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safety series

safety series No. 47

RECOMMENDATIONS

Manual on Early Medical Treatment of Possible Radiation Injury

A JOINT UNDERTAKING BY
IAEA · WHO · ILO

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1978

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CORRIGENDUM

IAEA SAFETY SERIES No.47

Manual on Early Medical Treatment of Possible Radiation Injury

p.113, item 4, 8th line:

for ALI ~ 25 kBq (0.68 mCi)

read ALI ~ 25 MBq (0.68 mCi)

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MANUAL ON EARLY MEDICAL TREATMENT OF POSSIBLE RADIATION INJURY

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SAFETY SERIES No. 47

MANUAL ON EARLY MEDICAL TREATMENT OF POSSIBLE RADIATION INJURY

with an appendix on sodium burns

A JOINT UNDERTAKING BY
THE INTERNATIONAL ATOMIC ENERGY AGENCY
THE WORLD HEALTH ORGANIZATION
AND
THE INTERNATIONAL LABOUR OFFICE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1978

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THIS SAFETY SERIES WILL ALSO BE PUBLISHED IN FRENCH

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FOREWORD

The International Atomic Energy Agency, the World Health Organization and the International Labour Office issued in 1968 a joint publication in the IAEA Safety Series entitled Medical Supervision of Radiation Workers (Safety Series No.25). The contents were restricted to the medical supervision of the radiation worker under normal working conditions.

The present manual complements Safety Series No.25, being exclusively directed to first-aid and early medical treatment of workers who might be concerned in an accident involving exposure to radiation, whether external or internal.

The three organizations asked the following experts to prepare the present manual: Dr. J.C. Nenot of the Commissariat à l'énergie atomique, Département de protection, Service de protection sanitaire, BP No.6, 92260 Fontenay-aux-Roses, France; Dr. C.C. Lushbaugh of Oak Ridge Associated Universities, Oak Ridge, Tennessee 37830, USA; and Dr. T.A. Lincoln, Medical Director, Oak Ridge National Laboratory, PO Box X, Oak Ridge, Tennessee 37830, USA. The following staff members of the three organizations helped the consultants in their work: Dr. H.T. Daw, IAEA; Dr. E. Komarov, WHO; Dr. D. Djordjevic, ILO.

An appendix on procedures for dealing with possible sodium burns encountered in liquid metal technology is included, written by Dr. W.M. Elder, Senior Medical Officer, Medical Centre, Y Block, United Kingdom Atomic Energy Authority, Reactor Group Headquarters, Risley, Warrington, Cheshire, United Kingdom. This material does not involve exposure to radioactivity but deals with a type of accident which would require specialized skill in treatment.

The views expressed are those of the authors and do not necessarily represent the decisions, the scientific opinion or the stated policy of the three co-sponsoring organizations.

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Chapter 1

BACKGROUND INFORMATION AND GENERAL PRINCIPLES

1.1. INTRODUCTION

In the past, and until quite recently, the risk of contamination or external exposure involved only a limited number of persons because the radionuclides available and the facilities were few. Furthermore, in cases of contamination the radionuclide was usually easily identified and, as a result, there was no problem in diagnosing the contaminant. The situation nowadays is quite different – we are witness to an ever-increasing dissemination of radioisotopes, mainly in the form of chemical and biological tracers; their widespread use can easily mean that radioactive sources will sometimes be handled by inexperienced personnel and in unsuitable premises. The increasing use of new and highly dangerous elements adds another cause for concern; for example, there is plutonium-238, used as the energy source in battery-powered cardiac pacemakers; americium-241, used in medicine to measure bone density and in industry to manufacture static eliminators; californium-252, used in cancer research; and polonium-210, which is incorporated in some air ionizers used where work must be carried out in a pure atmosphere. These elements are considered more hazardous than plutonium-239 for the reason that their specific activity is 50 to 10000 times higher. Similarly, the number of sealed high-activity sources intended for external irradiation in hospitals, research laboratories and industrial facilities is growing day by day. The exposure of personnel to radiation is a potential hazard, especially as a large number of facilities, though quite up to standard, employ only a limited number of staff, who are in many cases not specialists and hence not fully aware of the risks involved. This applies, for instance, to analytical X-ray equipment used in laboratories and industries and to cobalt-60 sources used in agriculture to induce mutations for bacterial sterilization.

It is for this reason that, from the very outset, the importance of the basic concepts of treatment and general principles of first aid should be stressed. There are two concepts of prime importance – knowledge of the level of risk and knowledge of the urgency of treatment. In the event of combined injuries where traumatic wounds are life threatening or shock is present, radiation contamination or exposure is not of prime importance.

1.2. EXTERNAL IRRADIATION

The general principles governing the action to be taken when a person is exposed to radiation are based on knowledge acquired from experiments with

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animals and from clinical cases, which are particularly well documented where serious exposure was involved. The medical approach to be taken is completely different, according to whether partial or whole-body exposure has occurred.

In cases of *partial-body irradiation* first aid is not required; the exposed person should be referred to a medical specialist who can then take up the treatment of any radiation injuries that occur in the following weeks. Such injuries have a clear-cut quantitative relationship with dose and, in order to make an exact evaluation of them, one has to wait for the clinical picture to develop. A period of latency always precedes the appearance of symptoms; the larger the dose, the shorter the latent period. Nevertheless, the therapist has time to assess the indications for treatment and it is pointless, sometimes even hazardous, to be in too much of a hurry. The health physicists must be given the requisite time to determine the exposure conditions and to ascertain, if this is possible, the dose received.

Conversely, in the event of *whole-body irradiation* a certain number of immediate measures are essential; if they are not taken in good time, in accordance with a fairly strict time-table, the information thereby lost could result in a degree of uncertainty that would greatly hamper diagnosis and prognosis, and would thereby affect the treatment itself. The action to be taken depends on the severity of the exposure, and it is for that reason that we have to know certain critical levels. For example, for a single whole-body dose delivered within a short time, the risk of fatality starts at about 2 Gy (200 rad) (gray or rad: units of absorbed dose, here in the more sensitive organs or the whole body); when no treatment is given and no independently associated pathology is present, the LD_{50} is considered to lie at about 3.5 Gy (350 rad) [1a, 1b], assuming a uniformly distributed and absorbed dose. Statistical data are more limited for higher doses; extrapolation of the curves for human beings and intercomparison of data on different animal species indicate that the LD_{90} lies around 5 Gy (500 rad), again assuming that there is no treatment and no other complication. To make the picture clearer, we can suggest a few other levels: at doses below 1 Gy (100 rad), the reversibility of the injury is virtually certain; between 1 and 2.5 Gy (100 and 250 rad) the radiation syndrome is of moderate severity and survival is both possible and probable, as long as there is no prolonged depression of the blood count; between 2.5 and 5 Gy (250 and 500 rad) recovery is still a possibility, provided the patient receives specialized medical attention; and from about 5 to 6 Gy (500 to 600 rad) survival depends on many factors and the selection of appropriate therapy becomes rather difficult.

The immediate action to be taken [2] depends on the severity of the symptoms which are usually related to exposure categories. Four main categories can be singled out in ascending order of severity [3, 4], though this classification is somewhat arbitrary as there is no clear-cut division between one category and the next:

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(a) virtually certain survival, (b) probable survival, (c) possible survival, (d) survival almost impossible.

In the first category of exposure (1 Gy (100 rad) or less), clinical symptoms are absent or confined to transitory nausea. There are only a few early changes in the blood count (consisting of agranulocytosis and lymphopenia), accompanied in some cases by mild thrombocytopenia. Treatment is usually not necessary, but medical surveillance should be kept up for several days – at least until dosimetric data confirm the clinical prognosis. The patient need not be hospitalized for the blood and urine tests necessary for further confirmation.

In the case of an exposure in the second category (about 2 Gy (200 rad) – probable survival) there is rarely a lack of clinical symptomatology: the onset of nausea and vomiting is relatively early (2–6 hours), but it rarely lasts longer than until the second day; the changes in the blood picture are more appreciable than in category (a). Recovery usually occurs, but the possibility of delayed effects within 3–6 weeks necessitates strict medical supervision; evacuation to a specialized centre is necessary, but the absence of urgency allows ample time to carry out the first clinical tests and biological sampling as well as to see to the comfort of the patient during transportation.

In the case of an exposure in category (c) – possible survival – correct medical decisions are necessary for survival. Here we are confronted with absorbed doses between 2.5 and 5 Gy (250 and 500 rad), which correspond roughly to the LD_{50} in human beings. The clinical symptoms are always severe and there are early laboratory findings of radiation damage. The prognosis is based on how early the clinical symptoms appear, and on the seriousness of the blood disturbances and the rate at which they occur. Evacuation should not be postponed unless the patient requires immediate medical care, for example, treatment of a serious injury not directly related to the exposure. In the case of traumatic shock, analeptics and/or vasopressors can be prescribed; a perfusion of plasma or macromolecular substitutes can be given with caution. Since it confuses the clinical picture, *in no case* should a blood transfusion be prescribed unless blood loss resulting from trauma threatens life.

The same rules apply to a category (d) exposure, i.e. survival impossible without treatment. The diagnosis is mainly based on an almost immediate drop in the lymphocyte count which falls to very low values within a few hours.

In all cases, certain examinations are obligatory. A *clinical examination* is of considerable importance – it should be thorough, no organ or system being neglected; particular stress should be given to *examination of the skin* to detect any erythema or oedema. The symptom may, moreover, be transitory. Equally important is *examination of the digestive tract,* due attention being given to the poor prognosis indicated by early and repeated vomiting and diarrhoea.

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The clinical examination may produce negative results, but the absence of symptoms should not be taken to indicate an insignificant exposure unless this is confirmed by biological tests (see Appendix A for technical details). The *biological tests* are, in fact, essential; after exposure to radiation, samples of an exposed person's blood and urine should be taken straight away for subsequent reference. Later on, peripheral and chromosome tests should be made. The standard tests should be repeated several times on the first day; a test repeated every three hours may bring out an early leucocyte peak (during the 36 hours following exposure). The biological sampling technique should be rigorously applied and the procedures strictly complied with; this is described in Appendix A.

Accidental whole-body exposure could conceivably involve more than one person. In such an event the first task of the physician and the medical service is to separate the victims into dose categories [5]. The problem is a difficult one in practice because, except in the most serious cases, the symptomatology is latent for the first few hours. In the event of a criticality accident where fission neutrons are involved, prompt measurement of ^{24}Na activity, using a radiation detector in contact with the head or abdomen, makes it possible to separate exposed persons from unexposed persons fairly rapidly. Otherwise it is only the clinical and biological indications that make it possible to assess the severity of the injury, together with all the hazards involved; unfortunately, experience shows that numerous cases are marginal, with risk levels difficult to classify. Furthermore, a psychological element always complicates the evaluation, since it is difficult, where a subjective symptom is observed, to decide what is attributable to genuine radiation injury and what is conditioned by emotional factors. Turning a healthy person into a sick one through a surfeit of care is something to be avoided.

1.3. CONTAMINATION WITH RADIONUCLIDES

1.3.1. Biological fundamentals

The treatment of any contamination requires a knowledge of the risk involved. The treatment is closely linked with metabolic information, which itself is dependent both on the biological state of the organism and on the physico-chemical state of the contaminant. The urgency and importance of the treatment depends on the efficiency of the therapeutic method and the seriousness of the contamination.

The seriousness of the contamination depends on several factors, among which are:

The organ(s) of deposition;
The nature of the emission from the contaminating radionuclide;
The effective half-life of the contaminating radionuclide.

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The effective half-life (a combination of the radioactive half-life and the biological half-life) is something often forgotten in initial evaluations; it is significant, for example, that the effective half-life of tritium is about 10 days whereas its radioactive half-life is 12 years.

Internal contamination involves four successive stages:

(a) **Deposition along the route of entry**: Possible pathways of contamination are the skin, mucosa, digestive tract, respiratory system, or wounds. The latter two pathways are definitely both the most dangerous and the most frequently involved in contamination accidents.

(b) **Translocation**: Movement from the site of deposition to the blood or lymph.

(c) **Deposition in the target organ(s)**: The target organ(s) of interest from a radiation protection point of view can be defined as the organ(s) whose injury by irradiation involves the greatest damage to the organism as a whole. For physiological and physico-chemical reasons, the concentration of radionuclide is the determining factor.

(d) **Clearance**: There are two distinct mechanisms for clearance, either *direct clearance*, for example filtration of the radionuclide-carrying blood by the kidneys, or *indirect clearance*, in which radionuclide uptake by tissues is reversed, with recirculation in the blood after reversal of the target organ/blood concentration ratio. Since there is a balance between the blood and the excreta, in this way it is possible for the radionuclide to leave the organism. The two mechanisms may coexist to a variable degree, depending on the contaminating element.

Treatment could theoretically be designed to operate at any of these stages, but, in actual fact, blockage of organ uptake by fixation of the radionuclide at the site of entry or trapping of it in the blood during translocation, with re-routing towards a natural excretory mechanism, constitute the two current methods of treatment. Treatment is aimed at stage (a) or stage (b). Action at stage (c), which would prevent deposition in the target organ, is possible in the specific case of the thyroid. Action at stage (d) is generally ineffective except for radionuclides like tritium which can be flushed from the body.

As a rough approximation, radionuclides can be classified on the basis of their behaviour in biological material into two categories: *transportable* elements and *non-transportable* elements. It should be noted that this classification is highly schematic, that both categories contain a full range of nuclide types and that the division between them is more apparent than real.

The elements described as *'transportable'* are soluble in biological material and able to diffuse throughout the organism; the *entire deposit* may pass rapidly

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through the metabolic pathways, leading to deposition in the target organ. They are usually present in the organism in the physiological form – either with a stable isotope (for example iodine) or a chemical analogue (for instance, caesium-potassium or strontium-calcium complex). Their biological behaviour, especially their deposition in a critical organ, depends on the metabolism of the corresponding physiological analogue. Thus, iodine accumulates in the thyroid and caesium in the muscles, while strontium and radium follow calcium in bone hydroxyapatite. Schematically speaking, the materials in question are mineral cations of valences I or II; their ability to spread through the organism is a function of their dis-associated ionic form at the pH of the biological material. Something to be noted is that they are capable, accordingly, of passing through the digestive tract.

Among such elements there are two large families of cations that have two different metabolisms: the *alkalis* (sodium, caesium, potassium, etc.), which spread through the whole organism, and the *alkaline earths* (calcium, strontium, barium), which accumulate in the bone structure. Caesium illustrates the importance of a knowledge of the metabolism if one is to apply effective treatment. It goes through a quantitatively significant intestinal cycle; secreted in the lumen of the intestine, it is almost completely re-absorbed unless the cycle is interrupted by a medicament present in the intestine which selectively complexes caesium (such as Prussian blue). Irrespective of what occurs at the nuclide's route of entry, such a drug reduces the caesium concentration in the blood and thereby speeds up the elimination of the radionuclide from the cells as an indirect effect.

Apart from these two large families, there are radionuclides exhibiting a specific type of behaviour, for example, carbon, iodine, tritium and the noble gases. Two radionuclides may give rise to special problems, namely carbon-14 and tritium. There are as many problems as there are labelled molecules; these radio-nuclides share the fate of the molecule or the fraction containing it if degradation occurs. In the case of carbon-14, for example, degradation generally yields $^{14}CO_2$ which must then be sought in exhaled air; otherwise only measurements of the excreta, coupled with an exact knowledge of the molecule's metabolism, can lead to an evaluation of the body burden. On the other hand, contamination by $^{14}CO_2$ does not give rise to any special problems because it has little contaminating effect. Carbon dioxide exchange in the lungs proceeds from the blood to the air, but tritium gas, although practically inert, poses a health hazard.

The elements described as *'non-transportable'* do not obey the criteria listed above, for either of the following two reasons:

(i) They are *insoluble* at all pH levels, like certain metals or oxides calcined at very high temperature which, for practical purposes, do not diffuse through the body at all. In such a case the target organ is the point of entry itself; a typical example is plutonium-239 oxide. Actually, there is always some local diffusion, however small.

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(ii) They are soluble only at acidic pH levels and their salts are hydrolized as the pH rises, producing hydroxides which are polymerized on the spot. However, at the moment of contamination and during the time required for equilibrium to be established between the initial monomeric form of the contaminant and the final polymerized form, there may be absorption of a small fraction of the quantity deposited. From then on, absorption depends on the degradation of the polymers by the organism and is in any case a very slow process. For such elements the important target organs and tissues are, in addition to the point of entry, the liver and the bone surface (sub-endosteal and sub-periosteal spaces). An example is plutonium-239 nitrate.

These elements are usually mineral cations with a valence higher than II. The rare earths, plutonium and the transplutonics are the most important examples. Their insolubility in the living organism disappears as they are present in complexed form and the complex is stable and soluble. Their biological fate is then that of the complex (and hence that of the chelating agent), not the element. This property is highly significant from the point of view of treatment; the elements are chelatable with DTPA (diethylenetriaminepentaacetic acid) and can therefore be redirected towards elimination by the kidneys during their passage in the blood, thereby avoiding prolonged deposition in the liver or bone structure.

It should also be borne in mind that *'solubility'* is relative and always in direct dependence on the medium. The medium varies according to the organ concerned, both in terms of pH and of redox potential. For example, an element inhaled in an insoluble form may be made *'absorbable'* in the digestive system if it dissolves in the stomach acid, with dissociation of the salt. Conversely, a soluble element may be made completely insoluble in the digestive system by alkalinization in the duodenum, with the formation of insoluble hydroxides.

Finally, absorption takes place rapidly whether we are dealing with a totally absorbed transportable radionuclide or a non-transportable radionuclide absorbed only partially or even to a negligible extent. Since transfer to the target organ is concurrent with absorption and since present-day techniques are usually ineffective in speeding up elimination, the success of the therapy is directly related to the *promptness with which treatment is given.* The time available is normally less than an hour; it may be no more than a few minutes.

1.3.2. General principles governing the treatment of internal contamination [6]

The concept of *urgency* emerges naturally from our biological and physico-chemical knowledge. If it is assumed that the quantities of radionuclide entering the blood are proportional to the diffusible quantities present at any moment at the point of entry, the effectiveness of local treatment decreases exponentially

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with time. Hence it is all the more important to deal with contamination at the point of entry when the elements concerned are those for which no effective therapy is available once they have been absorbed. Since deposition in the critical organ begins as soon as the radionuclide is present in the blood, every moment wasted increases the deposit almost irrevocably. As a result, even in the case of elements accessible only to treatment at blood level or by preliminary blocking of deposition in the target organ (for example by stable iodine), the concept of urgency remains. We can therefore formulate a general rule valid for any radionuclide and any route of entry:

First aid to persons involved in a radiation accident should be given merely on the presumption of internal contamination; aid, even without sure diagnosis, is preferable to no aid at all, provided that it does not involve undue hazard.

This rule is accompanied by three conditions:

(a) *The diagnosis of immediate importance is that associated with the accident, not a diagnosis of internal contamination.*

It is clear that the urgency associated with injury takes precedence over the urgency associated with the contamination and that the first aim must be to save the life and preserve the vital functions of the patient. Treatment of the contamination comes only second.

(b) *The medicaments used for first aid should be administered at non-toxic levels as preplanned by the physician in charge of the facility.*

To speed up the treatment it is desirable in specific cases for the contaminated person to administer the first aid himself at the site of the accident (for example, oral administration of stable iodine to block the thyroid, or local application of a chelating agent to a wound contaminated by plutonium or a transplutonic). Treatment takes precedence over definitive diagnosis, especially if waiting for the latter wastes precious time. The third condition is therefore:

(c) *The mode of application should be simple and confined to local administration, ingestion or inhalation of aerosols.*

Note: The idea of the contaminated person treating himself may give rise to difficulties in a medico-legal sense. On the one hand, the aim of securing maximum effectiveness of treatment requires that it should start from the moment contamination is suspected, without waiting for professional medical care; on the other hand, it could be hazardous to allow free access to drugs that would normally be supplied, prescribed and administered only under medical supervision. These difficulties can be overcome in several ways:

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(i) By using only simple products, for external application, whenever possible;
(ii) By entrusting the responsibility for such treatment to a radiological health and safety officer trained in first aid procedures who can assess the seriousness of the physical contamination;
(iii) By limiting the weighed amounts of drugs available for internal use (e.g. 50 mg of aerosol DTPA ready for use, instead of the usually prescribed 1 g).

When it is impossible to have medicaments available at the site of a potential accident, the importance of keeping the time lag between contamination and first aid of the patient to a minimum is clearly all the greater.

Whether or not first aid has been given, the contaminated person is evacuated to the first of the medical stations envisaged. The doctor then takes the necessary action:

(1) *He gives first aid if the immediate treatment stage has been omitted;*
(2) *He takes the necessary samples for definitive diagnosis of internal contamination (mucous from the nose, blood, urine, stools), and appropriate samples for later clinical evaluation;*
(3) *He completes external decontamination if required;*
(4) *He carries out special tests (or has them carried out) such as whole-body monitoring or direct organ counting;*
(5) *He continues or, if necessary, modifies the treatment.*

The methods by which the treatment is applied will vary depending on the route of entry of the contaminant. Consideration must be given to the different possibilities: contamination of the skin, intake via the digestive system, contaminated wounds and contamination through the respiratory system.

(a) *Contamination of the skin only* (for technical details see Appendix B)

Spreading of contamination through the organism must be prevented at all costs and, above all, nothing should be done which would favour it. The rule is to avoid the slightest abrasion of the skin and the use of products that could facilitate the passage of material through the skin. The radionuclide should thus be removed by washing, by solubilization or by the application of strippable material to the skin. There are special indications for each type of contamination. Generally speaking, preliminary decontamination of the skin is carried out on the spot; verification of removal and, if necessary, more elaborate treatment to remove residual or stubborn contamination are carried out at the plant medical facility.

(b) *Contamination of the digestive system* (for technical details see Appendix C)

Contamination of the digestive system is an infrequent event among workers; the chances of it occurring as part of an occupational accident are slight. Should

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such a case occur, the type of contaminant is of prime importance; it may either be a *non-transportable element,* insoluble in the gastro-intestinal tract, in which case the very small fraction absorbed does not usually justify treatment, or else a *transportable element,* absorbable in the digestive tract, in which case an attempt must immediately be made to insolubilize it, using drugs such as Prussian blue in the case of caesium, alginates in the case of strontium, or alkalinizing drugs in the case of elements with valences greater than II so as to induce hydroxide formation.

(c) *Contaminated wounds and burns* (for technical details see Appendix C)

Two things in particular must be assessed:

The *severity* of the injury. (It is clear that emergency treatment of the injury takes precedence over emergency treatment of the contamination.)

The *degree* of the contamination.

The action taken varies according to whether the element is transportable or not. If the contaminant is a transportable element it should be made insoluble at the wound site, if possible, to prevent diffusion through the body. It may be necessary, at a subsequent stage, to consider surgical excision if there is a persistent residual fixed contamination such as might constitute a danger to the injured person. If the contaminant is a non-transportable element and there is a merely local extension of contamination (rapid conversion to the hydroxide is needed if the element is soluble), the injury can be treated with a local therapeutic agent (chelating agent, for example) before surgery is considered. It is only in the rare case of contamination by solid particles that surgical excision offers the sole possibility of treatment. Surgery is not usually urgent, however, and there is enough time to get together a surgical team.

In all cases of contaminated wounds, it seems advisable to *evacuate the patient* to a specialized service or centre for surgical consideration. Indeed, for carrying out surgery in a contaminated medium it is essential to have a team trained in rapid evaluation of residual radioactivity during the operation (by means of wound probes suited to the type of radiation emitted by the contaminant) and in unusual operation room practices such as repeated monitoring of the surgical instruments.

(d) *Contamination through the respiratory system* (for technical details see Appendix C)

In a case of this type the internal contamination is difficult to evaluate; even so, an evaluation is essential as it indicates the extent of the treatment that must be given. The general rule applies here, too: the slightest suspicion of serious contamination means that treatment must be instituted. In view of the difficulties encountered in evaluating the level of lung contamination, the wisest solution in case of doubt is to send the patient to a specialized service for observation. Whatever the contamination level, one has to bear in mind that the lung normally clears

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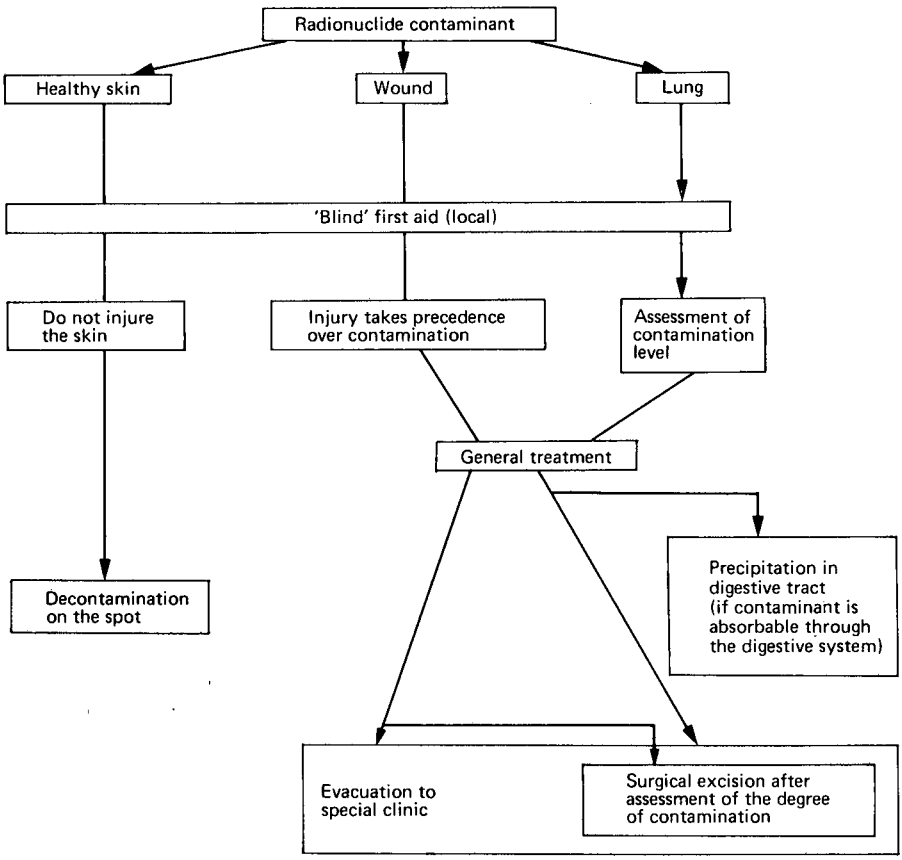

FIG.1. Diagram summarizing the general principles governing first-aid treatment for radionuclide contamination.

inhaled products to varying degrees and that one of the pathways for clearance is the digestive tract (following the return of inhaled material through the bronchial tree, secondary deglutition and passage into the oesophagus). Clearance via the digestive tract may in fact involve a large fraction of the total contamination – for example in the case of particles of relatively large diameter. As a result, there may be secondary digestive absorption, depending on the nature of the inhaled radionuclide. It is thus essential, after an accident involving serious contamination of the lungs by a radionuclide which is also absorbable in the digestive system, to try to make it insoluble in the gastro-intestinal tract. In the case of beta emitters, exposure of the mucosa can be reduced by using laxatives. When gaseous contaminants are involved, therapy has no resources at all. Moreover, the problem in this

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case is more one of *exposure to radiation,* which takes precedence over contamination in the normal sense. A special case is that of contamination by radioactive iodine, which necessitates immediate blocking of the thyroid with stable iodine.

