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Review

# Decontamination of radioisotopes

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ABSTRACT

Contaminations with radioactive material may occur in several situations related to medicine, industry or research. Seriousness of the incident depends mainly on the radioactive element involved; usually there are no major acute health effects, but in the long term can cause malignancies, leukemia, genetic defects and teratogenic anomalies.
The most common is superficial contamination, but the radioactive material can get into the body and be retained by the cells of target organs, injuring directly and permanently sensitive elements of the body. Rapid intervention is very important to remove the radioactive material without spreading it. Work must be performed in a specially prepared area and personnel involved should wear special protective clothing. For external decontamination general cleaning techniques are used, usually do not require chemical techniques. For internal decontamination is necessary to use specific agents, according to the causative element, as well physiological interventions to enhance elimination and excretion.


## 1. General aspects

Radioactive materials are widely used in medicine, industry, agriculture and research (Table 1). Unsealed sources of radionuclides can be easily dispersed and may be taken improperly into the body.

Contamination occurs when material that emits ionizing radiation is deposited on a person (skin, hair, clothing), or any place where is it not intended. People who are externally contaminated can become internally contaminated if radioactive material gets into their bodies, thus causing a hazard for internal radiation. The presence of radioactive substances inside the human body generates risk of internal intakes of radionuclides with organ's tissue and cell retention. A person contaminated with radioactive materials is being irradiated until the radioactive material is removed. Properly completed, rapid decontamination can limit the spread of contamination and reduce morbidity and mortality.

A quick survey should provide sufficient evidence of the presence or absence of gross contamination. Before decontamination procedures are started gross radioactive contamination is easily detected via a quick scan of the patient with appropriate instrumentation. Geiger–Muller counter is the most common detection device, being generally used for the survey; an increase in count rate above background indicates the presence of radiation. In general, areas that register more than twice the previously determined background level are considered contaminated. If the reading is less than twice the background radiation level, it is assumed that the person is not contaminated to a medically significant degree.[1] A detailed description of how to carry out a survey can be found

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**Table 1 – Common isotopes used in nuclear medicine.**

| Isotope | Symbol | Half-life | Photons, Kev (%) | Beta | Production | Use: diagnostic (D) therapy (T) |
|---|---|---|---|---|---|---|
| Technetium-99m | 99m-Tc | 6 h | 140 | | Generator | D |
| Gallium-67 | 67-Ga | 3.3 d | 93 (50) 185 (30) 300 (20) | | Cyclotron | D |
| Indium-111 | 111-In | 2.8 d | 173 (50), 247 (50) | | Cyclotron | D |
| Iodine-123 | 123-I | 13 h | 159 | | Cyclotron | D |
| Iodine-131 | 131-I | 8 d | 365 | 0.807 | Reactor | D, T |
| Thallium-201 | 201-Tl | 3 d | 69–81 (90), 167 (10) | | Cyclotron | D |
| Fluorine-18 | 18-F | 109.8 m | 511 | | Cyclotron | D |
| Nitrogen-13 | 13-N | 10 m | 511 | | Cyclotron | D |
| Rubidium-82 | 82-Rb | 1.3 m | 511 | | Cyclotron | D |
| Carbon 11 | 11-C | 20.4 m | 511 | | Cyclotron | D |
| Lutetium-177 | 177-Lu | 6.7 d | 208 (11), 113 (6) | 0.5 | Reactor | T |
| Phosphorus-32 | P-32 | 14.3 d | | 1.7 | Reactor | T |
| Rhenium-186 | 186-Re | 3.8 d | 137 (9) | 1.1 | Reactor | T |
| Samarium-153 | 153-Sm | 1.9 d | 103 (29) | 0.8 | Reactor | T |
| Strontium-89 | 89-Sr | 50.5 d | | 1.5 | Reactor | T |
| Yttrium-90 | Y-90 | 64 | | 2.3 | Reactor | T |

in several publications.[2,3] The use of uncollimated gamma-cameras to detecting and quantifying in vivo contamination, has been show useful for radionuclides emitting gamma-energies between 0.035 and 1.30 MeV.[4]

