated with the surface of the substrate by physical adsorption or by ion exchange with the reactive groups (usually acidic) present on the surface of most non-metallic materials. Anionic contaminants are repelled from these surfaces by the mutual repulsion of the negatively charged species and little adsorption is detectable. However, cations are attracted to the acidic surface and in favourable conditions, particularly at low concentrations, polyvalent cations are adsorbed almost quantitatively. Unfortunately most fission products and all the heavy natural radioelements are in this category.

Colloidal and particulate contamination can be adsorbed from suspensions and deposited on a substrate. To remove this contamination requires the use of specific reagents that will dissolve the particular contaminant.

4.3. Sources and processes of contamination

Probably the most important and least obvious source of contamination is merely the fact that work involving radioactive materials is going on in an area. Without any obvious spillages and accidents, the area still becomes contaminated. This is due to a multitude of reasons, such as:

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(1) Slight airborne contamination due to minute particles of the material getting into the atmosphere
(2) Leakages of air from fume cupboards where radioactive work is progressing
(3) Transfer of radioactive material from one area to another
(4) Spread of contamination from gloves used in various parts of the area
(5) Possible leakages from waste-disposal containers in the area.

Among the more obvious sources are:

(a) Accidental spillages – these are fairly common but their effect can be minimized by careful preparation and design of a radioactive area
(b) Bringing radioactive material into the area and removing it from the transport container
(c) Contamination of the container itself from the contents, which may not be efficiently wrapped
(d) Posting the radioactive materials into and out of glove boxes
(e) Chemical operations in the area, e.g. evaporation, solvent extraction, reactions between different chemicals, stirring in beakers, breakage of glass apparatus and aeration of solutions
(f) Leakage of filters
(g) Blockage of filters causing 'blow out' of contaminated vapours
(h) Mechanical handling of solid material by lathes, grinding and cutting machines, shredding machines.

All of these possible sources of contamination must be kept in mind when monitoring programmes are prepared.

4.4. Influence of nature and type of surfaces on contamination

When choosing materials and surface finishes which may be exposed to radioactive contamination, it is important to consider the mechanisms by which a surface can become contaminated and also the types of reagent and procedures that may be used in decontamination. The surface chosen must resist attack by the decontaminant, otherwise it will become progressively more prone to contamination and more resistant to subsequent decontamination. However, complete immunity to the decontaminant is unlikely to be achieved.

In general, there are only three types of surface: metallic, organic and vitreous. With metallic surfaces there is often a chemical similarity between the cationic contaminant and the substrate, which can result in the contaminating atoms becoming part of this substrate. In such cases decontamination can only be achieved by the removal of the metallic surface containing the contaminating

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ions. Most metals possess a surface oxide film which often acts as a protective layer and usually most of the contamination is trapped in it. Again, removal of this layer is the preferred decontamination method for such materials.

Contamination of organic and vitreous surface is brought about by a number of processes of which ion-exchange is probably the most important. All organic materials such as paints, plastics and textiles as well as vitreous surfaces like glass and porcelain, possess reactive acidic groups, with a definite ion-exchange capacity. In terms of conventional ion-exchange resins, the ion-exchange capacity of these surfaces is very low indeed but still sufficient to adsorb a relatively high level of radioactive ions. These surface acid groups may by present either inherently or by oxidative degradation and include high polar types such as hydroxyl, carboxyl and silicate. Although such groups will repel anions, any cationic contamination will be readily adsorbed.

If one considers a polymer or a polymeric surface immersed in acid solution above a pH value of about 2.5, the acid groups ionize and will adsorb polyvalent cations. This adsorption can follow two processes, one fast which can be attributed to a rapid equilibrium being set up with the readily available surface acid groups, and the second taking place slowly and taking some weeks to come to equilibrium. In this second process water diffuses between the polymer chains and ionizes the ionogenic groups in the process. When sufficient water has permeated the material to raise its dielectric constant sufficiently, it is possible for the large hydrated cations to pass into the material using the fixed ions on the membrane as 'stepping stones'.

In some cases contamination of an organic material is caused by the ability of the contaminant to dissolve in the organic phase. This has been noted with plasticized PVC and with various plasticized paint coatings where phosphate plasticizers were used.

Difficulties encountered in the decontamination of certain paint films using amine and polyamide curing agents have been attributed to the formation of complexes between the metal ion and the amine.

5. PREVENTION OF CONTAMINATION

Prevention of contamination is the preferred course in handling radioactive materials rather than decontamination. This helps in saving the money and time that is wasted on decontamination and maintenance. Prevention of contamination can be accomplished to a large extent by a combination of several processes. Proper design of working areas, proper choice of surface materials, the use of correct protective clothing, training of operating personnel and the use of appropriate monitoring equipment, all applied in combination, can prevent contamination to a great extent. Other important considerations are the proper planning of work with radioactive materials and writing the procedures of work.

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5.1. Preparation and design of radioactive areas

The first stage in contamination control is at the design and preparation of the area in which the radioactive work is to take place. A survey of the requirements listed for an easily decontaminable surface gives a basis for a preliminary evaluation of basic materials, structural, protective and to some extent decorative, for use in radioactive areas. Commercially available decontaminable materials suitable for use in laboratories, buildings, chemical plants etc. where surfaces are exposed to contamination and radiation under various conditions of moisture, temperature, chemical and mechanical effects are listed in Ref. [3]. The information therein is invaluable and there are probably similar instructive publications in most countries [4].

Whenever possible, the handling of radioactive materials should be confined to fume cupboards and glove boxes to ensure that accidental release of contamination can be confined to a small, well-defined area. One must also avoid unnecessary contamination traps so that there can be no activity build-up in small areas.

There are various surface coatings and normally they are required to adhere to the surface, both to protect it and to be decorative. They are also expected to withstand the environmental conditions or the usage which may be chemical, heat or abrasive. For walls there are three main types of paint from which a choice can be made:

(a) Chlorinated rubber based paints
(b) Epoxide resin based paints
(c) Alkyd and tung-oil phenolic resin based paints.

In addition, where contamination levels are likely to be high, strippable coatings based on vinyl acetate/vinyl chloride co-polymers have been used. Ceramic tiles and panels of plastic material like PVC are also commonly used for the walls of laboratories and other radioactive areas. In such cases it is important to note that the larger the tile used, the smaller the area of jointing, which is, of course, the place where the contamination tends to concentrate.

5.2. Benches

In spite of the variety of plastic materials that can be used for working areas such as bench tops, the use of a suitably polished wood still appears to be popular. The choice of a non-porous surface is essential but the use of temporary coverings is very popular. These can take the form of stainless steel or enamel trays, PVC or polyethylene sheeting and bituminous waterproof paper. In many cases the

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protective covering can be disposed of as solid radioactive waste when contamination occurs, thus saving time and keeping work continuing in the area. The avoidance of contamination of any permanent surface minimizes both the time and costs of a decontamination exercise.

5.3. Flooring materials

The floor in any building is the most abused surface and the one most likely to become contaminated. It must be capable of withstanding normal mechanical work undertaken in the area and be sufficiently abrasion resistant to ensure that dirt, grindings etc. are not worked into the surface. In areas subject to possible spillage of liquors the floor should be resistant to the liquids used there and sufficiently impervious that the base construction is protected. Where mechanical work is restricted to foot traffic etc. it is sufficient to use ordinary linoleum or PVC coverings bonded to the sub-floor. PVC is much better than linoleum from a decontamination angle, but is of course much more expensive. Such surfaces rely on sealing varnishes or wax polish to make them impermeable. If they become contaminated, it is then sufficient to remove the layer of wax or varnish to effect decontamination. When severe contamination occurs it is a simple operation to remove the covering and replace it. When such coverings are used it is important to keep the number of joints to a minimum as this is where any contamination will tend to concentrate. The joints should be neat, tight and well-sealed.

In areas where aqueous spillages are frequent a suitable flooring can be prepared from mastic asphalt. Such floors take heavier loads than linoleum or PVC coverings but are unsuitable for areas where high point loads are common or where contamination by oils and solvents is possible. Although used in some places, these surfaces cannot be generally recommended.

The most suitable material for heavy duty floors consists of ceramic tiles. They must be carefully bedded and jointed. Such floors can withstand heavy loads, corrosive liquors and solvents and, provided that a correct grade of tile and a suitable cement are chosen, are easily decontaminated. The tiles must be fully vitrified and have a very low water absorption while the cement used must have good qualities, and it is common to use an epoxide resin cement or a furane resin cement.

5.4. Pipelines

Pipes carrying radioactive effluent from laboratory sinks etc. to the effluent treatment system are invariably contaminated and must be cleaned periodically if a build-up of radiation is to be avoided. Such pipelines must withstand pressure, temperature and often severe corrosive conditions. Popular materials

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of construction are ceramic materials, rubber-lined mild steel and polyethylene. Both ceramic and polyethylene surfaces are relatively easy to decontaminate but rubber is more difficult unless it is a specially formulated synthetic type which has been found to be good for decontamination. The final choice of material must depend on the work going on in the laboratory or workshop and the local conditions, e.g. if there is a big fire hazard then any plastic pipework is unsuitable. Particular attention should be paid to joints, bends and traps where contamination tends to concentrate and leakage may occur.

5.5. Criteria for a good decontaminable surface

A good surface for use in areas where radioactive materials are handled should ideally:

(1) Be non-absorbent – really porous materials just cannot be decontaminated;
(2) Contain as few acidic groups as possible;
(3) Have as low a moisture content as possible;
(4) Avoid plasticizers, solvents etc. that are known to dissolve heavy metals;
(5) Possess sufficient chemical resistance to withstand the decontaminating agents;
(6) Be capable of withstanding any abrasive action associated with the area;
(7) Be as smooth as possible and so offer the minimum area to contamination and avoid cracks and ledges that could contain particulate matter;
(8) Where necessary be resistant to radiation and heat.

Usually it is impossible to satisfy all these criteria and some form of compromise is required. However, a careful study at the design stage will often reduce later decontamination problems. More detailed information can be found in Ref. [3].

