Abstract. Regulations for Radiation Protection require to guarantee adequate monitoring of radiation and contamination levels in controlled or supervised areas. Surfaces in working areas, clothing or skin must be regularly checked in connection with radioactive contamination by using a contamination monitor; on the other hand, radiation levels must be measured in a variety of situations, for example, behind shielding or in the vicinity of therapy patients before releasing, by using a survey meter, and the radiation exposition to the staff members must be estimated using personal radiation monitors. In this paper, control procedures to verify performance of monitoring instruments of radiation and contamination levels for practical use in hospitals in a proper way are described. Regarding survey monitors, evaluations of zero setting, alarm threshold, battery test and response to calibrated check sources of $^{137}$Cs, $^{60}$Co and $^{133}$Ba, were made. We also made sources with radionuclides used in the hospital which have been calibrated in a controlled dose calibrator. These sources were used to check the response of personal dosemeters, both pen sized and electronic ones. In order to check contamination monitors, plane sources with known activities from radionuclides usually used in our hospital were used, and the calibration factors ($s^{-1}$ per Bq cm$^{-2}$) for such radionuclides and geometry were obtained. In this way, we profit from having calibrated instruments for radionuclides used in the hospital workplace to determine whether working areas, protective clothing and the body surface have been contaminated. Measurements with calibrated plane sources ($^{14}$C and $^{36}$Cl) were also made. A comparison of these values with the calibration factors of the instruments supplied by CIEMAT, the Spanish Secondary Standard Laboratory, was made. These procedures do not intend to replace calibration procedures at secondary standard laboratories, but they are complementary ones to check the response to radionuclides used in the hospital workplace as well as to have available measurements for constancy check to make sure detectors do not work wrongly.

1. Introduction

Spanish Regulations for Radiation Protection [1] require to guarantee adequate monitoring of radiation and contamination levels in controlled and supervised areas. It is also required that monitoring instruments shall be calibrated and verified. In other countries there are regulations or recommendations in the same sense [2,3,4,5].

In this work, control procedures to verify performance of monitoring instruments of radiation and contamination levels for practical use in hospitals in a proper way are described. Furthermore, it is discussed if sources prepared by the user can be used. Finally, we have used this procedure in instruments in our hospital.

2. Kinds of detectors and tests

2.1. Kinds of detectors

Radiation protection instruments usually are gas-filled detectors, although pen and electronic dosemeters can also be used. Main applications in the medical field are:

- Survey instruments. Usually energy compensated GM detector type [6]. There are two types: portable and non-portable. Non-portable are used for the evaluation of gamma dose rates in radiation therapy units and detect possible source return failure. Portable instruments are used to evaluate dose rates of therapy patients containing radiopharmaceuticals or permanent implants, to find lost gamma sources or for shielding assessment.
- Contamination monitors: Usually GM detector type. They are used for checking surfaces with respect to radioactive contamination in working areas as well as personal contamination after having worked in these areas.
- Portable personal dosemeters: Usually pen or electronic dosemeters. They are direct-reading dosemeters, and are used for the evaluation of doses in special cases, such as pregnant workers or emergency situations, i.e. high dose rate source that do not return to the container.

2.2. Kinds of tests

The reference manual should be read before first use, following the instructions regarding batteries, warm up period, etc.

2.2.1. Calibration tests

Calibration must be done by accredited laboratories. It can be defined as the production of a correction factor to allow a better measurement of some quantity. Calibration certificate must contain information about the method followed in the calibration, what kind of sources were used and an estimation of the uncertainty associated with the calibration. These sources should be traceable to primary standards.

2.2.2. Verification tests

It can be defined as a functional test to be sure detectors do not work wrongly. It could be done by the user in his workplace and it does not need any specific material. Verification tests should include, as a minimum:

- Testing its response to a check source with well-known physical characteristics. This source of radiation should give a quality of radiation similar to that ones that are measured in the daily work.
- Checking alarm setting.

Some radiation detectors have a source attached for checking purposes. The reading with this source only will be taken as a constancy check with previous readings.

Usually, sources used for the calibration of a radiation protection instrument are different from those we want to evaluate in the medical field. So we can profit from verification tests to check response of the instrument to sources used in the hospital workplace.