Radioactive contamination consists almost always of radionuclides that emit high-energy alpha, beta, and/or photon gamma radiation. They have a broad range of penetration capabilities through tissues. Alpha particles are unable to penetrate to the basal cell layer of the healthy skin, but they can cause harm if internalized. Beta particles are able to penetrate several centimeters into tissue. High-energy gamma rays are non particulate forms of radiation that can traverse the human body and can be shielded only by significant thicknesses of lead. Accordingly, if a worker, person, or any place becomes contaminated from any isotope, the decontamination method to be used depends upon the location, the isotope type, half life, mode of radiation and the form of contamination.[2,5] Some publications provide complete individual data sheets for a wide range of commonly used radionuclides, classified into different groups as a function of risk level.[6]

Usually no immediate life-threatening hazard is associated with radiation contamination. A patient may have also suffered acute injury; in that case, the first priority is to treat other vital medical conditions to ensure the patient is medically stable, since contamination does not usually cause acute medical effects, even in cases of higher exposure.[7,8] Signs and symptoms of radiation injury and/or illness might not appear for hours to days and sometimes weeks.The challenge of the decontamination process is to remove the radioactive material without spreading it. These materials usually cannot be neutralized in the strict sense. The best form of eliminating them is to move from one point to another or transfer them to discard materials, thus avoiding prolonged contact with the patient, following basic common sense.[2] The first objective is to prevent the spread of radioactive materials since people who are externally contaminated with radioactive material can contaminate other people or surfaces that they touch.

To carry out the decontamination work is desirable to have an area that can be configured for decontamination, to prevent the spread of radioactive materials to other areas, equipment, and people. Movement of a contaminated patient should always be limited to that which is strictly necessary.[2]

Personnel involved in handling contaminated patients should be given a personal dosimeter and may wear appropriate protective clothing, like surgical gown, respiratory mask, double latex gloves and shoe covers. Outer gloves should be changed frequently to avoid cross-contamination. Eye protection should also be worn to prevent ocular contamination from any splashing during the decontamination procedure. Shielding devices that are normally used for radiology studies are not recommended because their bulk difficult the decontamination process and therefore leads to an increased exposure time, even are not effective shields for the high-energy emissions.[9] Radiation detection devices can readily locate contaminants in the area to allow decontamination to take place. In general, the four basic principles of ALARA (as low as reasonably achievable) recommendations should be taken into account to reduce exposure; these involve minimizing the time of exposure, maximizing the distance from the source, if it is possible, using shielding as appropriate, and the removal or containment of contamination.[10] Protective gear should be removed after use and placed in a clearly labeled, sealed plastic container.

General cleaning techniques for external decontamination usually involve washing with soap and lukewarm water, although the aid of other techniques may be needed, depending upon the location, the isotope type and the form of contamination; the whole process often demands a significant contribution of resources and can take substantial time.

Children have special medical needs during a radiologic emergency because the short- and long-term consequences of a radiation contamination are greater. Some of their tissues are inherently more radiosensitive to stochastic effect and they are at greater risk of developing cancer. Also, they tend to be emotionally less resilient and may incur in long-term psychological harm. The American Academy of Pediatrics has issued guidelines and recommendations for children in a radiologic emergency.[11]

Several readily available reports provide general guidance to those who may be called to respond to radionuclide contamination incidents and for specific medical therapies.[1,3,12–14]

## 2. External decontamination

### 2.1. General management

Diagnosis of contamination is achieved mainly by history. Historical information, including the location of the incident, duration of exposure, interval between exposure and clinical evaluation, activity and exact location at the time of exposure, and occupation of the victim should be documented. In the case of an incident, the patient, or any person who was involved in the incident, may know what isotope was being used. The incident history should provide some background for predicting possible internalization of radionuclides. It may be necessary to sample during the decontamination process, which can be analyzed to determine the radionuclide present.

The determination of external contamination will require inspection with standard detector equipped with beta-gamma and alpha probes. The first step would be to do a complete body survey to demarcate the areas in the body that are contaminated.[2] If the decontamination cannot begin immediately, locally affected areas should be outlined with a permanent marker and covered with wrapping until decontamination begins, to prevent its spread. Any wounds or abrasions should be carefully noted. If any breaks in skin continuity are noted it should be covered with waterproof adhesive plaster. The contamined wounds and the surrounding area should have priority in decontamination.

