ENVIRONMENTAL RADIATION MONITORING

IN HONG KONG

Technical Report No. 24

COST-EFFECTIVE CALIBRATION OF RADIATION CONTAMINATION MONITORING SYSTEMS FOR LIVESTOCK

by

J.K.W. Chan and S.W. Yeung

Hong Kong Observatory

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Published August 2004

Prepared by

Hong Kong Observatory
134A Nathan Road
Kowloon
Hong Kong

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ABSTRACT

This report describes a set of new and cost-effective procedures employed by the Hong Kong Observatory to calibrate the Livestock Contamination Monitoring System for monitoring radiation contamination in livestock. It depicts the replacement of the calibration source at lower cost and presents results to verify the suitability of the new source for calibration work. This report also describes simplified calibration procedures which save manpower and ensure radiation safety.
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1. INTRODUCTION

Two nuclear power stations with pressurized water reactors are in operation at Daya Bay in Guangdong some 50 km to the northeast of Hong Kong. In the unlikely event of a nuclear accident at these nuclear power stations, livestock entering Hong Kong from the mainland will be screened for radiation contamination in accordance with the Daya Bay Contingency Plan. The screening provides the data for assessing the consequences of the nuclear accident, and for considering the control of food movement to safeguard against radiation exposure of Hong Kong people through food ingestion.

The Hong Kong Observatory (HKO) developed three Livestock Contamination Monitoring Systems (LCMS) in the early 1990’s for use by the Food and Environmental Hygiene Department (FEHD). The systems are installed at the Man Kam To Animal Inspection Station, Lok Ma Chau and Sheung Shui Slaughterhouse Livestock Monitoring Stations (Figure 1) to screen livestock delivered from the mainland for radiation contamination. Three animal types in five geometries are screened - cow, porker, goat, roaster and weaner. Figure 2 shows the equipment setup for the screening of cow and porker.

Each LCMS consists of a sodium iodide (NaI) gamma detection system and a PC-based computer which performs spectral analysis (Figure 3). HKO calibrates the three LCMS each year using a phantom (Figure 4). The phantom holds vials of Europium-152 (Eu-152) as a calibration source, which are configured in accordance with the geometry of the animal type of interest.

A total of 336 vials of Eu-152 had been in use since the LCMS entered into operation in 1993. Eu-152 has a radiation decay half-life of 13.3 years. In the calibration exercise conducted in 2002, it was found that the performance of the currently used Eu-152 calibration source had deteriorated. This report describes the replacement of this source in a cost-effective way. The opportunity has also been taken to present a new calibration scheme which saves manpower and enhances radiation safety.
2. CALIBRATION PROCEDURES, AND PROBLEM ENCOUNTERED WITH THE ORIGINAL CALIBRATION SOURCE

The original set of 336 plastic vials containing Eu-152 (Figure 5 (left)) was made from a U.S. National Institute of Standards and Technique (NIST) traceable standard solution. The solution was uniformly mixed in an epoxy matrix before being transferred to the vials.

The Eu-152 nuclide provides multiple energy peaks ranging from 122 keV to 1408 keV. These cover the energy range in respect of radionuclides of interest in the livestock screening process. The radionuclides monitored include I-131 (284-722 keV), Cs-134 (475-1365 keV), Ru-103 (497-610 keV) and Cs-137 (661 keV), which are typical of the release from an accident at a pressurized water reactor.

The calibration consists of:

a) an energy calibration;
b) a full width half maximum (FWHM) calibration; and
c) an efficiency calibration for each of the five animal geometries.

In the energy calibration, each channel of the displayed spectrum in the multi-channel analyser (MCA) is correlated with a specific energy value (in keV or MeV). The correlation allows energy peaks to be identified by their locations in the energy spectrum on the MCA.

In the FWHM calibration, the peak width, by convention the energy width in keV measured at one-half of its maximum amplitude (hence the name FWHM), defines the resolution of a spectroscopy system. The variation of peak shape with energy is deduced based on the relationship between width and energy of the known peaks of the calibration source. Thus the peak width is useful in peak fitting and in computing the peak area in spectrometric analysis.

