Management of Internal Contamination Accidents

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The key to success in managing accidents is the prompt and accurate response of the emergency team. Literature data on the preparation of well conceived emergency plans for the management of internal contamination accidents include among others the following two publications : The Guidebook for the Treatment of Accidental Internal Radionuclide Contamination of Workers, Radiation Protection Dosimetry, vol.41, 1992 [1] and Assessment and Treatment of External and Internal Radionuclide Contamination, IAEA- TecDoc-869, 1996 [2].

Internal contamination by radionuclides occur most likely by inhalation, ingestion or absorption from wounds The consequences of the contamination depend upon the route of intake, on the physical and chemical properties of the radionuclide and on the amount of activity incorporated. Decisions about treatment of internally contaminated people should only be made by physicians However, an important part of the medical handling of exposed persons is the assessment of the magnitude of internal exposure and the informations on decorporation as a result of treatment.

The techniques to assess intakes depend on the mode and level of intake, the type and energy of the radiation emitted, the biokinetic of the contaminant and the sensitivity and availability of measurement facilities *In vivo* and *in vitro* techniques are used to quantify internal contamination

In Vivo Bioassay

In vivo bioassay consist of direct measurement of body or organs content It provides, in most cases, a direct measurement of the internally deposited radionuclide. *In vivo* monitoring in general consists of measurements made using whole body counters or special chest or thyroid counters. *In vivo* bioassay is feasible only for gamma emmiting radionuclides or for radionuclides that emit penetrating X-rays or energetic beta particles , detected by bremsstrahlung. It is an accurate method when sufficient quantities of radionuclides are present in the body The whole body counter consists of a number of highly efficient detectors, generally located in a shielded room. NaI(Tl) detectors are generally used to measure gamma emmiting nuclides with energies greater than 100 keV. Low energy photon emmitters require the use of phoswich or high purity germanium detectors [1,2].

When internal contamination involves very high levels of activity special systems for *in vivo* monitoring are required The Goiania accident consisted of the removal and rupture of a sealed teletherapy source of ^{137}Cs Fragments of the source were distributed among a large number of individuals, resulting in the internal contamination of 143 people An *in vivo* monitoring system was set up in Goiânia. It consisted of a NaI(Tl) detector, 20cm dia. x 10cm, with a 5 cm thick annular fitted Pb shield, positioned at 2.05 m from the floor. Bellow the detector, an area of 2 00 m x 1.00 m of the floor was covered by a raft of lead 14mm thick. Individuals were accomodated, for measurements, in a reclining fiberglass chair The system proved adequate for high activity measurements and the minimum detection limit was 9 kBq for 2 min counting time. It had the same efficiency for adults and children . A hollow fiberglass mannequin filled with packages of ^{137} Cs solution was used for calibration of the system [3].

External skin contamination and high levels of internal contamination may be screned through the use of portable radiation detectors. During the Goiânia accident, patients without external contamination were monitored through whole body counting and also using a GM detector which was positioned on 26 different areas of the body. There was a linear correlation between Cs body content and GM measured dose rates The axillas dose rates presented the best regression fit with body burdens, $r^2 > 0.92$ [3].

Special care should be taken to remove all external contamination before *in vivo* monitoring Care should also be taken to avoid contamination of the measurement facility. Externally deposited radionuclides interfere with monitoring results obtained from whole body counting. One example of a measleading measuring result was obtained in the IRD whole body counter, in a routine monitoring of an outsider technician who worked with ^{241}Am. An activity of 312 Bq of ^{241}Am was measured in the skull of the technician Lung, liver and knee measurements followed, showing that the contamination was localized only in the head. Washing of the hair reduced the contamination, but not substancially Only after a hair cut, monitoring results dropped to background level.