When carrying out decontamination procedures, personnel should wear double surgical gloves and an apron; in case the contamination is heavy it is better to be wearing complete surgical clothing and mask. For major incidents detailed recommendations have been published.[9,15]

If possible, contaminated patients should enter the treatment facility through a separate entrance. If a separate entrance is not available, the contaminated patient can be placed on a clean stretcher outside the emergency department and wrapped in a cloth sheet before transport to the desired area of the hospital. The decontamination room should be separated from the rest of the treatment areas of the emergency department and must be equipped with instruments for monitoring radiation like Geiger–Muller counters.

Convenient supplies for radiation decontamination include disposable waterproof paper for covering the floor, tape to secure the covers, emergency medical equipment, patient sheets and gowns, table with a drainage system to collect contaminated washings, large buckets for collection of waste water, plastic bags for disposal of swabs, clothing and trash, lead containers for possible radioactive foreign bodies, solutions for decontamination (saline, water, soap, hydrogen peroxide) and soft brushes. In addition the supplies for health care personnel include scrubs, gowns, masks, foot covers, hats, waterproof gloves, tape to secure the outer coverings, waterproof aprons, dosimeters and pens for labeling specimens.

The process begins by carefully removing all contaminated clothing, working from head to toe and rolling it outward away from the patient's skin, trapping the contaminant material inside. If necessary, clothing should be cut off, not tearing, to prevent spread of radioactive materials through contact or airborne transmission. This can reduce contamination by as much as 80–90%.[13]

The exposed intact skin should be showered or washed with regular warm water. Hot water must be avoided because it enhances the absorption of the radioactive material due to increased skin blood flow. Also, cold water should be avoided since it closes skin pores trapping contamination inside. Since most radiologic material is located on the head and hands, the patient should be in the "head-back" position during initial showering to prevent run-off into the eyes, nose, or mouth. Contamination material around these orifices should be removed; Some times patient's face may be protected. Early hand washing is also important.

Decontamination procedures must start from the periphery of the contaminated area and move towards the center. Care must be taken to ensure that, in any case, contaminated washings are allowed to run onto uncontaminated areas. The procedure should begin with soap and water, if this fails, a weak detergent may be used. Shampoo or detergent may be used for washing the hair if it is contaminated.

Ideally, all contamination should be removed; however there are certain considerations which should be taken into account for determining the damage of decontamination required. The radioactive substances usually rest on a thin film of oil that covers the outer layer of the skin. Accordingly, decontamination procedures are based on the removal of this oily film. Care must be taken not to irritate the skin. If it becomes erythematous or if the skin barrier is lost, some radionuclides could be absorbed directly through the skin. Hair may need to be clipped if washing is insufficient for decontamination; it should not be shaved, since shaving may increase absorption.

Final verification of decontamination completeness will be conducted on the stage. If the contamination persists the procedure may be repeated. If possible, a member of the trained team should use a radiation detection device to perform a head-to-toe survey of all areas of the patient's body.[2,3] Irrigation of the suspected areas should be done until acceptable levels are reached, that is, two times the normal background levels, or when additional efforts are not significantly reducing contamination. In general, no more than two or three cycles should be attempted. Signs of excessive decontamination efforts will be more evident 24 h later, and two or three less intensive decontamination efforts are less traumatic to the skin than one major effort.

In case of small areas of fixed contamination, it could be covered with adhesive plaster and left for a day. The residual contamination will come off when the plaster is removed.

Chemical techniques are rarely needed. The 0.5% hypochlorite solution used for chemicals will also remove radiological contaminants. For persistent external contamination abrasive soaps or heavy-metal chelating agents such as EDTA may be carefully used. Commercially available decontaminating agents appear to have little to offer over soap and water for the cleaning the contaminated skin by the short-lived nuclides. In general, 90 s of gentle washing with soap and water will remove 95–99% of radionuclide activity present on intact skin.[16,17]

All contaminated material, clothing, linen, swabs, etc. should be placed in large impervious plastic bags, sealed and labeled appropriately for special waste disposal, or, if the radioactive contaminant has not yet been identified, for further analysis.

If the patient is to be transferred to a specialist unit, he should be covered with some light non-absorbent clothes to minimize spread of contamination.

