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PROTOCOL TO TREAT PEOPLE WITH WOUNDS CONTAMINATED WITH RADIOACTIVE MATERIAL STANDPOINT OF RADIOLOGICAL PROTECTION

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ABSTRACT

People who work in research laboratories, radioisotope production center or nuclear artifacts, nuclear medicine center, or allocated in the vicinity of nuclear facilities that suffered accidents or bombardment, may be subject to wound with radioactive material should have special treatment and follow a protocol of care. If insoluble, much of the material will be retained at the wound site and the treatment is based on human anatomical structure and need to be evaluated the deposition, retention, and release for dosimetric purpose. The incorporation of soluble material may enter in the blood stream, distributed through the body and be deposited in organs, causing committed dose of ionizing radiation, before being excreted. The behavior and the assessment of radiation exposure mechanism are described with the use of biokinetic models. Upon the occurrence of these events, the first aid care of these people should follow a well-established procedure according to the scenario, the degree of severity of each case and type of radioactive material involved.
This paper seeks to establish a protocol for first care of people with wounds containing radioactive material as part of the preparation for their care in specialized medical center. Measurements were made with radionuclides, characteristic of each occurrence scenario, appropriate detectors for each situation, with the performance expected for each type or model for the depth of location, activity and committed dose rates involved, using tissue-equivalent material. Moreover, the estimated the activity and internal dose were made using the conversion factor obtained with AIDE software for radionuclide of interest.

1. INTRODUCTION

In many laboratories is common handle ampoules, flasks and jars containing radionuclide solutions for performing measurements, markings and conducting radiochemical steps procedures. In these operations can occur accidental rupture of these glassware and cause cuts and injuries, with penetration of chemical and radioactive material in the body of the operator.

The physical-chemical properties define the degree of solubility of the material. When the incorporation of radioactive material occurs through wound, the material incorporated immediately comes into contact with blood. Once in contact with the blood, which is considered the transfer compartment, the material will have the behavior described by the biokinetic models presented by the International Commission on Radiological Protection [1, 2, 3, 4].
If the incorporated compound is soluble, on contact with the blood, it will be dissolved and distributed throughout the body, depositing contaminant with chemical affinity and is excreted mainly via feces and urine. If the compound is insoluble, much of the radioactive activity is retained at the wound site.

According to the Report No.156, 2006 of the National Council on Radiation Protection and Measurements [5], the scientific literature contains reports of cases in more than 2,100 wounded contaminated with radionuclides. It was highlighted that:
- The vast majority of infected wounds occurred in facilities involved in the production, manufacture or maintenance of nuclear weapons components and the contaminants involved were actinides (uranium, plutonium and americium);
- More than 90% of injuries occurred in the hands and arms, particularly in the fingers;
- About 90% of the wounds were involved in mechanical damage perforations; chemical burns and acid solutions.

The vast majority of these reported injuries occurred with workers in facilities that process plutonium. Since 1990, the use of depleted uranium (DU) munitions in military resulted in injuries in combat with shrapnel of this material.

One of the dramatic and recent cases occurred during the Iraq war, when 21 American vehicles (tanks and armored cars) were bombarded by the American air force, with missiles made with depleted uranium (DU). In this event, 11 soldiers were killed and about 50 others were severely wounded, requiring special medical care. The depleted uranium contains about 99.8% ^{238}U mass, has high density and very high degree of hardness that allows use in ammunition to pierce tanks and armored cars. When a bullet pierces a tank, DU is fragmented into many pieces with high temperature and speed and reaches all its occupants.

These occurrences demanded hard work for teams of radiation protection technicians and medical staff, involving detection techniques and dosimetry to evaluate possible potential doses, X-rays to locate and measure the fragments in the bodies of soldiers, biokinetic models to monitor contamination and its consequences and the use of specialized surgical resources.

In addition to the contaminated wounds resulting in industrial and military situations, the medical use of radioactive materials as a radiographic contrast agent may result in the development of granulomas at the sites of injection, a kind of foreign body reaction complicated by the radiation spot. While there are numerous biokinetic and dosimetric models for radionuclides intake by inhalation, ingestion and injection, for use in accident situations in nuclear and radioactive facilities, a model of treatment for the infection of a person through contaminated wounds does not have the same degree of evolution, consensus and security than in previous cases.

