Implementation of Radiation Measurement Criteria and Limits for Guidelines for Small Radioactive Spills at Landspitali University Hospital, Reykjavik.

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Abstract. In this paper three categories of anticipated radioactive spills in the Landspitali hospital are defined; minor, major and emergencies. We put forward response guidelines for minor and major spills as well as methods of dose assessment. We recommend the use of dose rate for inital estimation of the severity of an incident. When estimating the activity spilled different geometric models are appropriate to different spills. In the case of an inhomogeniously spread spill we propose the use of mixed geometric models, evaluating different components of the spill seperately and adding them up to estimate the total activity spilled. Finally we put forward tentative dose rate limits for reference when determining access restrictions following a spill.

KEYWORDS: (medical, response, spill)

INTRODUCTION

This work came about when the authors were establishing response guidelines for minor radioactive spills (diagnostic dose levels) of short lived beta and gamma emitting radioisotopes occurring anywhere within the Landspitali hospital ($T_{1/2}$ < 7 days). We observed an abundance of literature on radioactive spills but found it dominated firstly by prevention measures, secondly by guidelines for laboratories and thirdly by instructions for very large scale incidents.

For lack of guidelines in the literature directly applicable to the scale of the Landspitali hospital (a general hospital, approx. 700 beds) we reviewed the literature and set out to delineate appropriate response guidelines, appropriate methods of radiation quantification and contamination limits applicable at Landspitali.

We run through three simple geometries of spills and lastly we discuss how the use of mixed models may be appropriate when a spill is unevenly distributed. Finally we apply the mixed model approach to a practical example of a broken Tc-99m syringe in a hospital staircase where the contamination has spread in such a way that the point source model alone can no longer be used to assess the radiation.

To guide us in the process of establishing guidelines we have principally referred to documents from the IAEA such as the international standards and the online resources; Radiation Protection of Patients. The IAEA's international standards are based on estimates on radiation health effects made by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and radiation protection recommendations of the International Commission on Radiological Protection (ICRP).

QUANTIFICATION OF THE SEVERITY OF SPILLS

Our observation is that the literature on radioactive spills is dominated by material concerning spills of very large scales, e.g. spills from nuclear power plants or the transport of large amounts of radioactive waste, we will be referring to these sorts of incidents as emergencies. In the daily routine of a hospital, e.g. in the nuclear medicine department, spills of smaller scales are most likely to occur.

The activity of such spills typically covers a range from a few Bq to a 1000 MBq and they don´t require the samevolume of response procedures. This is itself a large range of activity and is not enough to determine the scale of a spill. When establishing the scale of a spill many other factors must be considered, such as:

- The radiotoxicity[1] of the isotope
- Whether the spill is localised or spreading
- Whether the area where the spill occurred is controlled, supervised or public
- Whether the area where the spill occurred is permanently or occasionally occupied
- Whether staff or members of the public have been contaminated
- The amount of radioactivity contamination to staff or members of the public
- Whether the situation involves internal or external exposure of persons

We will here on after refer to three different scales of spills; *minor, major* and *emergency*.

Minor spill: A spill involving removable contamination of diagnostic dose levels in a controlled area that isn´t spreading and involves no contamination on persons.

Major spill: Every situation not defined as minor or an emergency, notably anything involving supervised or public space, non removable contamination (complicated to decontaminate) and contamination to persons.

An *emergency:* An incident involving serious injury or death, fire, explosion or significant release of a health or life threatening material, which is or may be coupled with a minor or major radiological incident (ORCBS, 1996).

PROPOSED ACTIVITY LIMITS TO DETERMINE ACCESS TO CONTAMINATED AREAS

In the event of an incidence involving contamination it is important to survey and monitor contamination and ensure that whenever possible exposure limits to individuals are not exceeded. Two main methods of surveying contamination are proposed in the literature: Measuring surface contamination (i.e. in $Bq.cm^{-2}$) and measuring the dose rate (e.g. in µSv/hr). These measurements then determine the action to be taken, e.g. in terms of decontamination and access restrictions to contaminated areas.

A report on derived working limits for surface contamination issued by the Advisory Committee on Radiological Protection (ACRP-7, 1993) states:

> *"The ICRP has not provided recommendations on generalised derived limits for surface contamination. In their view, such limits depend to a large extent on factors such as the chemical nature of the radioactive material, the possibility of resuspension, the working conditions, and the personal habits of the workers. The limits therefore are location- and job-specific and a matter for local professional judgement." (* ICRP, 1997)

Different regulatory bodies propose different limits based on different classification systems of the radionuclides as well as of the types of areas defined. It is not uncommon to find a difference of a factor of 10 in the definition of surface contamination limits for the same radionuclide between two different reports.