In some circumstances it may be more economical to provide a temporary surface, on top of a permanent decontaminable surface, which can be removed easily than to decontaminate a permanent surface. This is particularly useful under conditions in which the contamination can be severe [5]. Such temporary surfaces can be strippable coatings such as strippable paints (e.g. latex), PVC or PVA sheet, coated paper or polyethylene. The choice of the material for the temporary surface would depend on the specific circumstances. Good guidance on this is provided in Ref. [6].

5.6. Testing for decontaminability

To select suitable materials for areas where contamination may occur one needs reliable information of the behaviour of the material in question. A basic

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preselection is possible bearing in mind the above-mentioned criteria but the final decision requires more detailed testing. Some of the procedures used in various countries in the past have enabled standard procedures to be laid down. As a result of these it is possible to compare the decontaminability of various materials.

Standard procedures are laid down in many countries. Although these procedures differ in detail, they yield very consistent results for materials that are easy to decontaminate. Test results tend to be somewhat erratic on materials that are difficult to decontaminate, therefore it is most important always to use the same test procedure.

In order to assist people who are responsible for the selection of materials some of the standardized testing procedures mentioned are given in detail in Appendix I.

5.7. Other important considerations

Training of personnel in their specific jobs with radioactive materials as well as in radiation-protection procedures pertinent to such jobs is important in maintaining proper housekeeping and clean working areas. Similarly good planning of work with radioactive materials is equally important in minimizing the possibilities of radioactive spills. Poorly planned procedures and inadequately trained personnel were the frequent causes of radiation accidents even in exemplary laboratories.

There are some indirect ways of preventing radioactive contamination. For example, analyses of smears taken from the contaminated surfaces may enable identification of the procedures or stages of processing at which containment control failed. Such analyses will lead to corrective measures so that there will occur no such contamination in similar operations to be carried out later. Location and distribution of contamination and its time of occurrence are also indicators of causes of contamination. Location and time relate to responsible persons, inadequately controlled procedures or stages of processing or failure in the protection system (ventilation etc.).

6. DECONTAMINATION

6.1. Principles and methods of decontamination

Ideally, all contamination should be removed; however, there are certain circumstances that should be taken into account in determining the degree of decontamination required. One of the more important decisions that the decontaminator has to make is to decide whether to decontaminate an article or not.

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There is no need to decontaminate articles that can be disposed of by normal methods and there are many cases where it is easier to replace with a clean article and throw away the one that has been contaminated. Again, this decision may depend on legislation, cost, availability of disposable materials etc. and one must consider the practicability and the legality of getting rid of contaminated materials as radioactive waste. It is worth noting that working areas and surfaces in general can be kept in a relatively contamination-free state if regular 'housekeeping' is carried out using very simple cleaning procedures. Then specialized treatments will only be necessary in localized areas as a result of spills etc. As already mentioned, contamination control by careful planning will reduce the possibility of trouble in any radioactive area. All obvious porous surfaces like concrete and untreated wood must be protected if any work with radioactive materials is carried out on them.

It is very necessary to keep records of all contamination surveys carried out in radioactive areas. These will give information on the 'background' radiation in the area and deviations from this can then be investigated.

The first problem in decontamination is to ascertain what form the contamination takes, e.g. is it readily moveable grease or oil, is it removable dust, is it liquid on the surface, has the contamination penetrated the surface? Then one has to consider what type of surface has been contaminated as this will certainly affect the method of decontamination, e.g. is it a smooth plastic surface, is it porous concrete etc.?

When called upon to decontaminate a whole laboratory or other such area, there are certain procedures to follow. The first action is to restrict access to the area, then assess the radiation situation, then a survey of the area is carried out, wearing suitable protective clothing and equipment and taking care to keep exposure from external radiation as low as reasonably achievable.

A tent-like structure made of plastic sheeting can, if necessary, be erected taking in the entrance to the contaminated area. If the 'tent' and the contaminated area can be kept at a slight depression as compared with the outside area, the flow of the air will be into the contaminated zone, thus reducing any possibility of airborne contamination outside the area. The floor can be covered with plastic or bituminized waterproof paper for protection. A barrier will be necessary and protective clothing must be worn inside the area. It is essential to have definite routes into and out of the contaminated area to avoid confusion as operators go in and out. Receptacles for the contaminated waste will be necessary in the tent, as well as containers for the decontaminating solutions and rinse water. A good supply of any type of auxiliary material is also required. All monitoring equipment used inside the contaminated area should be wrapped for protection against contamination. Auxiliary monitoring equipment should be kept outside the contaminated area and passed over the barrier when required. When the operation is completed the floor covering and tent material must be

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carefully collected as radioactive waste. Local shielding may have to be erected for high β-γ contaminations and air monitors placed in general areas as well as 'suspect' areas.

Contact with the user of the area will result in useful information, e.g. where is the gross contamination, what radioisotopes are likely to be present and what other hazards are present. There are many cases in laboratories where fissile material is being used when alterations to the settings of taps and valves could give rise to criticality problems so it is essential for decontamination and health physics personnel to know exactly what can and what cannot be touched in the contaminated area.

One of the most important actions is to 'contain' the contamination and avoid spreading it to clean areas. Protective covers, e.g. PVC and polyethylene sheeting or bituminized waterproof paper, should be put on the floor near to where the decontamination is being carried out. All tools, contaminated swabs and similar materials can be placed in containers standing on the covering. Gloves will always be worn by the operator doing the decontamination and, if necessary, he will wear protective clothing and breathing apparatus. If there is a lot of contaminated dust or particulate matter present, there are two possible procedures, either to moisten them to prevent spread of contamination or to use a special type of vacuum cleaner to remove the dust.

General decontamination will then start at the floor area nearest to the access point, continuing into the area. Benches and equipment will be cleaned as the operator reaches them and the portable equipment may, if necessary, be wrapped up and posted out of the area for more efficient decontamination later. It may also be necessary to bring shielded flasks into the area to take out high β-γ emitting materials or other containers for fissile material.

In any decontamination exercise the first treatment is with the mildest cleaning agent, e.g. water or solvents to remove grease. When using swabs for decontamination it is most important to discard them after each complete wiping operation. After one wipe a swab is contaminated and using it again spreads contamination and in some cases tends to force it into the surface being cleaned.

If the first simple treatment is not sufficient then the use of mild acids or alkali detergents is recommended, leaving more stringent decontamination techniques as a final step. Regular monitoring must be carried out to assess the amount of contamination removed between each cleaning stage. Whenever it is necessary to remove any protective clothing worn by persons involved in the decontamination operation it must be done in such a manner that they do not become contaminated. The clothing can then be carefully packed in a receptacle and taken away for decontamination before re-use.

Having cleaned the floor and benches, the walls may then be decontaminated, but if the area is very big and enough personnel are available this may be started before the floor is actually finished.

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The general cleaning will then be followed by more efficient methods to achieve the required decontamination. Monitoring will again be necessary at all stages of these various processes.

When using smear tests for the final control it is essential to ensure that the surfaces are completely dry. Equipment that can be used in decontamination operations includes:

(a) Absorbent material for swabbing
(b) Steam cleaning equipment
(c) High-pressure water equipment
(d) Vapour blast units
(e) Ventilated decontamination cabinets
(f) Ventilated immersion tanks
(g) Shielded ventilation cabinets
(h) Remote handling equipment
(i) Scrubbing brushes
(j) Vacuum cleaners
(k) Automatic floor cleaners (specially adapted).

6.2. Decontamination agents and application techniques

In general all types of conventional detergents will act as decontaminating agents. They have the advantage of being readily available and cheap. Their general 'make up' also fulfils most of the necessary requirements for good decontamination, e.g. a good detergent is a mixture of:

(1) A synthetic detergent or wetting agent, e.g. alkyl benzene sulphate – this emulsifies and aids the removal of grease and oils;
(2) Sodium polyphosphate, which acts as a complexing agent for Ca and Mg salts in hard water. It also supplies sodium ions, which are available for reactions at ion-exchange sites on the contaminated surface;
(3) Carboxyl methyl cellulose, which is normally included to suspend dirt and prevent its redeposition. It also behaves as a soluble ion-exchange polymer and is quite an efficient decontaminating agent in its own right;
(4) Trace amounts of salts of EDTA, which complex the radioactive cations and hold them in solution;
(5) Bleaching agents such as perborates and persulphates, which are no aid to decontamination.

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These detergents are among the least aggressive decontaminants but if used in excess, can cause cracking in medium-density polyethylene and leach out plasticizers from PVC. Complexing agents like citric acid and salts of EDTA are good for decontamination but can cause trouble in the effluent treatment plant. Pickling or etching solutions, e.g. inhibited phosphoric, sulphuric and nitric acid solutions, are widely used to remove stubborn contamination from ferrous metals. There is a very wide variety of proprietary compounds available, all of which are based on the principles already mentioned. The important fact is to realize that different surfaces usually require different types of decontaminating agent. For walls and irregular surfaces it is useful to use pastes that contain the pickling or etching agents.

There are several well-established application techniques available, suitable for use with the various decontaminating agents. These include total immersion, continuous spraying, coating in thin layers with paste, brushing and wiping.

Physical desorption can often be assisted by raising the temperature of the system but this is not very practicable. Ionic bound cations, however, will require chemical reagents that can displace the cations. In theory the removal of cationic contamination should be favoured by the use of strong solutions of, for example, brine or polyvalent cations like aluminium sulphate but these approaches are costly and create serious effluent problems. Solutions of mineral acids are also effective but care must be taken to avoid damaging the substrate material. If hydrochloric acid is used, care must be taken to avoid pitting corrosion.

One of the more efficient methods for the removal of cationic contamination is by the use of complexing, chelating or sequestering agents such as citric acid or ethylene diamine tetraacetic acid (EDTA). Under optimum conditions dilute solutions of complexing agents will form stable anionic complexes with metals and these complexes will then be repelled by the surface negative ions. The complexes, being very stable in solution, are unaffected by dilution and are not re-absorbed during rinsing.