Since the mid-1990s the NCRP in collaboration with the ICRP established a scientific committee to develop a biokinetic model, which permits to estimate the absorbed dose in all organs and the whole body, including the most likely path taken by the radionuclide attached to the chemical and the most affected organs. This resulted in the NCRP Report 156 which submitted a comprehensive review and, in some cases, including the reanalysis of the data related to the animal behavior biokinetic radionuclides wounds.

The data were used to set values for the parameters of a comprehensive compartmental model based on biochemical and physiological response of the body to a wound. Information is also presented on the etiology of wounds contaminated with radionuclides and biological processes of healing, including carcinogenesis and strange body responses.

The NCRP report 156 details the main methods of measurement, monitoring and dosimetry wounds contaminated with radionuclides, medical management of injuries, chelation techniques and decontaminating chemicals. They are provided many data studies with ^{239}Pu, ^{241}Am, ^{232}Th, ^{235}U, ^{85}Sr, ^{137}Cs and Depleted Uranium and ^{227}Ac.

Human data of occupational exposures, military and medical are provided to relate the results obtained in animals with human experience. Dose coefficients for local doses and organs are presented, as well as a summary of the wound monitoring methodology. Finally, the current procedures for the treatment of infected wounds are discussed.

2. OBJETIVE

The lack of a protocol setting out the procedures and places to care for victims with injuries for measuring contamination, first aid and referred to a specialized medical center in the area, indicates the degree of doubt and uncertainty that an institution or a society may face when the occurrence of one or more events of this kind.

For this reason, the objective of this work is to establish a protocol for treating victims of injury with radioactive material from the standpoint of the Radiological Protection. To exemplify the protocol, possible emergency situations in the source preparation at National Metrology Laboratory on Ionizing Radiation (LNMRI) from Institute for Radiation Protection and Dosimetry (IRD) are discussed.

3. METHODOLOGY AND EXPERIMENTAL PROCEDURES

The method of working involves the determination the nature, activity of the radionuclide and the chemical form in which it lies when its penetration into the body via a wound. With this data it is possible to estimate the equivalent dose and effective dose, in the various organs components of the human body and whole body and particularly, the induced biological effect by the radioactive compound, directly or indirectly. This estimate is made by Bertelli *et al*, using a computer program for evaluating the committed dose and effective dose, called Activity and Internal Dose Estimates - AIDE [6] that provide the dose conversion factors.

With this estimation, the chelation procedures or mitigation the potential damage to the victim, may be suggested according the nature of the radionuclide, the type of compound and the site of injury, as first care. Then the victim will be referred to a specialized medical center and monitored by radiation protection technicians to release the patient. The procedures adopted in the treatment of victims will be based on an estimated activity built during the accident, as recommended by the publication NCRP Report 161, 2008 [7].

3.1. Inventory of radionuclides

This paper suggests establishing the inventory of radioactive material used by the institution, the activities and physical and chemical form involved. In the inventory, the radionuclides that can cause higher dose or physical harm should be marked and need to be handled with most care. For example, in the LNMRI, the radionuclides used for preparing and supplying calibrated radioactive sources for the country.

3.2. Selection of the most important radionuclides for protocol development

The selection of the radionuclide from the inventory cataloged, as a first approximation, is made using criteria as that have the biggest value of dose coefficient values using the, the degree of dangerous associated to its physicochemical proprieties, the requirements of experimental procedures for the measurement of the activity in the wound and the rest of the body, as also de decontamination process. The values of dose coefficients are published for radionuclide ingestion in the ICRP 67 and 69, for inhalation in ICRP 71 and Intake in ICRP 72 (1995) [2, 3, 4, 8].

3.3. Measurement System

Among the procedures for answering an emergency situation, a key concern is to check the health of the victim. After that it is need to seek information on the type of incident if has radioactive material involved, to prepare for first aid procedures. If the presence of radioactive material is confirmed, the service should only be started with the use of personal protective equipment, so there is no contamination of the attendant technician.

In many emergency situations is not possible to choose the appropriate or the best detector, for example, when one group of people is bombarded with artifact containing radioactive material. In this case, it uses what is available at the moment. The choice of the measurement system or detector depends of the type of radionuclide radiation, technical procedure to be done, the victim's status and the accident scenario occurred.