Figure 1 is a highly schematic illustration of the general principles governing the various possibilities of treatment following contamination by a radioactive element [6].

1.3.3. Biological samples

The properties directly related to the radioactive nature of the contaminant often make possible an exact evaluation of the contamination level through measurement of the excreta and the body burden. Measurement of the latter may be difficult, however, either because a whole-body spectrometer is not readily available or because the quality of the radiation makes the measurement too inaccurate (see Appendix C). Hence the importance of biological samples for following contaminant kinetics in excreta (urine and faeces); quantification of the excreta data based on metabolic models [7–9] permits an evaluation of the initial body burden and ultimately of the dose commitment.

The necessary biological samples will depend on the contaminant, its physico-chemical nature and its route of entry into the body. Basic treatment information, arranged in alphabetic order by radionuclide, is given in Appendix C. The sampling techniques are not unusual; details are given in Appendix A. Since the samples are sent later to a specialized analytical laboratory and may be numerous, they must be accompanied by an *information label* indicating, in particular, the time when each was taken.

1.4. PRACTICAL CONCLUSIONS

A distinction must be drawn between the two different kinds of external irradiation, partial or whole-body irradiation, and internal contamination, without reference to the pathway by which the radionuclide is introduced.

1.4.1. External exposure

Generally speaking, there is no need for immediate therapeutic action. Dose evaluation techniques should be refined to give as accurate an idea as possible of the dose received. The physician can evaluate the physical data with the data emerging from the clinical evolution of the case. Thus only a highly specialized service can assess the seriousness of the exposure and, except in hyperacute and fatal cases, the treatment will be suitably adapted as the clinical picture emerges. There is no emergency in the medical sense.

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1.4.2. Internal contamination

Internal contamination is quite different. Knowledge of the laws governing the fate of a radionuclide which finds its way into the human body, and the difficulty of applying treatment once accumulation in the target organ has occurred, imply two principles:

(a) *Urgency of first-aid treatment;*
(b) *Evaluation of the seriousness of the contamination.*

The concept of urgency, associated with a treatment often given 'blind', is followed immediately by the importance of *biological sampling*, more especially sampling aimed at bioassay of urine on specimens taken immediately after contamination.

The urgency of first-aid treatment has the following consequences: Under certain circumstances it may be desirable for everyone handling radioactive materials to be in possession of a small first-aid kit containing medicaments that are simple to use, non-toxic and made up into single units, i.e. individual doses intended for use at the site of the risk, together with exact therapeutic indications. Whether or not this simple first aid is given, there is usually a plant medical service or clinic available for the contaminated person before evacuation to a more specialized hospital. If it is to be effective, the plant medical service should have at hand a number of medicaments that are not normally found in current medical practice, but which are essential for occupational toxicology. This medication can, as required, be packed in group *'kits'* for treatment of several persons (or for treatment of one person several times) for the same radioactive contamination. The existence of two stages in first-aid treatment, i.e. at the site of the risk and in the medical unit of the plant where the accident occurs, therefore calls for the design of two kits for different purposes; it is clearly the duty of the physician in charge of radiological protection at a facility to make up a kit suited to the risks; Appendix D describes the typical composition of the two kits, intended basically for fissionable elements and for the main fission products [10].

The *personal kit* is intended for use by the contaminated person himself or by a fellow worker in his proximity at the time of the accident – in other words, by people who have no medical training. The safety regulations for the workers' posts should cover the use of the kit on the merest suspicion of internal contamination. The harmlessness of the treatments prescribed, in view of the quantities of medicaments available in the kit, should make possible a regulation of this kind without contravening the law. Naturally the use of the personal kit does not under any circumstances excuse the contaminated person from reporting to a physician whose job it is to confirm the contamination or not, to follow up the treatment as necessary, and to make up a fresh kit. The *group medical kit* may contain, for

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example, seven daily doses for treating one person for seven days or seven contaminated persons for one day. The purpose of this kit is to assemble in compact form all the non-current medication that should be available when a contaminated person is received in a medical unit. The aim is to simplify the action that needs to be taken, so that the medical requirements can be fulfilled promptly.

The second principle is much more complex. It is often possible to immediately gain an idea of the *order of magnitude* of the contamination; however, one has to be well aware of the fact that assessment errors can easily be made and that a truly accurate evaluation is possible only in a specialized medical department. It is this qualified medical service that, on the basis of special tests, including sampling of faeces, blood, etc., and whole-body or partial spectrometry, makes the final diagnosis, establishes the contamination level and takes the appropriate decisions as regards treatment.

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Chapter 2

NEW METHODS IN THE TREATMENT OF INTERNAL CONTAMINATION BY ALPHA EMITTERS

2.1. INTRODUCTION

The radionuclides incorporated as a result of contamination affect the biological material through the radiation they emit. In the case of human beings internal radioactive contamination cannot – save under exceptional circumstances difficult to imagine – result in an exposure such as would produce radiation sickness. It is theoretically possible, though highly unlikely, that the inhalation of plutonium oxide could lead to death (within 6 months) owing to vascular sclerosis and diffuse interstitial pulmonary fibrosis [1]. Generally speaking, however, internal contamination gives rise to chronic irradiation of a particular organ and the major risk is that the organ may become cancerous [2, 3].

For reasons associated with nuclear physics (type, energy and intensity of radiation) and because of the metabolic considerations discussed in Chapter 1, certain radionuclides are more interesting than others for the purposes of radiation protection. The degree of toxicity can be reckoned in terms of the maximum permissible body burden (MPBB), this being the quantity which, at equilibrium conditions, would deliver the equivalent of the maximum permissible dose to the target organ. These values have been established by the International Commission on Radiological Protection [4a]. However, the recently published ICRP report [4b] bases its recommendations in the case of internal exposure on annual limits of intake (ALI). These are calculated by ICRP Committee II from a knowledge of the various organ committed dose equivalent such that the risk of stochastic effects should be equal whether the whole body is irradiated uniformly or whether there is non-uniform irradiation. Further, the ALI are constrained such that the organ doses are limited to prevent non-stochastic effects. The new ICRP Committee II report has not as yet been published and therefore the quotations listed below are based on ICRP Publication 2 [4a]. The lowest MPBB values are assigned to alpha emitters since they are the most toxic group. Among these we have:

1.5 kBq (0.04 μCi) for plutonium-239, which corresponds to 6.5×10^{-7} g
1.5 kBq (0.04 μCi) for plutonium-238, which corresponds only to 2.4×10^{-9} g
1.11 kBq (0.03 μCi) for polonium-210
1.11 kBq (0.03 μCi) for uranium-235[1].

[1] Uranium is a special case since it is rapidly converted in biological media into the uranyl ion UO_2^{++}, which should behave like calcium were it not for the fact that it precipitates in the renal tubule; this accordingly constitutes the target organ.

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Transplutonics:

1.85 kBq (0.05 μCi) for americium-241
1.85 kBq (0.05 μCi) for curium-242
3.7 kBq (0.1 μCi) for curium-244
25.9 kBq (0.7 μCi) for berkelium-249
0.37 kBq (0.01 μCi) for californium-252
1.5 kBq (0.04 μCi) for einsteinium-253.

Organ contents giving the maximum permissible dose rates can be found in Table IIA of the IAEA Safety Series No.9 [5].

Although cases of severe contamination are rare, significant experience, based both on experiments with animals [1, 3, 6, 7] and cases of human beings [3, 8], has been acquired over the last few decades, enabling us to outline the courses of treatment to be applied in cases of contamination by the most toxic radionuclides. These are the alpha emitters, first and foremost plutonium and the transplutonics.

2.2. PLUTONIUM AND ITS METABOLISM

The metabolism of plutonium is directly dependent on its physico-chemical form. In a biological medium plutonium can be transported only when bound to natural compounds, i.e. proteins or other macromolecules (blood), or cellular components of low molecular weight such as citrates or other organic anions or amino acids (tissues). The plasma transport protein has been identified as transferrin, which normally serves for the transport of iron in the body. The existence of soluble plutonium in free ionic form is impossible in a biological environment because this would be incompatible with its chemical properties – it cannot in fact exist in solution except at highly acidic pH levels (roughly, less than 1). It precipitates as hydroxide as soon as the pH value rises, and this condition is realized when it is directly introduced into a tissue, for instance through a wound caused by an accident. It should be added that plutonium can exist in solution in a very wide range of forms, with valences ranging from 3^+ to 6^+. The form most frequently encountered in biological media is 4^+; this corresponds to the complexed form, which is in fact the biochemical fate of plutonium.

The most troublesome plutonium-239 compound from the health standpoint is undoubtedly the oxide, PuO_2, the properties of which make it a highly desirable fuel. The behaviour of plutonium oxide after it is incorporated into an organism depends on a variety of factors, such as its exact composition, the size and shape of the particle, its age, and the temperature at which calcination occurred.

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2.2.1. Absorption from the point of entry

Plutonium is absorbed hardly at all by the digestive system; the figure ranges from 0.003% for soluble compounds to 0.0001% for relatively insoluble compounds [6]. Penetration through healthy skin has never been proved. Inhalation is certainly the most probable way in which humans might absorb significant quantities of plutonium. Roughly speaking, the fraction deposited in the deep lung varies inversely to the diameter of the particle, whereas the fraction deposited in the upper air passages varies directly with it. It is the former fraction that it is important to account for, since it governs the deposits in the lung and various other organs after passage through the alveolar wall. The rate of passage is highly variable, covering a whole range of values from almost zero to rates corresponding to biological half-lives of several weeks. The same variation in absorption kinetics is found in cases of wound contamination.

2.2.2. Clearance from the point of entry [6, 9]

Having been deposited at the point of entry, the plutonium passes into the bloodstream. Whereas the kinetics of its passage vary greatly from one compound to another, the mode of deposition of plutonium carried by the blood depends hardly at all on the point of origin or the form in which it is carried; the only difference is the relative distribution between the different organs.

The lung[2] is a particular case since there is a natural clearance process which rids the bronchial tree of most of the inhaled particles; this clearance is carried out in three ways:

(a) *Tracheal/bronchial clearance,* resulting in removal of the plutonium compound by return along the bronchial tree to the pharyngeal junction, followed by secondary passage into the digestive tract, with almost complete excretion in the faeces and urine. This form of clearance has two components: a rapid, purely mechanical component, clearing the upper air passages, trachea and bronchi, with biological periods of the order of a day, and a slow component, combining cellular and mechanical processes and clearing the deep (alveolar) lung, with biological periods of from one month for the most soluble plutonium forms up to a year for plutonium-239 oxide. The cell responsible for this alveolar clearance is the alveolar macrophage which, having phagocytosed one or more particles, dies as a result of the exposure to alpha radiation and is eliminated from the lung.

(b) *Clearance to the tracheal/bronchial lymph nodes,* i.e. movement towards the thoracic lymph glands in which the plutonium is almost entirely retained. Thus, for plutonium-239 oxide, only about 10% of the amount deposited in the bronchopulmonary lymph nodes passes into the blood, and thereby into other organs, with a biological half-life of more than a year.

[2] For more details see Refs [3, 6, 9].

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(c) *Clearance to the blood.* For soluble inhaled plutonium clearance from the lung to the blood occurs first rapidly. In addition, slow clearance of insoluble material in the deep lung occurs over extended periods [9].

2.2.3. Translocation from the point of entry to other organs

The combined rates at which the different forms of lung clearance take place govern the size of the absorbed radionuclide fraction and, therefore, the deposition in the organs. The movement of plutonium into the tissues also obeys exponential laws with, it would seem, a number of components whose coefficients increase as one gradually moves away from the point of the initial contamination.

In the case of wound contamination, it is quite impossible to evaluate in advance the amount of radionuclide that will migrate into the body because this depends, among other things, on the characteristics of the wound such as location, depth, degree of attrition, and so on. In the case of plutonium in the form of a soluble salt, whether non-complexed or only slightly so (plutonium nitrate, for example), the quantity migrating into the body may attain a few per cent; in the long run, this could represent significant activity deposited in the skeleton. But, above all, this fraction does not migrate at a constant rate; the nearer to the contamination, the faster the rate, owing to competition between local hydroxide formation effects resulting in the formation in situ of only very slowly degradable hydroxides and natural complexes. This phenomenon is not confined to wound contamination, but it is more marked in such cases; it has one important and immediate consequence for the physician giving therapy, namely urgent emergency treatment of the contamination.

As a result of biochemical kinetics, the migration of plutonium leads to its deposition in certain organs, the two main ones being the *liver* and the *bone*. The biological clearance from the liver has a half-life of about 40 years, combining the two kinetics of clearance, i.e. by the liver cells proper and by the kupffer cells. In bone, plutonium is deposited preferentially on the endosteal surface; this localization is important because the position is particularly favourable for the induction of cancer. Depending on the rate of growth and renewal of this part of the skeleton, we find in varying degrees a progressive burial of plutonium in the deep-lying bone; concentration in the osteoclasts responsible for bone resorption is also possible. Migration towards the bone marrow takes place slowly because of macrophages which attack the plutonium freed on the surface. All these morphological changes tend to reduce the harmful effects of plutonium because the irradiation time of the critical endosteal cells is shorter than the total residence time of the plutonium in bone owing to remodelling. The residence time of plutonium is always very long, the biological half-life being calculated at about 100 years for the human skeleton.

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There are other areas where plutonium is retained, though to a lesser extent; at the same time the specific activities may be very high on account of the small weight of the organs concerned. Thus, significant quantities of plutonium may be found in such organs as the spleen, gonads and thyroid. In human beings it is estimated that about 10% of the plutonium fixed by the body, with the exception of the point of entry, is distributed in zones other than the liver and bone.

2.2.4. Natural excretion

Despite the very long periods of plutonium retention, there is a natural form of excretion which never involves more than a small fraction of the plutonium carried by the blood. It is, however, excretion in the urine that provides the greatest amount of data for human beings, since excreta analysis is the most sensitive method, and in many cases the only method, of detecting the presence of plutonium in the body. Many equations have been put forward to relate urinary excretion with the initial deposition of plutonium, but in no case can it be considered that the evaluation of the body content on the basis of urinary elimination is accurate.

All the numerical data quoted above apply to the isotope plutonium-239. The metabolic model is the same for the other isotopes, but the coefficients vary. The most interesting case is that of plutonium-238, for one often finds much more rapid migration than in the case of plutonium-239. This difference may be due to the heat generated during plutonium retention which modifies the physiological behaviour. In this sense one is often tempted to class plutonium-238 with the transplutonics.

2.3. THE TRANSPLUTONICS – COMPARISON WITH PLUTONIUM [10]

Let us recall that the elements involved in this group are *americium, curium, berkelium, californium, einsteinium, fermium, mendelevium,* and several others that are at present only of interest in theoretical research. Generally speaking, the fact that the transplutonics have the valence 3^+ gives them an *in vivo solubility* much higher than that of plutonium, and this is reflected in much faster migration rates from the route of entry. The faster migration of the transplutonics is associated with a much higher pH for hydroxide formation than in the case of plutonium and there is accordingly a much more uniform deposition in the lung. *Inhalation of curium or americium in solution results in deposition in the monomeric form,* whereas plutonium inhaled under the same conditions yields a non-uniform deposit in hydroxide form. Roughly speaking, the further we go in the transplutonic series, the more soluble the elements become in biological media. In practice this means both rapid clearance from the route of entry and

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rapid accumulation of a bone burden. Furthermore, unlike plutonium-239, whose oxide forms can be considered insoluble, transplutonic oxides always have some degree of solubility. There is always degradation, and some americium and curium oxides have even shown themselves to be more rapidly solubilized by biological material than hydrolysed soluble salts.

Thus, the transplutonics differ from plutonium-239 in being more rapidly absorbed and more widely diffused in the body. This means, for the therapist, that treatment is urgent.

2.4. TREATMENT OF CONTAMINATION BY PLUTONIUM AND THE TRANSPLUTONICS

Roughly speaking, treatment can be given at different stages [7, 11–13]:

(a) At the *point of entry,* e.g. by procedures such as decontamination of the skin, removal of the contaminant from a wound by washing, chelation, surgery;
(b) In the *blood,* during translocation, by means of a chelating agent which redirects the plutonium or transplutonic from its normal path and considerably speeds up renal excretion;
(c) Pulmonary lavage can be considered after severe contamination.

Since it is impossible to assess in advance the degree of insolubility of the contaminant, even in the case of plutonium, action must be taken, at least during the first-aid treatment, to clear the blood by means of a chelating drug. Accordingly, stress will be laid on this form of therapy. Regarding local decontamination and related techniques, the reader is referred to Chapter 4 and Appendix B.

2.4.1. Transportable compounds [14, 15]

For practical purposes this category includes all the plutonium salts and all transplutonics in either salt or oxide form. The chelating agent which combines the greatest effectiveness as a first-aid measure with the least toxicity is Ca-DTPA (calcium-diethylenetriaminepentaacetic acid) [16, 17], which acts on the plutonium or transplutonics only when they are in a soluble form and bound to a plasma carrier, and then only in the typical DTPA diffusion compartment, i.e. the extracellular compartment. Once bound to the chelating agent the radionuclide forms an extremely stable compound and follows the biological fate of the DTPA, which is eliminated rapidly in the urine; its clearance is comparable to that of inulin. DTPA is filtered in the glomerulus and not re-absorbed in the tubules, and therefore excreted. The biological clearance time is about 90 minutes.

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DTPA has been used extensively in human patients for many years; no secondary pathologic changes following the treatment have ever been observed. At the same time, the potential toxicity of DTPA should not be overlooked. The acute or sub-acute toxicity on which studies were first focused is twofold:

(a) Depletion of serum calcium, a problem which can easily be solved by using the calcium salt, Ca-DTPA;
(b) A nephrotoxic effect, which can be solved by administering a dose much smaller than the toxic dose, and in subjects free of kidney lesions.

At the present time there is much greater stress on the chronic toxicity of DTPA [18–22], the risk of which is limited in human beings by the relatively small doses given and the chronology of treatment, which is always discontinuous when prolonged. The possible teratogenic effects [23] constitute a problem of a different order; they have not been unambiguously demonstrated, but the problem of having to withhold treatment in the case of a woman contaminated during the first weeks of a suspected pregnancy may arise. The potential harm from DTPA has stimulated a number of research workers to try to develop a compound less toxic than Ca-DTPA. It has been shown that Zn-DTPA is less toxic [24, 25], but it is also less effective in clearance than the calcium salt during the initial period of treatment. This is why Ca-DTPA is advocated as the initial remedy (certainly for the first injection and even during the first week), with Zn-DTPA taking over for prolonged treatment if this is considered necessary. For the moment, however, the niceties of using a calcium or zinc salt of DTPA are purely academic, since only Ca-DTPA is widely available.

The success of treatment stands in relation to the chances of the DTPA and the plutonium or transplutonic elements combining with each other. In view of the metabolism of the two substances, the more transportable the element is in the body, the greater the chances of an encounter; but the other side of the coin, of course, is that greater transportability means less time available for treatment. All the clinical experience of the past bears out these two points [26–32]. On a practical plane, one should expect greater excretion with DTPA in the case of transplutonics than for plutonium in the same chemical form; conversely, the concept of urgency becomes all the more important in the case of certain transplutonic forms, since migration from a wound or from the lung is especially fast.

The various considerations above govern the dosage, method of administration and frequency of DTPA treatments. As part of the first-aid measures at the site of the accident, DTPA can conveniently be administered in *aerosol* form; in the case of respiratory contamination this is even more effective than an intravenous injection, at least as regards the kinetics of clearance, if not in terms of final retention. For subsequent treatment intravenous administration is to be preferred, since with the aerosol it is difficult to ascertain the amount of DTPA

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actually absorbed by the patient. For protracted treatment, however, the possibility of administering DTPA by inhalation could be envisaged as a way of sparing the patient multiple injections. It should be borne in mind that the conventional aerosol devices used for ear, nose and throat conditions are usually ineffective, since the large particle size of the aerosol produced prevents adequate deposition in the lung. Particular care should therefore be given to the particle size distribution (see Appendix D). Hence, if the exact amount of DTPA absorbed via inhalation is not known, *urgent treatment should always include an intravenous injection,* whether or not the patient has already had DTPA aerosol. The quantities prescribed are, conventionally, one gram per injection. Actually, although it seems advisable to keep to this dose for first aid, it is both possible and desirable to reduce the dose to 0.50 g or 0.25 g soon after, without loss of effectiveness on that account. Subsequent treatment, its frequency and duration, will depend on a variety of considerations such as evaluation of the body content and the effectiveness of the treatment. In the final analysis each case becomes a special case and it is difficult to prescribe an exact course of therapy beforehand (see Section 2.4.3).

In the literature there are numerous other references to drugs, chelating agents and others (encapsulated DTPA, glucan, phosphonated products, and so on), which are at the experimental stage and are hence only of theoretical interest to the physician or therapist [33].

2.4.2. Non-transportable compounds

A typical non-transportable compound is plutonium-239 oxide ($^{239}PuO_2$). Since, however, we do not know in advance the degree of non-transportability of the compound, and especially whether there are any associated transportable compounds present, first aid should still include the administration of DTPA. Since the effectiveness of chelating agents on completely insoluble compounds is nil, and since all the trials with a variety of drugs (expectorants, ciliostatic agents, draining procedures, steroids and so on) have been unsuccessful, the only possibility is surgical debridement in the case of wounds contaminated with $^{239}PuO_2$. With non-transportable pure alpha emitters there is no great urgency; one has enough time to form a clear picture of the patient's situation and to decide the need for local surgery or lung lavage.

In the case of a *contaminated wound,* the fact should not be overlooked that there will always be some local spread; this means that surgery, once decided on, should not be delayed too long because local spread of plutonium will enlarge the excision required. Contaminated wounds are often located on the hands, and any extension of contamination along the fascial planes, aponeuroses and synovial sheaths may lead to surgical difficulties. The operation is usually performed in a bloodless field [34–36]. Radiography can provide information

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on the presence of metallic foreign bodies. It is not possible to see plutonium since even 1 mg of ^{239}Pu, i.e. 0.05 mm^3, which represents 229 kBq (6.2 μCi) or 155 times the maximum permissible body burden, is too minute. If the plutonium, is on a metallic object, the contaminated object causing the wound might be visible, otherwise diagnosis is possible only by nuclear measurements. Apart from ^{241}Am, a gamma emitter, plutonium and the transplutonics cannot be detected, except by their X-ray emission, which is of very low energy and always represents a small percentage of the total emission. This illustrates the difficulties encountered in evaluating the contamination level, even in a finger. The general principle is therefore to ensure close collaboration and a constant dialogue during the operation between the surgeon and the health physicist responsible for the measurements. The specific principles applicable to surgical intervention are discussed in Section 2.4.3 and also in Chapter 5.

All surgical interventions should be performed with a prophylactic injection of DTPA in the case of contamination by plutonium, and even more so in the case of contamination by the transplutonics.

In the case of *inhalation of non-transportable plutonium* the only possible treatment is pulmonary lavage. This technique is used in clinical medicine for cases of obstruction of the respiratory passages or alveoli. The mortality rate for the operation is of the same order of magnitude as that due to anaesthesia (about 1/4000). Pulmonary lavage has been documented on the basis of a large number of experimental studies [37–39], and has once been performed for contamination of the respiratory system by $^{239}PuO_2$ [40]. Clearly, the indications must be carefully weighed and the intervention should be made only by a qualified specialist. The indication depends, above all, on the lung plutonium burden and the age of the patient. Since the main risk of lung contamination by plutonium is cancer of the lung and the latent period is more than 10 years (possibly several decades), it is customary to withhold treatment in the case of an older patient. For a younger person the problem is quite different. When we think of the difficulties involved in evaluating the lung plutonium burden and the high degree of uncertainty surrounding the measurement data, we see that it would be very difficult, except in extreme cases, to establish exact indications for treatment. In the long run the practical problem is: *beyond what level of contamination should one contemplate pulmonary lavage?* Some investigators [8] suggest 50 times the maximum permissible lung burden (50 MPLB) for a patient aged 30 or less as the starting point. A more cautious approach would be to select a figure ten times greater than this. Some technical details on lavage are given in Section 2.4.3.

2.4.3. Practical treatment schemes

First aid in the true sense may be followed by subsequent treatment which, depending on the particular case, will be medical and/or surgical and applied

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to a wound or to the lungs. We must therefore take into account:

First-aid treatment;
Long-term medical treatment;
Operative intervention.

2.4.3.1. First-aid treatment

First-aid treatment consists of several successive stages:

(a) *DTPA administration.* Whether or not the patient has received DTPA at the site of the accident (washing of the wound and/or administration of aerosol), the physician should immediately administer 1 g of DTPA in the form of a slow intravenous injection.

(b) *Biological samples.* Samples should be taken immediately afterwards and used to determine the radionuclide burden, the patient's blood data and the state of the kidneys. They comprise:

Urine specimens, to be taken when the injection of DTPA has been completed but before it has had time to work. They are used to measure the plutonium or transplutonic and albumin;

Blood samples, to determine the alpha emitter and establish the blood picture;

Faecal specimens are very important in the case of contamination of the respiratory system since they are required for an evaluation of the lung burden. The faeces of the first three days should always be collected or, in the case of delayed intestinal transit, the first three stools.

(c) *External decontamination.* This is carried out usually with acid solutions: an aqueous solution of DTPA, acid soap or HCl-acidulated water, gently applied. Sodium hypochlorite is particularly useful in a 25% solution for simultaneously removing dirt and unfixed radionuclides in wounds. The compresses used are collected in plastic bags for later analysis. If shaving is necessary, only clippers should be used; the micro-abrasions made by a razor must be strictly avoided. Do not forget to monitor the clippers and decontaminate them if necessary. External decontamination is checked with an alpha detector.

(d) *Assessment of burden.* This is done in two ways, the local burden providing an indication for surgical intervention, the body burden indicating follow-up medical treatment. The local burden is gauged by direct local measurement (X-ray detector) in the case of a wound or inhalation; the body burden is evaluated by radiochemical analysis of urine and faeces. The detection limits are shown in Appendix C for each element, but it should be borne in mind that the measurements are delicate and liable to contain numerous errors, and that they are all the more valuable when several measurement techniques show similar results.

(e) *Indication for operative intervention.* This should be discussed with the specialists; since the patient is kept on DTPA, there is enough time to decide

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TABLE I. GUIDELINES FOR LONG-TERM TREATMENT WITH DTPA

Time following the accident	DTPA		
	Dose	Pathway	Frequency
As soon as possible	1 g	Intravenous injection or inhalation	
First week	0.5 g	Intravenous injection or inhalation	One per day or three per week
First month or first two months	0.25 g to 0.50 g	Intravenous injection or inhalation	Two per week
Following month		No treatment	
Subsequently	0.25 g to 0.50 g	Intravenous injection or inhalation	One to two per week for the first month, alternating with pauses of two or three weeks

whether or not surgery is necessary. However, the tests on which the indication for surgery is based are difficult and time-consuming, so no time should be wasted. Surgery on a contaminated wound must be carried out without undue delay if one is to avoid having to enlarge the zone of excision, and pulmonary lavage should be carried out on the second or third day after contamination if it is to have the maximum effect.

2.4.3.2. Follow-up medical treatment

The subsequent course of medical treatment will depend on the results of the different radiotoxicological tests and direct measurements. The patient has to be kept on DTPA until the body burden is known. The programme of treatment is then adapted to each case. Table I [32] is intended only as an illustration and for general guidance.