Complexing agents can also be beneficial in holding the stabilized contaminant in solution and thus prevent redeposition and cross-contamination. However, they may also produce a liquid effluent that cannot be treated by chemical methods so one can end up with a large volume of effluent, which is a bigger problem than was the original contaminated object. If effluent treatment by evaporation is envisaged then this problem does not arise. Chemicals used for decontamination at AERE Harwell and in France are listed in Appendices II and III.

6.3. Decontamination of working areas

6.3.1. Walls

Whatever the walls are made of the general method of decontamination is to wash with a mild cleaning agent. One found good is a concentrated low-foam

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solvent assisted detergent formulated to remove a variety of soils from most surfaces. Such a decontamination agent will remove wax, carbonized oils etc. Washing can be by swabs or scrubbing brushes; the best type of swabs are paper tissues. It should first be used as a dilute solution and after thorough rinsing, if the contamination persists, then a stronger solution can be applied using possibly fine steel wool. If the wall is painted and the contamination persists, a gel-type paint stripper especially useful for applying to vertical surfaces can be applied.

6.3.2. Benches

Benches can be a variety of materials such as polished wood, PVC, other plastics and stainless steel. In all cases the first clean should be a mild agent such as has been described for walls. If this is not successful, more stringent treatments include:

(1) Polished wood – scrape off the wooden surface using a small vacuum cleaner to collect the particles;
(2) PVC etc. – clean with an organic solvent, preferably a non-flammable type. When using chlorinated organic solvents precautions must be taken to avoid inhalation of the fumes by the operator. Scraping should not be used as it will destroy the surface and make it unsuitable for future use;
(3) Stainless steel – use an inhibited phosphoric acid formulation which can be followed, if necessary, by dilute nitric acid.

6.3.3. Flooring

There is a wide variety of materials for floors, but again the first decontamination should be with the mild cleaning agent already mentioned. The types of floors are normally linoleum, PVC, asphaltic material (suitably polished), tiles and concrete. If a mild treatment is not sufficient the next stages are:

(1) Linoleum – wash with a solvent such as paraffin to remove all traces of wax. If this is not sufficient, the linoleum should be replaced;
(2) PVC – if the detergent cleaner does not decontaminate sufficiently, replace the affected parts;
(3) Asphalt – scrape off all the polish which should remove all the contamination;
(4) Tiles – the second step is to swab with a special inhibited phosphoric acid formulation containing a wetting agent;
(5) Concrete – clean as above for tiles and if this does not work, use an inhibited hydrochloric acid. If none of these are enough, the surface can be removed by mechanical means.

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6.3.4. Miscellaneous surfaces

As well as those mentioned as wall, bench and flooring materials, there are:

(1) Ferrous metals – clean as for stainless steel. Also a gel product can be used for vertical surfaces. If the surface is rusted, an inhibited hydrochloric acid can be used as a descaler and hence a decontaminating agent. For stainless steels solutions containing hydrofluoric and nitric acid are also used;
(2) Non-ferrous – a bright acidic dip solution based on nitric acid is good for cleaning copper, brass and bronze surfaces.

6.4. Decontamination of equipment and material

Decontamination of equipment can be done by swabbing and scrubbing and also by immersion in cleaning baths. The latter is a very versatile method as the article is totally covered by the decontaminant and contact times can easily be varied to suit the circumstances. Glassware can be decontaminated by immersion in chromic acid solution or solution of detergents.

Metal tools and machined surfaces can be washed in a mild solution of a low-foam solvent-assisted detergent. If this is not suitable, a very weak solution of inhibited phosphoric acid (1% deoxidene) can be used – this will not destroy polished surfaces. As a further treatment the use of a vapour blast machine using very fine abrasive is recommended. If the tools are crude types (spanners, etc.) then vapour blast using a heavy abrasive is possible.

Ceramic equipment can be cleaned by a detergent as described for metal tools followed, if necessary, by a very weak solution of an inhibited phosphoric acid containing a wetting agent.

If a tool that is 'crude' but has a machined end is to be decontaminated, each end can be wrapped in PVC or polyethylene sheeting while the other is being cleaned.

Large items like lathes and machines can be cleaned in cabinets or, if contaminated with high β-γ radiation, in shielded cells. With such items a vacuum technique can be applied to remove swarf etc., followed by a high-pressure water wash with a mild detergent formulation as already described. Where more stringent rinsing is thought necessary, steam cleaning can be done in such cabinets.

Electronic components must be carefully cleaned with suitable solvents, but if heavily contaminated, replaced. This equipment should, whenever possible, be positioned outside the radioactive area.

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6.5. Decontamination of spills

The first action with spills is to prevent spread of contamination. This can be done by surrounding the area with sand or any material that will absorb the liquid but not blow about causing airborne contamination. Excess liquor can then be removed by swabbing and a cover can be placed over the contaminated area to keep airborne contamination to a minimum. Decontamination can start by applying a gel-type soap which seals the surface. It then hardens and being soluble is removed easily by further washing.

If there is no problem in getting rid of liquid effluent, washing with excess water is recommended. However, dust and debris removal by vacuum techniques is recommended in all cases before 'wet' decontamination commences. The vacuum machines used must be fitted with high-efficiency filters to prevent any spread of contamination.

6.6. Decontamination of clothing and protective clothing

Cotton and woollen type materials are the most commonly used for protective clothing by personnel working in laboratories. As long as they are only very slightly contaminated they can be cleaned in the 'active' laundry. Such clothing is often worn by operators when carrying out low-level decontamination jobs. If the material gets contaminated in spots, a useful method is to try a vacuum cleaner over it to remove gross contamination or alternatively the spots can be washed with a detergent based on a blend of synthetic soaps in powder form. After this the garment is then sent to the active laundry in the usual way.

For incidents involving the spillage of liquids it is usually necessary to wear a better type of protective clothing. This can take the form of a cheap PVC suit normally worn over the conventional cotton clothing. At the end of the operation the contaminated oversuit is discarded. Alternatively such clothing can be made of more durable PVC, which is relatively easy to decontaminate. Such clothing can be worn with all types of self-contained respiratory equipment. The latter can range from simple face masks to fully self-contained breathing respirators. These breathing aids are normally constructed such that the parts exposed to decontamination are made of PVC or other easily decontaminated material.

When doing work in areas where contamination is high, especially if α-emitters or aerosols are present, it is advisable to wear fully self-contained pressurized suits with an external air supply. These suits are normally made of PVC. However, when contamination is likely to be very high, it is advisable to cover with a very thin PVC oversuit which takes most of the contamination and can then be thrown away. Another method of making decontamination easier is to smear 'barrier' cream over the suit before starting to work. The first step

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in decontamination is to wash and swab the suit before it is removed from the operator. This can be done by another man in a suit taking care not to get any contamination onto his own suit.

For operators working in sealed areas wearing pressurized suits it is important to have a standard procedure for decontaminating the suits; a recommended system is as follows:

(1) Operators discard a thin oversuit before leaving the area – this is disposed of as radioactive waste
(2) A man outside the area posts into the shower area a solution of a low-foam solvent-assisted detergent, in hot water, and also cotton or muslin swabs
(3) The operator enters the shower and pre-cleans his suit using the above materials, before having a shower and stepping out of the 'sealed area'
(4) A 'dresser' wearing PVC suit, gloves and an air hood dries the suit and monitors it
(5) The dresser performs any local decontamination to reduce any contamination to relatively fixed levels
(6) The dresser then removes the suit from the operator, taking care not to spead contamination either onto the man or onto the inside of the suit
(7) The suit entry is sealed by closing zips and buttons and it is posted into a decontamination cabinet
(8) The suit can then be inflated and completely decontaminated by methods already described for PVC clothing. It is also examined for damage etc. and records are kept of every individual suit.

Illustrations of operators carrying out decontamination duties which necessitate the wearing of special protective clothing are shown in Appendix IV.

6.7. Personal decontamination

If a person has contamination on the skin, e.g. hands, arms etc., the first step is to wash the affected areas using soap and water as normal. If the contamination persists then wash and scrub very lightly using soft soap and warm water. This can be done in a 'change room' sink and excessive soap and water must be used. If the bulk of contamination has been removed, then this treatment can be repeated. However, if the contamination persists after two wash and scrub treatments, the person affected must be handed over to the medical authorities for any further treatment.

If contamination is detected in the hair, it should be washed in the usual way using a shampoo and hot water; rinsing with plenty of water is essential.

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This can be repeated, but again, if the contamination persists, the operator must be sent to the medical department.

If it is suspected that a person has been subjected to airborne contamination, nose swabs must be taken by requesting him to blow his nose into a paper tissue for a rough indication and then he must be sent to the medical authorities for further control and treatment.

All injuries and illnesses requiring the attention of medical authorities should be immediately referred to medical authorities for medical treatment and decontamination. In no case should patient contamination interfere with life-saving measures.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safe Handling of Radionuclides, Safety Series No. 1, IAEA, Vienna (1973) 84–91.

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Monitoring of Radioactive Contamination on Surfaces, Technical Reports Series No. 120, IAEA, Vienna (1970).

[3] The Coating of Surfaces Requiring Decontamination, UKAEA and BNFL Rep. AECP 1002, Issue No. 5 (1972).

[4] AYRES, J.A., Decontamination of Nuclear Reactor and Equipment, Appendix B, Ronald Press, New York (1970).

[5] KIENHOFER, M., KUNZE, S., HEPP, H., A Method to Test Paints, Floorings and other Non-Metallic Materials for Decontamination, Rep. KFK 1499 (1972).

[6] BRITISH STANDARD BS 4247. Recommendations for the Assessment of Surface Materials for Use in Radioactive Areas, Part 1. Method of Test for Ease of Decontamination (1967); Part 2. Guide to Selection of Materials (1969), HMSO, London (see Appendix IB to this volume).