3.3.1. To check the presence of radioactive material in the wound

To check the presence of radioactive material in the wound a very sensitive detector is required, but the other its metrological properties not need to be so good. In this case, the use of a portable detector like a Personal Radiation Detector - PRD, constituted by a Geiger-Muller tube and one NaI(Tl) or CsI(Tl) detector coupled, is very useful. For the same purpose, the use of portables NaI(Tl) or Proportional counter are efficient. In many institutions or emergency attendance groups, the use of coupled Geiger-Muller probes is very frequent.

3.3.2. Identification of the radionuclide

To identify the radionuclide and determine its activity in the wound various measurement systems can be used. One most used is the IdentiFINDER2 detector, constituted by a NaI(Tl) cristal with multichannel in the electronic processor, that make the counting and shows the spectrum of the radionuclide.

Other detector that should primarily be used is the Cadmium telluride detector, which allows the identification of the radionuclide by detecting X-rays and / or gamma radiation emitted by it, with high resolution in energy.

Depending on the chosen radionuclide would be very useful for surgical debridement purposes to determine the depth of contamination within the soft tissue by, for example, ratios between measures of low energy X-rays or using the attenuation curves of gamma radiation emitted by the radionuclide with many kinds of portable detectors and laboratory set-up system. Theses attenuation curves are obtained, in the laboratory, using thin layers of absorber of equivalent tissue material, with many types of experimental setup, like: without collimation and shielding, with collimation, with collimation and shielding.

3.3.2. Activity Determination

The determination of the activity of the radionuclide will be performed through the use of calibration and efficiency curves constructed with standard radioactive sources like as existing in the in LNMRI, for each kind of detector available. Using the measurements data of counting or dose equivalent rate in the established distance from the surface of the person with wound and the attenuation curve for the present radionuclide, is possible to obtain one estimate of the activity of the fragment or source in one depth estimated or measured.

3.3.3. Determination of contamination in the body

If possible or needed, calibration procedures and measures *in vivo* using the whole-body counter are made to quantify the activity of the radionuclides in the event of wound contamination by soluble substance. Normally, this kind of measurements made for a follow-up of the decontamination process of the victims in the specialized medical center.

3.4. Estimation of the dose and efficacy of decontamination procedures

The estimate of committed equivalent dose in organs and effective dose will be made using the software AIDE. This program calculates the activity and the internal dose from the specification:
• contamination via: inhalation, ingestion, injection and wound;
• radionuclide;
• type of merger: acute, continuous or periodic;
• quantities to be calculated: the absorbed dose, equivalent dose,
• fraction of gastrointestinal absorption by blood, transport parameters;
• biokinectic model;
• type of output results: activity excreted in urine and feces and retained in organs.
The program also allows the interpretation of bioassays*: in vivo* and *in vitro*.

A comparison of the dose values obtained through injury measurements performed before the decontamination procedures and those obtained through *in vivo* measurements after decontamination can provide quantitative indicators on the effectiveness of decontamination performed.