2.4.3.3. Surgery on wounds

In addition to the surgical techniques that fall exclusively within the competence of the surgeon, there are certain requirements which tend to slow down the operation, such as local monitoring of the wound, the excised tissues, gloves and instruments. The surgical instruments should be changed during the

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operation, and possibly the surgical gloves as well, to avoid spreading of contamination. Such delays become important when the surgery involves the use of a tourniquet, for which there is always a time limit.

(a) *Preparation of the operating room.* A conventional operating room is entirely suitable, provided that it is not too cluttered and can accommodate the staff and monitoring equipment, and can be easily monitored. Everything should be covered with disposable plastic, i.e. the operating table, smaller tables, floor, etc.

(b) *Protection of staff.* The normal arrangements for asepsis are adequate protection against contamination. Provision should be made for a large-surface alpha detector within range of the surgeon so that his gloves and instruments can be continuously monitored. There is no need to wear a film badge in the case of alpha emitters. In some cases where the contamination is high it may be necessary for the surgical team to wear respirators.

(c) *Protection of equipment.* Even if the patient's lungs are also contaminated, the anaesthesia and breathing equipment are not at any risk. It is only components in direct contact with the respiratory passages (probes) that may become contaminated. The mucous extractor, however, should be fitted with a protective glass container which can be passed on later to the radiochemical analysis laboratory.

(d) *Sterile equipment.* All the equipment should be provided that would be required for the same surgery under conditions where there is no contamination, but in triplicate at least. If the wound has to be washed, it is wise to add one ampoule of DTPA per 100 ml of washing solution. If the anaestesia requires perfusion, an ampoule of DTPA should be added.

(e) *Measuring equipment.* Provision should be made for an alpha detector to monitor the gloves and instruments, and the extent of the contamination, and a photon detector for monitoring the wound and the excised tissue. The tissue is counted on compresses after removal; it is then preserved in labelled plastic bags for more exact measurement. There should therefore be an adequate supply of compresses and plastic bags.

(f) *Surgical procedure.* This is conducted in the same way as the normal excision of a wound, with additional radiological surveillance. The problem is to know where to stop during initial surgery, and this is a decision which must emerge from consultation between the surgeon and the radiobiologist in charge of measurements. The gain in decontamination must be continually weighed against the mutilation resulting from extensive surgery. Theoretically, a halt should be called when the bulk of the contamination has been removed and the count in the wound is low and constant. The aim should not be to remove all the contamination.

(g) *Indication for amputation.* An amputation should not be carried out on purely radiobiological grounds during the initial surgery. The indication for secondary surgery, and possibly amputation, will be based on an evaluation of the dose commitment from the contaminated tissue for the years to come.

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(h) *Contaminated waste.* The plastic sheets used to protect the operating room are rolled up and placed in plastic bags together with contaminated gloves, aprons and gowns. It has been demonstrated that it costs less to destroy them than to attempt to decontaminate them. Non-disposable instruments are wrapped in leak-proof plastic and passed on to the decontamination service. All waste, both solid and liquid, is made up into leak-proof packages and passed on to the specialized service for disposal.

2.4.3.4. Pulmonary lavage

(a) *Criteria for lavage.* These are discussed in Section 2.4.2. The clinical indication is based on the lung picture duly established by the physician, surgeon and anaesthetist. The radiotoxicological indication combines the age of the patient and the contamination level; the younger the patient, the lower the threshold level will be.

(b) *Timetable and frequency.*

Initial lavage: as soon as possible, after the second or third day; can be carried out on the second day.

From then on repeat twice a week for two weeks, then once a week; a total of about ten lavages represents an ideal number which it will most likely be difficult to attain.

(c) *Time interval between lung lavages.* If possible, the two lungs should be washed within one hour. Bilateral lavage is especially important during the initial lavages. Additional lavages of both lungs may be done with intervals of 3–4 days.

(d) *Techniques.*

Intubation equipment is needed, for example a Carlens probe.

Composition of washing fluid: Only normal physiological saline (9 g/ltr NaCl); the addition of any other component has proved hazardous. DTPA could be added if considered necessary (1 g/ltr) in the event that the plutonium inhaled is, or is thought to have been, transportable.

Volume: Normal volume of the lung (average 0.5 ltr).

Pressure: Between 20 and 25 cmH_2O; this can be obtained with a syringe fitted with a manometer or with a container placed higher than the patient. The washing fluid is drawn out of the lung with a syringe or simply allowed to run out by gravity; in the latter case the operation is facilitated by placing the patient's head in an inclined position.

Number of irrigations per lavage: The optimum number is six irrigations, and there is no point in increasing it. Duration of one irrigation: about three minutes.

(e) *Samples.* It is essential to keep intact all the washing fluids for purposes of histological and radiotoxicological testing. Exact labelling is vital.

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(f) *Criteria for discontinuing the lavage.* There are many criteria involved, such as contamination level, absolute effectiveness, an indication by what is shown in the lavage fluids compared with chest counting measurements, loss of effectiveness with time, and physical and psychological tolerance of the operation; no rigorous prescription fitting all cases is possible.

2.5. SPECIAL CASES: PLUTONIUM-SODIUM ALLOY, URANIUM, POLONIUM AND NEPTUNIUM

Some alpha emitters are only slightly amenable or not amenable at all to treatment with DTPA – invariably because of their physico-chemical state and, generally, their valence. This weakness of the therapeutic armamentarium may be serious here because substitutes have proven to be of little value.

2.5.1. Plutonium-sodium [41]

The industrial use of breeder reactors employing liquid sodium as coolant means that contamination by a plutonium-sodium mixture is a possibility that must be considered. The plutonium would then be present in the hexavalent or heptavalent form. Its solubility in the body is greater than that of plutonium in other forms and would accordingly entail a large body content. DTPA would be of doubtful effectiveness, at all events it would be less effective than is normally the case with the more usual forms of plutonium. Its effectiveness would vary, but it would certainly be related to the degree of instability of the plutonium-sodium mixture. Since no other form of treatment is available, there is no other course than to use DTPA, but action should not be postponed if an operation on the wound or lung is envisaged. However, if the plutonium-sodium mixture has caused sodium burns, their treatment (see Appendix F) should always be given priority over treatment of the contamination by plutonium.

2.5.2. Uranium

Only enriched uranium presents a radiotoxicological problem; natural uranium is problematic solely from the standpoint of chemical toxicology. Uranium exists in two valences: 4^+ and 6^+. The 4^+ form is insoluble and gradually becomes converted to the 6^+ form, which is transformed into the uranyl ion UO_2^{++}. The biological behaviour of this ion would be comparable with that of the alkaline earths, were it not for the fact that it is precipitated in the kidneys. This physico-chemical state leads to a fairly rapid diffusion despite the apparent insolubility of numerous salts. Although chelating agents undoubtedly act on uranium, they should not be used because the increased migrant fraction leads

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through renal precipitation to a greater kidney burden than would be received if there were no treatment at all; there is thus the risk of serious toxic nephritis. On the other hand, the complex formed by the uranyl ion with sodium bicarbonate is stable and is eliminated by the kidneys. The basic treatment is therefore the administration of a bicarbonated solution [42] which is given locally and in intravenous perfusion (one bottle of 250 ml at 1.4%).

2.5.3. Polonium

DTPA is ineffective for the treatment of polonium poisoning. British Anti-Lewisite, BAL® (2-3-dimercaptopropanol), is to some degree effective, though the effectiveness is variable with the compound and with time [18]. Despite the uncertainty, BAL® should be prescribed (see Appendix C).

2.5.4. Neptunium

The very long radioactive half-life of neptunium-237 means that its specific activity is low (1/90 that of plutonium-239 and 1/25000 that of plutonium-238). Biologically significant contamination of the lungs is thus unlikely because of the amount that would be required, and the chemical toxicity of neptunium (to the liver or kidneys) could well be just as important as its radiotoxicity (the lethal dose has been calculated at about 12 $mg \cdot kg^{-1}$, i.e. 31 $kBq \cdot kg^{-1}$ (8.4 $\mu Ci \cdot kg^{-1}$)). In general, the metabolism of neptunium places it closer to the alkaline earths than to the transplutonics. It is rapidly absorbed, excreted chiefly in the urine and fixed in the bone [32]. DTPA should not be prescribed, as the complex Np-DTPA is not stable and eventually results in a more appreciable bone burden than would be received if no treatment were given at all [43]. Unfortunately, there is no therapy that can be proposed at the present time for cases of neptunium contamination.

2.6. CONCLUSIONS

The general principle that emerges from the above considerations is the principle of immediate action. Treatment with DTPA, even if administered only locally in the first instance to a wound or in aerosol form to the lungs, offers protection for the target organ, enables an overall idea of the contamination to be gained and procures time for the decision whether or not there is indication for surgery. Surgical intervention entails only problems of surgical detail, whereas pulmonary lavage remains an exceptional form of treatment; its major disadvantage is not so much the risk involved, which is very slight, but the need to repeat the treatment, thereby imposing a considerable strain on the contaminated

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person. It should not be forgotten that DTPA is not a 'miracle drug'; indeed, it is at times ineffective and may even be hazardous (as in the case of uranium and neptunium).

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Chapter 3

EMERGENCY LOCAL DECONTAMINATION

3.1. GENERAL PRINCIPLES

The general principles governing emergency local decontamination are quite simple. The actions to be taken have the same aim, namely to remove the contaminant from the surface of the skin as quickly as possible, the first objective being to prevent the contaminant passing through the skin and causing internal contamination (one should never assume a contaminant to be insoluble), and the second objective being to prevent the contamination spreading either on the victim himself or to the other areas and other people in the vicinity. Accordingly the correct procedure is as follows:

Decontamination should commence at the site of the accident as soon as possible;
The contaminated surface should be quickly delineated;
The contaminated person(s) should be isolated.

Care must be taken to avoid damaging the physiological barriers in any way in order to prevent penetration of the contaminant. The methods and materials employed must not be aggressive to the skin nor should any substance be used which would solubilize the contaminant.

3.2. PRACTICAL MEASURES

For the initial decontamination measures on the spot to be effective it is necessary for the radiation protection staff to be specially trained; it is the latter who are the first on the spot, who make the initial assessment of the contamination and whose task it is to perform the first measures. They send the victim to the medical service as soon as emergency decontamination has been completed, this being particularly essential if there is residual contamination, or if contamination is accompanied by injury, or if a sensitive part of the body such as the eyes or mouth is affected.

Of course, if urgent surgery is called for, this stage should be skipped and the victim evacuated immediately to a specialized centre.

As soon as the patient arrives at the medical centre, several measures must be undertaken: checking of the parts of the body apparently free of contamination, delineation of the contaminated surface, isolation of the patient.

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Certain parts may have been overlooked in the initial inspection and the only way to establish the precise areas of contamination is to make a close examination of the patient with all his clothes off, using suitable detection equipment for the purpose. The contaminating substances can spread beyond the original limits of the contaminated surface either by themselves or as a result of the treatment undertaken. Appropriate measures must be taken to prevent the contaminant spreading, if necessary by covering the contaminated surface with an occlusive dressing. Special care must be taken to avoid the contaminant spreading to any non-contaminated wounds, which should be covered with a waterproof dressing, or to the natural orifices. It must also be borne in mind that any movement of a contaminated person could result in spreading of the contamination. Therefore the contaminated patient should have his working clothes and shoes removed so that he can be transported in as clean a state as possible. Disposable covering boots made of plastic, a smock or overall may be used to cover contaminated areas. Disposable plastic sheets may be placed under and over the patient on the stretcher and on the floor of the ambulance to prevent contamination. On his arrival at the medical service the patient should be kept in the room reserved for decontamination until treatment has been completed.

This treatment can and should be extremely simple in the majority of cases. The simplest measures and those least harmful to the skin should always be used at the start, and only after complete or partial failure should more specific types of treatment be considered, depending on the nature of the contaminant. One problem which often arises is that of choosing the criteria for deciding when treatment should be stopped. Each case is a special case depending on the general conditions of the accident and the nature of the contaminant, but the practitioner must draw a balance between the risk of residual contamination, resulting in doses in excess of the current limits, and the risks associated with certain drastic methods of decontamination.

The first means to employ is washing with pure water, then soapy water; an acid soap offers the double advantage of often possessing a higher decontamination factor than alkaline soaps and of not being very aggresive to the skin. In the majority of cases water and soap are sufficient to remove most of the contamination [1]. The water should be tepid, never hot, as this would cause hyperaemia. Special care must be paid when the patient suffers from skin disorders, in particular eczema [2].

It is only after the failure of repeated washing that one should consider using special techniques. Such techniques are described in Appendix B. Some of these call for a few comments. The method of applying paraffin or wax at a temperature of about 50°C, allowing it to set and then peeling it off with the contamination fixed in it, is recommended by several authors but in fact is rarely used, no doubt because of the long time it takes. The use of grease solvents is to be strictly avoided [1]; not only is this method completely ineffective but it can also facilitate

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or accelerate penetration of the skin by the contaminant as a result of the changes which it causes in the surface layers. For instance, uranium fluoride penetrates the skin barrier much more readily when it is in suspension in a fatty substance such as lanolin than when it is in an aqueous solution [3].

As it is virtually impossible to reduce the transportable fraction of the contaminating radionuclide by surface treatment, it would seem logical to try and influence the transfer mechanism. Theoretically, the most simple method would be to set up a mechanical barrier to the circulation by means of a tourniquet [4]. However, the medical risks associated with tourniquets and the strict rules governing their use must make this an emergency measure strictly reserved for severely haemorrhagic contaminated wounds of the limbs; moreover, tourniquets must be applied under medical supervision. Another means of reducing translocation is by reducing the blood flow using hypothermia [5]. Cooling not only reduces the blood flow in the area affected but also reduces the rate of absorption by the skin [1]. This is a minor but risk-free technique which facilitates the execution of the necessary measures, for example transportation by ambulance.

The use of chelates for decontaminating the skin in the case of rare earths, plutonium and the transplutonics has long been a subject of controversy. Authors opposed to that method argued that there was an increase in penetration through the skin due to the formation of a complex. This is undeniable [2] and also quite consistent with the liposolubility of the complexes formed by the chelates with the heavy metals. This argument would certainly be valid if the complex were unstable in the body and distributed the contaminant to the retentive organs after its translocation. The real situation is quite different, since DTPA has been proved to form perfectly stable complexes 'in vivo' with elements of valences greater than 2^+ which are eliminated very rapidly via the urine with a very high clearance rate. When it is a question of elements involving fairly considerable risks, such as alpha emitters, it does not seem reasonable, on the one hand, to refuse to accept the risk of a minor exposure, which is extremely limited in time and space, due to transfer of the element into the blood and then through the renal system, and, on the other hand, to accept the risk of quasi-permanent transfer to the skeleton of a fraction which, though minute, can represent a considerable dose integrated over the life of the individual. As it is impossible to predict the extent of penetration of an 'insoluble', this being a function of multiple excoriations of the skin, it would seem essential to perform decontamination of the skin and even more so decontamination of a wound with a DTPA solution.

Some special cases call for special techniques. For example, any contamination of the eye must be treated immediately by copious washing with tap water and then with an isotonic solution in the medical service. In view of the aim of the treatment one should never use eyebaths or the like but rather a continuous and copious supply of fluid.

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3.3. CONCLUSION

Decontamination of the skin, the prime objective of which is to avoid transfer of the contaminating radionuclide, should be performed with simple methods and should be accompanied by continuous monitoring. It should never be allowed to delay general treatment and sometimes constitutes the first stage of such treatment, as for example washing of a contaminated wound with DTPA. The dressings, washing water and any appendages of the skin removed from the body, e.g. hair, should be carefully stored away for subsequent examination to help establish the level of contamination and the effectiveness of the decontamination procedures.

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Chapter 4

PRECAUTIONS TO BE TAKEN IN THE EVENT OF HOSPITALIZATION

4.1. INTRODUCTION

In certain cases the contaminated or irradiated person must be removed to a hospital. The decision to hospitalize a person should be taken by the plant physician, but the victim can also be sent straight to the hospital if the physician or his staff are not available. As stressed in Chapter 6, preplanning between the medical service and the hospital unit is necessary to assure that the latter is prepared for the special problems posed by a contaminated or irradiated patient. The extreme case, which should be avoided by such planning, is for a hospital to refuse to admit a person on the grounds of wishing to avoid contamination of its premises and staff.

As well as assuring that the hospital is provided with the necessary scientific and technical information, it is important that the particular problems associated with the nuclear nature of an accident are put in their proper perspective with respect to medical and/or surgical problems; moreover, we should not forget the psychological aspect often attached to anything involving the 'mystical radiation'. These secondary but important aspects are reduced to a minimum if the hospital service is trained in the handling of radioactive sources as is the case, for example, with a nuclear medicine service. Hospitalization of the affected person can be justified for two different reasons: either on account of the scale or the nature of the accident and the resulting treatment requirements, or simply for reasons of convenience as, for example, for the purpose of making a clinical and biological assessment requiring numerous specialist services and difficult to conceive of on an ambulatory basis.

It is clear that the measures to be taken, whether they belong to the radiation protection, diagnostic or therapeutic category, differ fundamentally depending on whether an irradiation or a contamination accident is involved.

This chapter deals almost exclusively with the special measures necessitated by the nature of the accident, showing how they fit into the framework of a conventional hospital service. Thus no reference will be made to current medical, surgical and biological techniques nor to the specific treatment of irradiated or contaminated patients, as emergency treatment is dealt with in the preceding chapters and the appendixes, and extended treatment is beyond the scope of the present study.

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4.2. EXTERNAL IRRADIATION

In the case of a patient exposed to radiation no measures are necessary to protect the premises or personnel. Since cases of whole-body exposure are rare and there is no urgency in the medical sense of the term, there is no point for all hospitals in permanently setting aside a room for the admission of possible victims of radiation accidents. However, in view of the rarity of such cases and the possibility of their being serious it is essential that a plan be drawn up and adhered to. In particular it is necessary to co-ordinate the actions of the various specialist services involved fairly frequently. These specialist services are numerous and often far removed from each other, both as regards the nature of their normal activities and their geographical location, and it is essential that continuous liaison should exist between them. Thus, to name only the principal ones, it will be necessary – on the clinical side – to be able to call upon specialists in dermatology, neurology, gastroenterology, cardiology, dentistry and otolaryngology, as well as a reliable resuscitation unit and a wide range of biologists from fields such as pathology, with its highly specialized forms as, for example, cytogenetics, bacteriology. immunology, cellular kinetics and histopathology.

The ideal hospital service for the admission of a whole-body exposure victim, whose prognosis is uncertain, is a resuscitation unit or a unit for the treatment of burns; the staff of such a department is familiar with all the methods of isolation and asepsis. A major problem is whether or not to confine the patient in a sterile room. As it is unthinkable that a room should be permanently reserved as a sterile room and as moreover it might not always be possible to make such a room available for an exposure case by displacing another patient, it would seem preferable to use a light plastic isolation tent, kept folded away and regularly inspected, with its own independent filtration system and preferably maintained at overpressure while in use. Such a tent can be erected quickly inside any ordinary hospital room. The choice between sterile isolation and simple isolation against exogenous infections (infections of dental origin should not be overlooked here) is left to the specialist or team of specialists taking charge of the exposed patient. In any case, apart from specialized personnel, the hospital should have some special facilities available, including at the very least a means of isolating the patient.

Although an isolated patient should not as a general rule leave his place of isolation during his illness and it is rather the various specialists who should come and visit him, it is desirable to release the patient to his family at home until changes in his blood values suggest that further hospital care will be needed (about the 21st day). As it is clearly not desirable to expose a patient with agranulocytosis to the attacks of microorganisms which he is bound to encounter in moving about, it is a good plan to have individual sealed transport systems such as stretchers covered with a transparent plastic bubble. Provisions should be made for the isolated patient to have an audio-visual contact with family and friends, to prevent psychological pressures.

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4.3. INTERNAL CONTAMINATION

The contrast between a case of exposure and one of contamination can be readily understood when we consider the measures that have to be taken in a hospital. Whereas in the case of exposure, efforts are directed towards protecting the victim, in the case of a contaminated patient varying measures have to be considered for protecting the staff and the premises and sometimes the public as well. Moreover, an externally irradiated patient does not generally constitute a medical emergency; on the other hand, the prognosis of contamination depends most often on the speed with which treatment is commenced. Generally speaking, accidental contamination of persons occurs at levels not representing any risk of contamination to other persons or to the environment. It is only in the exceptional case of incorporation of a very large quantity of a highly active radionuclide, for example as a result of a misadministration for diagnostic purposes, that measures have to be taken to prevent irradiation of personnel.

4.3.1. Measures for dealing with contamination

Admission to hospital does not generally pose any special problems, because in the majority of cases the external contamination of the victim has been treated and there is no further risk of its spreading. In exceptional cases the patient may have come directly from the place where he was contaminated (case of a person both injured and contaminated, for example); in this case it is desirable for the patient to be admitted by another route than that normally used by patients. Except in cases of medical emergency the patient should be taken to a shower room or to an autopsy table, i.e. a place where decontamination will be facilitated and spreading of the contamination within the hospital avoided.

The risk of staff being contaminated is very small in the majority of cases. Particular attention should be paid to residual contamination of the skin which can be spread during residual desquamation, or contamination of a wound which can be spread when the scab is shed, as well as to contamination which could be caused by excreta. The use of disposable gloves and disposable plastic containers reduces possible risks. Special vigilance is called for in the case of an unconscious patient who is incontinent or vomits in the period following a digestive contamination, as well as in the handling of dressings placed on a contaminated wound. Not only should the usual precautions be observed in handling these dressings but arrangements should be made for keeping and labelling them for subsequent examination to establish the level of contamination.

Ideally, apart from the equipment usually available in a hospital, the following facilities should be available:

An isolated room that can be used for external decontamination of the patient, with a shower and an ocular douche;

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Measuring equipment (for alpha, beta, gamma and X-radiation), capable of detecting low-level contamination, that can be used for the skin and clothes, the ground and walls;
Containers for taking biological samples for radioanalysis;
A sufficient stock of sheets, towels, masks, gloves, general and surgical instruments, and plastic bags for storing contaminated solid waste.

Clearly, these facilities and equipment can only be of avail if a minimum essential number of staff knows how to use them and has thus received appropriate instruction or been provided with all the necessary basic information.

To avoid loss of time, which could have serious consequences in the case of personal contamination, it is essential that informal or, better still, formal arrangements exist between the facility medical service and the hospital unit and that the persons working together know each other personally. This is also desirable in cases where two different nations are involved, so that each knows exactly the possibilities and limitations of the other.

If the level of contamination is high, the staff who has treated the contaminated patient should be required to undergo medical examinations (conducted by physicians or ancillary medical staff) of a kind and at a frequency depending on the nature and amount of the contaminant (for more detailed information see Ref. [1]).

4.3.2. Measures to protect personnel against irradiation from a contaminated patient

So far, there has never been a case where the irradiated patient has been a radioactive threat to hospital personnel. If such a case should arise it would be necessary to cut down the time spent on both medical and general treatment of the patient and to check that the sum of the doses received during the time spent near the patient and/or from his excreta is less than the public dose limits. It is even more unlikely that recourse to the use of screens or markers (zone delineation) will be necessary. Isolation of the patient in a room with one bed usually solves most problems.

4.3.3. Measures for dealing with waste

Contaminated waste should be dealt with in accordance with the generally accepted regulations for handling radioactive waste [2].

As far as excreta are concerned, the problem is not one with which the hospital must concern itself directly since radiotoxicological tests are performed throughout the patient's stay in hospital and the laboratory concerned is used to dealing with the problem of waste. On the other hand, the hospital service may

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have to dispose of various liquid or solid wastes. Any suspect waste should be considered as a contaminant, as long as no proof to the contrary exists. Putrefying material such as faeces and urine should be stored in a freezer. When the radioactive contaminant has a short half-life, it is a good idea to keep it for the necessary period in a locked, ventilated room with a warning on the door. With certain highly contaminated materials it is often better to dispose of them as soon as authorized than to undertake a long, difficult, costly and incomplete decontamination process.

4.3.4. Measures to be taken in the event of a surgical procedure

The measures to be taken in the event of surgical procedures on wounds and pulmonary lavage are dealt with in Chapter 2, § 2.4.3. Only the special precautions intended for protecting the hospital and its staff will be recalled briefly here:

Protect the operating theatre, covering the table, floor, etc. with disposable plastic sheets;
Provide detection instruments appropriate to the nature of the contaminant, some for monitoring the operative fields, surgical instruments and gloves, and others for monitoring the theatre and waste;
Monitor the respiratory or digestive probes in the case of pulmonary or digestive contamination. Fit the mucous extractor with a catch bottle;
Use disposable materials as much as possible and consider as waste all contaminated clothing worn by the surgical team.

4.3.5. Measures to be taken in the event of death of a contaminated patient [3]

It is difficult to formulate general rules concerning the autopsy, burial or cremation of a body containing a certain amount of radioactive material, because the laws on these subjects vary from one country to another. Storing a body for several days at −20°C or −30°C helps to overcome the problem when short-lived emitters are involved. It is in fact rare for the contamination level to be such as to pose problems for burial. On the other hand, it is necessary to consult the regulations if the body is to undergo special preparation, to be cremated, or to be embalmed. This practice should be avoided unless it simply involves injecting a fixing substance. Nevertheless, the persons performing the embalming should take all the usual precautions for handling radioactive contaminants.

The same precautions should be taken during the autopsy, which should be made as brief as possible if the contamination level is high. In the latter case the pathologist should be assisted by a radiation protection officer.

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REFERENCES TO CHAPTER 4

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Medical Supervision of Radiation Workers, Safety Series No. 25, IAEA, Vienna (1968).

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

[3] FROST, D., JAMMET, H., Unsealed Sources, Vol. 2 of Manual on Radiation Protection in Hospitals and General Practice, Sponsored by ILO, IAEA, WHO, Published by WHO, Geneva (1975).

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Chapter 5

ASSESSMENT OF FITNESS TO RESUME WORK AFTER CONTAMINATION OR IRRADIATION ACCIDENTS

5.1. GENERAL PRINCIPLES

Any accident involving internal contamination or external exposure requires certain decisions to be taken by the physician; as some of these decisions can have important consequences for the worker concerned, all the factors must be weighed very carefully. In all cases lessons should be drawn from the accident and steps be taken to improve plant operation protection of workers. To this end, the investigation of the accident should:

(a) Examine the circumstances of the accident in consultation with the radiation protection staff and those responsible for the operation of the facility in question;
(b) Record all the results of measurements carried out, noting carefully the dose to organs or tissues, as well as decisions of a medical and/or administrative nature that have been taken as a result of dose limits having been exceeded.

In addition, the physician should conduct follow-up examinations on such persons to determine whether or not the accident has physical or biological sequelae. Any change of a medical nature occurring some time after the accident should be recorded.

The physician should ensure that the worker concerned is fully informed of the situation. In particular he should inform him of all the risks to which he is subject as a result of his contamination or exposure, this being especially important when the worker is returning to his former job. Thus, in the case of a job involving the risk of further contamination or exposure the physician should explain clearly in terms comprehensible to the worker the pathological effects which could result in the long term. Talking to the worker in this way is also likely to make him take extra care so as not to allow the accident to happen again.