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Appendix I

EXAMPLES OF THE CODE OF PRACTICES FOR TESTING OF DECONTAMINABILITY OF SURFACES

A. FEDERAL REPUBLIC OF GERMANY

DECONTAMINATION OF SURFACES

Methods of testing decontaminability

This Standard is designed to lay down objective conditions under which the decontaminability of surfaces can be tested. It is not intended to describe a general decontamination method, since the different types of possible contamination require special methods in each particular instance.

This Standard does not deal with mechanical action (agitation, scrubbing etc.) in the various decontamination stages. Because of the different types of procedure involved, the results of this decontamination method cannot be compared with procedures set forth in other provisions or standards, for example:

The American Standard USASI N.5.9 (1967) Protective Coatings (Paints) for the Nuclear Industry;

The British Standard BS 4247 "Recommendations for the Assessment of Surface Materials for Use in Radioactive Areas":
Part 1 (1967) "Method of Test for Ease of Decontamination",
Part 2 (1969) "Guide to the Selection of Materials".

Further additions to this Standard relating to "Determination of Surface Decontamination" and "Testing of Decontaminants" are in preparation.

1. PURPOSE AND APPLICATION

The purpose of the testing is to determine the decontaminability of surfaces.

The provisions of this Standard apply to the testing of surfaces that have become contaminated by radioactive materials.

The provisions of this Standard do not apply to contamination that has been caused by iodine radioisotopes since it cannot be satisfactorily eliminated at the present stage of technical progress.

It should be noted that the results of the testing may depend largely on the initial mechanical, chemical or thermal loading.

The test report should therefore contain a reference to that subject.

2. DEFINITIONS

2.1. Contamination

Contamination for the purposes of this Standard is the soiling of surfaces by radioactive materials (Surface Contamination as defined in DIN 6814, Part 5).

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2.2. Decontamination

Decontamination for the purposes of this Standard is the removal or reduction of contamination as defined in section 2.1.

2.3. Decontamination factor

The decontamination factor F_D is the ratio between the measured count rate before decontamination and the count rate after decontamination:

$$F_D = \frac{\text{count rate measured before the first decontamination stage}}{\text{count rate measured after the particular decontamination stage}}$$

Note: **This definition may refer to the activity of one particular radionuclide or to a mixture of radionuclides.**

The residual activity A_R (in %) is given as

$$A_R = 1/F_D \times 100$$

3. SAMPLES

3.1. Manufacture and pre-testing

Samples made from any type of material may be subjected to testing, e.g. coatings, floorings, non-metallic or metallic materials. The samples should be proof against the solutions to be applied, as defined in section 5. If necessary, appropriate preliminary testing, for example as stipulated in DIN 53 168, should be carried out at ambient temperature for a period of ten minutes.

The sample should be tested in addition, in conformity with DIN 53 168, for stability under the action of ethyl alcohol, acetone, toluene, methylene dichloride, 1M hydrochloric acid and 1M sodium hydroxide.

The results should be noted in the report.

3.1.1. Non-metallic material samples

Non-metallic samples, such as high polymers, glass or ceramics, are manufactured in the normal industrial form. Coatings should be applied, as far as is possible, in the normal industrial form to a suitable underlay (e.g. steel sheeting). Additional treatments, for example heat ageing, are not permitted. The reverse sides and edges should be coated in such a way as to be properly decontaminable (for example, with epoxy or polyurethane coatings).

Particular care should be taken in coating the reverse side and edges whenever the former consists of another material or possesses different surface characteristics (PVC, ceramic, etc.).

In the case of testing paints[1] a sample is taken as prescribed by DIN 53 225 and prepared for testing in accordance with DIN 53 226. As the underlay for the application of the paint sample use is made of standard test plates prescribed by DIN 53 227. Unless otherwise stated, RRST-1405 metal sheeting is used, as defined under DIN 1623, Sheet 1.

The earliest possible test date should be stipulated by the party submitting the samples.

[1] For definition see DIN 55 945.

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3.1.2. Samples of metallic materials

Samples of metal or materials with a metal overlay are surface-treated mechanically or chemically in the normal industrial manner. The reverse sides and edges of the samples should be coated in such a way that there is no possibility of the decontamination test results being distorted. Testing of metal samples should not be carried out until at least three days after the surface treatment, so that there is stabilization of the surface potential. The surface roughness as defined in DIN 4763 should be recorded in the test report.

3.2. Number of samples and sizes

Ten samples of the same kind should be prepared for testing; of these at least three should be tested in a parallel series, one sample being used as control and the rest as a reserve for further examinations. The samples should be 70 mm × 150 mm in size and their thickness should be between 0.5 and 1.5 mm. Samples of other sizes and made under other conditions of manufacture require special agreement, which should be noted as such in the report.

3.3. Pre-treatment

The sample should be held for about 20 seconds in a mixture of petroleum benzine and methanol[2] at room temperature. After it has been dried in air, the sample should be rinsed with distilled[3] water and kept for one hour in a drying cupboard at $(40 \pm 5)^{\circ}C$.

4. EQUIPMENT

4.1. 600-ml beakers, of the shallower type (e.g. as prescribed by 600 DIN 12 332).

4.2. Beta-measuring instruments with adequate response and sufficiently long time resolution.

5. CONTAMINANTS AND DECONTAMINANTS

5.1. Contaminants

Under normal circumstances use is made of a radionuclide mixture consisting of ^{137}Cs, ^{45}Ca, $^{106}Ru/^{106}Rh$ and ^{60}Co.

The activity concentration should be 1–5 μCi/ml.[4]

The different radionuclides should have more or less the same activity in the solution. They should be carrier-deficient, i.e. have a carrier concentration of 10^{-4} to 10^{-6} mol/ml in 10^{-4} M hydrochloric acid.

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[2] The boiling point of the benzine should lie between 60 and 90°C, e.g. standard benzine as prescribed in DIN 51 635 and 51 557, boiling point 65–95°C; the benzine and methanol are mixed in a ratio of 1 : 1.

[3] Instead of distilled water use can be made of deionized water.

[4] The unit of measurement prescribed under the Units and Measurements Act of 2 July 1969, and Directives for Implementing the Units and Measurements Act of 26 June 1970, is the SI unit S^{-1} (1/s) 1 Ci = ns^{-1}. The curie can still be used, however, until 31 December 1977.

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In special cases where the anticipated contamination is not due to radioactive fission and corrosion products, the radionuclides chosen as contaminants should be suitable in type and chemical behaviour for the purpose for which they are intended.

5.2. Decontaminants

The following decontaminants are used for the test:

- Distilled water[3]
- Acidic surfactant solution consisting of:

Nonylphenolpolyglycolether[5]	5.00 g/l
Citric acid	4.00 g/l
EDTA–Na_2 (ethylenediaminetetraacetic acid sodium salt)	4.00 g/l

  Distilled water[3] adjusted to pH 4.5 with NaOH
- 1M hydrochloric acid (in the case of metal surfaces use 1M nitric acid).

6. TESTING

6.1. Contamination

6.1.1. Procedure

The sample is contaminated on the basis of the drying technique. For this purpose a circle 50 mm in diameter is stencilled onto the sample (using a felt-tipped pen or something similar). By means of a micro-pipette, 0.1 ml of the contaminant is applied at the centre of the circle. The sample is then kept for two hours in a drying cupboard at (40 ± 5)°C. At least three samples are contaminated in this way at the same time.

6.1.2. Measurement of the beta count rate

When the sample has dried, the beta count rate is measured with a device of the type described in section 4.2.

The measurement geometry, i.e. distance and position of the sample and detector in relation to each other, should be exactly the same for all measurements. The measurement time is adjusted to the count rate for the sample and the relative standard deviation should be less than 10%. Each measurement is performed twice, the natural background being deducted. Dead time loss should be taken into account. The mean is given in the test report in counts per minute.

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[5] Information on sources of supply is provided by the Technical Standards Commission, Nuclear Technology, DNA, D-1000 Berlin 45, Unter den Eichen 87.

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6.2. Decontamination

6.2.1. Procedure

The decontamination is carried out in three stages.

The sample is placed diagonally in a beaker of the type prescribed in section 4.1 in such a way that the contaminated side faces downwards and the circle described in section 6.1.1 is fully immersed in the decontaminating agent. After each of the three decontamination stages the sample is dipped for ten seconds in a beaker of the same size filled with distilled water and dried in the drying cupboard at $(40 \pm 5)^{\circ}C$. The measurement is then made in accordance with section 6.1.2.

Decontamination stages:

- Immersion in distilled water at room temperature for two minutes;
- Immersion in an acidic surfactant solution at room temperature for two minutes as described in section 5.2;
- Immersion in 1M hydrochloric acid at room temperature for two minutes (1M nitric acid in the case of metallic samples).

6.2.2. Testing for changes

Following the decontamination tests a determination is made, by comparison with a control, of whether there are visible changes in the gloss and colour of the samples, or any cracking, blistering, swelling, shrinking or roughening of the surface. The type and extent of the changes are recorded in the report.

7. EVALUATION OF RESULTS AND ASSESSMENT OF DECONTAMINABILITY

After the individual decontamination stages the decontamination factor F_D is calculated, as described in section 2.3.

The decontamination factor arrived at after the last decontamination stage is the only one used for assessment of the sample.

The assessment is made in accordance with Table I.

TABLE I. ASSESSMENT OF DECONTAMINABILITY

F_D	Decontaminability
>100	very good
$100 - 50$	good
$50 - 25$	moderate
<25	poor

8. TEST REPORT

A report is prepared on the results of the tests (see Annex).