The assessment of wound contamination is important and many times require specialized wound probes (scintillators or germanium detectors) to locate the radioactive material within the wound, provinding guidance to the decontamination procedures [2] In the Goiânia accident, some people showed localized skin lesions, from handling fragments of the source or from rubbing ^{137}Cs fragments on their skin, attracted by the glittering it produced Portable scintillation detectors and Geiger Muller were used to indicate the presence of external skin contamination Three years after the accident a high purity germanium detector (HPGe), type N, collimated with a 10cm (wide) x 0 5cm (thick) layer of copper, was used to detect the Cs activity remaining in the scarr tissues. The measurements of k_a and k_b X - rays of ^{137m} Ba were used to to show that two people still presented activities located at the scar [3]. The same technique was used to show that four people, 3y after the accident presented Cs activities located in the region of the liver [3] .

In Vitro Techniques

In vitro techniques are used to assess internal contamination exposures by indirect methods The activity of the radioactive material is determined in biological samples, usually urine, feces, breath or blood or in physical samples, such as air samples. In general, a radiochemical laboratory is required to quantify the concentrations of the radionuclides present in the collected samples. The relationship between the activity concentration in the sample analysed , the intake and the amount present in the body and in body organs is determined through the use of biokinetical models

In Vitro Bioassay

The biological samples that are most commonly used to assess internal contamination are urine and feces. However breath samples are used in special cases such as in determining radon produced in the body and nasal swabs or nose blows may provide an indentification of the inhaled radionuclides Measurements of radionuclides present in the blood are not frequently used to assess intakes, because of medical restrains and also because they provide only limited information on the systemic activities, since the clearance from blood to tissues is very fast and interpretation of results is not simple [4].

The choice between urine or feces samples will depend on the solubility of the radioactive compound and on the major route of excretion , as determined from the physicochemical form of the compound, from the mode of exposure and from the biokinetical model.

Urine analysis is the most used bioassay method for assessing intakes. The samples are simple to collect and are usefull indicators of the presence of radionuclides present in the systemic circulation and thus of the solubility of the radioactive material Early samples of urine excretion should be interpretd with caution, because of mixing in the bladder and because of indefinitions in some biokinetic models. If possible,the contaminated individual should empty the bladder after the accident and then a second and subsequent samples obtained. All samples should be collected and analysed for radioactive material content After the first few days, 24h samples of urine provide a good basis for intake assessment [4].

Urine excretion will depend on kidney function. Differences in individual excretion rates and day to day variations are significant sources of uncertainties. For the first two months of the follow-up of the Goiânia accident, total 24h urine excretion samples from the most contaminated individuals were collected daily For the same individual there was a large day to day flutuation of results. It was very difficult to determine Cs retention half-times using the raw data. Results were smoothed by using three days excretion averages, and then were entered in the regression model to calculate half -times

Feces samples are used to assess intakes from materials transported through the gastrointestinal tract, including unabsorbed materials cleared from the lungs, metabolic products cleared from the body via the bile and by gastrointestinal secretion and ingested materials. Feces samples are difficult to obtain There is a large variation between individual samples from the same person and thus fecal excretion should generally be analysed based on total collection over 3-4 days [4]

In general excreta samples are very usefull to assess internal contamination However results must be considered carefully, because of uncertanties due to individual and day to day variations and in the biokinetic model used During the follow-up of the Goiânia accident, whenever enough data were available, biological half-times were calculated using sequencial results from ^{137}Cs concentrations in 24-h urine, feces and total excreta and also using specific activities in urine and feces Although theoretically all five estimates of the Cs half-times should be the same, there were significant differences among them, up to 40% of the highest value

Frequently, in an accident involving internal contamination, it is necessary to determine the route of intake and many times there are multiple routes of intake. Sometimes the time of intake is not known. When the time and/or route of intake are not known, a series of measurements are necessary to provide reliable results, delaying informations to be given to the medical team in charge of the accident victims. Samples that require extensive radiochemical procedures are also of little use for the immediate care of contaminated individuals. In practice treatment decisions will have to be based on the accident history Additional therapy should then be based on bioassay information [2]

When large amounts of external contamination interferes with direct methods, excreta analysis may be the only reliable technique to assess intakes In vitro bioassay methods were used for screening people with cesium internal contamination in Goiânia During the first two months after the accident assessment of internal contamination was made exclusively through urine and feces analysis In vitro bioassay proved

adequate, since many individuals involved in the accident presented external contamination for some time after the accident

When chelation or other decorporation treatment is used, analysis of activity concentrations in excreta samples may provide valuable informations on the efficiency of the therapy. During the follow-up of the Goiânia accident, urine and feces analysis proved usefull for qualitative information on the efficiency of Prussian Blue, a drug given to enhace the elimination of ^{137}Cs from the body Prussian Blue acts in the lumen of the intestine decreasing the enterohepatic circulation of Cs Prussian Blue increases the excretion of Cs via feces Feces to urine ratios were used as a qualitative indicator of the effectiveness of the drug. The efficiency of increased water ingestion was also tested Water only increased the volume of urine excreted and not the amount of Cs excreted [5].