### 2.2. Special considerations

Body entrance cavities and open wounds require special decontamination procedures[2,18,19] because radioactive material uptake may be faster through orifices and mucous membranes.

Swabs samples should be taken from the mouth, nose and eyes with a cotton-tipped applicator, preferable between gums and teeth, under the tongue and one from each naris. Moistened swabs are recommended for the eyes and ears. If the possibility of internal contamination is strongly suspected, negative counts may mean nothing, depending on the time since the incident occurred.

Mouth rinsing and tooth brushing are encouraged if radioactive material has entered the oral cavity, not swallowing the fluids. The nose and auditory canals can be irrigated with a syringe filled with saline warmed to body temperature, taking care to avoid irritation. The eyes should be rinsed by directing a stream of water from the inner canthus to the outer canthus, without causing bleeding.

Contaminated open wounds may provide continuous irradiation of surrounding tissues and increase the likelihood of systemic incorporation. This hazard remains until the contaminant is removed by cleansing, surgical debridement, or radionuclide decay. Intervention require copiously irrigation of the area and re-inspection, as in intact skin, cover the wound with waterproof dressing to prevent contamination from irrigation run-off from other areas, and obtain wound swabs. Standard or povidone-iodine surgical soap may be used if there is a concern for microbial contamination. If any particulate material foreign bodies are present, they should be removed with forceps and saved for analysis. If surgery is needed, continuous monitoring of the wound site and any material removed should be carried out, while intervention is being undertaken. After surgery it is mandatory to monitor all the used instruments, following suitable decontamination procedures before the instruments can be utilized again.

## 3. Internal decontamination

Internal contamination occurs when radioactive material is breathed in, swallowed, enters the body through an open wound or is absorbed through the skin; then, it crosses the capillary membrane through passive and active diffusion mechanisms and can be incorporated into body cells, tissues, or organs. This can be the case of iodine uptake in the thyroid or radium, plutonium and americium primarily in the bone. The rate of distribution to each organ is related to the organ metabolism and ease of chemical transport.[1]

Treatment for internal contamination begins when the patient is medically stable and external decontamination is complete. Rapid intervention is critical, because some isotopes can be incorporated by the end organ within hours or minutes, and then is very difficult to remove them. In addition to knowing what radionuclides are involved, it may be necessary to estimate the approximate level of internal contamination of the patient in order to know whether a decorporation treatment is necessary at all. Suggestion of internal contamination by positive nasal or oral swabs should be confirmed through bioassay monitoring of feces, urine and possibly of blood. Agencies such as The Centers for Disease Control and Prevention have developed protocols to convert thyroid scanners, gamma cameras, and other radiation detection equipment, commonly found in hospitals, for use as whole-body counters in case of an emergency event.[20]

Specific management of internal contamination depends upon the radioactive element involved and its chemical form. In general, radioactive materials are distributed throughout the body based upon their physical and chemical properties, this playing a significant role in determining treatment. A soluble radionuclide will be more readily absorbed; hence, its potential for passing across membranes into circulation is high. For example, radioiodine and cesium are rapidly absorbed; plutonium, radium, and strontium are not. The effect of insoluble isotopes may be more localized.

The goals of internal decontamination are to reduce absorption and to enhance elimination and excretion to avoid or minimize the passage to the systemic circulation system. Once there has been internal tissue deposition, the effectiveness of any treatment will be significantly reduced. Table 2 shows common decorporating agents used for internal decontamination.

### 3.1. Reduction of gastrointestinal absorption

Gastric absorption can be reduced by stomach lavage and emetic agents. These strategies may decrease absorption of radioisotopes if initiated early after gastric contamination, but they also create the risk of aspiration of radioisotopes, leading to respiratory contamination.

Laxatives or purgatives, preferably of fast action, will stimulate intestinal motility, and saline cathartics will increase water movement into the intestine and induce removal of contents within 3–6 h.

Some enteral binding methods have been shown to effectively bind specific agents of contamination. Barium sulfate, commonly used for radiographic contrast studies, forms irreversible bonds with strontium and radium. Prussian blue – ferric III hexacyano-ferrate II – binds to cesium-137 and isotopes of thallium and blocks the absorption of rubidium.[21] Sodium alginate binds strontium and prevents its absorption. Aluminum and magnesium salts, administered by mouth or nasogastric tube at a dose of 100 ml, bind to strontium, radium and phosphorus[2,22] (Table 2).