The administrative decisions which the physician has to take are rarely simple. It is only exceptionally that one encounters clear-cut issues that are easy to resolve, as is often the case in ordinary occupational pathology, with concrete lesions or sequelae determining whether a person is physically or physiologically capable of doing a particular job. In the case of a nuclear type accident resulting in clinical changes it is clear that the job must be changed or adapted so that the risk of aggravating these sequelae is reduced as much as possible. The possibility of another accident occurring, which would result in the person concerned

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receiving another dose in addition to that received in the original accident, should not be the sole determining factor. However, attention should be paid to whether the worker was personally partly to blame for the accident which could then be a decisive argument for moving him to another job.

In the majority of cases, management in consultation with the physician and the radiological health and safety officer must take into account non-objective criteria such as socio-economic status, age, sex and job expertise to arrive at a decision on the patient's job fitness. The problem is not just to evaluate the probability of sequelae but to evaluate the possible risks in the far distant future. The management team must base its decision on several considerations: knowledge of the risk with all the uncertainties which this involves, knowledge of the problems of re-classification for the person concerned, and knowledge of the psychological problems which a decision of unfitness for work could result in for the worker, his colleagues and his family. However, the physician himself should decide on the frequency and nature of the medical examinations the patient should undergo, taking into account the nature and the gravity of the accident.

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Chapter 6

ORGANIZATION, PLANNING AND TRAINING [1–4]

6.1. INTRODUCTION

The proper functioning of any first-aid station depends on the planning and outfitting of the facility, and the training and organization of its personnel. This is particularly true for first-aid establishments with responsibilities for caring for injured personnel in radiation accidents. It is, however, quite difficult to maintain high levels of readiness and efficiency because dedicated radiological safety practices successfully reduce the incidence of radiation accidents by many orders of magnitude below that of heavy industry at large. Organization, planning and training must therefore be tested by well-planned drills held at unpredictable times which address the potential problem of a specific site of some specific plant. In this section suggestions are made concerning organization, outfitting, planning, training and drilling.

6.2. GENERAL MEDICAL ORGANIZATION – PRINCIPLES

The rules governing medical assistance determine the infrastructure that must exist in advance and must be capable of being put into operation at any moment. Whatever the nature of the accident – irradiation or contamination – the various stages in medical treatment form a chain in which each successive link is of an enhanced degree of sophistication.

6.2.1. On-site emergency treatment

Clearly, only first aid for a contaminated individual is involved here, since an irradiation casualty does not require any emergency treatment. The principle that *emergency treatment should be given when there is any suspicion of contamination,* as discussed in Chapter 1, §1.3.2, calls for the implementation of this treatment even before the doctor arrives, in order to reduce to the minimum the time between contamination and treatment. It is therefore desirable that anybody exposed to any risk of contamination should have a first-aid kit (see Appendix D) of compact size and containing a small selection of simple, non-toxic medicaments put up in individual dose units and intended to be taken by the contaminated patient himself at the site of the accident. This first-aid kit can only be used if the staff is properly informed and trained. Therefore education and instruction must be one of the main tasks of the medical service.

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6.2.2. Facility medical service

This service constitutes the second stage for the casualty. Whereas first aid as described above can, if necessary, be dispensed with, it is inconceivable that the medical service responsible for the casualty should not intervene in an appropriate manner. The means at its disposal are extremely variable in their extent, as they depend on the size of the facility and the hazards incurred there. The ideal is a medical service on the site of the facility itself, having the resources necessary for isolation, decontamination and rapid measurement of external and internal contamination of casualties, in addition to premises suitable for these purposes. The service must possess equipment and laboratories enabling it to handle these casualties in an efficient manner, i.e.:

(a) Rapidly to perform the necessary sampling and biological examinations;
(b) To treat several contaminated persons at the same time without spreading the contamination (i.e. availability of rooms for undressing and others for showers or baths, separated by airlocks and of a one-way system ensuring that a decontaminated individual does not go back into a suspect area);
(c) To provide radioactivity measuring equipment adapted to the hazards involved, ranging from a portable detector to a whole-body counter;
(d) To ensure that the facility has a list with names, phone numbers and addresses of specialists who may be called in for assistance;
(e) To provide – and this is most important – the medicaments needed for treating these particular casualties. In small- or medium-size medical services it is desirable to have first-aid kits similar to those for individual use on the site of the accident, but intended for the physician himself (see Appendix D).

The small size of many nuclear facilities does not justify a medical service with such resources and a large staff. It is here that an accident could present most problems. In large facilities the first two stages in treatment – emergency treatment and treatment at the facility medical service – can be combined in time and space, normally without any undesirable effects for the casualty, but in a small facility with only a small medical service this is more difficult, especially if the medical service is situated away from the site. In this case the physician in charge, who would not have at his disposal large-scale resources for the purpose of making a preliminary assessment, can only refer the casualty to the nearest or best equipped hospital. In every case transport must be adapted to the person's condition. Whereas an irradiated individual can be evacuated without particular precautions, in the case of a contaminated patient it is necessary to take steps to avoid spreading the contamination, especially if the facility has no means of external decontamination. Certain items of special equipment, such as stretchers with isolation sheets that are air-tight and adaptable to various uses, ambulances lined

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inside with disposable plastic, etc., can for the most part solve this problem and, moreover, make it possible to transport the contaminated individual even when he is also injured.

6.2.3. Regional hospital

The essential role of the regional hospital is to make up for the inadequacies of the local medical service. The regional hospital must also be provided with a list of experts in a variety of disciplines (surgery, haematology, internal dosimetry, etc.) who can be called in for consultation or assistance. The names, addresses, phone numbers, etc. have to be incorporated in the overall emergency scheme. It may be essential, on surgical grounds for example, to hospitalize the patient urgently, and in this case only a regional hospital can cope with the situation. It may also happen that it is preferable for social, economic and/or psychological reasons not to move the patient and that the regional hospital is sufficiently well equipped. This is the case where, for example, a contaminated wound requires only simple surgical intervention; here the operation can only be done with the attendance of a specialist in radioprotection and it is this specialist who must come to the patient together with his measuring equipment.

Thus, although it is desirable to reduce the involvement of the regional hospital, the latter should be in a position to deal with a certain number of situations. Although it is inconceivable that vast resources should be devoted to equipment at this level, e.g. isolation chambers and operating theatres designed from a nuclear viewpoint, and built and maintained against the eventuality of an accident, it is none the less necessary to make a survey of existing resources and to adapt them to specific needs. Thus it is, for example, preferable to have a special entrance for contaminated patients, with direct access to a suite of rooms that can be adapted for purposes of decontamination and that are immediately available. Standard operating theatres equipped for aseptic conditions are suitable for typical operations, and effective external decontamination of the casualty makes it possible to avoid spreading radioactive contamination to any extent.

6.2.4. Central hospital

It is at the level of the central hospital and only at this level that the large-scale medical treatment resources are to be concentrated. One central hospital is sufficient for a country of medium size and can even cope with accidents occurring in several countries. There are two conditions governing the design of large-scale resources to be used in cases of irradiation or contamination: (a) these resources should be used throughout the year for other, routine purposes, on grounds both of economic viability and of reliability; (b) they should be immediately available in case of accident.

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A typical example is that of a hospital capable of dealing with the consequences of irradiation and of contamination accidents, although the resources used in each case are very different. Both cases can be handled efficiently only if there is close co-operation with specialized laboratories, some of which may not have any normal relationship with the central hospital; i.e. it is important at this level that the various measures to be taken should be effectively co-ordinated, final decisions naturally remaining the responsibility of the chief physician of the central hospital.

Unfortunately, in many countries the existing hospital infrastructure does not provide for such a service, and the procedures adopted must be based on what is available. In the case of an irradiation accident, the choice of the appropriate procedure, and hence of the medical service involved, is relatively limited. Resuscitation units and units for severely burned casualties are among those which provide the optimum conditions for the patient; the staff of such units is familiar with all techniques for isolation and asepsis. Confinement in a sterile atmosphere, if it is decided that this is necessary, can be achieved by setting up a light plastic isolation tent, which has the advantage of being immediately disposable and portable and making it unnecessary to move an ordinary patient in order to permit treatment of the irradiated individual. The specialists involved are very numerous and among these are the members of the dosimetry team. Although in most cases the latter have no organic link with the hospital, they must go into action rapidly. Apart from the preliminary results which indicate an order of magnitude of the irradiation, reconstitution of the accident provides information on the spatial dose distribution, which is a vital element in prognosis.

A contaminated patient presents problems of a very different nature. A nuclear medicine or radiopathology service can handle such a situation without undue adjustments having to be made, as it will possess measuring equipment and facilities to store and dispose of radioactive effluents; in particular, it will have a staff that is used to the problems presented by the handling of radionuclides. However, the special conditions attending surgical intervention on a contaminated individual must be met by insisting on co-operation between the surgeon and the specialist in radioprotection. In this case information plays an important role, since certain manoeuvres are quite unusual for a conventional operating theatre.

In general, the central hospital, however sophisticated it may be, does not have on its staff all the specialists needed for a nuclear accident of any size – whether involving internal contamination or external irradiation – since the disciplines called for are numerous and sometimes go beyond the medical sphere. Co-ordination of these numerous specialists, each of whom has different responsibilities, is essential, even if only in order to draw up an order of priority for the measures to be taken. It is with this in mind also that relations between the medical service of the facility and the central hospital must be maintained, and the latter must be regularly kept abreast of the particular problems posed by casualties involved in nuclear accidents.

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Each accident is an individual case, and the number and type of specialists involved and the resources employed must be adapted to each case. Thus, there is no strict rule governing evacuation of the casualty; it is clearly preferable to evacuate the person to the specialized unit in which he will find the treatment best adapted to his condition. However, it may be that for medical, logistic or psychological reasons the best solution is to minimize the movement of the casualty and to keep him in the local hospital. In this case it is the specialist team, accompanied by the necessary equipment, that comes to the bedside of the patient.

6.3. FIRST-AID STATION

6.3.1. Organization and planning

The complexity of the organization of first-aid stations is dependent on the number of people employed, the particular hazards of the operation and the potential seriousness of the radiation accidents. For instance, large radiopharmaceutical manufacturing plants do not have to take precautions against the potential accidents likely to occur at fuel fabrication plants, and power reactors have less potential for accidents than fuel reprocessing plants of similar size. The first step therefore in the organization of a specific first-aid programme depends upon an intimate knowledge of the operations of the plant and the radionuclides involved. Such an analysis must also include the identification of geographical and transportation problems in relation to the size of work-forces at satellite sites. From this the number and location of first-aid stations and their staff and equipment needs are determined. The station and staff then are integrated into the medical management of the central plant dispensary. The complexity of the communication network is defined by the need for back-up support between individual first-aid stations as well as by the dependence of their staff upon central dispensary direction. A redundant communication system in an accident response plan, where the central and outlying sites are integrated, makes it unnecessary for all sites to have the same capabilities for responding to the maximum credible accident at the plant or to be equally equipped. The response plan to be developed starts therefore with an analysis of the hazards in the immediate territory of a particular first-aid station and plans are tailored individually to meet them. The plans should then provide for increasing levels of inter-site support and all-facility response as the seriousness of an accident and the number of people involved increase beyond the capabilities of one or several first-aid stations.

Even though a small plant or laboratory may not require a full-time physician, paramedical staff or health physicist, it will need a consultant physician, a well-trained first-aid team and an experienced radiological safety officer. In the event

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of an accident, the first-aid team could handle immediate first aid while contacting the consulting physician who would direct the next actions. Based on a previously established plan, the patient could be taken to an area hospital which has a decontamination facility and a trained medical staff, or he could first be transported to another, larger and better equipped in-plant decontamination facility or occupational medical department and later to the hospital if necessary.

Pre-planning is obviously of paramount importance. Knowing the potential radiation hazards in a particular plant or laboratory and having a careful action plan designed to handle all credible accidents is far more important than elaborate and expensive facilities.

The basic first-aid team member is a physician trained in the management of radiation accidents. The other first-aid team members are radiation workers who have received special first-aid training, and/or trained nurses and/or technicians. One or several health physicists or radiological safety officers familiar with radiation detection instrumentation and the special radiation protection problems associated with accidents are also essential. A designated central manager, not actually involved in administering first aid, must be available to perform the valuable service of co-ordinating communication, technical support, transportation and management of personnel in the accident area who have not been obviously contaminated or exposed, but who require careful monitoring for radioactivity.

6.3.2. Facilities and equipment

A minimum first-aid facility should have an area where both decontamination and first aid can be performed. It may consist only of a room painted with strippable paint, equipped with an autopsy table with a central drain, and hot and cold water which can be mixed and delivered in a flexible plastic or rubber tube with a shower head. A moveable lead shield, lead apron and lead gloves covered with plastic gloves should usually be all that would be required for most accidents involving skin or wound contamination with beta and gamma emitters. Alpha-emitting radionuclide contamination requires no shielding, but inhalation and skin contamination of team members must be avoided. Elaborate decontamination facilities have been designed and constructed for large plants [2–4], but some are probably overdesigned and unnecessarily expensive.

The waste water from the decontamination table should be collected in a holding tank for later monitoring and special disposal as required. Special ventilation and air-conditioning may be necessary to prevent air contaminated with alpha-emitting radionuclides from flowing to other rooms. The members of the first-aid team must have effective respiratory protective devices that have been prefitted so that they are protected from inhaling radionuclide contamination which may become airborne during the decontamination effort. Full protective clothing, including coveralls, shoe-covers, caps and plastic gloves, should be put on

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by the members of the first-aid team before they arrive on the site of an accident; it may have to be changed if it becomes excessively contaminated during the initial decontamination effort.

If possible, the patient should have all contaminated clothing removed at or close to the site of the accident. If he is ambulatory, he can shower and wash himself under monitoring supervision. The patient is covered with sheets or blankets if it is necessary to keep him thermally comfortable. If the initial decontamination cannot be completed, a plastic bag or sheet is used to prevent spread of contamination to the transporting vehicle, e.g. the ambulance. If the weather is warm, it should be remembered that a patient placed in a plastic bag can be subjected to considerable heat stress when transported 30–70 km in an ambulance.

A well-equipped first-aid kit with splints, bandages, tourniquet, life support medications, airway, basic emergency surgical instruments, intravenous fluids, etc. should be provided at all designated sites and periodically checked to ensure that all supplies are in good functioning order and sterile if necessary. The contents of such a kit are described in Chapter 1 and in Appendices D and E.

The contents of a group medical kit containing medications that prevent the uptake of radionuclides are described in Appendices D and E. Skin decontamination supplies and techniques are described in Appendices B and E. The required containers and instructions for collecting blood and urine samples in cases of exposure to penetrating radiation are included in Appendix A.

Each first-aid facility should have plastic bags for collecting and labelling clothing, jewellery, etc., containers for collecting urine and faeces, and specimen bottles with formalin if freezing facilities are not available nearby. A portable tape recorder, enclosed in a plastic bag, with the microphone suspended near the decontamination table, can be helpful to record details of the history of the accident, physical findings and details of the decontamination effort and treatment. Felt pens (black and red) are useful for marking areas of contamination when the patient has to be moved for further decontamination. Several extra pairs of large bandage scissors should be included in any first-aid kit, since clothing may need to be cut off the patient.

6.4. TRAINING AND DRILLING

Since radiation accidents are relatively rare, personnel who will have to handle the first-aid care cannot expect to derive their skill from experience. They must receive careful training at formally held courses, by practice drills and by taking on responsibilities for inspection and review of their own facility and, if possible, other production or research facilities. The results of the drills should be recorded and kept, including records of first-aid exercises.

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Practice drills, if realistically staged with a carefully developed scenario, can identify deficiencies in the preparations for an accident. After a drill, a critique should always be held. Experienced observers can then advise all participants of their mistakes or lack of judgement and skill. Revisions in plans and up-grading of skills, which should occur after each exercise, help prepare for the real accident, if and when it occurs.

Inspections of production and research facilities, at least by senior members of the first-aid team, enable the team members to challenge their supervisors to speculate on possible accidents. They learn what radiation devices, sources or radionuclides are being used and how an accident might occur. Armed with the knowledge of the possible accident, the preparation for handling it should be relatively easy. Members of a team can be required to develop written plans for accident responses which can then be reviewed for completeness and clarity.

6.5. NATIONALLY AND INTERNATIONALLY AVAILABLE RADIATION ASSISTANCE PROGRAMMES

Since 1959 the IAEA has had an action plan to arrange for assistance after an accident involving radioactive materials. There are three main aspects to the current plan:

(a) Member States are encouraged to determine in advance what outside assistance would be needed in the event of an accident and then enter into a multilateral assistance agreement with neighbouring states. In 1963, the 'Nordic Agreement' was signed by representatives from Denmark, Finland, Norway, Sweden and the IAEA.

(b) Through training programmes Member States have been encouraged to develop their own capabilities to handle emergencies. Such programmes have been conducted in Manila, Teheran and Buenos Aires.

(c) The IAEA is prepared to arrange for specialized assistance after an accident, e.g. for medical and radiological support. Starting in 1963, the IAEA has issued periodically an internal report on Mutual Emergency Assistance for Radiation Accidents [5] which identifies what assistance can be made available at the request of another state. WHO, FAO and ILO have participated in later revisions of this publication; the most recent was issued in 1971.

The IAEA maintains the capability to have a senior technical person available through a duty officer roster in the event of a telex or telephone request for assistance and to act as the intermediary in transmitting requests for assistance. The programme also includes the capability to send a small group of observers or consultants to the site. The facilities of the Agency's laboratory for radiochemical

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analysis of environmental samples and for bioassay and whole-body counting are also available.

In April 1977 the IAEA entered into an agreement with the United Nations Disaster Relief Organization (UNDRO) by which technical support will be provided in the event that disaster relief involves radiological aspects.

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APPENDIXES

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Appendix A

SAMPLES TO BE TAKEN IN CASES OF EXTERNAL IRRADIATION OR INTERNAL CONTAMINATION

A-1. EXTERNAL IRRADIATION

In all cases a certain number of samples are necessary. It is essential to follow the prescribed techniques carefully if the samples are to give the desired results.

A-1.1. Blood

The blood is used for:

(a) Haematological tests: Differential and absolute white blood cell and platelet counts: haematocrit reading, blood picture, haemoglobin;

(b) Biochemical measurements: electrolyte balance;

(c) Chromosome analysis: lymphocyte cultures for analysis of chromosome breaks using banding technique if possible.

The following samples should be taken (by vein puncture with disinfection by means of alcohol or alcohol-ether, never iodine):

(a) 2–5 ml in dry EDTA (2 mg per 1 ml of blood); stir immediately; prepare smears on slides, recording the date, time and subject's name on the label;

(b) 5 ml with heparin (1.25 mg); for electrolyte study;

(c) 10 ml with heparin (2.50 mg) in a sterile, hermetically sealed flask (penicillin type) for cytogenetics;

(d) Bone marrow aspiration (usually there is no time for it).

As far as possible, test (a) should be repeated several times during the first six hours. At the specialized treatment centre lymphocyte counts will be obtained at daily intervals. Cytogenetic tests should be repeated at the specialized treatment centre for confirmation. If shipment to a cytogenetic laboratory is required, a cytogeneticist should be consulted.

A-1.2. Urine

The first urine passed after the accident is especially important and should therefore not be mixed with subsequent specimens for the first day. The time of passing should be carefully recorded. Great care should be taken to avoid radioactive contamination of the sample. Urine is preserved in a cold state, preferably in a refrigerator.

A-1.3. Induced radioactivity

This is a special case, since neutrons activate light nuclei. Hence, in addition to *whole-body spectrometry,* which gives an indication of level and permits separation into

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categories, *all objects carried by each patient should be tested.* While avoiding all external contamination, not only the identity of the object but also its exact position on the body of the patient should be carefully noted for later physical dosimetry. Particular attention should be given to objects made of, or containing, gold, copper, sulphur, phosphorus, wool, i.e. jewellery, wrist-watches, spectacles, cigarette lighters, match-boxes and clothing. The general rule is to preserve everything, placing it in bags and labelling it.

Similarly, measurements on hair, nails and so on may be made; the patient should therefore not be shaved, except in emergency surgery cases; if shaving is essential, head and body hair should be kept in labelled bags.

This biological sampling should of course be conducted at the same time as the collection of *physical dosimetry data* relating to the source of exposure, environmental radiation, individual geometric parameters and, above all, *time;* the very great difficulty of subsequently evaluating the duration of an exposure is well known.

A-2. INTERNAL CONTAMINATION

Biological samples, in conjunction with direct measurement of the body burden or the burden of the organ affected, enable the contamination to be diagnosed, the seriousness of it to be assessed, and the treatment to be decided on or worked out in broad outline. The type of sampling depends on the contaminant and the mode of contamination; each specific case is dealt with in Annex C. Certain requirements, however, apply in common to all radiotoxicological tests.

A-2.1. Blood

In addition to the routine clinical haematological blood tests as described in § A-1.1, additional blood may be used for radionuclide investigation since the greatest amount of data possible is needed in such cases.

Amount to be taken:

(a) 20 ml, untreated, without preservative or additive;
(b) 10 ml with heparin.

The analytical laboratory should preferably have the two samples, one untreated and the other with heparin, since the contaminant cannot always be identified right away and, even if it is, a second analysis frequently produces unexpected results.

If the contamination leads to exposure, either internal because of its high level, or external because of the type of radiation emitted as, for example, in the case of ^{24}Na, the blood samples described in § 1.1 should be taken in addition; thus the sample with heparin would be used for both groups of samples.

A-2.2. Urine

The first specimen is required immediately; after that, urine should be collected. The amount collected during every 24 hours should be kept separately.

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A-2.3. Faeces

All stools passed during the first 3 or 4 days should be collected, the minimum number required for this period being three.

A-2.4. Miscellaneous

Handkerchiefs used at the time of respiratory contamination, smears on paper handkerchiefs, nasal smears and induced cough specimen should be collected for radionuclide identification and quantitation.

Medico-legal and other post-accident investigation requires that no blood, urine or other samples taken during the first-aid period be disposed of without authorization.

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Appendix B

TECHNIQUES FOR LOCAL DECONTAMINATION OF THE SKIN

B-1. GENERAL RULES

Before any other action, the following steps must be taken:

(a) Provision of radiological first aid if the radionuclide is known to be rapidly absorbed (e.g. iodine);
(b) Verification that there is no wound;
(c) Treatment of skin wounds before dealing with the contamination in the event of injury to the skin from chemical contaminants (concentrated acid or base, or a burn caused by the sodium in a plutonium/sodium mixture, for example);
(d) Prompt verification of the contamination level.
In the case of an extremely high contamination level it may be important to consider:
The wearing of a mask by the patient and attendant personnel;
Prompt, rough and ready decontamination, after immediate removal of all clothing (the clothes being preserved in leak-proof plastic bags) to avoid whole-body over-exposure;
If possible at all, all clothing should be removed before transportation;
(e) In all cases, adoption of measures required to prevent the spread of contamination;
(f) In the case of contamination of the eyes, nose and/or buccal cavity, flushing of the affected part copiously with running water.

B-2. TECHNIQUES

B-2.1. Skin contamination covering a very large area

The patient should be given a warm shower. The water used should be collected and monitored before disposal; hence the advantage of special facilities set up solely for this purpose at the site of the risk. Use only soft soap, preferably acid. Always wash from the top downwards; after the patient has been dried off, further monitoring should be carried out. In the case of residual contamination, proceed as indicated in Section B-2.3.

B-2.2. Localized contamination

Hands: Avoid introducing contamination through existing excoriations and microcuts. Any brushing that proves necessary should be done gently with a soft brush. With a large number of small contaminated spots, special care should be taken not to spread the contamination and thereby produce a contaminated surface larger than the sum of the original spots. A 25% $NaHClO_3$ solution is particularly helpful.

Hair: Wash repeatedly with soap, making sure that the contamination does not get into the eyes, mouth or nose during rinsing. In some cases the hair will need to be clipped.

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B-2.3. Residual contamination

If residual contamination persists after the immediate action described above, more specialized decontaminants may have to be used:

(a) Rare earths, plutonium, transplutonics: Wash with an acid 1% DTPA solution (pH 3-5); rub gently, working from the centre of the contaminated spot towards the outside; if DTPA is not available use an aqueous HCl solution (pH 1); repeat as many times as required, but always stop if hyperaemia of the skin occurs.

(b) Alkalis, alkaline earths: Washing with water should be enough and should therefore be continued; in the case of strontium, check carefully to see whether there are any wounds, no matter how small; if there are, try local insolubilization (for example, with potassium rhodizonate [B-1]).

(c) Uranium: Wash with a bicarbonate solution.

(d) Fission products: Wash with 1% DTPA or HCl solution.

(e) If the desired results are not achieved, try painting with potassium permanganate or – still better – a saturated solution composed of $KMnO_4$ and 0.2N H_2SO_4; the mixture is applied with gentle rubbing; after drying the skin is washed; persistent spots are removed with a solution of 5% sodium sulphite ($NaHSO_3$), care being taken not to let the solution remain in contact with the skin for more than 2 minutes.

(f) In some cases, localized hotspots of insoluble material embedded in the horny layer of the skin can be removed by sand paper or sticky tape.

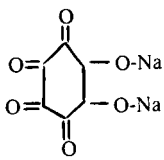
B-2.4. Final procedures

If monitoring of the dry skin shows that there is a fixed residual contamination, the application of a neutral fat such as lanolin will prevent crack formation (the integument may have been subject to mechanical or chemical action) and spreading of the contamination during natural desquamation. As an additional precaution an occlusive protective dressing could be applied; this should be kept and monitored upon ablation. The dressing may be of the plastic type, or applied in liquid form or as a spray.

B-3. SPECIAL CASES

Contamination of the eyes. Wash profusely; a special cabinet should always be available for eye washing at the site of the risk.

[B-1] Potassium rhodizonate: Empirical formula: $C_6O_6K_2$; the sodium salt $C_2O_2Na_2$ is just as efficient. The structural formula is:



The crystal form is violet, it is soluble in water (yellow orange), insoluble in alcohol, solutions are unstable, even if kept in a refrigerator.

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Contamination of the nose. Wash with isotonic saline after the products resulting from cleaning of the nostrils and nose-blowing on compresses have been collected for monitoring purposes. Nasal irrigation is usually feasible only under hospital conditions.

B-4. EQUIPMENT AND SUPPLIES TO BE PROVIDED

No special medical equipment is necessary, but since any chance of the contamination spreading has to be avoided and the effectiveness of the decontamination evaluated, the number of compresses, swabs, etc. required is always very large. Provision should therefore be made for a large stock of such materials, i.e. boxes of compresses and gauze, rolls of cotton wool, cotton wool plugs, rubber gloves, tongue depressors, eye baths and soft brushes. The medical compounds and drugs required are quite specific, and prepared solutions appropriate for the type of facility risk involved should be available. (The specialized radiological equipment is discussed in Chapter 6.)

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Appendix C

BASIC TREATMENT INFORMATION FOR THE PHYSICIAN

INTRODUCTION

This information in the form of data sheets is arranged in alphabetical order by radionuclide; some radionuclides are dealt with in groups when their biological behaviour and therefore the treatment is similar. These groups are the rare earths, i.e. the entire lanthanide series, and the actinide series including the plutonics. In the lanthanide series only the main elements, i.e. La, Ce, Pr, Pm, Yb and Lu, are characterized, and in the transplutonic series Am, Cm, Bk, Cf and Es are characterized. A special data sheet is used for fission products as it is conceivable that contamination could be caused by a mixture of fission products; this sheet describes the principles of treatment in a generalized form. For details of treatment, one need then only refer to each element concerned. The data on each sheet are given under the following headings:

Therapy

The emergency treatment to be given, either at the site of the accident or in the plant medical service or clinic, is summarized here. Subsequent treatment, possibly prolonged or requiring a high degree of specialization, is hardly touched on, since the techniques involved call for the services of trained hospital staff. Further, no attempt is made to prescribe treatment for special cases lying outside the normal occupational context (for example, children and pregnant women). First-aid treatment should, in cases of females, be applied with caution when pregnancy is suspected.