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SAMPLE OF A TEST REPORT ON THE DECONTAMINABILITY OF SURFACES, AS PRESCRIBED IN DIN 25 415, SHEET 1

Testing station:

Report No.:

Client:

(Name and address):

1. Description of samples submitted by client
1.1. Brief description of material and purpose for which used (e.g. ED for floor coatings, PUR for container coatings, Thiokol for joint fillings)
1.2. Name of manufacturer
1.3. Name of product
Details of colour of each layer and formula
1.4. Major components of top layer (binder, hardener, pigments and fillings)
1.5. Details of application (e.g. application technique, hardening time and temperature)
1.6. Gloss (Boller scale)
1.7. Underlay
1.8. Pre-loading of sample (mechanical, thermal or chemical)
1.9. Date of manufacture of sample

2. Tester's data
2.1. Appearance of sample before testing (shade of colour, surface characteristics, gloss, roughness)
2.2. Decontaminability test data
2.2.1. Measuring instrument
2.2.2. Detector
2.2.3. Contaminant (radionuclide)
2.2.4. Activity (μCi/ml or s^{-1}/ml)[4]
2.3. Measurement results
A. Before decontamination
B. After decontamination with water
C. After decontamination with acidic surfactant solution
D. After decontamination with hydrochloric acid (or nitric acid in the case of metal samples)
E. Sample; F. Count rate, min^{-1}; G. Decontamination factor, F_D
2.4. Changes in the surface, as defined in DIN 25 415, Sheet 1, Section 6.2.2
2.5. Assessment of decontaminability

3. Results of pre-testing

3.1. Resistance to testing agents (DIN 53 168); Duration of agent action – 10 min	Ethyl alcohol Acetone Toluene Methylene dichloride
3.2. Resistance to acid and alkali (DIN 53 168); Duration of agent action – 2 h	1M HCL or 1M HNO_3 1M NaOH

3.3. Other remarks

(Stamp) (date) (Signature)

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B. UNITED KINGDOM

RECOMMENDATIONS FOR THE ASSESSMENT OF SURFACE MATERIALS FOR USE IN RADIOACTIVE AREAS (BS 4247)

Part 1. Method of test for ease of decontamination

Foreword

As the first stage in the preparation of recommendations for the selection of surface materials for use in areas subject to contamination by radioactive substances, it has been found necessary to establish a standard method of test, so that the ease of decontamination of different surfaces can be compared. This standard test has been developed for comparison purposes, and the results should not be interpreted to imply that under actual decontaminating procedures the surfaces will retain similar levels of contamination.

The method is based on a standard 'wet' technique which involves the contamination of a surface by a solution of radiocaesium and radiocobalt, followed by a two-stage decontamination procedure. The contaminants chosen, the contamination and the decontamination methods are necessarily arbitrary, but inter-laboratory tests have proved that the contaminant solution is reasonably stable and that the method can give reproducible results and differentiate reasonably well between various surfaces.

The test is based on an earlier test method of many years standing, but, as now standardized, is of comparatively recent origin and only limited results have so far been obtained; it should nevertheless help to provide useful information for the assistance of architects, civil engineers and others concerned with the selection of surface materials.

Attention is drawn to the fact that the permissible levels of contamination on surfaces of working areas may be specified in legal requirements or codes of practice.

The Institution gives due acknowledgement to the assistance received from a number of laboratories in the development of this method of test – in particular to the Atomic Energy Research Establishment (Harwell), Berkeley Nuclear Laboratories, The Paint Research Station, The Admiralty Research Laboratory, and to the parent organizations concerned.

Method

NOTE 1. Attention is drawn to the existence of regulations issued by the Ministry of Housing and Local Government and the Ministry of Labour governing the use, storage and disposal of radioactive materials.

1. Materials

1.1. Unless otherwise agreed, only complete systems should be supplied for test (see notes).
1.2. Thin flexible sheets of material should be fixed to steel plates so as to maintain the sheet in a flat condition (see notes).
1.3. Number of test samples. A minimum of six samples representative of each material should be tested.
1.4. Size of test samples.
1.4.1. Paint and similar materials having 'edge effects'. Panels approximately 15 cm X 10 cm.
1.4.2. Ceramic tiles. Whole tiles of not less than 50 mm square as supplied by the manufacturer should be used for the test without further cutting.

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1.4.3. Grouting cement used for tiles. These should be pads of not less than 50 mm square and 13 mm thick.
1.4.4. Other materials. Samples not less than 50 mm square.

2. Preparation of test samples

For the purposes of this test the submitted samples should be flat.
2.1. Paints and coatings having 'edge effects'. The complete system should be applied and where necessary cured according to the manufacturers' instruction on the appropriate substrate. Metal panels should be of steel and prepared according to BS 3900 Group A Part A3.[6] Concrete or similar backing should be clean, dry and smooth. Panels should be stored in a dirt-free well-ventilated atmosphere at room temperature (21 ± 3°C) until at least fourteen days have elapsed from the application of the system.
2.2. Ceramic tiles. Tests should be made on the samples as supplied.
2.3. Grout. Pads of grout should be prepared according to the manufacturer's recommendations.
2.4. Other materials. These should be prepared and surface-finished, according to the manufacturer's recommendations, where applicable.

3. Contaminant

3.1. The contaminant should be a solution containing 5 millicuries per litre of caesium-134 (as chloride) of specific activity 0.5 curies per gram of caesium and 5 millicuries per litre of cobalt-60 (as cobaltous chloride) of specific activity 5.0 curies per gram of cobalt.

The pH of the solution should be adjusted to 5 by the addition of sodium hydroxide solution or hydrochloric acid solution.

4. Decontaminants

The decontaminants should consist of two solutions made up as follows:

4.1. Solution A

(1)	Sodium carboxymethylcellulose	0.25 g
(2)	Sodium di (2 ethylhexyl) sulphosuccinate	1.0 g
(3)	Sodium tripolyphosphate	4.0 g
(4)	Ethylene diamine tetra acetic acid (EDTA)	1.0 g
(5)	Distilled water and sodium hydroxide to make 1 litre of solution of pH 9.	

4.2. Solution B

(1)	Disodium EDTA	10.0 g
(2)	Sodium di (2 ethylhexyl) sulphosuccinate	0.2 g
(3)	Distilled water and sodium hydroxide to make 1 litre of solution of pH 5.	

5. Counting equipment

5.1. Geiger-Müller tube. The Geiger-Müller tube should have a mica end window of 2.5 cm (1 in nominal) diameter, 1.5 mg/cm^2 'window thickness', and should be used with a suitable holder.

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[6] BS 3900 'Methods of test for paints', Group A Part A3: 1965 'Preparation of panels prior to painting'.

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5.2. Associated equipment. The Geiger-Müller tube should be operated with a EHT unit, a scaler and a device for predetermining the dead time.
5.3. The standard source. The standard source should be a 1.0 cm diameter disc containing thallium-204 (see notes).

6. Test procedure

6.1. Contamination

6.1.1. The surface of the test sample should be wiped with cellulose wadding B.P. soaked in a 0.1% solution of sodium di (2 ethylhexyl) sulphosuccinate (see notes) rinsed with 100 ml of distilled water and dried with wadding.
6.1.2. A circle of 38 mm internal diameter is drawn on the surface with a soft wax pencil.

An 0.1 ml portion of the contaminant is placed on the surface at the dead centre of the wax circle using a micropipette and is spread out to cover an area 1 cm in diameter. In cases where the contaminant spreads over an area greater or less than the 1 cm diameter circle the area so covered should be noted (see notes).
6.1.3. The test sample is then allowed to dry for 24 hours at a temperature of 21 ± 3°C with the contaminated area covered with a 50 mm diameter (2 in nominal) Petri dish.

6.2. Decontamination

6.2.1. The contaminated area is washed with solutions A and B consecutively, using the following technique.
6.2.2. Three washes of solution A. Each wash consists of pipetting 1 ml of the solution on to the contaminated area and leaving it for five minutes. Cellulose wadding is then used to swab the surface gently and remove the contaminant. Fresh wadding is used to dry the surface, and the next wash is applied.

After three washes the area is rinsed by pouring 50 ml of distilled water over the contaminated area with the test sample tilted. The sample is then dried by dabbing with cellulose wadding and the residual contamination counted according to the procedure in 6.3.
6.2.3. The procedure in 6.2.2 is repeated using solution B and the residual contamination again counted.

6.3. Counting

6.3.1. The Geiger-Müller tube and counter assembly should be calibrated using the standard source before each set of tests (see notes).
6.3.2. The contaminated area should be covered with a 500 gauge film of clear unfilled Polythene and the Geiger-Müller tube accurately positioned on the film over the 38 mm internal diameter wax circle. The film should be renewed after each panel has been counted.
6.3.3. Counting shall proceed for 5000 counts or 10 minutes, whichever takes the shorter time.

7. Reporting

7.1. Results are to be expressed as counts per minute per square centimetre corrected for background, dead-time and to a counter efficiency of 100%.

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NOTES ON METHOD OF TEST

The following advice will be found helpful in applying the method of test. (The numbers at the beginning of each paragraph refer to the corresponding clauses in the method of test.)

1.1. Individual systems should be stored and packed separately to avoid pick-up of volatiles and other contamination from other systems.

1.2. It is essential to avoid cockling of the sheet during the test. The use of strips of double sided adhesive tape covering a rectangular area larger than that of the test area is recommended for attaching the test sheet to the steel panel.

3.1. The contaminant can be obtained in glass containers by arrangement with the Radiochemical Centre, Amersham, England.

4.1. (2) Also known as sodium di-octylsulphosuccinate.

5.3. Standard source reference TERC 1 = 5%, Radiochemical Centre, Amersham.

6.1.2. As the wax pencil circle is intended to contain the decontaminating reagents it is essential that a pencil (or crayon) is chosen which is not soluble in or lifted by the detergent solution. As a safety measure to prevent the spread of the contaminated solution in the event of failure of the circle to hold the reagent, a second circle may be drawn some distance outside the first.

6.1.2. It is essential to avoid scratching the test material by the pipette during application of the contaminating solution. The E-mil auto-zero micro-pipette has been found to be particularly suited, the back of the curved jet being used for spreading of the spot of contaminant. Various aids may be constructed to guide the spreading of the contaminant over the required area, but it is essential that they do not come into contact with the contaminant solution.

6.3.1. The standard source should be separated from the Geiger-Müller tube by a 500 gauge film of unfilled Polythene and placed in the same position as that occupied by the contaminated spot on the test sample.