2.2.3. General maintenance

Before each use, the following inspections and tests should be performed:

- The instrument should be free of radioactive contamination.
- Inspect the instrument for physical damage and repair minor damage if necessary.
- Check the batteries or the power supply to verify proper operational voltages.
- Avoid extreme temperatures or fast changes.
- Turn on the instrument and allow it to warm up according to manufacturer specifications.
- Zero setting should be adjusted in an area of known low background if necessary.
3. Verification of survey monitors

3.1. Description of the method

Verification tests should include:

- Looking for visible signs of damage.
- Checking batteries, and change them if necessary.
- Warming up before measurements.
- Measuring background.
- Checking response against sources. These sources are used in quality control for dose calibrators. We evaluated dose rate at 0.5 m and 1.0 m. Portable instruments were measured in a clear room to minimize scatter.
- Testing alarm setting, visual and audible ones, bringing sources closer to the detectors. We also put the sources in touch with the instruments to verify performance under overload conditions.

It also should be recorded last calibration date, resolution and measurement units and range.

3.2. Results

11 survey meters, 5 portables and 6 installed, were checked out. The non-portable ones are placed in 3 Teletherapy bunkers, one in a brachytherapy bunker and two in the Nuclear Medicine facilities. In Table I, there is a description of the equipments, their measurement units, range and if they have alarms and check sources.

Visual inspection was correct in all of them. In one of the monitors, battery level was low, so the battery was changed before the measurements were made. Measurements of dose rate at 0.5 m and 1 m were made. For one monitor, the readings were oscillating. An inspection of the monitor was done and it was found that one electric junction was damaged. This monitor was repaired. After that it worked correctly, resulting in correct and stable readings.
Table I. Survey meters.

<table>
<thead>
<tr>
<th>Model/Type</th>
<th>Placement</th>
<th>Measurement units</th>
<th>Range</th>
<th>Alarm</th>
<th>Check source</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.S Electrónica Zaragoza</td>
<td>Radiotherapy Bunker LINAC</td>
<td>mR/h c/s</td>
<td>0.01-50 mR/h 0.2-1000 c/s</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>B.S Electrónica Zaragoza MR870</td>
<td>Radiotherapy Bunker LINAC</td>
<td>µSv/h, c/s</td>
<td>0.1-50 µSv/h 0.2-1000 c/s</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Minialarm MC-10/7-R</td>
<td>Portable</td>
<td>Sv/h</td>
<td>0.5 µSv/h – 5 mSv/h</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Nardeux Babyline 81 E-793</td>
<td>Portable</td>
<td>Rad Rad/h</td>
<td>0.02 mrad/h – 100 rad/h</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Nardeux Babyline 81-1836</td>
<td>Portable</td>
<td>Gy Gy/h</td>
<td>0.2µGy/h-1Gy/h</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Radiametre ARA Duk 806 m.1435/6</td>
<td>Radiotherapy Bunker Co-60</td>
<td>mR/h</td>
<td>N/A</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Texas Nuclear LOG Series</td>
<td>Nuclear Medicine</td>
<td>mR/h</td>
<td>0.05-200 mR/h</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Victoreen 451 P</td>
<td>Portable</td>
<td>Sv/h</td>
<td>0-50 mSv/h</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Victoreen 813 m. 05/423</td>
<td>Nuclear Medicine</td>
<td>mR/h</td>
<td>0.1 –100 mR/h</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Victoreen PRIMALERT 35 m. 05/37</td>
<td>Brachytherapy Bunker high dose rate.</td>
<td>N/A</td>
<td>N/A</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Victoreen 290 SI</td>
<td>Portable</td>
<td>Sv/h</td>
<td>0-10 mSv/h</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

4. Verification of contamination monitors

4.1. Description of the method

As a minimum, a verification should contain the following steps:

- Visual inspection of the monitor, looking for cracks, damages, etc.
- Battery check.
- Background measurement. If possible, integration modes should be used for a better accuracy.
- In order to assess the response of the monitor, planar sources should be used.

We have used two kinds of planar sources. The first ones are two certified area sources for calibrating contamination monitors with $^{14}$C and $^{36}$Cl. The second ones are constructed $^{99m}$Tc planar sources. The
readings with certified sources will be taken to assessment of performance over time and the readings with constructed sources will be used to evaluate real-life contaminations.

The constructed sources used consisted of three PMMA sheets with 2 mm of thickness. In one of them has been done a 15 cm diameter hole, so if this sheet is put between the two others, we can get a quasi-planar cavity that can be filled in with solution.

One must regard the following steps:

- Get an activity of $^{99m}$Tc measured with the dose calibrator.
- Fill in the phantom with the solution.
- Calculate activity concentration in the phantom (Bq/cm$^2$)
- Let the $^{99m}$Tc decay until the levels of surface contamination we want to measure are reached. Several days may be necessary, depending upon the starting activity, the volume of liquid and the phantom’s active surface.
- Scattering conditions should be reproducible.