Note on metabolic behaviour

This brief reminder is intended to supplement the information in the preceding section. This part is sometimes intentionally omitted when it does not add anything worth while.

Personnel monitoring

The methods of personnel monitoring for workers working with the element in question are summarized here. The techniques of greatest value to the radiological protection experts are emphasized.

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Chief characteristics

These are the characteristics which may be useful for the physician called upon to give first aid and to assess the extent of the dose delivered as a result of contamination. They are given in the following order:

(a) Type of radiation emitted.

(b) Maximum energy.

(c) Relative percentage.

(d) Radioactive half-life: $T_{\frac{1}{2}}$.

(e) Target organ: In a case in which there are several possibilities, for transportable and non-transportable radionuclides for example, it is the most restrictive and/or the most likely one which is given; sometimes two possibilities are indicated.

(f) Biological half-life: $T_{\frac{1}{2},biol}$.

(g) Effective half-life: $T_{\frac{1}{2},eff}$.

$$T_{\frac{1}{2},eff} = \frac{T_{\frac{1}{2}} \times T_{\frac{1}{2},biol}}{T_{\frac{1}{2}} + T_{\frac{1}{2},biol}}$$

(h) Annual limit of intake (ALI) based on inhalation of radioactive material[C-1].

(i) Effective energy (in the case of non-uniform radiation, the energy of the uniform radiation which under the same conditions would be absorbed in the same way).

Note for (g), (h) and (i): If two target organs are indicated under (e), the two corresponding values of the biological and effective half-lives and the effective energy are given.

(j) Specific gamma-ray constant, Γ. A dash indicates that either the number was not available, or that it was not evaluated because of an uncertain or complex decay scheme, or because daughter radiations contribute appreciably to the gamma dose rate.

[C-1] The annual limits of intake quoted here are those listed in Table IIA of the IAEA Safety Series No.9 [1], which are based on the ICRP Report of Committee II [3]. These values should be replaced by the forthcoming ICRP values for annual limits of intake when they are available.

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On the basis of these data a simplified calculation of the dose delivered can be made. Thus for irradiation by *alpha or beta emitters* we may use the following notation [2]:

f – number of particles emitted per disintegration: the number of particles emitted per second per kilogram = fc;
c – concentration of radionuclide ($Bq \cdot kg^{-1}$)
(Note: $1\ \mu Ci \cdot g^{-1} = 3.7 \times 10^{7}\ Bq \cdot kg^{-1} = 37\ MBq \cdot kg^{-1} = 37\ kBq \cdot g^{-1}$);
E – effective energy (MeV);
$T_{\frac{1}{2},eff}$ – effective half-life (d).

The dose rate, therefore, for alpha or beta emitters, $D_{\alpha,\beta}$, in units of grays per second ($Gy \cdot s^{-1}$), is given by[C-2]:

$$\frac{D_{\alpha,\beta}}{(Gy \cdot s^{-1})} = 1.6 \times 10^{-13}\ f \cdot \frac{c}{(Bq \cdot kg^{-1})} \cdot \frac{E}{(MeV)}$$

where 1.6×10^{-13} is the conversion factor for MeV to joules (J) since E is given in units of mega-electronvolts. If the dose per day is required, the formula given below will apply for radionuclides having half-lives longer than about 20 days:

$$\frac{D_{\alpha,\beta}}{(Gy \cdot d^{-1})} = 1.38 \times 10^{-8}\ f \cdot \frac{c}{(Bq \cdot kg^{-1})} \cdot \frac{E}{(MeV)}$$

When the timespan of incorporation is more than, for example, two half-lives, since the average life is $1.443\ T_{\frac{1}{2},eff}$, with $T_{\frac{1}{2},eff}$ measured in days, a conservative estimate of the total dose is given by:

$$\frac{D_{\alpha,\beta}}{(Gy)} = 2 \times 10^{-8}\ f \cdot \frac{c}{(Bq \cdot kg^{-1})} \cdot \frac{E}{(MeV)} \cdot \frac{T_{\frac{1}{2},eff}}{(d)}$$

(In the traditional special units, the total dose in rads is given by:

$$\frac{D_{\alpha,\beta}}{(rad)} = 73.8\ f \cdot \frac{c}{(\mu Ci \cdot g^{-1})} \cdot \frac{E}{(MeV)} \cdot \frac{T_{\frac{1}{2},eff}}{(d)}$$

where c is in units of $\mu Ci \cdot g^{-1}$.)

C-2 In this Appendix, the symbolism used in the equations is the one given in International Standard ISO 31/0, section B.2.3 (ISO, Geneva (1974)), parentheses being retained around the units of the various quantities to make them stand out. Hence $\frac{c}{(Bq \cdot kg^{-1})}$ is *read* as concentration measured in units of becquerels per kilogram, etc. The factors are not dimensionless and contain the necessary conversions from days to seconds, μCi to Bq, MeV to joules, etc. Simple dimensional analysis will provide the reader with the units of the factors if required.

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To determine c, we have to know the mass of the organ under consideration [3, 4].

	Mass[a] (kg)	Percentage of whole-body weight
Whole body	70.	100%
Bone mineral	7.	10%
Red bone marrow	1.5	2.1%
Gastro-intestinal tract	2.	2.9%
Stomach	0.25	
Upper large intestine	0.135	
Liver	1.7	2.4%
Lungs	1.	1.4%
Kidneys	0.3	0.43%
Spleen	0.15	0.21%
Thyroid	0.02	0.029%

[a] Note: when c is used in units of $\mu Ci \cdot g^{-1}$, the organ mass must be converted to grams.

For *gamma emitters* [5], assuming uniform distribution throughout the body, the mean dose to the soft tissues can be calculated using the formula:

$$\frac{D}{(Gy)} = 9.35 \times 10^{-12} \frac{\Gamma}{(R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1})} \cdot \frac{c}{(Bq \cdot kg^{-1})} \cdot \frac{T_{\frac{1}{2},eff}}{(d)} \cdot \frac{\bar{g}}{(cm)}$$

where Γ is the specific gamma-ray constant[C-3], given in the tables, c is the concentration of the nuclide, $T_{\frac{1}{2},eff}$ is the effective half-life already defined, and $\bar{g}$ is the average value of the geometrical form factor for the human body determined from Fig. C-1.

[C-3] Since there is no SI unit for the unit of exposure, it was decided that data for Γ would in this Appendix continue to be given using the special units roentgen and curie. The data are taken in the main from Ref. [6].

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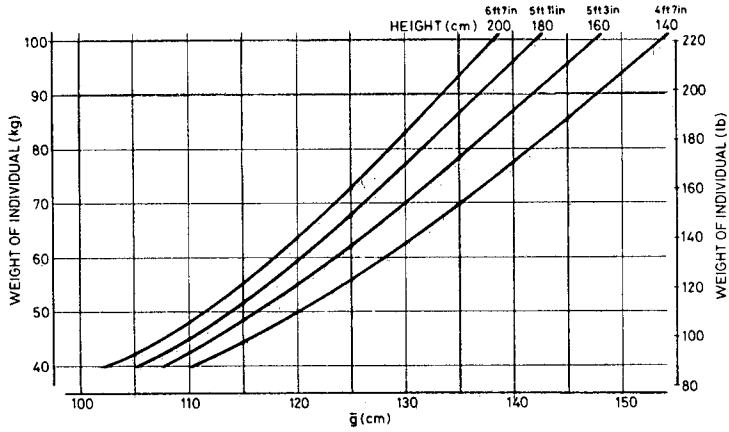

FIG.C-1. Average value of the geometrical factor for the human body, $\bar{g}$, based on data from Ref. [7] *for a gamma-ray emitter uniformly distributed throughout the human body. See also* [5].

For the dose in rads, using a concentration expressed in microcuries per gram:

$$\frac{D}{(\text{rad})} = 0.0346 \frac{\Gamma}{(\text{R}\cdot\text{cm}^2\cdot\text{h}^{-1}\cdot\text{mCi}^{-1})} \cdot \frac{c}{(\mu\text{Ci}\cdot\text{g}^{-1})} \cdot \frac{T_{\frac{1}{2},\text{eff}}}{(\text{d})} \cdot \frac{\bar{g}}{(\text{cm})}$$

where Γ, $T_{\frac{1}{2},\text{eff}}$ and $\bar{g}$ are identical with those used above.

(It should be noted that these factors not only contain the normal conversions (see footnote C-2), but also: (i) the conversion for grays per roentgen or rads per roentgen, respectively, assuming the factor to be 1 rad·R^{-1} (the actual value for muscle at photon energies from 0.2 to 3 MeV varies between 0.95 and 0.98 [5], i.e. it can be taken to be unity); and (ii) the tissue density, assuming that the soft tissue has a density of 1 g/cm^3).

It is then easy to arrive at the *dose equivalent,* in units of sievert (Sv) or rem:

$$\frac{H}{(\text{Sv})} = \frac{D}{(\text{Gy})} \cdot Q \cdot N$$

or

$$\frac{H}{(\text{rem})} = \frac{D}{(\text{rad})} \cdot Q \cdot N$$

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where

H is the symbol for dose equivalent (previously DE)
Q is the symbol for the quality factor (previously QF)
N is the symbol for other weighting factors including the distribution factor (previously DF)

(see ICRU Report 19 [8]).

The quality factor, Q, is a function of the type of radiation and of its energy [9]:

Radiation	Q
X-rays, gamma rays, electrons	1
Neutrons, protons and singly charged particles of rest mass > one atomic mass unit	10
Alpha particles, multiply charged particles	20

At present, the value of 1 is assigned to N.

Detection limits

It is often difficult to quote a value for the lower limit of detection of a radionuclide because there are enormous differences in efficiency between facilities; the limit may vary by factors of 10 or even 100 between a highly sophisticated facility and an ordinary laboratory with modest measuring equipment. For this reason it is the *practical limit* for the normal performance of a measuring laboratory with *standard equipment* that is given. An indication is sometimes given of the theoretical limit, either because there are no data available for the practical limit or for purposes of comparison.

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BROMINE (Br)

1. Therapy

The very short effective half-life of bromine-82 (1.27 days) makes therapy either useless or illusory in most cases. The sedative – not to say soporific – properties of bromine compounds such as sodium bromide mean that the isotopic dilution method is difficult to employ as a first-aid treatment; moreover, at the doses necessary for treatment by the isotopic dilution method, bromine compounds are cardiac depressants. On the other hand, the stimulation of renal excretion by increased fluid intake or by means of mild diuretics increases the effectiveness of treatment. Major contamination of the digestive system may justify washing out the stomach.

2. Personnel monitoring (^{82}Br)

Individual film dosimetry.
Measurement of emitted radiation; bioassay, toxicological urinalysis.

3. Chief characteristics (^{82}Br)

Type of emission	β^-				γ					
Maximum energy (MeV)	0.444	0.55	0.62	0.7	0.78	0.82	1	1.3	1.4	
Percentage	100	72	44	27	83	27	27	28	17	
Radioactive half-life	35.3 h									
Target organ	Whole body [1]									
Biological half-life	8 d									
Effective half-life	1.27 d [1]									
Annual limit of intake (ALI)	103.6 MBq (2800 μCi)									
Effective energy (MeV)	1.8									
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	13 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)									

4. Detection limits

Whole-body counting: 740–1850 Bq (20–50 nCi).

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CALCIUM (Ca)

1. Therapy

As with all the other radioisotopes of elements normally present in the body, the only conceivable therapy in the event of contamination by radioactive calcium is isotopic dilution, calcium being administered in pharmacologically conventional forms, either orally or (better) intravenously.

2. Personnel monitoring

Bioassay – urinalysis; measurement of emitted radiation (^{47}Ca).
The wearing of a film badge is not warranted in the case of calcium-45.

3. Chief characteristics

	^{45}Ca	^{47}Ca				
Type of emission	β^-	β^-		γ		
Maximum energy (MeV)	0.25	1.98	0.67	0.49	0.81	1.3
Percentage	100	18	82	5.7	5.7	76
Radioactive half-life	165 d	4.53 d				
Target organ	Bone (endosteum) [1]	Bone (endosteum) [1]				
Biological half-life	1.8×10^4 d	1.8×10^4 d				
Effective half-life	165 d	4.53 d				
ALI	~ 3 MBq (80 μCi)	~ 16 MBq (430 μCi) (^{47}Ca + ^{47}Sc)				
Effective energy (MeV)	0.43 [2]	2.6 [2]				
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0	5.4 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)				

4. Detection limits

^{45}Ca: Liquid scintillation measurement of radioactivity in urine; practical limit: 1.11 kBq·ltr^{-1} (0.3 μCi·ltr^{-1}) [3].
^{47}Ca: Whole-body counting: 3.7 kBq (0.1 μCi).

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CARBON (C)

1. Therapy

In view of the short biological half-lives usually observed in the case of ^{14}C, accidents warranting therapy are very rare. However, as it is difficult to specify when therapy may be necessary, accidentally exposed persons should be referred to specialized centres.

2. Note on metabolic behaviour

(a) In the form of $^{14}CO_2$, carbon-14 causes only slight internal contamination as carbon dioxide moves from blood to air in the lungs.

(b) When part of a molecule, carbon-14 takes the same metabolic fate as the molecule itself. Usually, metabolism results in the formation of $^{14}CO_2$. A small proportion of such molecules, however, may become incorporated into chains in structures whose turnover proceeds especially slowly (collagen, for example). After the degradation of a molecule the carbon-14 has to be sought in the exhaled air. When molecules are being eliminated intact, the activity of the excreta should be measured.

3. Personnel monitoring (^{14}C)

Bioassay of urine (liquid scintillation technique) or of exhaled air.
It is of no use to wear a film badge.

4. Chief characteristics (^{14}C)

Type of emission	β^-
Maximum energy (MeV)	0.155
Percentage	100
Radioactive half-life	5730 a
Target organ	Whole body
Biological half-life	0.4 d [1]
Effective half-life	0.4 d
ALI	~ 321 MBq (8.7 mCi)
Effective energy (MeV)	0.054 (CO_2)
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0

5. Detection limits

Liquid scintillation measurement of radioactivity in urine:
Theoretical limit: 0.37 kBq·ltr^{-1} (0.01 μCi·ltr^{-1}) [1].

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Please see http://www-ns.iaea.org/standards/

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CAESIUM (Cs)

1. Therapy

As with all rapidly absorbed radionuclides, treatment is a matter of *urgency*. All caesium compounds should be considered soluble; one reputedly insoluble compound (caesium silico-aluminate, used in caesium sources) is in fact soluble in the body after a time, no doubt because of the considerable radiolysis of the compound, which has a high specific activity.

In the case of wound contamination, local decontamination should not delay intestinal *precipitation* with a solution of Prussian blue [1]; treatment should be general, as for digestive or pulmonary contamination. Such treatment will also prevent intestinal re-absorption by interrupting the intestinal cycle [2]. Dose: *1 g three times a day in a little water.* Some authorities suggest 11 g per day – 1 g initially, 5 g after 4 hours and another 5 g after another 4 hours. The dose for the next day is 10 g at 8 hour intervals [3, 4].

In all cases, the exposed person should be moved to a specialized centre as soon as emergency treatment has been completed and biological samples (urine and faeces) have been obtained.

2. Note on metabolic behaviour

Caesium is an alkali with a valence of one and its metabolism closely resembles that of potassium. It is very quickly absorbed and migrates into cells. Intestinal absorption is complete (100%) [5, 6]. It is secreted, moreover, in the lumen of the gastro-intestinal tract, between the stomach and the small intestine. It concentrates, among other places, in the muscles [7]. It is eliminated with a biological half-life of 50–150 days [8, 9]. Excreta sampling is particularly important as one can determine the body burden with an acceptable accuracy [10] on the basis of the urine/faeces activity ratio.

3. Personnel monitoring (^{137}Cs)

Individual dosimetry.
Measurement of emitted radiation; bioassay of excreta.

4. Chief characteristics (^{137}Cs)

Type of emission	β^-	γ
Maximum energy (MeV)	0.51	0.66
Percentage	94	84
Radioactive half-life	30 a	
Target organ	Whole body	
Biological half-life	70 d [11]	
Effective half-life	70 d	
ALI	~ 6 MBq (160 μCi)	
Effective energy (MeV)	0.59	
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	3.2 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)	

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5. Detection limits

Whole-body counting: Theoretical limit = 55.5 Bq (1.5 nCi);
Practical limit = 370 Bq (10 nCi).

Note: The population is often contaminated with caesium-137 in amounts (370–750 Bq (10–20 nCi)) exceeding the detection threshold.

Urine radioactivity measurement: Theoretical limit = 5.5 Bq·ltr^{-1} (15 pCi·ltr^{-1}) [12, 13].

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CHROMIUM (Cr)

1. Therapy

The effectiveness of treatment for contamination by radiochromium depends on the physico-chemical state of the metal:

(a) For contamination by a chromium salt in which the metal is present as a cation, try a chelating agent – for example, give a slow intravenous injection of 0.5 g (half of a 1 g ampoule) of Ca-DTPA; in the case of a wound, wash with a concentrated Ca-DTPA solution. It is also possible to use DFOA (Desferrioxamine B or Desferal®) in a dose of 1 g (two 0.5 g ampoules) administered intramuscularly; in the case of a wound, irrigate with a concentrated solution of the same product.

(b) If the chromium is in *anionic* form, no treatment is effective.

2. Note on metabolic behaviour

There is no fixed metabolic pattern for chromium, the physico-chemical forms – and especially the valence states – being the main factors responsible for its biological fate [1]. Generally speaking, the behaviour of chromium is similar to that of colloids.

3. Personnel monitoring (^{51}Cr)

Individual dosimetry.
Measurement of emitted radiation or bioassay of urine.

4. Chief characteristics (^{51}Cr)

Type of emission	e^-	X	γ
Maximum energy (MeV)	0.0045	0.005	0.319
Percentage	70	21	9
Radioactive half-life	27.8 d		
Target organ [2]	Gastro-intestinal tract		Lungs
Biological half-life	–		125 d
Effective half-life	–		22.8 d
ALI	~ 1 GBq (26.0 mCi)		207 MBq (5.6 mCi)
Effective energy (MeV)	0.01		0.014
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0.18 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		

5. Detection limits

Whole-body counting: 1850–3700 Bq (50–100 nCi).

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Please see http://www-ns.iaea.org/standards/

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COBALT (Co)

1. Therapy

As most cobalt salts are insoluble, special therapy is not necessary after ingestion. A person with a wound contaminated by radioactive cobalt should be given a slow intravenous injection of Ca-DTPA – 0.5 g (half an ampoule). Since the ideal treatment – the administration of a Co-DTPA chelate [1, 2] – is not possible at present because this product is not available commercially, it is best to carry out isotopic dilution with a generally available pharmacodynamic drug; either a conventional salt such as cobalt gluconate or a chelate such as trimethylamine hydroxy-cobalt-di-8-oxyquinoline-5-sulphonate can be used. These cobalt compounds are vasodilators and should therefore be used with care.

2. Note of metabolic behaviour

Intestinal absorption is a function of the solubility of the salt and the amount (by weight) of cobalt in it; in the case of a soluble salt such as a chloride, intestinal absorption may attain 50% [3]. Repeated intravenous injections, such that the intake is relatively constant, are followed by retention of about 75%, with urinary excretion (17%, predominating over faecal excretion (6%)).

3. Personnel monitoring

Individual dosimetry.
Measurement of emitted radiation or radiotoxicological urinalysis.

4. Chief characteristics

	^{57}Co		^{58}Co		^{60}Co		
Type of emission	e^-	γ	β^+	γ	β^-		γ
Maximum energy (MeV)	0.007	0.12	0.47	0.81	0.31	1.17	1.33
Percentage	180	97	15	100	100	100	100
Radioactive half-life	270 d		71.3 d		5.26 a		
Target organ [4]	Lungs[C-4]		Lungs[C-4]		Lungs[C-4]		
Biological half-life	125 d		125 d		125 d		
Effective half-life	85.5 d		45.5 d		117 d		
ALI	~ 15 MBq (400 μCi)		~ 4.5 MBq (140 μCi)		814 kBq (22 μCi)		
Effective energy (MeV)	0.053		0.29		0.72		
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0.93 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		5.4 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		13 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		

[C-4] For non-transportable compounds the target organ is the gastro-intestinal tract (lower large intestine), the ALI being 296 MBq (8.0 mCi) for cobalt-57, 88.8 MBq (2.4 mCi) for cobalt-58 and 29.6 MBq (0.8 mCi) for cobalt-60.

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5. Detection limits

	^{57}Co	^{58}Co	^{60}Co
Whole-body counting – practical limit	370–1850 Bq (10–50 nCi)	370 Bq (10 nCi)	185 Bq (5 nCi)[C-5]
Urine – practical limit	–	–	18.5 Bq·ltr^{-1} 0.5 nCi·ltr^{-1}

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[C-5] This is fairly easy to attain; however, the theoretical limit is 37 Bq (1 nCi) [5]. The detection of 185 Bq (5 nCi) corresponds, for one examination per month, to one investigation level.

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GOLD (Au)

1. Therapy

Not very much can be achieved by therapy in the event of contamination by gold, especially as the latter is usually in colloidal form. The chelating agents of the DTPA series are totally ineffective. Some promising results have been obtained with *penicillamine*, which would appear to increase the excretion of gold [1]; better effects can be expected when the transformation of the salt into a colloid is less pronounced. All methods aimed at mobilization of the macrophages retaining the gold particles have proved completely ineffective [2].

Furthermore, the normally low level of gold contamination and the short effective half-life of radioactive gold (at the most 2.7 days) make general treatment for contamination unnecessary. In the case of contamination of the digestive system, a mild, non-irritating *laxative* reduces the time during which the digestive tract is exposed to radiation.

2. Note on metabolic behaviour

Absorption of gold by the digestive system is slight and occurs only in the case of soluble salts, which are rare. Excretion – exclusively in the urine – is almost zero in the case of the stable colloidal forms. About half of the amount retained in the body is fixed in the skeleton [3] except in the case where gold is in a colloidal form; then about 80% concentrates in the liver. The biological half-life given below is for the soluble forms; in the case of the colloids, it clearly is the same as the radioactive half-life.

3. Personnel monitoring (^{198}Au)

Individual film dosimetry.
Measurement of emitted radiation or radiotoxicological urinalysis.

4. Chief characteristics (^{198}Au)

Type of emission	β^-	γ
Maximum energy (MeV)	0.96	0.41
Percentage	100	100
Radioactive half-life	2.7 d	
Target organ	Kidneys	Gastro-intestinal tract
Biological half-life	1.5 d [4]	–
Effective half-life	1 d [4]	–
ALI	–	~ 30 MBq (800 μCi)
Effective energy (MeV)	0.41	0.38
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	2.3 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)	

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5. Detection limits

Whole-body counting: Theoretical limit = 37 Bq (1 nCi) [5];
Practical limit = ~ 148 Bq (~ 4 nCi) [6].
With this limit, two examinations per month are required for establishing one level of investigation.

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INDIUM (In)

1. Therapy

The very short effective half-life of indium-113m contributes to its classification as a low-radiotoxicity nuclide (Group III). In other words, most contaminations by indium-113m do not warrant therapeutic action. The situation may be different, however, in the case of nuclides having longer half-lives, such as indium-114m (radioactive half-life 49 days). Chelating agents such as BAL®, EDTA and 8-hydroxyquinoline are ineffective, but given the effectiveness of iron ferrocyanide (Prussian blue) in the case of thallium [1], one can assume (in view of the respective positions of thallium and indium in the periodic table) that it would also be effective in the case of indium (see under CAESIUM for dosage).

2. Note on metabolic behaviour

Ideas about the metabolism of indium have been obtained by extrapolation from experiments with animals [2]. Absorption by the digestive system is low – about 0.5%. For the other routes of entry, absorption is after four days, independent of the pathway, and amounts to 50% or more. Deposition is especially high in the kidneys, liver, spleen and salivary glands; deposition in the skeleton is also observed. Excretion, which does not depend on the route of entry, follows two exponential curves – one indicating a rapid process and the other, indicating a slower one, starting after three weeks. Approximately 40% is excreted in the urine or faeces by the end of one month.

3. Personnel monitoring (^{113m}In)

Individual film dosimetry.
Measurement of emitted radiation or radiotoxicological urinalysis.

4. Chief characteristics (^{113m}In)

Type of emission	e^-	X	γ
Maximum energy (MeV)	0.365	0.024	0.393
Percentage	28	20	65
Radioactive half-life	99.4 min		
Target organ	Kidneys [3]	Gastro-intestinal tract (upper large intestine)	
Biological half-life	60 d [3]	–	
Effective half-life	1.61 h [3]	–	
ALI		~ 630 MBq (17 mCi)	
Effective energy (MeV)	0.24	0.17	
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	1.4 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		

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5. Detection limits

Whole-body counting: 370–740 Bq (10–20 nCi).

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IODINE (I)

1. Therapy

The treatment for contamination by radioiodine is simple; it consists in loading the thyroid with stable iodine *as quickly as possible* [1, 2]. Since the speed with which the thyroid becomes saturated with iodine is directly proportional to the intake, higher doses provide better protection; the recommended dose is 100 mg of iodine given orally in the form of potassium iodide (130 mg of KI), sodium iodide or magnesium iodide. The promptness of therapy determines its effectiveness. For example, the thyroid can be completely protected by the administration of stable iodine *before* contamination by radioiodine [3, 4]. The reduction of the radioiodine load is less if the treatment is delayed, i.e. 10% less if treatment takes place at the same time as the contamination and 50% less if it takes place four hours after contamination. Treatment with stable iodine 24 hours after contamination does not affect the radioiodine load, but it does slightly reduce the biological half-life of the radioiodine [5].

2. Note on metabolic behaviour

The iodine concentration is highest 24 hours after intravenous administration of labelled iodine [6]. Given the effective half-life of iodine-131, the fraction transferred to the thyroid is about 30% of the amount taken up. Iodine clearance proceeds on the basis of two biological half-lives: one of six hours, representing elimination of the whole-body fraction (70%), and one of approximately 100 days, representing elimination of the thyroid fraction (30%).

3. Personnel monitoring

Individual film dosimetry.
Measurement of emitted radiation (thanks to the effectiveness and rapidity of thyroid radioactivity measurements, sampling is not necessary).