C. UNITED STATES OF AMERICA

3. CONTAMINATION – DECONTAMINATION TESTS

3.1. Purpose and scope

The purpose of this section is to provide methods and procedures for the quantitative evaluation of the ease and the degree of contamination and decontamination of protective coatings.

The scope includes (a) preparation of samples (section 3), (b) contaminant composition and contamination test procedures, (c) radiation detection equipment, (d) decontamination reagents and procedures, and (e) a guide to some decontamination factors desired in a typical nuclear complex.

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3.2. (Not applicable for the purposes of this volume)

3.3. Contamination (contaminant)

The radioactive contaminant to be used in these tests shall be a solution of mixed fission products obtained by the dissolution of spent uranium fuel previously irradiated to about 20 000 MW·d/t (megawatt days per metric ton) and cooled at least 90 days and no more than 3 years. The solution of mixed fission products shall have a beta-gamma activity of 5×10^6 dpm (disintegrations per minute)/0.1 ml. The photopeaks distinguished by a gamma-ray spectrometer in the contaminating solution will be those associated with ^{144}cerium-praseodymium, ^{106}ruthenium-rhodium, ^{95}zirconium-niobium, and ^{137}caesium-^{137m}barium. All these combinations will be of the same order of magnitude. The stock solution of this material (in 8M HNO_3) shall be stored in a polyethylene bottle or other approved container that will not absorb the radioactive nuclides. Glassware is not acceptable.

Before contamination all specimens shall be thoroughly degreased, then placed on a level surface inside a laboratory hood and allowed to dry. A minimum air velocity of 150 ft/min shall be maintained at the face of the hood.

A portion of the stock contaminant solution (in ~ 8M HNO_3) shall be transferred to a clean polyethylene (or other approved) container and immediately adjusted to a pH of 4 with NH_4OH (ammonium hydroxide).

Two drops (0.1 ml each) of near-neutral contaminant shall be quickly pipetted onto each specimen. Immediate application of the contaminant is necessary to prevent the zirconium and niobium from precipitating. The drops shall be placed near the end opposite the suspension hole and on the centre line for maximum submergence during decontamination. The contaminant, after drying, should cover an area about 1 cm in diameter.

The specimens shall be air-dried in a laboratory hood at 25 ± 2°C, with a gentle air flow passing over the surfaces. After drying, each specimen shall be placed in a separate plastic bag (~1.5 mils thick) preparatory to scanning (counting) with a gamma-spectrometer.

3.4. Counting equipment

The detector shall be a gamma-sensitive device such as a sodium iodide crystal with photomultiplier and amplifier coupled to a pulse-height analyser. The test specimen shall be properly mounted to give an optimum scanning geometry of the surface of the specimen. The detector shall be shielded to eliminate excessive background counts. Disintegration rates of the various radioactive nuclides are calculated from the recordings posted by the instrument.

3.5. Counting and decontamination

All specimens shall be scanned by use of the same geometry, with both the original count and the count following each decontamination step being recorded. Specimens shall be decontaminated by placing each one in a stirred solution of the decontamination reagent. Each specimen shall be subjected, in succession, to three decontamination steps (see sections 3.5.1.1, 3.5.1.2 and 3.5.1.3).

3.5.1. Decontamination procedure

Each specimen shall be removed from its plastic bag, and the first decontamination by washing with tap water shall be done as follows:

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3.5.1.1. Decontamination with water

Place a 600-ml polyethylene beaker containing 400 ml of tap water and a plastic-covered stirring bar on a magnetic stirrer. Suspend each specimen in the water to a depth of 2 inches near the side of the beaker, with the contaminated side of the specimen facing the centre of the beaker. Turn on the stirrer and accelerate until the water vortex touches the stirring bar. Stir for 10 minutes, remove the specimen, rinse the back (uncontaminated side) with water, and air dry with the contaminated face up.

After each specimen is dried, transfer it to a plastic bag and again scan as before. The ratio of the original radioactivity (counts per minute) to the radioactivity detected (counts per minute) after the water wash, is recorded as the *Water DF* (Decontamination Factor).

3.5.1.2. Decontamination with room temperature (25°C) acid

Using the same specimens, perform a second decontamination as described in section 3.5.1.1 except use 400 ml of an aqueous mixture of 0.4M $C_2H_2O_4$ – 0.05M NaF – 0.30M H_2O_2 at 25 ± 2°C. Scan after drying and determine the *Acid DF*, which is defined as the ratio of the radioactivity (counts per minute) after the tap-water wash to the radioactivity (counts per minute) after the acid wash.

3.5.1.3. Decontamination with heated (80°C) acid

Continuing to use the same specimens, perform a third decontamination as described in section 3.5.1.2 except heat the mixture to 80 ± 2°C. The decontamination factor achieved by the heated acid is the ratio of the radioactivity (counts per minute) after the room-temperature acid wash to the counts per minute after the heated-acid wash. The overall decontamination factor for the three decontaminations is the ratio of the radioactivity (counts per minute) before the tap-water wash to the radioactivity (counts per minute) after the heated-acid wash.

A contaminated untreated control specimen shall also be scanned at the time the original and final counts are made on the test specimens, and any decrease in radioactivity resulting from decay shall be recorded. The final radioactivity detected on the test specimen shall be corrected for nuclide decay before the decontamination factor or percentage of contamination removed is calculated.

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Appendix II

CHEMICALS USED AT AERE HARWELL, ENGLAND, FOR DECONTAMINATION

1. ORCENE CHEMICAL CO. PRODUCTS

565

Light-duty alkaline cleaner for use as an additive when using steam cleaning techniques. Suitable for removal of light oily soils and deposits. Three ounces to 1 gallon of water.

575

Medium-duty cleaner as above.
Suitable for removal of heavy oil deposits and grease.

585

Heavy-duty cleaner as above.
Removal of heavy grease deposits.

606

Quick-drying chlorinated solvent formulated to replace carbon-tetrachloride.
Used for cleaning electrical components, e.g. generators, motors, switchgear, instruments etc. 606 has high flashpoint and toxicity risk is negligible.

615

De-rusting and descaling solution.
Concentrated liquid phosphoric acid cleaner containing effective inhibitors and wetting agent.
Normally used undiluted.
Mainly used for cleaning and decontamination of metals, but also ideal for treatment of concrete and similar surfaces.
May be used contained within a suitable vat and heated to 120°F to speed cleaning process.
Wetting agent will in the cold state produce a light foam blanket to eliminate unpleasant fumes.

611J

Similar to 615, the difference being that this product is in a gel form and will adhere to vertical surfaces when applied.

Thixstrip Paint Remover

Gel-type paint stripper especially useful for applying to vertical surfaces. Removal of most types of paints including stoved enamels and epoxy resins.
May be used safely on any base metal.

626

Concentrated bland of liquid detergents which foam and wash efficiently without scum formation. Used at Building 462 for cleaning pressurized suits and other PVC wear.

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555

Compound blend of synthetic soaps in powder form. Fast removal of most types of soil from painted finishes. Extremely useful when washing down an area particularly dirty, where grease fume or smoke deposit are present.

2. APPLIED CHEMICALS LTD. PRODUCTS

443

Concentrated low foam solvent assisted detergent, formulated to remove a variety of soils from most surfaces. Useful for removal of wax, carbonized oils and tar etc. In general use at AERE as a decontaminant.

2–25

Acidic bright dip solution. For cleaning copper, brass and bronze.

2–87

Inhibited hydrochloric acid.
Useful for rapid de-rusting and descaling of mild steel and castings. Used with considerable success on decontamination work.

3. AERE STORES ITEMS

Deoxidine 125

Phosphoric acid de-ruster.
Used mainly for specialized cleaning of mild and stainless steel components.

Commercial grades of nitric and hydrochloric acids, used at various dilutions.
These are only used when chemicals with less detrimental effect are unsuitable for the work.

Metal polishes.

Perspex polishes.

Vapour blasting.

RBS 25. AWRE Stores Item. Detergent in liquid form.
Mainly used on reactor components, test rigs, etc.

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Appendix III

CHEMICALS USED IN FRANCE FOR DECONTAMINATION

1. PRODUCTS OF LUNIGE, TAVERNY

LUNIPHOS 45

This is a grease remover-phosphating agent, suitable for decontamination of metal components and concrete surfaces.

W 83

Scouring paste used for the decontamination of painted surfaces.

Ferramine 80
Dalar
Anco

These are the decontaminating agents for metals and, when used in the order mentioned, give a good appearance to the treated material.

2. PRODUCTS OF HENCKEL

Kalto (baths)
Grato 80 (spray at 80°C at 50 bars)

Suitable for decontamination of greasy components.

3. PRODUCTS OF PARKER, CLICHY

Parcoline 120

Components contaminated with sodium can be treated with it either in immersion or by smearing.

PARKOFIX Z

Suitable for equipment contaminated with tritium; particularly copper and stainless steel materials.

4. PRODUCT OF SHELL

Flin Koote

This is a bituminous product, used for confining radioactive dust. It is diluted with water before applying and while drying, ensures confinement of dust until removal.