3.5. Detectors used and laboratory infrastructure

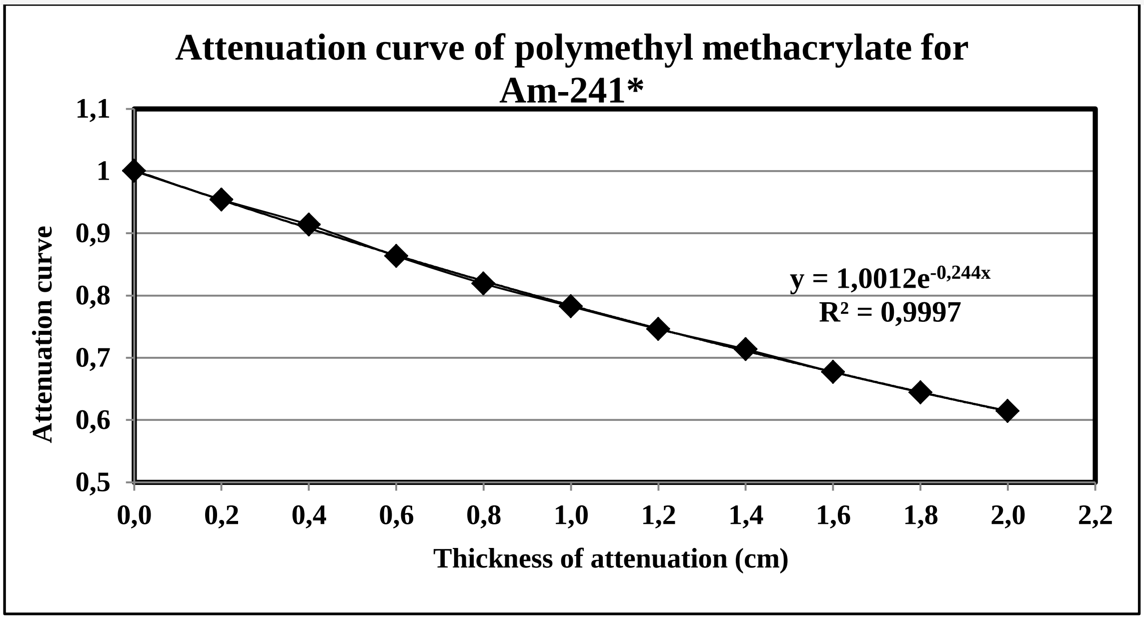
For the realization of the measurement *in vivo* or in the laboratory, the detectors used can be:
a) Personal Radiation Detector (PRD);
b) IdentiFINDER2 NHG, 1.4"x 2" NaI(Tl) and an internal GM tube, Flir model;
c) Cadmium Telluride detector (CdTe);
d) High Pure Germanium detector (HPGMX).

The measurements were made in Radionuclide Metrology Laboratory of LNMRI of the IRD, which has currently many absolute and relative calibration systems of radionuclide and other detection systems.

To obtain the attenuation curves for each type of detector were made 10 measurements for each point expressed by its mean value and standard deviation.

4. RESULTS AND DISCUSSION

To exemplify the type of measurements made, the Figure 1 shows the results obtained for ^{241}Am as radionuclide and attenuation curve, using the polymethyl metacrylate as tissue-equivalent material as absorber, with experimental set-up without collimation and shielding.



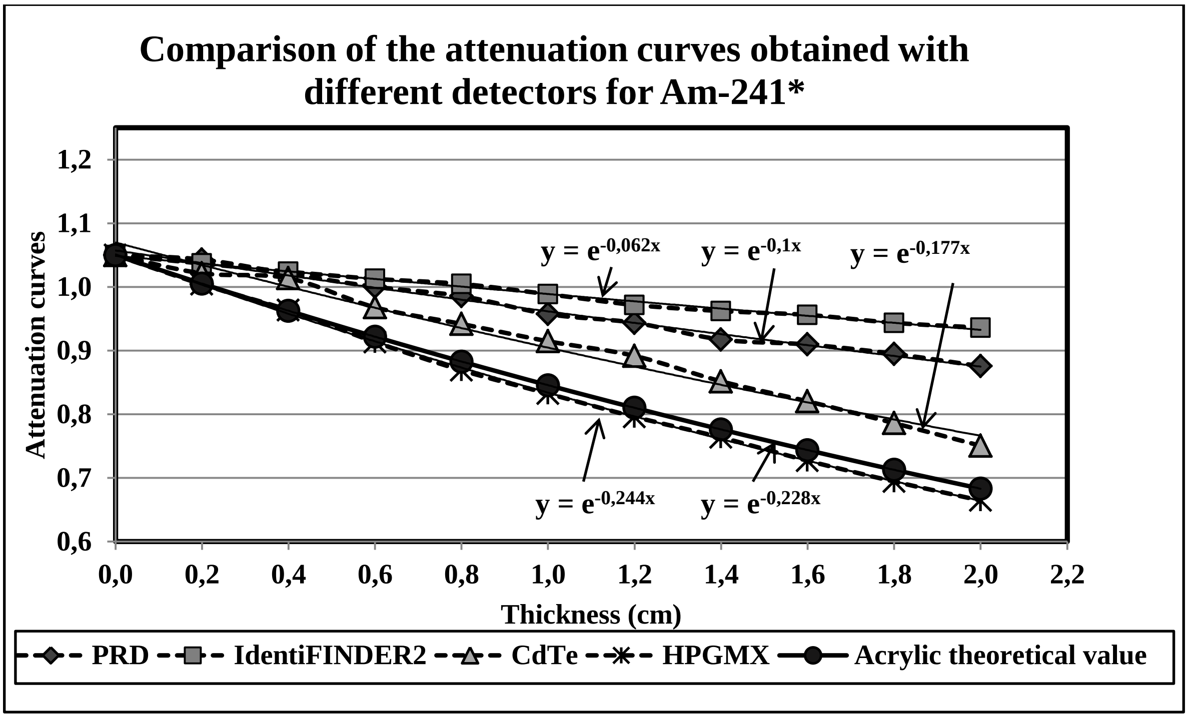
*The uncertainty values were expressed by the standard deviation and were less than 0,01%.