4. Chief characteristics

	^{123}I			^{125}I		^{131}I	
Type of emission	e^-	X	γ	e^-	X	β^-	γ
Maximum energy (MeV)		0.027	0.16	0.004	0.03	0.61	0.36
Percentage		70	84	75	136	90	84
Radioactive half-life	13.3 h			60.2 d		8.05 d	
Target organ	Thyroid			Thyroid		Thyroid	
Biological half-life	0.35 d/138 d [7]			0.35 d/138 d [7]		0.35 d/138 d [7]	
Effective half-life	0.54 d			41.8 d		7.6 d	
ALI	~ 6 MBq (160 μCi)			~ 0.5 MBq (12.8 μCi)		~ 0.8 MBq (21 μCi)	
Effective energy (MeV)	0.05			0.037		0.23	
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	2.2 [8] ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)			1.23 [8] ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		2.2 [8] ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)	

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5. Detection limits

	^{123}I	^{125}I	^{131}I
Whole-body counting	–	Pract. lim.: 74 kBq (2 μCi)	Theor. lim.: ~ 30 Bq (0.8 nCi) Pract. lim.: 370 Bq (10 nCi) [9]
Direct thyroid radioactivity measurement	Pract. lim.: 370–1850 Bq (10–50 nCi)	Theor. lim.: 3.7 Bq (0.1 nCi) Pract. lim.: 37 Bq (1 nCi)	Pract. lim.: 111 Bq (3 nCi) [10]
Urine radioactivity measurement	–	–	Theor. lim.: 3.7 Bq·ltr^{-1} (0.1 nCi·ltr^{-1}) [7]

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IRON (Fe)

1. Therapy

Internal contamination by iron should be treated with DFOA (Desferrioxamine B or Desferal®), which selectively chelates excess iron and eliminates it in the urine. The exposed person should be given an intramuscular injection of 1 g (two ampoules) on the first day, followed by 0.5 g daily.

DTPA is also very effective (the stability constant for DTPA-Fe III is very high): 0.5 g (half an ampoule) administered in a slow intravenous injection.

2. Note on metabolic behaviour

The mean absorption of iron by the digestive system is about 10%; it is inversely proportional to the iron reserves and depends on the form in which the iron is absorbed [1]. The highest concentration is found in the spleen (concentration factor $\geqslant 10$); of the amount absorbed into the blood approximately 0.02% [2] is deposited in the spleen. The liver and bone marrow also concentrate iron to a high degree. Whether administered orally or parenterally, after 24 hours iron is no longer eliminated by the kidneys.

3. Personnel monitoring

Individual dosimetry (^{59}Fe only).
Measurement of emitted radiation (^{59}Fe only) or bioassay of urine (^{55}Fe) (these are only valid on the first day).

4. Chief characteristics

	^{55}Fe		^{59}Fe			
Type of emission	e^-	X	β^-		γ	
Maximum energy (MeV)	0.006	0.0064	0.27	0.46	1.1	1.29
Percentage	70	30	46	53	55	44
Radioactive half-life	2.6 a		45 d			
Target organ [3]	Spleen		Spleen			
Biological half-life	600 d		600 d			
Effective half-life	388 d		41.9 d			
ALI	~ 80 MBq (2.100 mCi)		~ 13.7 MBq (370 μCi)			
Effective energy (MeV)	0.0065		0.34			
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	–		6.3 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)			

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5. Detection limits

^{59}Fe: The practical limit for detection in urine is approximately 37 Bq·ltr^{-1} (1 nCi·ltr^{-1}); in the case of whole-body counting, the theoretical limit is 74–740 Bq (2–20 nCi) [4]. A practical limit of a few tens of nanocuries seems reasonable.

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KRYPTON (Kr)

1. Therapy

Since krypton is not absorbed by the body (however, krypton is slightly soluble in fat), contamination by krypton-85 may be regarded as impossible. The real problem is immersion in a mixture containing krypton, where irradiation of the skin and lungs would occur.

2. Note on metabolic behaviour

Krypton is for all practical purposes inert and does not react with biological molecules [1].

3. Personnel monitoring (^{85}Kr)

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4. Chief characteristics (^{85}Kr)

Type of emission	β^-
Maximum energy (MeV)	0.69
Percentage	100
Radioactive half-life	10.7 a
Target organ	Whole body
Effective energy (MeV)	0.24
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0.01 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)

5. Detection

The problem of detecting krypton in the body or the excreta does not arise since the gas is for all practical purposes not metabolized.

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This publication is no longer valid
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LANTHANIDE SERIES (rare earths)

Elements 57–71 (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) and the related elements Y and Sc

1. Note

The elements in the lanthanide series – from lanthanum (57) through cerium (58) to lutetium (71) – are very similar in their biological behaviour as they have much the same chemistry. Accordingly, they all warrant the same Ca-DTPA therapy with the same degree of *urgency*.

2. Therapy

(a) *Contaminated wound:* Give slow intravenous injection (rapid local diffusion) of 0.5 g of Ca-DTPA (half an ampoule) immediately and wash with a concentrated Ca-DTPA solution (1 g = 1 ampoule); then evacuate the exposed person to a specialized centre after taking urine samples [1–3].

(b) *Contamination of the respiratory system:* Prepare a Ca-DTPA aerosol immediately (using a DTPA ampoule in a conventional generator, or preferably a capsule of micronized DTPA in a generator producing an aerosol of suitable particle size – the Spinhaler® turbo-inhaler, for example [4, 5]) and inject 0.5 g of Ca-DTPA intravenously. Take urine samples and evacuate the exposed person. In the case of massive inhalation of an insoluble compound, pulmonary lavage under hospital conditions is not incompatible with Ca-DTPA treatment [6].

3. Note on metabolic behaviour

Except in the case of stable complexes with the same pH as living matter, the lanthanides are in hydroxide form from the moment they enter the organism. This explains the limited absorption by wounds and the very slight absorption by the digestive system [7]. Distribution through the various organs depends on the amount – by weight – taken up. Generally speaking, rare earths are fixed mainly in the skeleton and liver, and as one moves from lanthanum to lutetium (i.e. with increasing atomic number) the bone fraction increases while the liver fraction decreases [8].

4. Personnel monitoring

Individual film dosimetry (except for pure beta emitters such as ^{147}Pm).
Measurement of emitted radiation or radiotoxicological urinalysis.

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5. Chief characteristics

	^{140}La		^{144}Ce		Daughter product ^{144}Pr	
Type of emission	β^-	γ	β^-	γ	β^-	γ
Maximum energy (MeV)	2.2	1.6	0.32	0.13	2.98	0.69
Percentage	27	1	76	10.9	98	1
Radioactive half-life	40.2 h		285 d		17.3 min	
Target organ	Gast.-int. tract		Bone			
Biological half-life	–		1500 d			
Effective half-life	–		243 d			
ALI	~ 14 MBq (390 μCi)		~ 1 MBq (27 μCi)			
Effective energy (MeV)	0.8		6.3			
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	11 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		0.08 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		0.3 [9]	

	^{147}Pm	^{169}Yb			^{177}Lu	
Type of emission	β^-	X	γ		β^-	γ
Maximum energy (MeV)	0.22	0.05/0.06	0.11	0.2	0.5	0.113
Percentage	100	154 80	20	38	90	
Radioactive half-life	2.62 a	31.8 d			6.74 d	
Target organ	Bone	Bone			Gast.-int. tract	
Biological half-life	1500 d	1000 d			–	
Effective half-life	570 d	29.8 d			–	
ALI	~ 6 MBq (160 μCi)	~ 34 MBq (920 μCi)			~ 60 MBq (1.6 mCi)	
Effective energy (MeV)	0.35	0.495			0.16	
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0	–			0.08 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)	

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6. Detection limits

	^{140}La	^{144}Ce	^{147}Pm
Whole-body counting	–	Theor. lim. = 370 Bq (10 nCi) [10] Pract. lim. = ~ 1300 Bq (35 nCi) [11][C-6]	–
Urinalysis (practical limit)	1.8–18 Bq·24 h^{-1} (0.05–0.5 nCi·24 h^{-1})	1.8–18 Bq·24 h^{-1} (0.05–0.5 nCi·24 h^{-1})	1.8–18 Bq·24 h^{-1} (0.05–0.5 nCi·24 h^{-1})

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[C-6] An examination every two years is sufficient for one investigation level.

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LEAD (Pb)

1. Therapy

2-3-dimercapto-1-propanol (Dimercaprol: BAL®) is the compound preferred for the treatment of lead poisoning [1]. Its action is limited to the blood compartment.

Dosage [2]: 3 mg/kg, given by intramuscular injection every four hours; injections should not be given for more than three days and should always be given under hospital conditions; individual sensitivity should be tested at the time of the first injection (quarter of an ampoule).

Chelating agents of the polyamino-acid series are also effective (e.g. EDTA or, preferably, DTPA, which is less toxic). However, kidney damage caused by a lead chelate is not rare, even after a single injection [1].

2. Note on metabolic behaviour

The long half-life of lead-210 (21.4 years) and the high radiotoxicity of its daughter product ^{210}Po (alpha emitter) mean that retention is a cause for concern. In man, 50% [3] to 70% [4] of the amount initially taken up is still retained 800 days after contamination.

Following ingestion, absorption by the digestive system is relatively high (up to about 20% [5]). There is considerable deposition in the skeleton. Excretion is normally through the faeces in the case of insoluble compounds; the fraction eliminated via the kidneys depends on the physico-chemical state of the contaminant.

3. Personnel monitoring (^{210}Pb)

Radiotoxicological excreta analysis.

4. Chief characteristics (^{210}Pb)

Type of emission	β^-	γ	
Maximum energy (MeV)	0.015	0.047	
Percentage	81	4	
Radioactive half-life	21.4 a		
Target organ	Kidneys		Bone
Biological half-life [6]	1.5 a		10 a
Effective half-life	1.2 a		6.8 a
ALI	~ 11 kBq (0.3 μCi)		–
Effective energy (MeV)	10		29
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0.02 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		

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5. Detection limits

Measurement of radioactivity in urine: 37×10^{-3} Bq·24 h^{-1} (1 pCi·24 h^{-1}).
Whole-body measurements: Theoretical limit = 37 Bq (1 nCi)
Practical limit = 185 Bq (5 nCi) [7].

Note: This measurement is difficult and should, if possible, be made by a specialist.

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MANGANESE (Mn)

1. Therapy

The effectiveness of treatment for contamination by radioactive manganese depends on the physico-chemical form in which the metal is present:

(a) In the case of a manganese salt in which the metal is present as a *cation*, treatment with a chelating agent should be tried – for example, a slow intravenous injection of 0.5 g of Ca-DTPA (half a 1-g ampoule). Wounds should be washed with a concentrated DTPA solution. It is also possible to use DFOA (Desferrioxamine B or Desferal®) – intramuscular injection of 1 g (two ampoules of 0.5 g); wounds should be irrigated with a concentrated solution of the same product.

(b) If the manganese is present as an *anion* (for example, in a permanganate), treatment is not possible.

2. Personnel monitoring (^{54}Mn)

Individual dosimetry.
Measurement of emitted radiation or radiotoxicological urinalysis.

3. Chief characteristics (^{54}Mn)

Type of emission	X	γ
Maximum energy (MeV)	0.005	0.83
Percentage	24	26
Radioactive half-life	314 d	
Target organ	Lungs	Liver
Biological half-life	125 d	25 d
Effective half-life	88.5 d	23 d
ALI	~ 3 MBq (88 μCi)	~ 35 MBq (950 μCi)
Effective energy (MeV)	0.23	0.23
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	4.6 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)	

4. Detection limits

Whole-body counting: Theoretical limit = 37 Bq (1 nCi [1]
Practical limit = ~ 3.7 kBq (~ 0.1 μCi)
Measurement of gamma activity of urine: Practical limit = ~ 3.7 $Bq \cdot ltr^{-1}$ (~ 0.1 $nCi \cdot ltr^{-1}$).

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MERCURY (Hg)

1. Therapy

In the case of contamination by radioactive mercury, one should try using Ca-DTPA or Dimercaprol (2-3-dimercapto-1-propanol; BAL®), bearing in mind that only mercurcy in the form of Hg^{2+} can be chelated by Ca-DTPA. These two compounds have some effect on the renal deposition of mercury, but do not act at all levels of the organism [1].

Dosage: Ca-DTPA: half an ampoule (0.5 g) given by slow intravenous injection; further injections during the following days at a specialized centre;

BAL®: 3 mg/kg body weight, given by intramuscular injection; further injections every four hours during the following three days at a specialized centre (test the sensitivity of the patient during the first injection by administering a reduced dose).

Note: The BAL® derivative 2-3-dimercapto-propane-1-sulphonate is said to be equally effective [2].

2. Note on metabolic behaviour

The absorption of mercury depends on its physico-chemical form. In the digestive tract it is almost zero for mercury present in the elemental form; it is approximately 10% for the inorganic salts and almost 100% for methyl mercury. When inhaled in the elemental form or as an inorganic salt, more than 85% of the mercury is absorbed [3]. A high concentration is observed in the kidneys. The organic compounds are degraded more rapidly than the other forms and excreted chiefly in the urine [4]. The biological half-life varies according to the compound, the longest being 1–2 months (inorganic forms) to 2–3 months (methyl mercury); it is also a function of the amount (by weight) taken up [5].

3. Personnel monitoring

Individual film dosimetry.
Measurement of emitted radiation or radiotoxicological urinalysis.

4. Chief characteristics

	^{197}Hg			^{203}Hg	
Type of emission	e^-	X	γ	β^-	γ
Maximum energy (MeV)		0.067	0.077	0.21	0.28
Percentage		56	18	100	100
Radioactive half-life	65 h			46.6 d	
Target organ	Kidneys [5]			Kidneys [5]	
Biological half-life	14 d [6] or more			14 d or more	
Effective half-life	2.3 d			11 d	
ALI	~ 107 MBq (2.900 mCi)			~ 6.7 MBq (180 μCi)	
Effective energy (MeV)	0.043			0.15	
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0.08 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)			1.2 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)	

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5. Detection limits

For whole-body counting: 740–1850 Bq (20–50 nCi) (^{203}Hg).

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PHOSPHORUS (P)

1. Therapy

Since phosphorus is normally present in the body, contamination by phosphorus-32 can only be treated by the isotopic dilution method. There are many special products containing exchangeable phosphorus, but as the aim of treatment with such a special product is not the same as the primary purpose served by the product, treatment should be based on massive doses: 5 g of PO_4, in a glass of water, e.g. two capsules of 'Neutrophos' containing dibasic Na and K phosphate and monobasic Na and K phosphate.

2. Note on metabolic behaviour

After ingestion, approximately 75% of the phosphorus is absorbed in the digestive tract; it then spreads through the organism. The fraction deposited in the skeleton after absorption is about 37% [1, 2].

3. Personnel monitoring (^{32}P)

Individual dosimetry.
Radiotoxicological urinalysis; measurement of emitted radiation.

4. Chief characteristics (^{32}P)

Type of emission	β^-
Maximum energy (MeV)	1.71
Percentage	100
Radioactive half-life	14.3 d
Target organ	Bone [3]
Biological half-life	1155 d
Effective half-life	14.1 d
ALI	~ 6.6 MBq (180 μCi)
Effective energy (MeV)	3.5
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0

5. Detection limits

Whole-body counting: ~ 5.5 kBq (~ 150 nCi) [4].
Measurement in urine: Theoretical limit = ~ 1.5 $Bq \cdot ltr^{-1}$ (40 $pCi \cdot ltr^{-1}$).

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PLUTONIUM (Pu)

1. Therapy

Any contamination or suspicion of contamination warrants general *emergency* treatment with *Ca-DTPA* [1–5]: 0.5 g (half an ampoule) diluted in 250 ml of physiological saline; given by slow intravenous injection; evacuation of the patient to a specialized centre after biological samples have been taken (*all excreta*, blood samples – exact labelling). Since Ca-DTPA acts only in the blood and in the extracellular fluids, the promptness of treatment determines the extent of plutonium deposition in the skeleton and liver. The quantity of plutonium mobilized by Ca-DTPA is proportional to the in vivo solubility of the radionuclide; in the extreme case, an insoluble compound such as plutonium oxide cannot be dealt with by chelating agents. Since the degree of insolubility of the plutonium involved in contamination is not known, Ca-DTPA treatment *must* be given. The form of treatment depends on the circumstances of the case.

(a) *Contaminated wound:* Inject Ca-DTPA intravenously and wash the wound locally with a concentrated Ca-DTPA solution (one ampoule); possible surgical removal of the plutonium in the wound is a matter for discussion by specialists.

(b) *Contamination of the respiratory system:* Prepare a Ca-DTPA aerosol immediately (using a Ca-DTPA ampoule in a conventional generator or, preferably, a capsule of micronized Ca-DTPA in a generator producing an aerosol of suitable particle size – the Spinhaler® turbo-inhaler, for example [6, 7]) and always inject 0.5 g of Ca-DTPA intravenously; pulmonary lavage should be considered only by highly specialized experts [8, 9].

2. Note on metabolic behaviour [10]

The speed of migration of plutonium from the route of entry depends on its physico-chemical form (transportability) and on the nature of the route of entry. It should be stressed that intestinal absorption is virtually zero. Generally, plutonium becomes distributed between the liver, from which it is eliminated very slowly, and the bone, from which it is for practical purposes not eliminated at all; the biological half-lives are 40 years for the liver and 100 years for the bone.

3. Personnel monitoring

The wearing of a film badge (or a neutron film dose meter for ^{238}Pu) is not warranted. Measurement of emitted radiation (X-rays) and *radiotoxicological analyses of urine and faeces.*

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4. Chief characteristics

	^{238}Pu			^{239}Pu			
Type of emission	α		X	α			X
Maximum energy (MeV)	5.49	5.45	0.015	5.11	5.14	5.16	0.015
Percentage	72	28	9	12	15	73	3
Radioactive half-life	86 a			24 360 a			
Target organ	Bone			Bone			
Biological half-life [10]	100 a			100 a			
Effective half-life	46.2 a			100 a			
ALI [11]	178 Bq (4.8 nCi)			~ 160 Bq (4.3 nCi)			
Effective energy (MeV)	280			270			
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	<0.01 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)			<0.01 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)			

5. Detection limits [12][C-7]

Measurement of radioactivity in urine (^{238}Pu or ^{239}Pu):
Practical limit = 3.7×10^{-3} Bq (0.1 pCi).
Measurement of radioactivity in faeces (^{238}Pu or ^{239}Pu):

(1) Direct measurement (scintillator 5 cm in diameter):
Practical limit = 0.074 $Bq \cdot g^{-1}$ (2 $pCi \cdot g^{-1}$);

(2) Measurement after chemical separation:
Practical limit = ~ 0.02 $Bq \cdot 24\ h^{-1}$ (0.5 $pCi \cdot 24\ h^{-1}$).

Whole-body counting: Limit = 185–740 Bq (5–20 nCi) for ^{239}Pu in the lungs
(limit for ^{238}Pu = limit for $^{239}Pu \times 1/3$).

Always bear in mind that:

(a) A minor external contamination may give the impression of being a major internal contamination;

(b) Completely different values are obtained depending on what is measured – i.e. whole body, lungs, skeleton, etc.

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POLONIUM (Po)

1. Therapy

The only treatment for poisoning by polonium is the administration of 2-3-dimercapto-1-propanol (Dimercaprol; BAL®); its effectiveness varies, and treatment should not be continued for too long. Its action is limited to the blood compartment.

Dosage: 3 mg/kg body weight, given by intramuscular injection every four hours; injections should not be given for more than three days and should be given under hospital conditions; individual sensitivity should be tested at the time of the first injection (quarter of an ampoule) [2].

Note: The BAL® derivative 2-3-dimercapto-propane-1-sulphonate is said to be equally effective [3].

2. Note on metabolic behaviour

Absorption of polonium by the digestive system is moderate: 3–5% [4]. There is considerable retention in the body [5]. Excretion takes place partly in the urine and partly in the faeces, in very variable proportions. The biological half-life is of the order of 40–50 days [6–8]. The retaining organs are the liver, the spleen and, above all, the kidneys, which concentrate approximately 10% of the metabolized activity [9].

3. Personnel monitoring (^{210}Po)

The wearing of a film badge is not warranted;
Radiotoxicological excreta analysis.

4. Chief characteristics (^{210}Po)

Type of emission	α	
Maximum energy (MeV)	5.305	
Percentage	100	
Radioactive half-life	138.4 d	
Target organ	Kidneys [8]	Lungs [10]
Biological half-life	40 d [8]	125 d
Effective half-life	31.7 d	65.7 d
ALI	44 kBq (1.2 μCi)	18 kBq (0.5 μCi)
Effective energy (MeV)	55	55
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	<0.01 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)	

5. Detection limits

The whole-body detection limit for polonium-210 (3.7 MBq (100 μCi)) is too high to be used in radiological protection [11];
Measurement of radioactivity in urine: 3.7×10^{-3} Bq·ltr^{-1} (0.1 pCi·ltr^{-1} [8].

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POTASSIUM (K)

1. Therapy

The physician has few means of dealing with contamination by radioactive potassium. However, the short radioactive half-life of potassium-42, the most commonly used isotope, limits in time the exposure due to internal contamination. The only conceivable treatment is isotopic dilution, with due regard for the hazards of potassium overloading; furthermore, contra-indications are not rare, even at a medical centre. Strict medical supervision, with special emphasis on the heart, is necessary in all cases.

Dosage: approximately 4 g of stable potassium per day for not more than three days (given the short half-life of ^{42}K, treatment lasting three days is in any case warranted only when the degree of contamination is high).

2. Note on metabolic behaviour

In contrast to sodium, potassium in the body undergoes mainly intracellular deposition. It is absorbed rapidly, and in the intestine absorbed almost completely. It is excreted primarily in the urine, with the kidney acting as a homeostatic regulator.

3. Personnel monitoring (^{42}K)

Film dosimetry of personnel.
Blood tests.
Measurement of emitted radiation (or radiotoxicological urinalysis).

4. Chief characteristics (^{42}K)

Type of emission	β^-	γ
Maximum energy (MeV)	3.56	1.52
Percentage	82	18
Radioactive half-life	12.4 h	
Target organ	Stomach	
ALI	~ 180 MBq (5.00 mCi)	
Effective energy (MeV)	1.5	
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	1.4 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)	

5. Detection limits

Whole-body counting: 3.7×10^{-3} Bq (~ 0.1 μCi).

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FISSION PRODUCT MIXTURE

1. Recapitulation of general principles governing treatment

The fission products of interest are essentially ^{137}Cs, ^{89}Sr and ^{90}Sr (transferable nuclides), ^{144}Ce (a non-transferable nuclide), and the iodines (if the mixture is of recent origin or less than about a month old).

This means four kinds of treatment as a matter of urgency. The general rule for the priority to be given to the different kinds of treatment is based on the *toxicity of the nuclide* and *the speed with which it is transferred in the body*, and also on the effectiveness of the therapeutic agent (for example, employ a 100% effective treatment immediately – an uncertain one can be employed later).

It is possible to classify the fission products in order of:

Diminishing toxicity: I, Sr, Ce, Cs;
Diminishing speed of transfer: I, Cs, Ce (ionic form), Sr, Ce (colloidal form);
Decreasing therapeutic effectiveness: I, Ce, Cs, Sr.

There are, accordingly, two general rules:

(a) If the mixture contains iodine, always treat the iodine contamination immediately with stable iodine;
(b) Administer Ca-DTPA, the method depending on the nature of the contamination.

2. Practical rules for treatment

For dosage, contraindications and general rules, refer to the data sheet for the element concerned.

Contamination of the skin only

(i) Iodine given orally (100 mg of KI at one time).
(ii) Wash with dilute Ca-DTPA solution (pH 5) or, failing that, with water acidulated with HCl.

Contaminated wound

(i) General treatment: Iodine given orally (100 mg of KI at one time); Ca-DTPA given intravenously (0.5–1 g).
(ii) Local treatment: Potassium rhodizonate sprinkled onto the wound (1 g); dilute Ca-DTPA solution either injected into the area immediately around the wound or used for washing the wound.
(iii) Prussian blue (1 g) given orally.
(iv) Take biological samples (urine, faeces and blood).
(v) Evacuate to a specialized centre for general assessment of the situation and surgery, if necessary.

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Contamination of the respiratory system

(i) Iodine given orally (100 mg of KI at one time).
(ii) DTPA as an aerosol and by intravenous injection.
(iii) Calcium alginate (or magnesium sulphate and Prussian blue), given orally.
(iv) Take biological samples (urine, faeces and blood).
(v) Evacuate to a specialized centre.

Note: For metabolic data, considerations regarding surveillance and chief characteristics, the reader is invited to refer to the data sheets for the individual elements (iodine, cerium, caesium, strontium).

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SELENIUM (Se)

1. Therapy

There is no therapy for selenium contamination, but 2% sodium sulphate in the diet increases selenium excretion three-fold [1].

2. Note on metabolic behaviour

After absorption, selenium is methylated in the liver and excreted in the form of $Se(CH_3)_2$ through the lungs; this is accompanied by a pronounced odour similar to that of garlic.

3. Personnel monitoring (^{75}Se)

Individual film dosimetry.
Measurement of emitted radiation or radiotoxicological urinalysis.

4. Chief characteristics (^{75}Se)

Type of emission	e^-	γ			
Maximum energy (MeV)	0.01	0.13	0.26	0.28	0.40
Percentage	43	70	60	25	13
Radioactive half-life		120 d			
Target organ [1]	Lungs		Kidneys		
Biological half-life	125 d		11 d		
Effective half-life	61 d [2]		10 d		
ALI	~ 12 MBq (310 μCi)		~ 120 MBq (3100 μCi)		
Effective energy (MeV)	0.1		0.08		
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)		2 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)			

5. Detection limits

Whole-body counting: 1850–3700 Bq (50–100 nCi).

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SODIUM (Na)

1. Therapy

Not very much can be achieved by therapy in the event of contamination by sodium. The only conceivable treatment is isotopic dilution, and the limits are soon reached. A daily dose of 52 g of sodium chloride (representing double the daily intake in certain regions) seems reasonable for a healthy person. Large doses of sodium chloride for several days would reduce the irradiation due to sodium-22 by 96% and that due to sodium-24 by 50% [1]. Clearly, treatment of this type should be given only to persons with satisfactorily functioning vascular and renal systems and under strict medical supervision.

The problem raised by sodium isotopes is more one of external exposure than of internal contamination.

2. Note on metabolic behaviour

Sodium is distributed in the human organism as follows: 58% in the extracellular fluids, 9% in the intracellular fluids and 33% in the skeleton.

3. Personnel monitoring

Individual dosimetry.
Blood tests.
Measurement of emitted radiation.

4. Chief characteristics

	^{22}Na		^{24}Na		
Type of emission	β^+	γ	β^-	γ	
Maximum energy (MeV)	0.54	1.27	1.39	1.37	2.75
Percentage	100	100	100	100	100
Radioactive half-life	2.6 a		15 h		
Target organ	Total body		Gastro-intestinal tract		
Biological half-life	11 d		11 d		
Effective half-life	11 d		0.6 d		
ALI	~ 16 MBq (430 μCi)		~ 120 MBq (3100 μCi)		
Effective energy (MeV)	1.6		2.7		
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	12 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		18 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		

5. Detection limits (^{22}Na, ^{24}Na)

Whole-body counting: Theoretical limit = 37 Bq (1 nCi) [2];
Practical limit = 222 Bq (6 nCi) [3].
This limit corresponds to one level of investigation 770 days after contamination by sodium-22.

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STRONTIUM (Sr)

1. Therapy

Whatever the route of entry of strontium and the therapeutic agent chosen, emphasis should be placed on the *urgency* of treatment since strontium is absorbed very quickly. Treatment is based on rendering strontium non-transportable, either by precipitation or by trapping, so as to inhibit its absorption.

In the case of a contaminated wound, rendering strontium non-transportable on the spot is possible and effective, especially if treatment is carried out during the first quarter of an hour [1]; sprinkle on 1 g of *potassium rhodizonate* or *sodium rhodizonate* and dab to make it penetrate.