Care should be taken to avoid cross-contamination of samples, of equipment and of the laboratory facility Excreta samples from persons contaminated in the Goiania accident were handled in a laboratory which has two entrances, one from the inside and the other from the outside of the building Next to the outside entrance is the storage room where samples were placed until analysis All surfaces and equipments were covered with plastic The urine samples were collected in plastic bottles and an aliquot of 0 25L was transferred to a recipient free of contamination, labelled and sealed in plastic bags. Similar procedures were taken with feces samples, collected in appropriate plastic containers and completelly transferred to another recipient. The laboratory was constantly monitored to prevent the spread of contamination. The entry to the laboratory was restricted to the personnel involved in the bioassay. Special care were taken by the personnel in terms of radiation protection [3].

Discussion on Bioassay Monitoring Techniques

In general whenever *in vivo* counting methods are possible, results obtained provide the basis for the most accurate assessments of internal dose However, as much information as possible and pratical should be gathered from all bioassay techniques. The assembly of data may be required for exposure assessment, to guide medical assistance and for dose reconstruction

During the follow-up of the Goiânia accident 897 people were monitored either through *in vivo* or *in vitro* techniques or both. After screening, 157 individuals presented measurable internal contamination. Approximatelly 4000 samples from a total of 90 people were analysed by in vitro bioassay during October, November and December 1987. Total feces and urine excretion were collected daily from individuals that were hospitalized. Excreta samples from the other contaminated individuals were collected every 4d, because people complained of the disconfort of daily excreta collection. As patients were released to go home, *in vitro* bioassay became irregular or stopped completelly During a certin period of time, both *in vivo* and *in vitro*

monitoring techniques were used. For each individual, with enough data for the comparison, the total ^{137}Cs activity excreted in a time period matched the difference between two whole body measurements at the same time period The biological half-times of ^{137}Cs estimated using excreta data were similar to the ones obtained using whole body monitoring results [3 5]

Sequencial bioassay measurements provide information on biokinetics and on treatment results. In Goiânia, Prussian Blue was used to enhace ^{137}Cs elimination from the body Prussian Blue was administered in dosages ranging from 3 to 10g per day for adults and adolescents and 1 to 3g per day for children, with no standard pattern for treatment [5] . The drug reduced the half-times of ^{137}Cs in the body to 26 ± 10d, independent of age, weight or prescription dosage The half-times of ^{137}Cs in all individuals increased when they were sent home, probably because patients did not follow directions very carefully, as they were not medically supervised [5] . The decision on the length of the treatment depend upon the efficiency of the therapeutic agent in diminishing the committed dose. In the Goiânia accident, upon cessation of treatment, more than 95% of the internal dose had already been committed

Direct plus indirect bioassay results are very useful for the identification of time and/or intake pathway An example is the accidental exposure that occurred in a facility where ^{131}I solutions for distribution to nuclear medicine services are prepared. An irresponsible person took two vials of ^{131}I and spread part of the sources in the coffee room. Five people became internally contaminated, from eating and drinking in the room. The accident was detected in the same day, when one of the workers passed to the controlled area and a monitor accused the contamination. The radiation protection team, in an attemp to decontaminate the coffee room, involuntarily made the contamination volatil Some people became exposed to ^{131}I by inhalation as well as by ingestion The five internally contaminated individuals were monitored through sequential urine anlysis and were also measured in the whole body counter As the time of the accident was known, the results from both bioassay measurements were used to identify the persons that were only exposed through ingestion from those that were exposed by inhalation and ingestion. The ICRP [6,7] model for ^{131}I was used to derive the expected fractions of the intake in urine and in the thyroid at different times after ingestion and after inhalation, making possible the determination of the pathway of intake

Physical Samples

Physical samples consists of air samples and surface wipes They are the least preferable indirect method.