Figure 1: Attenuation curve for 60 keV of ^{241}Am with polymethyl methacrylate as tissue equivalent material as absorber, and HPGMX detector, without collimation and with shielding.

In figure 1 is observed that, the value of attenuation coefficient obtained for Am-241 with 60 keV of energy has 0,244 cm^{-1}, that is 7% less than expected value 0,228 $^{cm-1}$. This is due the experimental setup without collimation.

Using the relative difference of dose equivalent rate counting between two points, and one estimate of wound depth in the victim, is possible to obtain the activity of the fragment or its value in their medium point, or the equivalent dose rate correspondent. Another way to obtain the depth of the wound is by variation on the ratio between the areas of two peaks with different energies in the spectrum of a radionuclide with and without absorber tissue-equivalent of material thickness.

To illustrate the different procedures of measurements in real situation of the scenario of the accident occurrence and using different detectors, the results are shown in the Figure 2

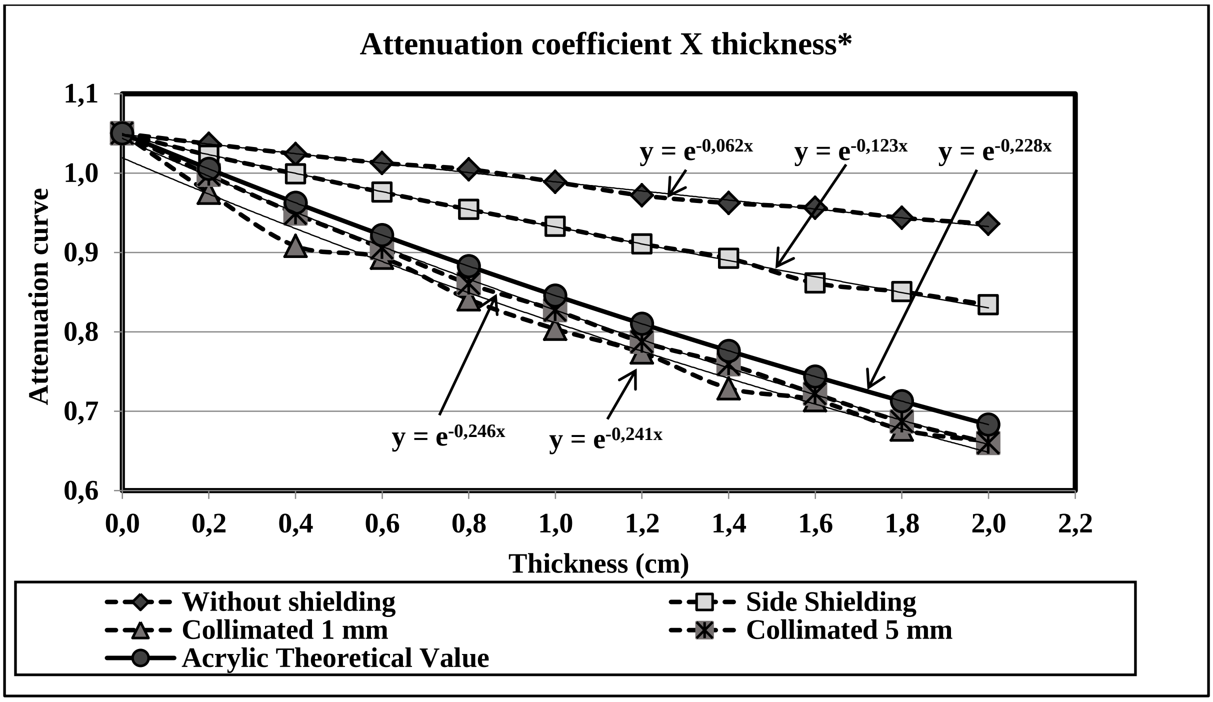


*The uncertainty values were expressed by the standard deviation and were less than 0.05%.