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Appendix IV

ILLUSTRATIONS

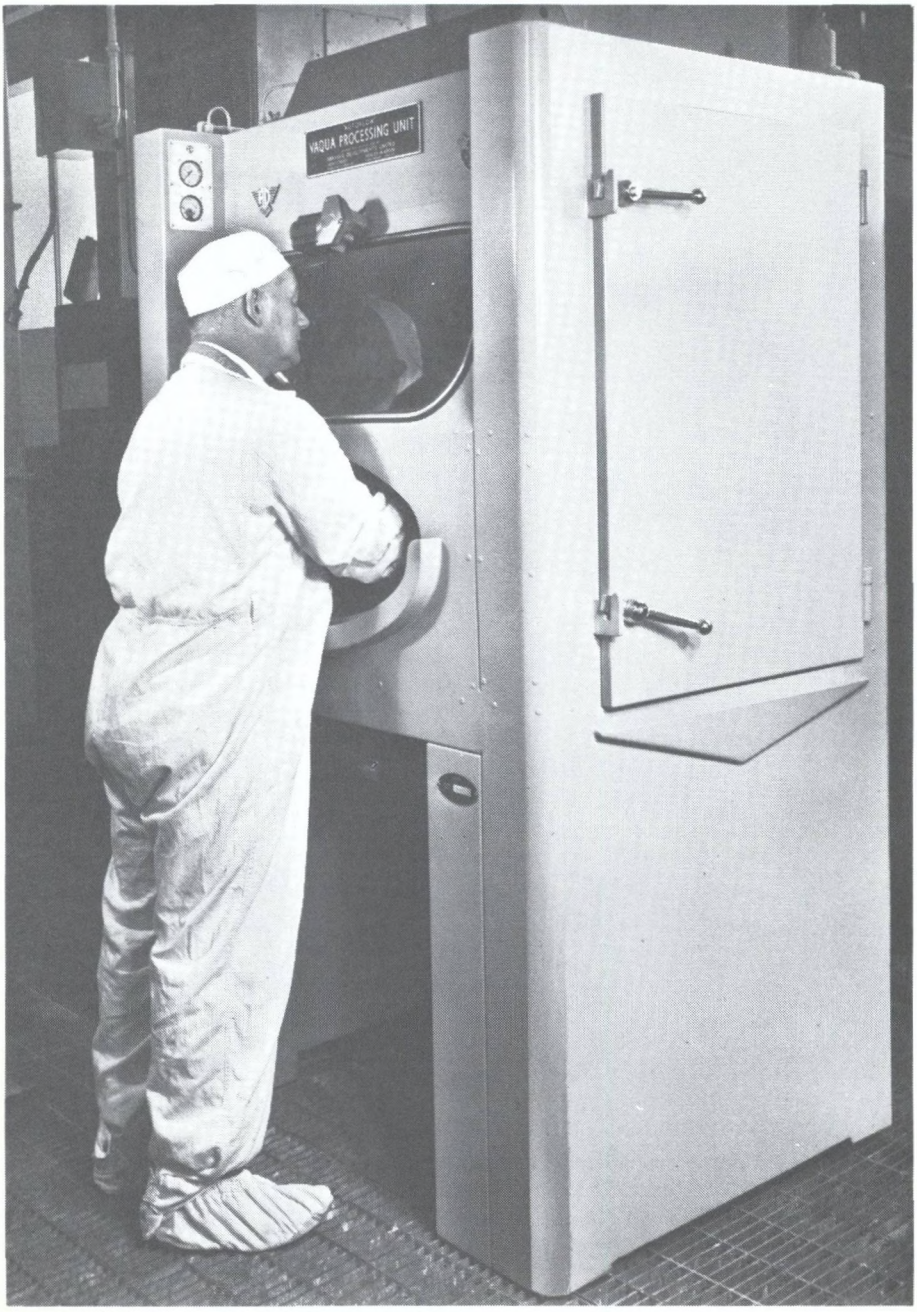


FIG.1. Operator using the Vaqua Processing Unit. This is a 'vapour blast' type unit using high-pressure water and an abrasive. The unit is fully self-contained so the operator has no face protection and wears ordinary cotton overalls.

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FIG. 2. Operator decontaminating the inside of a transport container. His cleaning reagent is in the bucket and he is using forceps to hold the swab. Note that he is wearing googles for eye protection. Note also that the whole operation is contained in a stainless steel tray to contain drips and prevent the spread of contamination. The operator is wearing a PVC suit.

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FIG.3. General decontamination area. In the left foreground are two baths for immersion treatment, one of which has its lid open. Then there are cabinets in which decontamination operations can take place. One operator is about to use the crane to lower an article into one of the baths. Note the monitors situated on the benches.

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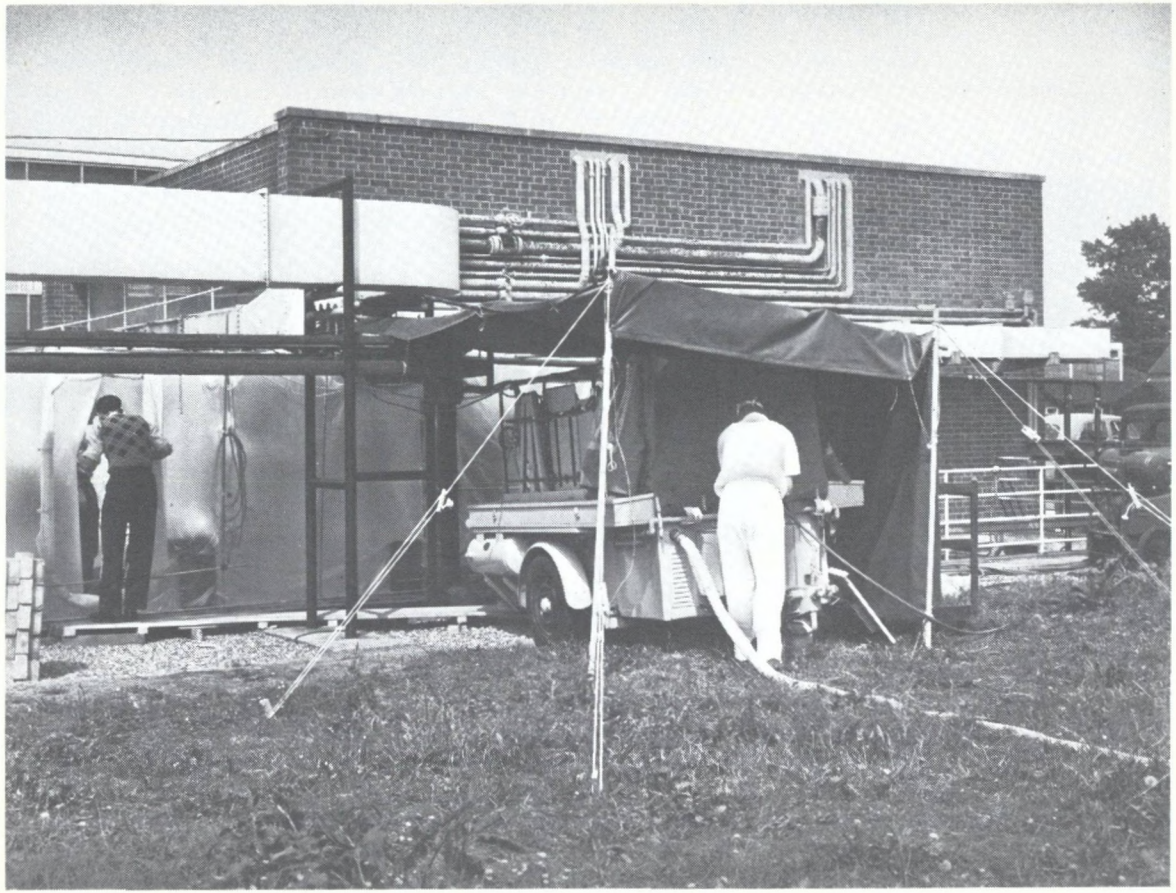


FIG.4. Rigging a tent outside a building. From this the men work to decontaminate the inside. Note that the 'door' to the clean side can be sealed so as to keep airborne contamination inside.

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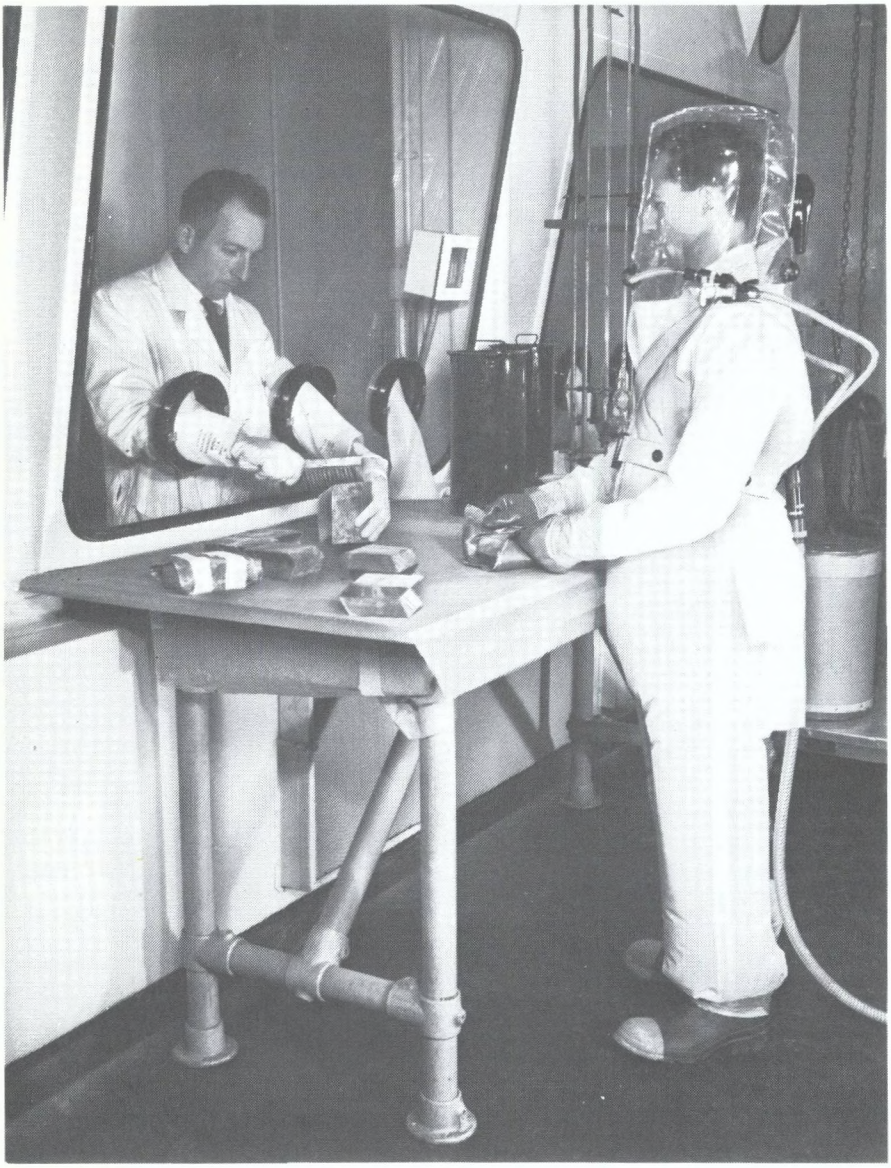


FIG. 5. Operator in a 'sealed area', wearing a pressurized suit and carrying out simple decontamination of bad bricks, assisted by another operator outside the area and working through glove ports. Note that the operator outside is only wearing a cotton coat for protection as there is virtually no hazard where he is standing.