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[1] For reference below is the radiotoxicity of medical isotopes (LHS isotopes in bold) as given by the IAEA (IAEA, 2010b):

Very high	Am-241, Cf-252
High	Na-22, Ca-45, Mn-54, Co-60, **Sr-89, I-125, I-131**
Medium	C-14, F-18, P-32, **Cr-51,** Co-57**, Ga-67,** Se-75, Mo-99**, In-111, I-123,** Au-198, Tl-201
Low	H-3, C-11, N-13, O-15, **Tc-99m**, Xe-133

For radionuclides used in medical applications the ICRP have suggested the following limits (ICRP 2002, ACRP 1992):

	Controlled areas Bq.cm^{-2}	Supervised and public areas Bq.cm^{-2}
I-131, I-125, Sr-89, Se-75	30	3
Tc-99m, In-111, I-123, Tl-201, Ga-67, Cr-51, C-11, N-13, O-15, F-18	300	30
H-3, C-14, Kr-81m, Xe-127, Xe-133		

Table 1.

The Radionuclide and Radiation Protection Handbook (Delacroix et al., 2002) states derived limits of surface contamination in Bq.cm^{-2} but these limits refer to laboratory conditions. To obtain the limits in supervised or public areas one could reduce these limits by a factor of 10 but this provides another source of inconsistency as e.g. the limits for Tc-99m would be 200 and 20 Bq.cm-2 while defined by the ICRP as 300 and 30 (see table 1).

To conclude, surface contamination values in Bq/cm2 are not descriptive enough of a spill situation as they doesn´t describe the extent of the spill or the radiation dose a person in the vicinty of the spill is likely to recieve. Given that surface contamination values are less straight forward to assess, that there isn´t consistency in the definintion of surface contamination limits and that this quantity is itself not descriptive enough of a spill situation we propose using the dose rate as a reference radiation assessment quantity (e.g. in µSv/hr) in the event of an incidence. If necessary the level of surface contamination in Bq/cm^2 may be estimated a posteriori from dose rate measurement using appropriate radiation source models.
As stated in the IAEA report from 1997 the dose rate is a criterion which can easily be measured during an emergency, on which the need for protective action can be rapidly ascertained. (IAEA 1997). Our conclusion is that this quantity, the dose rate, is the quantity to be monitored in the event of a spill.

RESPONSE GUIDELINES

Based on our classification of incidents into minor, major and emergency we have outlined response guidelines for minor and major incidents that we present in the form of lists below. These guidelines area an adaptation of instructions given by the IAEA (IAEA 2010a, IAEA 2010c, IAEA 2000). The hospital currently does not have a designated Radiation Protection Officer (RPO) the role of whom is thoroughly described in reference (IAEA 2010c). The IAEA recommend a clear organisation of radiation protection within the hospital emphasising the importance of appointing an in-house radiation protection officer, radiation protection committee and a press liaison officer to handle the communication with the media and with staff via internal media (IAEA 2010c). We propose that Landspitali follow these recommendations.

Response guidelines for a minor radioactive spill:

- Inform others in the area
- Stop the spill from spreading
- Inform RPO
- Decontaminate the area
- RPO is responsible for dose assessment in the area
- After decontamination put any contaminated gloves, wipes etc into labelled bags and dispose of the bags in a radioactive waste container
- RPO is responsible for registering the incident

Procedure for decontamination of areas and equipment in case of a minor radioactive spill:

- Use protective clothing and disposable gloves
- Quickly blot the spill with an absorbent pad to keep it from spreading.
- A plastic bag to hold contaminated items shall be available as well as some damp paper towels
- Remove the pad from the spill
- Wipe with a towel from the edge of the contaminated area toward the centre
- Dry the area and perform a wipe test
- Continue the cycle of cleaning and wipe testing until the wipe sample indicates that the spill is cleaned (IAEA. (2010a)

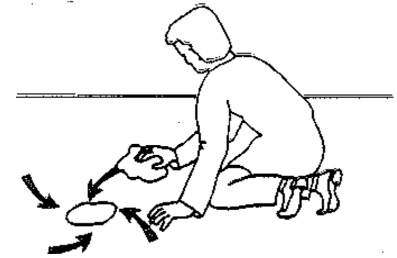


Figure 1. Decontamination: Wiping towards the centre of the spill .