Figure 2. Attenuation curves for 60 keV of ^{241}Am, obtained with different detectors without collimation, using the Dose Equivalent rate in tissue as quantity, simulated by polymethyl methacrylate.

The figure 2 shows the different results obtained with different type of detectors for the same radionuclide measurement.

To show the influence of the setup arrangement, different situations are shown in the Figure 3, and the data are compared with the expected value published by the National Institute of Standards and Technology (NIST), USA, for polymethyl methacrylate [9].



*The uncertainty values were expressed by the standard deviation and were less 0,05%.

Figure 3: Attenuation curves with IdentiFINDER2 detector obtained with different experimental setup of measurement, for example, with shielding and appropriate collimation.

It is seen that in good conditions of measurements, the experimental value obtained for attenuation coefficient is nearly to the theoretical or expected value of u= 0,228 cm^{-1} in about 5%.

5. CONCLUSIONS

With the sequence of the experimental measurement suggested in this work is possible to construct the one protocol for attendance the victims with wound with radioactive material before to transfer the victim to specialized medical center for treatment and decontamination.

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ANNEX

PROTOCOL TO TREAT PEOPLE WITH WOUNDS CONTAMINATED WITH RADIOACTIVE MATERIAL

In an accidental situation of contamination by radioactive material in a laboratory that makes handling radioactive sources, whether in the form of solution or powder, must follow a protocol of first aid measures. However, there is not a protocol in our country and also in the National Laboratory of Metrology of Ionizing Radiation (LNMRI) of the IRD.

In the IRD, handling solution in ampoule involves concentrate radioactive solution and can breaking the same, so it is essential to pay much attention and be careful, however, can happen some ampule be very old and the glass be more fragile or operator break the wrong way the ampoule, accidentally to stick with the glass and be contaminated by the solution of material. As a result, the operator can receive an external and internal dose, depending on the type of radionuclide and their activity.

Below are some essentials steps that must be performed when there is this type of accident.

<u>Phase I: First care</u>

- The patient must first be stabilized;
- To evaluate whether there were internal and external contamination;
- In the case of external contamination, contaminated clothing should be removed;
- The area of contamination must be determined and surrounded, and the paged alarm signal;
- It is necessary to wash the area that was damaged with a physiological saline solution or soapy water for a few minutes to prevent further incorporation of radioactive material through the wound. It is contraindicated the use of hot water due to subsequent vasodilation, which can increase the uptake of the radionuclide;
- The medical physicist must start with the identification and quantification of contaminants radionuclides through a portable detector that is available. If the detector used is a PRD it only indicates whether there is contamination and estimate the dose rate value. Already identifiers, such as IdentiFINDER2, identify the radionuclide and provides the dose rate which if determinate in two points, can to estimate depth of the wound contamination.

Phase II: Monitoring and Treatment

- After the identification of the radionuclide, dose rate and its energy of emission is possible to obtain deposited activity in the wound;
- If such intake activity remains high, it is recommended to perform an *in vivo* counting at whole body counter and collect biological samples for *in vitro* analysis; and treatment with decontamination agents may be sufficient in that cases or, in more severe cases, the excision of the contaminated tissue should be considered;
- Measurements more accurate with the solid state detector can be useful to provide reliable results for excreta measurements;

- Feeding AIDE software with bioassays data can obtain activity in each organ, as well as the committed and equivalent doses. Also can be used tables from "Dose Coefficients for Intakes of Radionuclides via Contaminated Wounds" (2014) to obtain the activity and doses estimates;
- The effectiveness of decontamination process and activity values that remain can be obtained by repeating the previous measurements;
- If the doses are still high, the patient should be referred to the Naval Hospital Marcilio Dias who specializes in this type of treatment, for better evaluation. Therefore, it is necessary to contact the professional hospital and give then all previous information;
- All information must be documented by the radiation safety and medical personnel;
- Ideal situation: it is necessary have a radiation protection security staff and medical staff available at the contamination site;
- The occurrence of internal contamination with or without damage should be sending to a hospital emergency department or facility for special radiation treatment (if available) to medical treatment and evolution, as well as evaluation of internal contamination.