Certain care must be taken in account if we want to measure low levels of surface contaminations: because when an elution of $^{99m}$Tc is made with a typical generator, there is always a small amount of $^{99}$Mo that passes into the elution. This is usually called “Molybdenum breakthrough” [7]. NRC limits for $^{99}$Mo breakthrough is 10-4 Bq $^{99}$Mo /Bq $^{99m}$Tc. When a generator is sent to a Nuclear Medicine Department, the level of $^{99}$Mo Breakthrough must be measured. When the initial activity decays, since half-life of $^{99}$Mo is longer (66 h) than that of $^{99m}$Tc, it may happen that Molybdenum’s contribution to the reading of the surface monitor would be of the same order, or even bigger, than $^{99m}$Tc contribution. As an example, if an activity of about 5 mCi (185 MBq) filled into a phantom of 177 cm$^2$, the surface contamination is about 1 MBq/cm$^2$. 96 hours later, surface contamination due to $^{99m}$Tc is about 16 MBq, while Molybdenum surface activity is about 38 MBq/cm$^2$.

The variation of detector response with contamination area has not been considered. In other publications this effect may be up to factor of 4 [8].

4.2. Results

Four surface monitors were checked, three of them portables and one non-portable. Results are listed in Table II.

<table>
<thead>
<tr>
<th>Monitors</th>
<th>Effective area</th>
<th>Window thickness</th>
<th>C-14</th>
<th>Cl-36</th>
<th>$^{99m}$Tc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berthold LB 123</td>
<td>12x19 cm$^2$</td>
<td>5 mg/cm$^2$ (Titan)</td>
<td>4.0</td>
<td>41</td>
<td>1.1</td>
</tr>
<tr>
<td>Berthold LB 1210</td>
<td>100 cm$^2$</td>
<td>5 mg/cm$^2$ (Titan)</td>
<td>7.9</td>
<td>49</td>
<td>0.88</td>
</tr>
<tr>
<td>Eberline ESP</td>
<td>15.5 cm$^2$</td>
<td>5 mg/cm$^2$ mica</td>
<td>2.7</td>
<td>10</td>
<td>---</td>
</tr>
<tr>
<td>Victoreen 290 SI</td>
<td>4.5 cm$^2$</td>
<td>5 mg/cm$^2$ (Steel)</td>
<td>1.2</td>
<td>4.3</td>
<td>0.015</td>
</tr>
</tbody>
</table>

5. Checking of personal dosemeters

5.1. Description of the method

35 pen dosemeters were checked out. A $^{99m}$Tc source of 22.0 mCi was made, in a 20ml vial with 10 ml of elution. Pen dosemeters were put in a circumference of radius 40 cm, and the vial was put in its
centre. Dosemeters were irradiated for 21.5 hours. Readings of the pen dosemeters were taken. A source strength of $2.24 \times 10^{-5} \text{mSv} \cdot \text{h}^{-1} \cdot \text{MBq} \cdot \text{m}^{-2}$ was used for $^{99m}\text{Tc}$ [9].

Three electronic dosemeters were checked out. A high dose rate brachytherapy unit, microSelectron, was used. It has a source of $^{192}\text{Ir}$, with a source strength of $2.32 \text{cGyh}^{-1} \cdot \text{m}^{-2}$. Dosemeters were irradiated for 107 seconds at 50 cm. Three irradiations were made. For each detector, an average of the three readouts was taken. Measurements were compared against a calibrated energy-compensated portable radiation detector at the same distance.

5.2. Results

For pen dosemeters, the values of measurements were 15% below the real value of the dose. This underestimation may be due to the fact that there was any material just behind the dosemeters, while pen dosemeters are usually calibrated in a phantom that simulates a person, so there is an additional contribution of back-scattered radiation.

For electronic detectors, there is a good agreement between the electronic ones and the ionization chamber, and the measurements are within tolerances.

6. Conclusion

Several verification methods of different kinds of radiation detectors widely used in hospitals and health facilities have been described. The purpose of these protocols is not to replace calibration protocols, which must be done regularly, but to detect abnormalities in the performance of the equipment, as well as to keep it in working order for the isotopes that are usually managed.

References

1. Real Decreto 783/2001, de 6 de Julio, por el que se aprueba el Reglamento sobre protección sanitaria contra radiaciones ionizantes.