Air samples collected on fixed or personal devices provide valuable information on the severity of an accident and on the composition of the material inhaled. These samples may represent the only early information on which medical treatment may be based [1] Size selective air samplers provide valuable data to the interpretation of the results from bioassay measurements Particle size and solubility are needed to determine the magnitude of the intake, deposition pattern and to assist on the correct choice of the biokinetic model for dose assessment

Surface samples are useful to indicate the potential for significant intakes and to indicate the relative amounts of radionuclides in a mixture. Results should not be used for quantitative dose assessment.

Interpretation of Results

The management of internal contamination accidents requires a knowledge of the potencial risk involved Treatment is dependent on the amount of the contaminant that enters the body and on its metabolic behavior. Transfer from the site of entry, e.g. lungs, gastrointestinal tract or wounds, depends upon the specific compound. Some materials are rapidly and totally absorbed into the blood, while others are slowly or only partly absorbed. From blood the radionuclides are distributed among systemic organs and /or tissues, according to specific biokinetic models Radionuclides are cleared from the organs and tissues through biological elimination and through radioactive decay. Some radionuclides decay to other radioactive elements and their biokinetic behavior should also be analysed Excretion is the last step in radionuclide metabolism [2].

Slowly transferable materials are retained in the site of deposition and are very slowly metabolized. Treatment consists of clearing the material from the site of deposition and preventing the absorption of the tranportable fraction to blood. For rapidly transferable materials, the primary therapeutic action is of systemic nature and is specific for the radionuclide [2] .

Bioassay monitoring data provide information on the type and quantity of radionuclides that have entered the body The interpretation of bioassay data require biokinetic models which describe body and organs contents and activities in excreta as a function of time after intake. Reference biokinetic models for most radionuclides have been published generally by the International Commission on Radiological Protection (ICRP) [5 7 8 9]. However, these are generalized models and the evaluation of doses in accidental situations may

require specific data on the biokinetic of the radionuclide In emergency situations or when the intakes are small compared to the anual limits of intake, the ICRP models are adequate for dose assessment and for diagnostic In Goiânia after indentification of internally contaminated individuals, informations on ^{137}Cs incorporation and preliminary estimates of committed absorbed doses were provided using results from urine analysis and Legget's age specific metabolic model for ^{137}Cs [10]. Legget's model was latter adopted by the ICRP [6] It was necessary to adapt the model to the Goianian children's biotypes, since for each age group , the weights and heights of most of the children were smaller than the reference values. During the follow-up of the accident, sequential individual *in vitro* and/or in vivo bioassay data were gathered and results were used to estimate the biological half-times of ^{137}Cs during different phases of Prussian Blue treatment and when Prussian Blue was not used. Absorbed internal committed doses were calculated using actual data from each person. In general, the first preliminary dose assessments produced results that were lower than the actual commited doses without the influence of Prussian Blue, except for the adult female and for the adolescents Significant differences occurred when committed absorbed doses were very large, indicating a problem in the estimation of large intakes from a few urine samples [11].

For the assessment of internal exposure, it is important to gather as much information as possible. Excreta bioassay and measurements of body activity provide complementary data needed for adequate estimates of intakes and of doses. Air samples and surface wipes provide valuable informations concerning the severity of an accident and the radionuclide composition of the material inhaled The deposition pattern in the respiratory tract can be assessed if size selective air samplers are used. Nose blows, face wipes and skin contamination levels are important to indicate the severity of the exposure. External dosimetry results is needed for exposure assessment, in medical assessment and in the reconstruction of the accident Sometimes different sources of data will produce contradictory results and inconsistencies will have to be resolved.

The reliability of direct and indirect monitoring results depend on the accuracy of measurements. The uncertainties in intakes and dose assessment relate to the monitoring results and to the models used to interpret these results The best assessment of internal exposure is made by considering as much data gathered as feasible.

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