In the event of contamination through the digestive or respiratory tract, the strontium has to be trapped with *sodium alginate* [2] or *calcium alginate* – 10 g in a glass of water. Should no such drug be available, an inert substance like *aluminium phosphate* is effective [3–5] and its use recommended. Failing that, 10 g of *magnesium sulphate* [6] speeds up digestive transit and reduces absorption.

2. Note on metabolic behaviour

The metabolism of strontium (an alkaline earth of valence 2^+) is very similar to that of calcium. Most of the salts are soluble [C-8] and rapidly absorbed. It is estimated that about 25% is absorbed by the extracellular fluids after ingestion and 30% after inhalation, half of the absorbed amount being rapidly fixed in the skeleton, i.e. the bone hydroxyapatite [7–9]. Elimination is very slow, the biological half-life being many years, whatever metabolic models are chosen [9, 10].

3. Personnel monitoring

Film badges are not warranted for ^{85}Sr.
With ^{89}Sr and ^{90}Sr only bremsstrahlung can be measured, and special equipment is necessary for measuring it.
Radiotoxicological analysis of urine and faeces.

[C-8] Sulphates are regarded as insoluble; however, 140 mg·ltr^{-1} are solubilized at 30°C, which corresponds to quite a lot of activity – 7 mg of ^{90}Sr corresponds to 3.7×10^{10} Bq (1 Ci).

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4. Chief characteristics

	^{85}Sr	Daughter product ^{85m}Rb		^{89}Sr	^{90}Sr	Daughter product ^{90}Y
Type of emission	γ	e^-	X	β^-	β^-	β^-
Maximum energy (MeV)	0.514	0.5	0.013	1.46	0.546	2.25
Percentage	100	7	52	100	100	100
Radioactive half-life	64 d			52 d	28.1 a	64 h
Target organ	Bone [10]			Bone	Bone	
Biological half-life	1.8×10^4 d			1.8×10^4 d	1.8×10^4 d	
Effective half-life	64 d			52 d	6.4×10^3 d	
ALI	~ 20 MBq (520 μCi)			~ 2.5 MBq (69 μCi)	107 kBq (2.9 μCi)	
Effective energy (MeV)	0.091			2.8	5.5	
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	2.9 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)			< 0.01 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)	0	

5. Detection limits

Urine radioactivity measurements (^{89}Sr and ^{90}Sr): 0.37 Bq·ltr^{-1} (10 pCi·ltr^{-1}) [10]
(with special instruments one can detect 0.037 Bq·ltr^{-1} (1 pCi·ltr^{-1}) [11]).

Whole-body counting:

^{85}Sr: Theoretical limit = 37 Bq (1 nCi) [12]
Practical limit = 111 Bq (3 nCi) [11] or even 370 Bq (10 nCi)

^{89}Sr: Theoretical limit = ~ 5.5 kBq (150 nCi) [12]

^{90}Sr: Theoretical limit = 370 Bq (10 nCi) [12] (on the basis of ^{90}Y bremsstrahlung measurements).

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SULPHUR (S)

1. Therapy

The only conceivable treatment for internal contamination by radioactive sulphur is isotopic dilution using compounds with, for example, a magnesium hyposulphite base and, for obvious reasons, administering large amounts. For contamination by ^{35}S-labelled molecules, the ideal treatment would be to give as large a dose as possible of the same molecule with the sulphur in stable form.

2. Note on metabolic behaviour

Inorganic sulphur compounds concentrate in the cartilaginous tissues and in the bone marrow [1, 2]. Urinary excretion is considerable (30–90%) and rapid (48 h) after intravenous injection [3].

3. Personnel monitoring (^{35}S)

Radiotoxicological urinalysis (liquid scintillation technique).
There is no need to wear a dose meter.

4. Chief characteristics (^{35}S)

Type of emission	β^-
Maximum energy (MeV)	0.167
Percentage	100
Radioactive half-life	88 d
Target organ	Whole body
Biological half-life	7 d [4]
Effective half-life	6.5 d
ALI	~ 25 kBq (0.68 mCi)
Effective energy (MeV)	0.056
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0

5. Detection limits

Urine radioactivity measurements: Theoretical limit = 3.7 $Bq \cdot ltr^{-1}$ (0.1 $nCi \cdot ltr^{-1}$) [4];
Practical limit = 37 $Bq \cdot ltr^{-1}$ (1 $nCi \cdot ltr^{-1}$).

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TECHNETIUM (Tc)

1. Therapy

The very short radioactive half-life of ^{99m}Tc (six hours) makes therapy unrealistic.

2. Note on metabolic behaviour

Absorption of technetium by the digestive system is slight and varies from 0.5% [1] to 1% [2], approximately. It is to be noted that technetium pertechnate is well absorbed after rectal application.

The administration of technetium in the form of pertechnetate [2] is followed by considerable excretion in the urine – about 30% on the first day, dropping rapidly to about 1% per day during the rest of the first week, regardless of whether the nuclide has been administered orally or intravenously. Two hours after administration, the metabolism kinetics no longer depend on the route of entry into the organism. Large deposits have been noted in the salivary glands (specific activity about 20 times that of the plasma), in the wall of the stomach, and in the liver and kidneys. Salivary localization could be exploited in therapy based on hypersialorrhoea (cholinergic drugs, with due regard for all the contraindications and necessary precautions) in the event of contamination by a technetium isotope with a relatively long half-life (such as ^{95m}Tc – 60 days) or a very long one (such as ^{99}Tc – 2×10^5 years). It is noted that washout from the salivary gland with potassium perchlorate or lemon juice per os works very well.

^{99m}Tc is used in a wide variety of radiodiagnostic examinations and its distribution through the body is ultimately a function of the form in which it is administered, provided the latter is stable in vivo. The target organs [3] for ^{99m}Tc-labelled iron are the *kidneys* (renal or pulmonary scintiscanning), for pertechnetate the *thyroid* (thyroid, parotid and stomach scintiscanning) or the *large intestine* (cerebral scintiscanning, cardiac flow), and for colloids the *liver* (hepatic scintiscanning).

3. Personnel monitoring (^{99m}Tc)

Individual film dosimetry.
Measurement of emitted radiation or radiotoxicological urinalysis.

4. Chief characteristics (^{99m}Tc)

Type of emission	e^-	γ
Maximum energy (MeV)	0.12	0.14
Percentage	11	98
Radioactive half-life	6 h	
Target organ	Thyroid	Gastro-intestinal tract [1]
Biological half-life	1.6 d, 3.7 d, 22 d [2]	–
ALI	–	~ 1.3 GBq (35 mCi)
Effective energy (MeV)	0.022 [4]	0.035
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0.59 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)	

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TRANSPLUTONIUM ELEMENTS
(AMERICIUM, CURIUM, BERKELIUM, CALIFORNIUM AND EINSTEINIUM)

1. Note

The transplutonium elements, which are actinides of valence 3^+, are all more transportable in the body than plutonium; furthermore, the quantities involved are always minute but the specific activities very high. Hence the importance *in all cases* of *prompt, rapid* treatment. However, treatment is generally more effective than in the case of plutonium, especially since completely insoluble forms of the transplutonium elements are extremely rare. Ca-DTPA treatment is therefore *always* indicated.

2. Therapy [1–3]

(a) In all cases administer Ca-DTPA immediately; 0.5 g (half an ampoule) given by slow intravenous injection. Wash wounds with a concentrated Ca-DTPA solution (1 g = one ampoule). If there is contamination of the respiratory system, prepare a Ca-DTPA aerosol as well (one ampoule in a conventional generator or, preferably, one capsule of micronized Ca-DTPA in a generator producing an aerosol of suitable particle size – for example, the Spinhaler® turbo-inhaler) [4].

If it helps to save time, treatment can commence with the administration of Ca-DTPA in aerosol form, which is easier; such action is particularly appropriate in cases of respiratory tract contamination. Under no circumstances, however, should intravenous injections be dispensed with or delayed.

(b) The immediate treatment should be followed by biological sampling (*all excreta*, blood samples – careful labelling) and evacuation of the exposed person to a specialized centre for evaluation of the body burden, follow-up treatment and medical supervision.

3. Note on metabolic behaviour [5–10]

The absorption of actinides of valence 3^+ is much more rapid than that of plutonium, especially as one moves along the chain. Diffusion may therefore be rapid; as with all the actinides, deposition is mainly in the skeleton, with very high retention, and in the liver, with moderate clearance. Urinary excretion is fairly high, compared with that of plutonium, during the days following contamination and is related to the diffusion of the element.

4. Personnel monitoring

Individual film badge for ^{241}Am (γ), ^{252}Cf (neutrons) and ^{253}Es (γ).
Measurement of emitted radiation and radiotoxicological excreta analysis (urine and faeces).

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5. Chief characteristics [11]

	^{241}Am			^{242}Cm		^{244}Cm	
Type of emission	α		γ	α	X	α	
Maximum energy (MeV)	5.44	5.49	0.06	6.12	0.019	5.77	5.81
Percentage	13	86	36	74	9.5	23	77
Radioactive half-life	457.7 a			162.5 d		17.6 a	
Target organ	Bone			Bone		Bone	
Biological half-life	100 a			100 a		100 a	
Effective half-life	83.9 a			161.8 d		15 a	
ALI	~ 550 Bq (14.8 nCi)			~ 1,2 kBq (320 nCi)		~ 850 Bq (22.8 nCi)	
Effective energy (MeV)	280			400		300	
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0.1 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)			–		–	

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	^{249}Bk		^{252}Cf			^{253}Es
Type of emission	β^-	γ	α		fission	α
Maximum energy (MeV)	0.125	0.32	6.1	6.2		6.64
Percentage	100		15	82	3.1	90
Radioactive half-life	314 d SF[a] = 6×10^8 a		2.6 a SF[a] = 85 a			20.4 d SF[a] = 6.4×10^5 a
Target organ	Bone		Bone			Bone
Biological half-life	100 a		100 a			100 a
Effective half-life	311 d		2.5 a			20.4 d
ALI	~ 85 kBq (2.3 μCi)		~ 590 Bq (16 nCi)			~ 70 kBq (1.9 μCi)
Effective energy (MeV)	20		1100			370
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	<0.01 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		–			–

[a] SF = Spontaneous fission

6. Detection limits[C-9]

Measurement of the 60-keV peak of ^{241}Am makes possible:

(1) Measurement of the lung burden: Limit = 11–37 Bq (0.3–1 nCi).

(2) Measurement of the liver burden: Limit = 15 Bq (0.4 nCi).

Measurement of high-energy gamma radiation from ^{252}Cf makes possible:

Whole-body counting: Theoretical limit = 111 Bq (3 nCi) [12].

Measurement of urine radioactivity [13] (efficiency of the same order for each element):

Limit = 3.7×10^{-3} Bq · 24 h^{-1} (0.1 pCi · 24 h^{-1}).

Measurement of faeces radioactivity [13] (efficiency of the same order for each element):

(1) Direct measurement: Limit = 0.074 Bq · g^{-1} (2 pCi · g^{-1});

(2) Measurement after chemical separation: Limit = ~ 0.018 Bq · 24 h^{-1} (0.5 pCi · 24 h^{-1}).

[C-9] Whether one measures the gamma radiation emitted by ^{241}Am or the alpha radiation emitted by the transplutonium elements, the measurements are extremely delicate and can only be carried out at a laboratory with highly trained staff; furthermore, the interpretation of these results is subject to numerous uncertainties.

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TRITIUM (^{3}H)

1. Therapy

The only emergency therapy possible for tritium contamination is to speed up the body water cycle by increasing the liquid intake and by promoting diuresis. It is possible to reduce the biological half-life of tritium from 10 days to 2.4 days simply by increasing the consumption of drinking water [1]. The addition of diuretics may be indicated, but the risks and contra-indications of this therapy should be borne in mind. The consumption of large amounts of beer can fulfil both functions [2]. In the exceptional event of massive contamination, there might be a need for special treatment such as peritoneal dialysis or treatment with an artificial kidney, but this could be provided only by a specialized hospital service.

2. Note on metabolic behaviour

Tritiated water may be absorbed through a wound, by the lungs or through the skin. Tritium may be incorporated in three different chemical forms:

(a) *Tritium gas:* This form is practically inert and produces only slight internal contamination;

(b) *Tritiated water:* This form is easily absorbed and behaves like ordinary water, except for a small fraction of the tritium, which becomes fixed to proteins;

(c) *Labelled molecules:* The tritium follows the metabolic cycle of the labelled molecule or, in the case of degradation, of the fraction enclosing it. In such cases there are at least as many problems as there are labelled molecules.

3. Personnel monitoring (^{3}H)

Radiotoxicological urinalysis (liquid scintillation measurements).
Wearing of a film badge is not warranted.

4. Chief characteristics (^{3}H)

Type of emission	β^-
Maximum energy (MeV)	0.018
Percentage	100
Radioactive half-life	12.3 a
Target organ	Whole body (tissue)
Biological half-life	10 d (tritiated water)
Effective half-life	10 d
ALI	~ 450 MBq (12 mCi)
Effective energy (MeV)	0.01
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0

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5. Detection limits

Urine radioactivity measurements by the liquid scintillation technique:
Theoretical limit = 7.4×10^{-3} Bq·ltr^{-1} (0.2 nCi·ltr^{-1});
Practical limit = 370 Bq·ltr^{-1} (10 nCi·ltr^{-1}) [3].

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URANIUM (U)

1. Therapy

Chelating agents *should not be used,* despite their effect on uranium, since an increase in the migrant fraction might result, through precipitation in the kidneys, in a high renal tubule burden, accompanied by the risk of severe anuric nephritis. The complex formed by uranyl ions with sodium bicarbonate ($Na_4[(UO_2)(CO_3)_3]$) is stable and is excreted rapidly in the urine. Hence, treatment is based on the use of *bicarbonated physiological solution.*

(a) *Contaminated wound:* Wash the wound immediately (because of rapid local spreading) and give a slow intravenous infusion of bicarbonated physiological solution (250 ml at 14%); evacuate to a specialized centre for surgery.

(b) *Contamination of the respiratory system:* Give immediately a slow intravenous infusion of bicarbonated physiological solution (250 ml at 14%); evacuate to a specialized centre.

In both cases, urine and faeces samples should be taken.

2. Note on metabolic behaviour

Uranium possesses two valence states: 4+ and 6+. The 4+ form is insoluble, but in a biological medium it is gradually converted to 6+, which is rapidly changed into the uranyl ion UO_2^{++} this ion would behave like calcium or – more generally – like the alkaline earths if it was not precipitated in the renal tubules. An excessive uranium burden in the kidneys involves the risk of *severe toxic nephritis,* apart from radiotoxicological problems.

Despite the insolubility of many of its salts, uranium spreads through the organism fairly rapidly.

Enriched uranium alone presents a radiotoxicological problem; natural uranium is only a chemical problem.

3. Personnel monitoring

Individual film dosimetry.
Measurement of emitted radiation; *radiotoxicological analysis of excreta.*
Urinalysis: tests for *proteinuria.*

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4. Chief characteristics

	^{235}U				^{238}U			
Type of emission	α		γ		α	X	e^-	
Maximum energy (MeV)	4.40	4.37	0.14	0.18	4.19	–	0.03	0.04
Percentage	57	18	11	54	77	–	23	
Radioactive half-life	7.1×10^8 a				4.49×10^9 a			
Target organ	Kidneys				Kidneys			
Biological half-life	15 d				15 d			
Effective half-life	15 d				15 d			
ALI	37 kBq (1 μCi)[C-10]				~ 6 kBq (0.16 μCi)[C-10]			
Effective energy (MeV)	46				43			
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	–				–			

5. Detection limits

Urinalysis by fluorimetric methods: 5–10 $\mu g \cdot ltr^{-1}$.

[C-10] On the basis of chemical toxicity and recent metabolic models (assuming a daily uptake of 1.8 mg) (ICRP 2: ALI for ^{235}U = 48 kBq (1.300 μCi) and ALI for ^{238}U = ~6.5 kBq (0.180 μCi)).

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XENON (Xe)

1. Therapy

Xenon is only slightly soluble in fat[C-11], so that no serious contamination can result from this nuclide. The real problem is irradiation by a mixture containing xenon.

2. Note on metabolic behaviour

Xenon is completely inert and does not react with any biological material [1].

3. Personnel monitoring (^{133}Xe)

Wearing a film badge is indicated.

4. Chief characteristics (^{133}Xe)

Type of emission	β^-	γ
Maximum energy (MeV)	0.35	0.089
Percentage	100	36
Radioactive half-life	5.27 d	
Target organ	Whole body	
Effective energy (MeV)	0.19	
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0.13 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)	

5. Detection limits

The problem of detecting xenon in the body or in excreta does not arise since the gas is not metabolized.

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[C-11] The absorption coefficient for xenon is 0.08 in H_2O and 1.7 in olive oil.

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YTTRIUM (Y)

1. Therapy

The short radioactive half-life (64 h) of yttrium-90 means that cases of slight contamination (especially via the digestive system) do not require treatment. In other cases, or when there is doubt, administer 0.5 g of Ca-DTPA (half an ampoule) by slow intravenous injection (diluted in 5% glucose or physiological NaCl) and evacuate the exposed person to a specialized centre.

Note: The high beta energy and short half-life together mean that the absorption of a large quantity of yttrium-90 entails a serious risk of intestinal exposure and thereby justifies the use of a purgative (for example, magnesium sulphate: 10 g in 100–200 ml water).

2. Note on metabolic behaviour

Yttrium behaves like a rare earth (lanthanide series); absorption by the digestive system is very slight [1]. The nuclide is deposited in the bones and in the liver. The soluble salts are mainly nitrates, chlorides, acetates and citrates.

3. Personnel monitoring (^{90}Y)

There is no need to wear a film badge;
Radiotoxicological analysis of urine and faeces.

4. Chief characteristics (^{90}Y)

Type of emission	β^-
Maximum energy (MeV)	2.27
Percentage	100
Radioactive half-life	64 h
Target organ	Gastro-intestinal tract
ALI	~ 12 MBq (320 μCi) for transportable compounds ~ 9.6 MBq (260 μCi) for non-transportable compounds
Effective energy (MeV)	0.89
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)	0

5. Detection limits

Urine: 0.74–1.5 Bq·24 h^{-1} (20–40 pCi·24 h^{-1}).

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ZINC (Zn)

1. Therapy

The treatment for contamination by radioactive zinc is the administration of DTPA: 0.5 g (half an ampoule) given by slow intravenous injection.

The ideal method for treating contamination by radioactive zinc – with Zn-DTPA [1, 2] – is unfortunately not feasible since the molecule has not (yet) been put on the market.

Long-term treatment can only be undertaken at a specialized centre, its effectiveness being judged by the relative increase in urinary excretion of the radioactive zinc. Prolonged treatment should be carried out only under supervision at a hospital, and even then it should be intermittent, so as to enable the physiological zinc pool to re-form (which does not take very long, however) [3]. It is possible to reduce the deposition of radioactive zinc by a factor of 10–20 through DTPA treatment [4].

2. Note on metabolic behaviour

The organs in which zinc is deposited to the greatest extent are the liver, kidneys, spleen, muscles and skeleton [5]. Intestinal absorption of zinc is considerable – approximately 80% [6]. The injection of zinc is followed – during the next two days – by slight excretion in the urine (less than 1% [7]) and about three times as much excretion in the faeces [8]. The fraction excreted declines rapidly during the following days.

3. Personnel monitoring (^{65}Zn)

Individual film dosimetry.
Measurement of emitted radiation or radiotoxicological urinalysis.

4. Chief characteristics (^{65}Zn)

Type of emission	e^-	β^+	X	γ	
Maximum energy (MeV)	–	0.33	0.008	0.51	1.11
Percentage	–	1.4	35	2.8	50.6
Radioactive half-life			245 d		
Target organ	Whole body			Lungs [10]	
Biological half-life	933 d [9]			120 d [10]	
Effective half-life	194 d [9]			80.5 d	
ALI	~ 9.6 MBq (260 μCi)			~ 5.5 MBq (150 μCi)	
Effective energy (MeV)	0.32			0.15	
Γ-value ($R \cdot h^{-1}$ at 1 cm, 1 mCi source)			3 ($R \cdot cm^2 \cdot h^{-1} \cdot mCi^{-1}$)		

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5. Detection limits

Whole-body counting: Theoretical limit = 37 Bq (1 nCi) [11].
Practical limit = 370 Bq (10 nCi).

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Appendix D

STANDARD FIRST-AID KITS

Caution: Some of the drugs listed here are not as yet included in the national pharmacopoeia of all countries and practice has to be modified according to national requirements.

It is difficult to contrive a kit containing all-purpose remedies suitable for any kind of internal contamination. It is up to the physician responsible for radiological protection and first aid at a facility to design a kit appropriate to the risks.

As indicated in Chapter 1, § 1.4.2, the best way of ensuring effective treatment is to have two types of kit – a personal kit and a group medical kit.

D-1. PERSONAL KIT

This is intended for use by the contaminated person himself or a nearby fellow worker at the site of the accident. Use of the kit does not relieve the patient of the responsibility of reporting immediately to the medical unit. The physician alone is competent to diagnose the contamination, assess its level and decide whether or not to continue treatment. As soon as it has been used, the kit should be reassembled. Very simple instructions for use should be clearly visible, for example, either attached to the inside of the lid or readable through it.

A first-aid kit of this kind is for emergency treatment, by means of a single dose, of cases involving contamination of wounds by iodine, rare earths, yttrium, plutonium, transplutonics, caesium, strontium and a mixture of fission products, or cases involving inhalation or ingestion of these substances [1]. The kit should contain:

Iodine: 100 mg, in the form of potassium iodide (130 mg of KI);
DTPA: One 500 mg ampoule in trisodium monocalcic salt solution (250 $mg \cdot ml^{-1}$);
DTPA: Ten capsules of micronized powder of the same salt;
A simple aerosol generator for inhaling the contents of the DTPA powder capsules (for example, a Spinhaler® turbo-inhaler [2];
Colloidal Prussian blue: 1 g;
Calcium alginate: 10 g;
Potassium rhodizonate: 1 g.

The standard personal kit is used in the manner described in Table D-I.

D-2. GROUP MEDICAL KIT

The purpose of this kit is to provide in a simple form a number of remedies not commonly used which might be needed when a contaminated person is received at a clinic. It should thereby be possible to start the prescribed medical treatment promptly.

The kit should contain several doses of each medicament – the suggested number is seven daily doses – in boxes labelled with the name of the contaminant; cards with instructions for treatment should be placed in each box. The cards should indicate certain data on the radionuclide, for example, the usual chemical forms, maximum quarterly intake, and so on.

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TABLE D-I. INSTRUCTIONS FOR USERS OF THE PERSONAL KIT

Radionuclide	Type of contamination	
	Wound	Ingestion or inhalation
(a) Iodine	Drink the contents of the potassium iodide ampoule in a little water.	
(b) Rare earths, plutonium, transplutonics	Wash the wound with the contents of the DTPA ampoule.	Inhale 5 capsules of DTPA, using the aerosol generator.
(c) Caesium	Drink the Prussian blue mixed with a little water.	
(d) Strontium	Pour the rhodizonate onto the wound and dab with cotton wool to ensure penetration.	Drink the alginate in a large glass of water sweetened with sugar.
(e) Fission-product mixture	1. Drink the potassium iodide (a) 2. Apply the rhodizonate (d) 3. Wash with DTPA (b) 4. Inhale DTPA (b) 5. Drink the Prussian blue (c)	1. Drink the potassium iodide (a) 2. Inhale the DTPA (b) 3. Drink the alginate (d) 4. Drink the Prussian blue (c)

A standard kit could thus be used to deal with contamination by iodine and rare earths, plutonium and the transplutonics, caesium, strontium, polonium and uranium [1]. It should contain:

An iodine box: seven bottles of potassium iodide tablets (each containing 100 mg of iodide);
Rare earth, plutonium and transplutonic boxes:
10 ampoules of DTPA (or 10 self-injecting syringes) containing 1 g per ampoule (4 ml);
One wash-bottle containing 500 ml of 1% DTPA (pH 4) for decontaminating skin or wounds;
A caesium box: 21 tubes containing 1 g of Prussian blue (1 g three times a day);
A strontium box: 7 tubes of calcium alginate (for cases of ingestion)
7 tubes of potassium rhodizonate (for wounds)
7 packets of magnesium sulphate (for speeding up intestinal transit);
A uranium box: one 250-ml bottle of 14% bicarbonate serum and a perfusion kit;

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TABLE D-II. INSTRUCTIONS FOR USERS OF THE GROUP MEDICAL KIT

Radionuclide	Type of contamination		
	Wound	Ingestion	Inhalation
(a) Tritium	Have the patient drink 5–8 litres of water per day.		
(b) Iodine	Give the patient a potassium iodide ampoule in a little water.		
(c) Rare earths, plutonium, transplutonics	1. Wash with the contents of a DTPA ampoule or with the DTPA solution. 2. Give a slow intravenous injection of 1 g of DTPA.	1. Have the patient inhale a DTPA ampoule in aerosol form and, if necessary, speed up intestinal transit with $MgSO_4$.	
(d) Caesium	Give the patient 1 g of Prussian blue to drink in a little water, three times a day.		
(e) Strontium	Sprinkle with 1 g of rhodizonate; dab to ensure penetration.	Have the patient drink 10 g of alginate in a large glass of sugar-sweetened water.	
(f) Uranium	1. Wash with bicarbonate serum. 2. Perfusion with bicarbonate serum (to be considered in the case of ingestion).		
(g) Polonium	Inject 1 ampoule of BAL intramuscularly every four hours for three days (test sensitivity at first injection with a quarter ampoule).		
(h) Fission-product mixture	1. Give the patient 1 ampoule of potassium iodide in a little water (b). 2. Sprinkle rhodizonate on the wound (e) 3. Wash with DTPA (c) 4. Have the patient inhale DTPA (c) 5. Give Prussian blue to drink (d)	2. Give alginate to drink (e) 3. Give Prussian blue to drink (d) 4. Have the patient inhale DTPA (c)	2. Have the patient inhale DTPA (c) 3. Give alginate to drink (e) 4. Give Prussian blue to drink (d)

A polonium box: 12 ampoules of British Anti-Lewisite, BAL® (dimercaptopropanol);
A sampling box (for technical details see Appendix A) containing:
14 sets of material for nasal sampling;
14 blood sampling tubes, seven containing heparin;
7 bags or boxes for collecting faeces;
7 bottles for urine specimens.

Instructions for using this standard medical kit are given in Table D-II.

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The physician receiving a contaminated person should always bear in mind the difficulty of diagnosing the body burden and consequently of deciding on the therapeutic action to be taken subsequently. Furthermore, it must be remembered that certain drugs such as BAL are not entirely free from toxicity, that certain indications for treatment belong to the specialist's realm, and that certain types of contamination may have legal as well as medical implications. All patients receiving these medicaments should be carefully followed for early detection of toxic reactions. All these considerations should induce the facility physician to refer to the specialized service with which he is in contact.

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Appendix E

DECONTAMINATION ROOM SUPPLIES

E-1. CLOTHING

Complete protective clothing for each staff member (surgical scrub suits, coveralls, plastic shoe covers, surgical caps, sterile and non-sterile masking tape, plastic or rubber gloves (short and long), pre-fitted respirators). Clean, long patient gowns or coveralls, shoes, shoe covers, socks and blankets for patients.