Response guidelines for a major radioactive spill:

- Inform others in the area, vacate but make sure any possibly affected persons do not leave the scene
- Stop the spill from spreading
- Confine the area of the spill
- Inform RPO
- Persons injured:
  - Immediate first aid
- Persons contaminated:
  - Remove any contaminated clothing
  - Decontaminate skin with cold or lukewarm water and Radiac wash (available in NM unit)
  - Measure radiation on skin and continue to wash until no more contamination is being removed.
- RPO measures dose rate and assesses immediate risk
- RPO supervises contamination of people the area
- PRO informs the radiation protection authority and the hospital authorities
- RPO determines if access restrictions are needed based on dose assessment and implements them
- RPO should leave simple easy to understand information in the area concerning the gravity of the incident, including the RPO´s contact details should people have any questions regarding the incident
- RPO is responsible for surveying contamination on people and in the area. This should involve measuring hands, shoes, clothing and face of anyone involved in the incident.
- RPO either handles or nominates a person in charge of communication with the media and with staff (e.g. via internal communication routes)
- RPO is responsible for writing an incidence report.

GENERAL EXPOSURE LIMITS TO STAFF AND THE PUBLIC

The general occupational dose limits in Europe are 20 mSv/year (IAEA, 1996) and 50 mSv/year in the U.S. (Nuclear Regulatory Commission, 2011) although both limits come with a list of exceptions and conditions, notably with respect to dose equivalents to individual organs. The NRC and the IAEA agree on the general annual radiation limits for members of the public of 1 mSv/year (IAEA 1996, Nuclear Regulatory Commission, 2011). This limit is generally not attained unless an individual becomes affected by a incidence involving radiation contamination. The general nature of these limits means they are of little practical use when dealing with minor to major spills in a hospital environment. We therefore set out to find dose rate limits in the litterature that we could refer to in the event of incidents. In the context of storage of sources in nuclear medicine the IAEA has defined limits of radiation in the working environment to be < 2 µSv/h at 1 m in permanently

occupied areas and < 20 µSv/h at 1 m in temporarily occupied areas (IAEA 2010b). The NRC (NCR 2011) in turn has defined a limit of radiation to members of the public in unrestricted areas as being 20 µSv/h. According to Icelandic regulations on the storage of open sources members of the public should not be exposed to a radiation field exceeding 2.5 µSv/h. (IRSA,2003)

When determining access restrictions after decontamination of an area we propose confining the spill in such a way that a worker standing at the perimeter of the confined area recieves no more than 2.5 µSv/h at 1 m in permanently occupied areas and 20 µSv/h at 1 m in temporarily occupied areas (IAEA 2010b). To a member of the public the limit from the Icelandic regulations applies: 2.5 µSv/h. (IRSA,2003)

CALCULATING RADIATION LEVELS FROM CONTAMINATION

To estimate contamination resulting from a spill we consider the contamination as an open source of radiation. The way that the intensity of radiation varies with distance from this source is strongly influenced by the geometry of the source. Three simple cases of spill geometries are commonly described in the literature; the point source, the line source and the plane or surface source. The mathematical models proposed for these cases all assume no attenuation within the source or by intervening media and in the case of line or plane source uniform distribution of activity or constant activity per unit length or area.

The point source model

For a spill covering a small area and when the measurement is made at a distance of at least 3 times the diameter of the spill area the point source model may be applied. A point source is a credible representation of an extended source and provides an accuracy of about 1% whenever the distance from the extended source reaches about three times the maximum source dimension. (Bevelacqua, J. J. 2005)

The basic equation of the point source model is the following (Stabin, M.G., 2010):

Where *A* is the activity of the source, CF_6 is a conversion factor specific to the isotope in question (IAEA 2000), T_e is the time of exposure in hours and *X* is the distance to the source. The quantities *d* and $d_{1/2}$ are related to shielding, *d* is the shielding thickness and $d_{1/2}$ is the half value layer. To disregard shielding *d* is set to 0.

To estimate the source activity based on measurements of the dose rate we rearrange equation 1 and express the activity of the source as a function of the dose rate (Stabin, M.G., 2010):

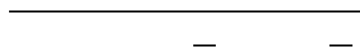
Where *A* is the source activity in kBq, is the measured dose rate at distance *X* from the source and CF_7 is a conversions factor specific to the isotope in question expressed in units of (mGy/h)/(kBq) (IAEA tec doc 1162).