### 3.2. Block uptake in the target organ

All patients who were potentially exposed to radioactive iodine should be treated with supersaturated potassium to block thyroid deposition. Potassium iodide competitively blocks thyroid uptake of radioactive iodine and technetium. It should be administered immediately after intake or at least

**Table 2 – Decorporation treatment summary.**

| Decorporation drug | | Dosification | Radionuclide |
|---|---|---|---|
| Ammonium chloride | Oral | 1–2 g q.i.d., for up to 6 consecutive days | Strontium |
| Ca-DTPA, Zn-DTPA | i.v. | 1 g in 250 ml normal saline or 5% dextrose in water, over 1 h | Americium, plutonium |
| Calcium | oral | Generous doses | Radium, strontium, barium |
| Calcium gluconate | i.v. | 2.5 g administered in 0.5 l D5W over a 4 h period. Daily for 6 consecutive days | Strontium |
| D-Penicillamine | Oral | 250 mg daily between meals and at bedtime. May increase to 4 or 5 g daily in divided doses | Cobalt, indium, palladium |
| Potassium iodide | Oral | 130 mg, as soon as possible, and repeat dose daily until needed | Iodine |
| Potassium phosphate | Oral | 250–500 mg four time daily with full glass of water each time, with meals and at bedtime | Phosphorus |
| Propylthiouracil | Oral | 100 mg three times daily for 8 days | Iodine |
| Prussian blue | Oral | 1 g, three times per day, for up to 3 weeks or longer as required. | Cesium, thallium, rubidium |
| Sodium alginate | Oral | 10 g powder in a 30 cc vial, add water and drink | Strontium |
| Sodium bicarbonate | i.v. | 8.9%, 100 or 200 cc vials. | Uranium |

during the first 4–6 h. Potassium iodine is specially recommended for children and pregnant women. Adult dose is 300 mg/day by mouth for 1–2 weeks; it is contraindicated in persons with a known allergy to iodine.

Calcium gluconate or calcium chloride limit the incorporation of strontium or radioactive calcium into the bone. Dose of 1 g of calcium chloride or 3 g of calcium gluconate administered intravenously are recommended.

Oral or intravenous sodium bicarbonate produces urine alkalinization and converts uranium into uranium bicarbonate which is less nephrotoxic.

### 3.3. *Diluting agents*

Oral fluid administration in large doses produces dilution and increase renal excretion of the contaminant. This is particularly indicated if tritium (H-3) is present. Approximately 5–10 l/d should be administered for 1 week. Sometimes diuretics can be used to promote urinary excretion.

Oral loading with phosphorus salts can increase the elimination of radioactive phosphorus.

### 3.4. *Chelating agents*

Chelating agents such as calcium or zinc diethylenetriamine-pentaacetic acid (DTPA) form compounds with specific radioisotopes poorly excreted by the kidneys, like rare earths and actinides such as californium, plutonium, and americium, rendering them more easily excreted and enhancing elimination. The dose for either agents is 1 g in 250 ml of normal saline or 5% dextrose in water, intravenously over 1 h. No more than 1 dose per day should be used, and the dose should not be fractionated.

D-Penicillamine has been used to treat Wilson's disease, a genetic defect leading to copper overload, by chelation and accelerated excretion of internally deposited copper. A similar effect is achieved in the case of contamination caused by radioactive cobalt, reducing to 1/3, approximately, the total radiation absorbed dose that would have occurred without treatment. The recommended dose is 250–500 mg by mouth 4 times per day.[23]

### 3.5. *Wound excision*

Wound excision may be considered when the wound is contaminated with an isotope that has a very long half-life, such as plutonium.

Overall, the decision to treat or not to treat for internal contamination is based on risk/benefit considerations of the dose and the age and condition of the individual patient.[19,24] Likewise, the decision on when to stop treatment is sometimes a complex issue, which requires the evaluation of the effectiveness of treatment by sequential bioassays and consideration of the risks versus the benefits of continuing the therapy. Several available reports provide general medical guidance, including dosage, method of administration and precautions for the use of medications.[2,3,13,24,25]

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