E-2. DETECTION EQUIPMENT

Portable beta-gamma Geiger-Müller survey meter (background up to 6.5 μC/kg·h and up to 52 mC/kg·h (25 mR/h and up to 200 R/h)).
Portable ionization chamber meter (gas ionization) (for higher dose rates).
Portable alpha survey meter (air proportional, gas flow or scintillation type) with probe.
Personal dose meters – ionization chamber type.
Tritium detector.
Beta-gamma sensitive surgical probe.
NaI scintillation surgical probe, e.g. for Pu or Am.
Cotton applicators for nasal swabs.
Sterile suture sets with additional sterile scissors (2), forceps (10), clamps, retractors.
Ca-DTPA – group medical kit (see Appendix D).
Topical antiseptic (benzalkonium chloride).
Local anaesthetic (lidocaine 2%).
Sterile irrigation set.
Sterile applicators – miscellaneous dressings and bandages.
Airway.
Intravenous sets with cannulas.
Six bottles of sterile physiological saline and six bottles of 5% dextrose in distilled water.
Emergency medication tray.
Suction apparatus.
Clippers, razor with extra blades and aerosol shaving soap.
Sterile sheets, towels, drapes.
Large plastic bags for collection of clothing.
Adhesive labels and tags.
Large towels.
Soft scrub brushes.
Plastic sheets.
Large fibreboard waste baskets lined with plastic bags.
Detergent.
Acid soap.
Sodium hypochlorite 25%.
Potassium permanganate and $NaHSO_3$.
Paraffin with heater.
Sticky tape.
Disposable syringes and needles.
Complete surgical first-aid kit, splints.

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E-3. MISCELLANEOUS

Tape recorder.
Felt pens, note books, papers and pencils.
Specimen bottles for collecting urine and faecal specimens, with complete instructions for collecting and labelling specimens.
Specimen containers with and without heparin and with EDTA for blood counts and chemistries.
Specimen bottles for tissue specimens (Formalin may be used if freezing facilities are not available).

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Appendix F

LIQUID METAL TECHNOLOGY: PRACTICAL FIRST-AID AND MEDICAL PROCEDURES FOR SODIUM BURNS [1]

F-1. INTRODUCTION: PROPERTIES OF SODIUM AND SODIUM/POTASSIUM MIXTURES AND THEIR HEALTH HAZARDS

Increasing amounts of sodium and sodium/potassium (NaK) mixtures are being used as coolant in fast breeder reactors and reactor experimental facilities. The field covered includes road transport of molten metal to the cleaning of components for re-use or disposal. It is these activities which usually lead to accidents.

F-1.1. Nature and physical properties of sodium

Sodium burns in dry air, producing an oxide and peroxide; it reacts with oxygen so quickly that the use of breathing apparatus fed by oxygen is ruled out. The usual practice is to have air cylinders available for rescue teams.

Sodium is liquid above 98°C but does not ignite spontaneously in air until around 130°C. Sodium potassium (NaK) is liquid at room temperature but does not ignite spontaneously unless it is agitated, wiped or squashed.

Sodium reacts explosively with water, producing irritating fumes and generating hydrogen which is explosive in air in concentrations of 4–78%. The reaction of sodium with water is strongly exothermic.

Fumes from burning sodium with water are toxic and extremely irritating, but in a normal atmosphere they absorb water and are quickly converted to sodium hydroxide, which is ten times less toxic than the oxide. Further absorption of carbon dioxide produces an even greater reduction in toxicity.

Sodium reacts with and removes water from most materials including human tissue. Hence the use of proper protective clothing, as described below, is most important.

Sodium/potassium alloy is more reactive than pure sodium.

F-2. PERSONAL PROTECTIVE CLOTHING FOR SODIUM AREAS

Protective clothing for sodium rig operations comprises:

(a) Cloth cap (white cotton – fire proof);
(b) Box goggles or a visor or both (industrial eye protectors);
(c) Heavy cotton jacket and trousers or overall;
(d) Gloves of special leather or neoprene (chrome leather formed by hot chrome sulphate solution gives better resistance);
(e) Leather safety boots.

Protective clothing for large metal disposal or for fire fighting comprises:

(a) Fire-resistant asbestos cloth overall with elastic waist and neck fastening (worn for opening a circuit);

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(b) Chrome leather coat or apron – full length;
(c) Metal hood with full face visor and chrome leather shoulder and neck shield; suitable for wearing over safety goggles or self-contained breathing apparatus face mask;
(d) Surgeons' or rubber boots with reinforced toe-caps;
(e) Self-contained breathing apparatus to be worn as needed.

Complete protective clothing should always be worn for:
(a) Transfer of liquid metal from one container to another;
(b) Opening a circuit;
(c) Handling of liquid sodium or NaK in air;
(d) Dealing with actual or suspected emergencies.

Cap, goggles, gloves and boots are worn for:
(a) Handling solid sodium in air;
(b) Destruction of sodium or NaK with a jet of water from a distance of more than 5 m (this may be done if small amounts of sodium are present and the spill is well away from large quantities of sodium).

Remarks:
(a) Both special and ordinary clothing *must* be dry;
(b) A shirt made of nylon or other pure man-made fibre is not suitable for work in sodium areas;
(c) Coveralls are not advised;
(d) Molten metal would destroy an airline.

Where gross contamination is present and, for example, hair is involved, the use of deluge showers, eye wash fountains and jump tanks entirely separate from the sodium area may be necessary.

F-3. SAFETY EQUIPMENT FOR SODIUM AND NaK AREAS

Solvents:	(a)	Liquid ammonia (anhydrous)
	(b)	High molecular weight alcohols
Extinguishants:	(a)	Dry sodium carbonate (soda ash)
	(b)	Zirconium carbonate
Disposal:		Fine water spray on to large open steel trays
Protective clothing for:	(a)	Sodium rig operations
	(b)	Large metal disposal or fire fighting (see Section F-2)
First-aid equipment:	(a)	Light liquid paraffin in eye wash bottles and spare bottles
	(b)	Cotton gauze swabs
	(c)	Spare safety goggles
	(d)	Burn dressings or bandages (preferably large sizes)
	(e)	Breathing apparatus (air-fed)

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F-4. CLEAN-UP AND DECONTAMINATION PROCEDURES FOR SPILLS

Cleaning operations must be performed under the supervision of a designated person. Appropriate protective clothing must be worn. All cleaning should be done in designated areas with suitable warning signs.

Individual components may be cleaned of the main bulk of sodium residues by heating in a liquid paraffin bath or in oils with a density lower than sodium.

If the spillage is very small, a fine water spray may be used to disperse it, ensuring that the liquid runs away from the unreacted sodium.

Dry steam may be used to clean up spillages from apparatus. If steam has access to all surfaces it is the most efficient cleansing process. The apparatus should be trace-heated to above 100°C before the passage of steam.

Alcohol may be used for cleaning up components of a simple shape (e.g. plates or tubes) where small amounts of sodium are present. Alcohol is particularly applicable to glassware where the whole reaction can be observed.

Anhydrous liquid ammonia may be used as it results in a 'safe' solution of sodium. The solution of sodium or NaK in ammonia is deep blue in colour; complete solution is indicated by the disappearance of the blue colour when the ammonia is changed. This method is useful near zirconium or uranium which readily catch fire if cleaned with alcohol or water.

Cleaning of spillages involves the following general considerations:

(a) Assessment of amount of sodium or NaK.
(b) The location of the spillage and its proximity or otherwise to large volumes of sodium or NaK.
(c) The presence or absence of fire.
(d) Whether the sodium or NaK is combined with other metals.
(e) The presence or absence of radioactive material.

F-5. DAMAGE PRODUCED BY SODIUM BURNS

F-5.1. Skin damage

(a) If first aid is administered quickly the amount of burning may be very limited. The burn may range from slight erythema to minor blistering with first-degree or possibly second-degree burns. An assessment at this stage must also consider the area involved on a percentage basis; treatment of a surface area of more than 20% may be difficult with limited facilities.

(b) If first aid is delayed or if sodium is trapped in clothing, ignition may occur and burning may involve deeper layers of tissue. The areas involved have a sharp edge with surrounding erythema and a dark brown or black centre. It is important to note that severe pain occurs during the actual burning and rapidly lessens thereafter.

(c) If the skin is exposed to oxide or hydroxide fumes above 2 mg/m^3 for several hours an irritant rash may appear.

F-5.2. Eye damage

When sodium or NaK enters the eye, a severely painful reaction results. The pain greatly hampers any first-aid efforts.

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The strongly caustic sodium hydroxide produces extensive damage which may well be irreversible, depending on the amount entering the eye and the length of time it is in contact with the conjunctiva. This may result in corneal opacities, following corneal ulceration, vascularization of the cornea, or adhesions of the eyelid and cornea (symblepharon) with or without ectropion or entropion, i.e. 'turning-out' or 'turning-in' of the eyelids.

The vascularization of the cornea makes subsequent corneal grafting impossible. Secondary glaucoma and cataracts may also follow on severe eye damage which may require eventual removal of the eye.

F-5.3. Respiratory tract damage

If strongly alkaline fumes are inhaled they can produce moderate to severe respiratory tract damage. Highly irritant fumes produce initial violent coughing which usually acts as sufficient warning to ensure rapid evacuation of the area. Persons who cannot leave the area, e.g. who are trapped or unconscious, may suffer severe damage to the respiratory tract resulting in pulmonary oedema.

F-5.4. Digestive tract damage

Caustic chemical damage to the digestive tract can produce oesophageal and stomach irritation which may result in nausea and retching. It is unlikely that large amounts of a caustic mixture would be swallowed because of its unpleasant taste and irritant quality.

F-6. TREATMENT – GENERAL PRINCIPLES

It must be emphasized that *all* treatment is directed at removing sodium or sodium/potassium compounds by dilution with water or a similar agent. Water is the ideal diluent and is the accepted form of treatment, and should be used whenever possible. However, its use may be prevented near large amounts of sodium in rigs or reactors. In a number of countries, light liquid paraffin is not popular for treating sodium burns. There the general philosophy is that close to sodium areas facilities specially designed to allow washing the eye with water should be installed. Also the idea of whole-body immersion into a bath of paraffin is not universally accepted. In some areas it is customary to use light liquid paraffin[F-1] (0.83–0.87 g per ml) or olive oil. The light paraffin can be easily washed off after the patient is removed to a safe area.[F-2]

F-6.1. First aid – General

(a) The injured persons should make as few movements as possible.
(b) The first-aid personnel must wear at least protective goggles (see Section F-2).

[F-1] Specifications for light liquid paraffin: Pour point 45°F, boiling range at 10 mm pressure 124–248°C, specific gravity 0.866, kinematic viscosity 14–14.5 centipoises, flash point 150°C, airline point 96°C.

[F-2] The light paraffin 'floats' particles of NaK off the skin and prevents them from causing local burns.

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F-6.2. Skin

(a) Pour the diluting fluid or covering agent (liquid paraffin) on the affected part to cover the whole area.
(b) Remove visible pieces of metal by wiping gently with cotton wool or gauze.
(c) If the splashes are on the face, wipe *away* from the eyes, mouth and nose.
(d) If protective goggles are worn, see that they are held tightly until the face is clean and then ensure that the eyes are closed while the goggles are removed.

F-6.3. Eyes

(a) If a splash has entered the eye this should be irrigated with water or liquid paraffin. In view of the intense pain it will be necessary to have the eyes held open by a third person.
(b) It should be emphasized that each eye contaminated or thought to be contaminated *must* be irrigated immediately. There are *no* exceptions to this rule, no matter how badly damaged the eye might appear. First-aid treatment given immediately is much more valuable than later prolonged irrigation because the damage done to the eye increases rapidly with every minute of contact with the strong alkali.

F-6.4. Respiratory tract

(a) Ensure that an open airway is maintained.
(b) Use breathing apparatus to supply air if necessary.

F-6.5. Digestive tract

Use water or water and milk to encourage dilution of the alkaline swallowed.

F-7. MEDICAL TREATMENT

F-7.1. Skin

On arrival at the medical centre the oil-soaked area is wiped clean. Areas which can readily be immersed in water or water and ice are treated this way, e.g. hands. Other areas may require prolonged copious lavage with water.

Depending on the depth and the area involved, the burn is covered with sterile dressings, or a paraffin gauze dressing may be used to prevent adhesion to the area. The gauze may be impregnated with a suitable antibiotic if preferred. These dressings should be left undisturbed as long as possible. With this method good results have been obtained in all cases of small burned areas.

For larger areas where fluid loss and skin loss is considerable, removal to a burns unit will be necessary for further, more specialized treatment.

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F-7.2. Eyes

When the eye is injured, prolonged irrigation is necessary in *all* cases. Where more than superficial injury is present, referral to an ophthalmologist is imperative. Treatment to prevent or lessen the complications listed above can only be performed in specialist units.

In less severe cases where only dilute alkali has entered the eye, treatment with antibiotic drops (e.g. chloramphenicol) will be all that is necessary for a few days.

F-7.3. Internal contamination

Copious fluid intake is necessary in all cases and water or water and milk must be administered to ensure a high excretion volume.

F-7.4. Respiratory tract involvement

Inhalations of steam with added acetic acid are very soothing on the upper respiratory tract.

If lung damage is suspected and oxygen uptake reduced the addition of oxygen may be necessary.

A cough suppressant (e.g. codeine) may be useful where explosive, irritant coughing is present.

F-7.5. Some variations in treatment

It may be advantageous to immerse the patient totally in a bath of water or oil (liquid paraffin or olive oil). From a practical point of view this presents problems of availability of such a bath and the amount of oil necessary. These facilities might be available in a decontamination centre for radiation areas and could be adapted for use in sodium burns. The patient may well be shocked and nervous and unable to co-operate in such a procedure which might possibly aggravate his condition.

In the unlikely event of either sodium or NaK remaining on the skin in sufficient quantity, it can be removed by careful scraping but not rubbing.

If the sodium is burning it should be removed while burning, the attendant wearing protective clothing. If sodium is trapped in clothing, careful removal without rough handling is sufficient and the clothing is disposed of in a suitable container.

The use of dilute acids, e.g. 2% boric acid or 2% acetic acid, on the eye or skin may be advantageous but should not outweigh the importance of massive irrigation of both areas in every case. It is difficult to maintain clean quantities of these substances in industrial situations.

F-8. CONTAMINATION BY RADIOACTIVE SUBSTANCES

If sodium burns may be caused by metal contaminated by fission products, priority must be given to the burn and not to the radioactive problem, which can be dealt with later.

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F-9. SUMMARY

The extent and severity of sodium burns can be considerably reduced by effective and speedy first-aid treatment. All workers should be familiar with the treatment of sodium burns and especially the treatment of eye contamination by sodium or its compounds. To this end, easily identifiable first-aid kits with clear instructions should be available near all facilities using metallic sodium.

REFERENCE TO APPENDIX F

[1] Guidance in the Safe Handling of Alkali Metals, UKAEA Rep. TRG-25 (C), Thorley and Raine (1961).

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The following conversion table is provided for the convenience of readers and to encourage the use of SI units.

FACTORS FOR CONVERTING SOME OT THE MORE COMMON UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI) EQUIVALENTS

NOTES:

(1) SI base units are the metre (m), kilogram (kg), second (s), ampere (A), kelvin (K), candela (cd) and mole (mol).

(2) ▶ indicates SI derived units and those accepted for use with SI;
▷ indicates additional units accepted for use with SI for a limited time.
[*For further information see The International System of Units (SI), 1977 ed., published in English by HMSO, London, and National Bureau of Standards, Washington, DC, and International Standards ISO-1000 and the several parts of ISO-31 published by ISO, Geneva.*]

(3) The correct abbreviation for the unit in column 1 is given in column 2.

(4) * indicates conversion factors given exactly; other factors are given rounded, mostly to 4 significant figures.
≙ indicates a definition of an SI derived unit: [ ] in column 3+4 enclose factors given for the sake of completeness.

Column 1 *Multiply data given in:*	Column 2	Column 3 *by:*	Column 4 *to obtain data in:*	
Radiation units				
▶ becquerel	1 Bq	(has dimensions of s^{-1})		
disintegrations per second (= dis/s)	1 s^{-1}	≙ 1.00×10^{0}	Bq	*
▷ curie	1 Ci	= 3.70×10^{10}	Bq	*
▷ roentgen	1 R	[= 2.58×10^{-4}	C/kg]	*
▶ gray	1 Gy	[≙ 1.00×10^{0}	J/kg]	*
▷ rad	1 rad	= 1.00×10^{-2}	Gy	*
sievert *(radiation protection only)*	1 Sv	[= 1.00×10^{0}	J/kg]	*
rem *(radiation protection only)*	1 rem	[= 1.00×10^{-2}	J/kg]	*
Mass				
▶ unified atomic mass unit ($\frac{1}{12}$ of the mass of ^{12}C)	1 u	[= $1.660\,57 \times 10^{-27}$	kg, approx.]	
▶ tonne (= metric ton)	1 t	[= 1.00×10^{3}	kg]	*
pound mass (avoirdupois)	1 lbm	= 4.536×10^{-1}	kg	
ounce mass (avoirdupois)	1 ozm	= 2.835×10^{1}	g	
ton (long) (= 2240 lbm)	1 ton	= 1.016×10^{3}	kg	
ton (short) (= 2000 lbm)	1 short ton	= 9.072×10^{2}	kg	
Length				
statute mile	1 mile	= 1.609×10^{0}	km	
nautical mile (international)	1 n mile	= 1.852×10^{0}	km	*
yard	1 yd	= 9.144×10^{-1}	m	*
foot	1 ft	= 3.048×10^{-1}	m	*
inch	1 in	= 2.54×10^{1}	mm	*
mil (= 10^{-3} in)	1 mil	= 2.54×10^{-2}	mm	*
Area				
▷ hectare	1 ha	[= 1.00×10^{4}	m^2]	*
▷ barn *(effective cross-section, nuclear physics)*	1 b	[= 1.00×10^{-28}	m^2]	*
square mile, (statute mile)^2	1 $mile^2$	= 2.590×10^{0}	km^2	
acre	1 acre	= 4.047×10^{3}	m^2	
square yard	1 yd^2	= 8.361×10^{-1}	m^2	
square foot	1 ft^2	= 9.290×10^{-2}	m^2	
square inch	1 in^2	= 6.452×10^{2}	mm^2	
Volume				
▶ litre	1 l *or* 1 ltr	[= 1.00×10^{-3}	m^3]	*
cubic yard	1 yd^3	= 7.646×10^{-1}	m^3	
cubic foot	1 ft^3	= 2.832×10^{-2}	m^3	
cubic inch	1 in^3	= 1.639×10^{4}	mm^3	
gallon (imperial)	1 gal (UK)	= 4.546×10^{-3}	m^3	
gallon (US liquid)	1 gal (US)	= 3.785×10^{-3}	m^3	
Velocity, acceleration				
foot per second (= fps)	1 ft/s	= 3.048×10^{-1}	m/s	*
foot per minute	1 ft/min	= 5.08×10^{-3}	m/s	*
mile per hour (= mph)	1 mile/h	= 4.470×10^{-1} m/s = 1.609×10^{0} km/h		
▷ knot (international)	1 knot	= 1.852×10^{0}	km/h	*
free fall, standard, g		= 9.807×10^{0}	m/s^2	
foot per second squared	1 ft/s^2	= 3.048×10^{-1}	m/s^2	*

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Column 1 *Multiply data given in:*	Column 2	Column 3 *by:*	Column 4 *to obtain data in:*	
Density, volumetric rate				
pound mass per cubic inch	1 lbm/in^3	= 2.768×10^4	kg/m^3	
pound mass per cubic foot	1 lbm/ft^3	= 1.602×10^1	kg/m^3	
cubic feet per second	1 ft^3/s	= 2.832×10^{-2}	m^3/s	
cubic feet per minute	1 ft^3/min	= 4.719×10^{-4}	m^3/s	
Force				
▶ newton	1 N	[≡ 1.00×10^0	m·kg·s^{-2}]	*
dyne	1 dyn	= 1.00×10^{-5}	N	*
kilogram force (= kilopond (kp))	1 kgf	= 9.807×10^0	N	
poundal	1 pdl	= 1.383×10^{-1}	N	
pound force (avoirdupois)	1 lbf	= 4.448×10^0	N	
ounce force (avoirdupois)	1 ozf	= 2.780×10^{-1}	N	
Pressure, stress				
▶ pascal	1 Pa	[≡ 1.00×10^0	N/m^2]	*
▷ atmosphere[a], standard	1 atm	= $1.013\,25 \times 10^5$	Pa	*
▷ bar	1 bar	= 1.00×10^5	Pa	*
centimetres of mercury (0°C)	1 cmHg	= 1.333×10^3	Pa	
dyne per square centimetre	1 dyn/cm^2	= 1.00×10^{-1}	Pa	*
feet of water (4°C)	1 ftH$_2$O	= 2.989×10^3	Pa	
inches of mercury (0°C)	1 inHg	= 3.386×10^3	Pa	
inches of water (4°C)	1 inH$_2$O	= 2.491×10^2	Pa	
kilogram force per square centimetre	1 kgf/cm^2	= 9.807×10^4	Pa	
pound force per square foot	1 lbf/ft^2	= 4.788×10^1	Pa	
pound force per square inch (= psi)[b]	1 lbf/in^2	= 6.895×10^3	Pa	
torr (0°C) (= mmHg)	1 torr	= 1.333×10^2	Pa	
Energy, work, quantity of heat				
▶ joule (≡ W·s)	1 J	[≡ 1.00×10^0	N·m]	*
▶ electronvolt	1 eV	[= $1.602\,19 \times 10^{-19}$	J, approx.]	
British thermal unit (International Table)	1 Btu	= 1.055×10^3	J	
calorie (thermochemical)	1 cal	= 4.184×10^0	J	*
calorie (International Table)	1 cal$_{IT}$	= 4.187×10^0	J	
erg	1 erg	= 1.00×10^{-7}	J	*
foot-pound force	1 ft·lbf	= 1.356×10^0	J	
kilowatt-hour	1 kW·h	= 3.60×10^6	J	*
kiloton explosive yield (PNE) (≡ 10^{12} g-cal)	1 kt yield	≃ 4.2×10^{12}	J	
Power, radiant flux				
▶ watt	1 W	[≡ 1.00×10^0	J/s]	*
British thermal unit (International Table) per second	1 Btu/s	= 1.055×10^3	W	
calorie (International Table) per second	1 cal$_{IT}$/s	= 4.187×10^0	W	
foot-pound force/second	1 ft·lbf/s	= 1.356×10^0	W	
horsepower (electric)	1 hp	= 7.46×10^2	W	*
horsepower (metric) (= ps)	1 ps	= 7.355×10^2	W	
horsepower (550 ft·lbf/s)	1 hp	= 7.457×10^2	W	
Temperature				
▶ temperature in degrees Celsius, t where T is the thermodynamic temperature in kelvin and T_0 is defined as 273.15 K	$t = T - T_0$			
degree Fahrenheit	$t_{°F} - 32$	$\times \left(\frac{5}{9}\right)$ gives	t *(in degrees Celsius)*	*
degree Rankine	$T_{°R}$		T *(in kelvin)*	*
degrees of temperature difference[c]	$\Delta T_{°R}$ (= $\Delta t_{°F}$)		ΔT (= Δt)	*
Thermal conductivity[c]				
1 Btu·in/(ft^2·s·°F) *(International Table Btu)*		= 5.192×10^2	W·m^{-1}·K^{-1}	
1 Btu/(ft·s·°F) *(International Table Btu)*		= 6.231×10^3	W·m^{-1}·K^{-1}	
1 cal$_{IT}$/(cm·s·°C)		= 4.187×10^2	W·m^{-1}·K^{-1}	

[a] atm abs, ata: atmospheres absolute; atm (g), atü: atmospheres gauge.

[b] lbf/in^2 (g) (= psig): gauge pressure; lbf/in^2 abs (= psia): absolute pressure.

[c] The abbreviation for temperature difference, deg (= degK = degC), is no longer acceptable as an SI unit.

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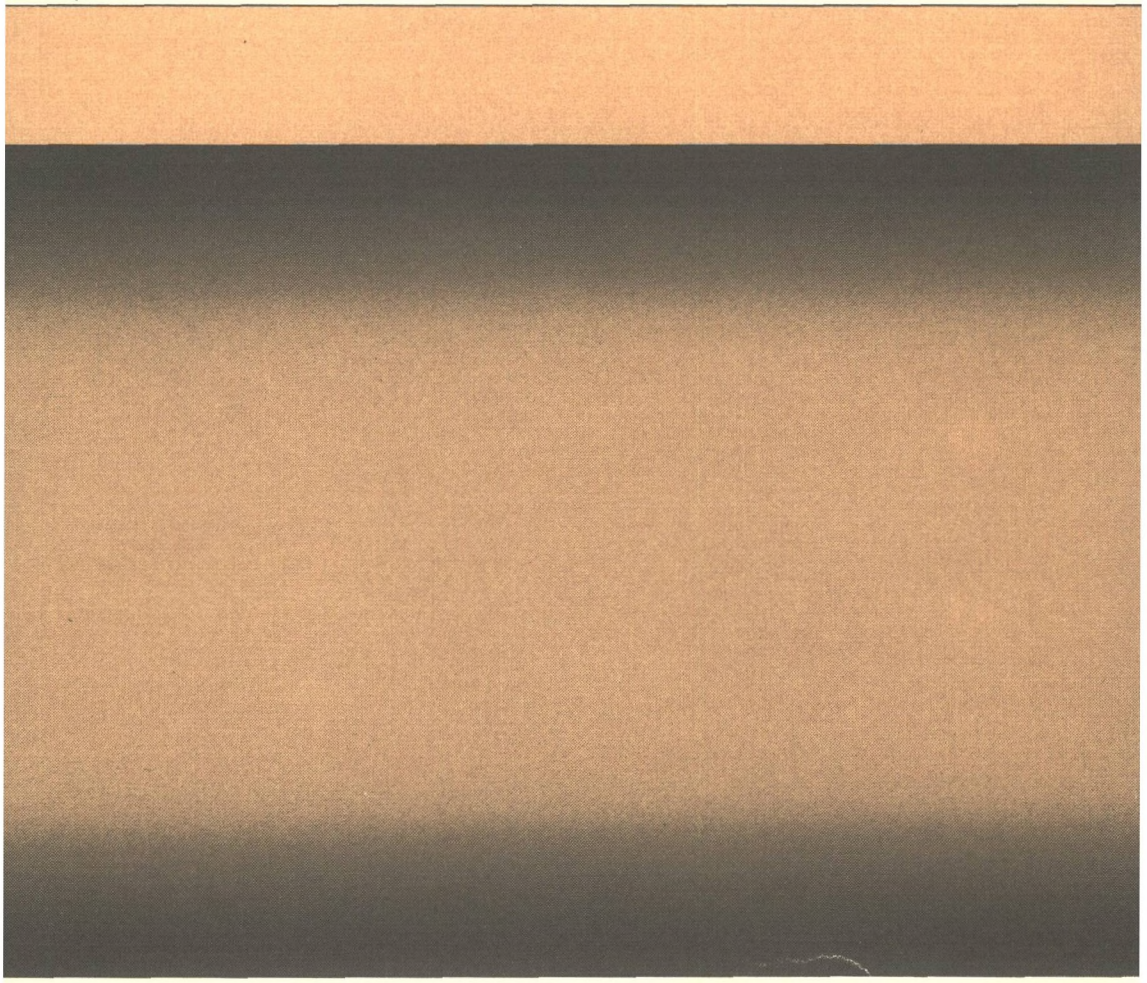

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