The line source model

The next level of complexity that might be encountered is that of a 1 dimensional source of finite length, typically pipe or rod sources. Two main conditions qualify a line source: The distance to the

source being large compared to the diameter of the cylindrical source (by a factor of 10 or more) and the distance to the source should be small compared to the length of the source (if the distance is more than 10 times the length the source may be considered as a point source) (Stabin, M.G., 2010).

Although the general pattern of intensity as a function of distance here is an additional geometrical factor is added by some to account for the position of the point of measurement w.r.t. the source (Stabin, M.G., 2010):



The geometrical factor refers to the distance X to the line source, which itself is divided into two lengths l_1 and l_2 (see image below.)

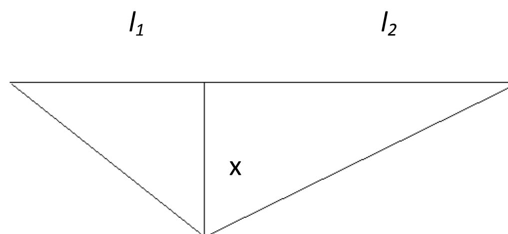


Figure 2. The geometry of a large line source of length l1+l2. X is the distance of the observer to the line source

If the total length of the source is 100 and we move the position of the point of measurement along the axis of the source at a fixed distance of 10 away from the line source we obtain the curve seen in the image below. This effectively models how the dose rate is reduced when measured near either end of the line source and is maximal when measured by the centre of the line source.

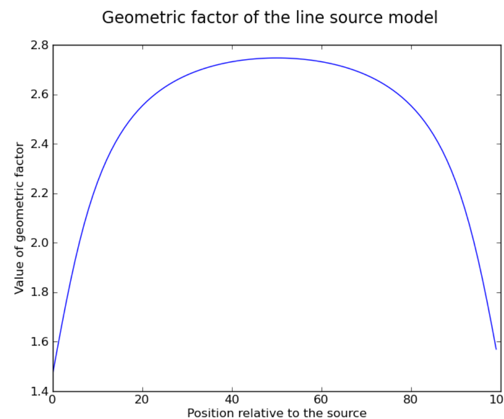
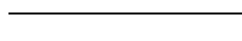


Figure 3. The geometric factor sometimes added to the line source model. This models how the exposure is reduced near the ends of the line source (Stabin, M.G. 2010).

The surface or plane source model

For a source such as a spill of liquid, which may indeed produce a circular pattern on a surface, a two dimensional disk model may prove useful(IAEA 2000):



Here X is the distance to the plane source and R is the spill radius (IAEA 2000).

Using mixed models

In some cases the source of the radiation may be complex and it may be difficult to estimate the activity from a measured dose rate given any one of the models described above. In this case we propose using a mixed models approach where the spill is subdivided into different geometries that together describe it´s shape. We shall now go on to describe an example of when this may be appropriate.

A PRACTICAL EXAMPLE OF AN INHOUSE CONTAMINATION INCIDENT

The mixed models approach may be of use in a situation such as the one described here:
During transport of a Tc-99m syringe within the hospital the lead basket opens. Consequently the Tc-99m syringe and a glass vial fall on the floor and the syringe cracks. The radiographer handling the transport assumes the glass vial has broken and not the syringe and therefore grabs both to put them into the lead basket, wipes up the spilled liquid and rushes to the patient due to be injected.
The result of the above described incident is the contaminated hands of the radiographer and an amount of contamination in the staircase of the hospital known to be less than one diagnostic dose (bone scan) of Tc-99m.
When it comes to assessing the contamination in the staircase the spill has spread in an inhomogeious fashion. The point where the spill occurred is the most contaminated but the floor around it is contaminated too although to a lesser extent. Here neither the point source model nor the plane model describes the distribution of the contamination. We propose using a mix of the plane and point source models for this kind of geometry. The point source model may be used to assess the activity in the spot where the spill occurred if the distance at which the dose rate is measured reaches about three times the maximum source dimensions. We routinely measure dose rate at one meter above the floor so the spill spot may be approximated to a point source if it´s diameter is of the order of 30 cm or less.
The extended area of the spill may be approximated to a plane source if it´s geometry can be approximated to a disc. The activities estimated using the two models may be summed up to find the total activity spilled in the area.

DISCUSSION

When we set out to define response guidelines for minor to major incidents in the hospital we found the litterature on the matter but that contained quite a lot of inconsistency especially in terms of exposure limits. We tentatively put forward these guidelines and limits in the context of this meeting in hope of generating a discussion that may contribute to their ongoing improvement.

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