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FIG.6. Decontaminating an article in a cabinet. It is obviously only slightly contaminated as the operator is not wearing a face mask. His cleaning chemicals are in the buckets. Note that there is an air sampler positioned almost at the point where he is breathing. The operator is wearing ordinary cotton overalls and overshoes.

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FIG.7.



FIG.8.

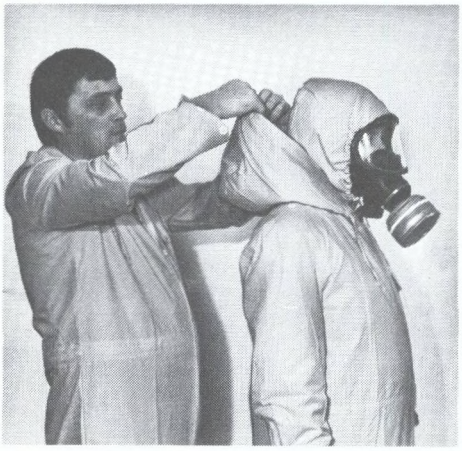


FIG.9.

FIGS 7–9. The decontamination worker is assisted by a member of the health physics group to fix rubber gloves to the sleeves. The worker is wearing two cotton overalls and shoes, the latter protected by two foil shoes on each. After dressing the respiratory mask is put on and the cowls of the overalls are carefully sealed to the mask body to protect the head area from contamination.

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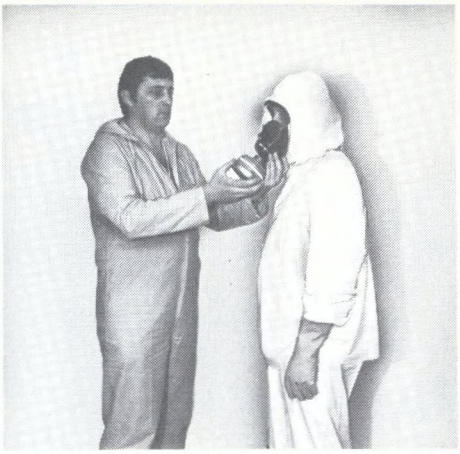


FIG.10. The last action when dressing a worker in a 'wet' area is to screw the filter into the mask. Additional rubber gloves are worn to protect the hand area of the PVC shirt from being punched or cut while working.



FIG.11.



FIG.12.

FIGS 11, 12. On leaving a 'wet' area after decontamination the PVC suit must be taken off and discarded in the waste drum positioned on the right. An assistant is necessary for this procedure to prevent cross-contamination of the person to be undressed. Subsequently the person is monitored (see Fig. 13).

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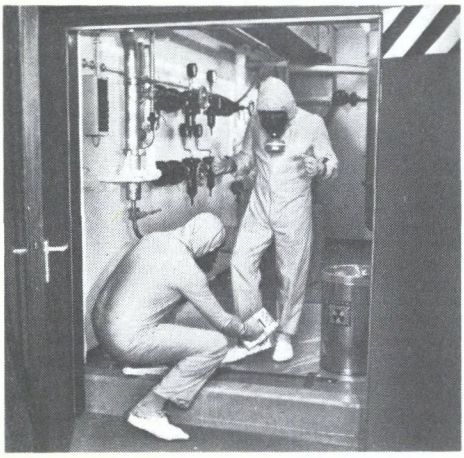


FIG.13.



FIG.14.



FIG.15.

FIGS 13–15. On leaving a 'dry' prior to any other action careful monitoring of the person to be undressed is mandatory. Then the rubber gloves are removed, followed by the outer cotton overall.

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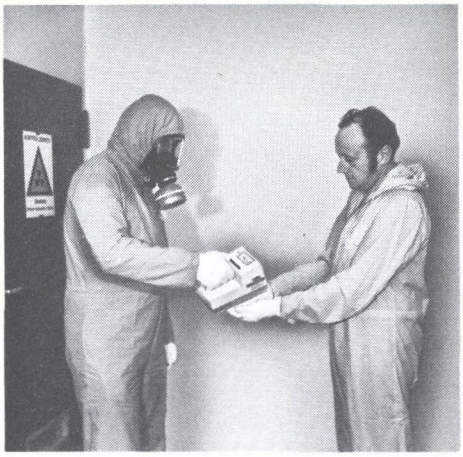


FIG.16.

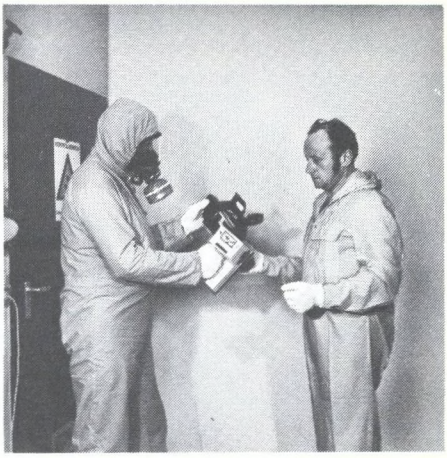


FIG.17.

FIGS 16, 17. The undressed person still wearing the inner cotton overall or the one overall worn under a PVC suit is accompanied by a member of the health physics group to the active site of the persons interlock where a detailed monitoring is carried out. Note that the health physics group member retains his filter as long as there is no definite certainty that there is no contamination on the clothing of the person who has taken off his outer protective clothing.

REMARKS

The above figures do not show all stages of the dressing and undressing procedures of a person engaged in decontamination work.

Apart from some minor details, the protective clothing differs in that in 'dry' areas two cotton overalls and in 'wet' areas one cotton overall and a PVC suit, consisting of trousers and a shirt with a cowl and gloves connected to the sleeves, are worn.

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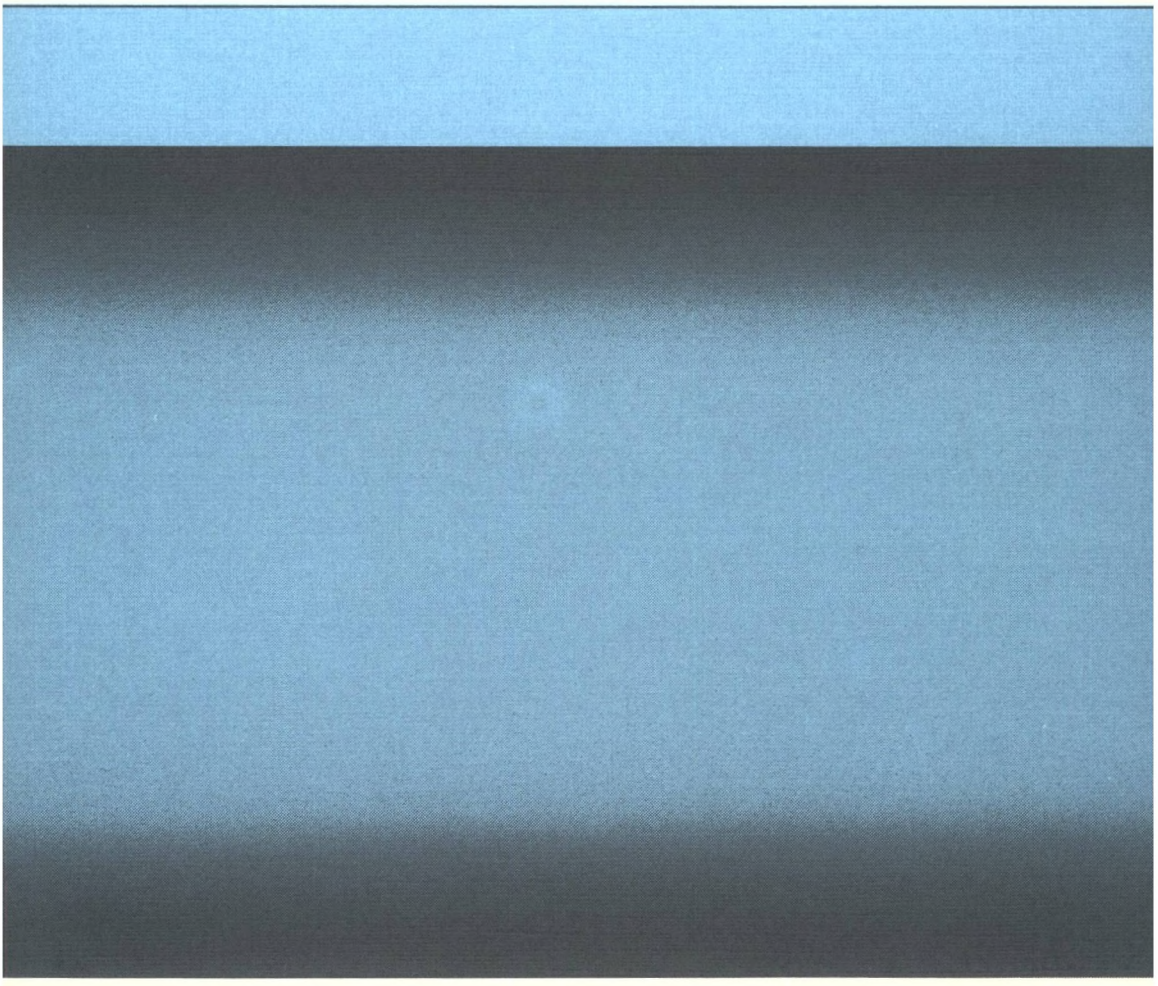
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