Lastly, the efficiency calibration correlates the number of counts made by the detection system in specific peaks with the known energy peaks in a calibration source. This relates the peak area to the activity of the source and depends on the geometrical arrangement of both the source and detector. The ‘efficiency curve’ thus obtained is then used to convert the peak area to activity in the spectrometric analysis of other measurements with the same geometry. In total, five efficiency calibrations are conducted, one for each of the different animal geometries of interest (each of which entails a different set-up of the
Eu-152 vials). Each measurement is made for 30 to 60 minutes depending on the number of vials used. The spectra obtained are then analysed to relate the count rate to the activity for each of the known energy peaks.

The efficiency calibrations are later double-checked using an independent Caesium-137 (Cs-137) source, which also consists of a number of vials made with a similar epoxy matrix as the Eu-152 calibration source. Cs-137 has a half-life of some 30 years, ensuring a long usage period. Moreover, it has a single, high-yield peak at 661 keV that minimizes peak interference. The vials are planted in the phantom according to the cow geometry.

The Eu-152 calibration source normally provides six energy peaks for establishing the calibration curves. However, in the annual calibration exercise performed in March 2002, it was found that the radioactivity in the calibration source had decayed to a level that two low energy peaks, 122 keV and 245 keV, were no longer well distinguished from the background signals. This leads to high uncertainties in the calibration results. The calibrations were eventually accomplished by using the four remaining peaks from 344 keV to 1408 keV. In view of the deterioration, a replacement had to be made.
3. THE NEW CALIBRATION SOURCE

3.1 Replacement of the calibration source

The cost of direct replacement of the calibration source was quite high. A viable alternative was eventually found, which was based on a commercially available radioactive source at an affordable price. Commercially available radioactive sources come in different geometries, and some are traceable to the NIST standards. Once such a source was procured, the next step was to adapt it to a form with the desired geometry and radioactivity.

In selecting radioactive sources, a multi-nuclide gamma standard source containing radionuclides with emissions between 88 keV and 1836 keV was first considered. However, although the source had sufficient peaks to cover the desired energy range, those peaks below 300 keV were low-yield peaks narrowly separated. These features rendered the peaks unresolvable and subsequently undetectable by the LCMS because of the limited resolving power inherent in NaI detectors.

Consideration eventually went back to the use of an Eu-152 standard. It was found suitable as it provided sufficient energy peaks to cover the energy range of radionuclides of interest and the yield of those peaks at low energies was adequate for calibration.

3.2 Adoption of a liquid-based source

The new calibration source is liquid-based instead of epoxy-based. An advantage of this is that it minimizes the error due to non-homogeneity in mixing. On the other hand, a liquid-based source poses a higher risk of contamination to the worker and the working area in the event of a spill, leading to unnecessary radiological exposure due to skin absorption, ingestion, or to a lesser extent, inhalation of the liquid source.

The possible dose that a worker might sustain in case of a spill or accidental contamination was evaluated before deciding on the activity of the liquid source. Here the Annual Limit on Intake (ALI) is relevant. Recommended by the International Commission on Radiological Protection (ICRP, 1978), ALI is the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation, ingestion or through the skin within a year. For occupational exposures, the 1990 recommendations of the International Commission on Radiological Protection (ICRP, 1990) limit the effective dose to 100 mSv in a 5-year period (giving an average annual dose of 20 mSv) with a further
limit of 50 mSv in any single year. The ALI for ingestion and inhalation of Eu-152, in respect of the maximum limit of 50 mSv in any year, are calculated to be $3.6 \times 10^7$ Bq and $1.9 \times 10^6$ Bq respectively (ICRP, 1994).

The activity of the liquid Eu-152 source was chosen to be $8.5 \times 10^5$ Bq, which was well below the ALI figures. This ensures that the radioactive material intake by a worker would not exceed the ALI even in the worst scenario of accident ingestion or inhalation of the liquid source in its entirety. The chosen activity also ensures that sufficient spectral information can be obtained within a typical counting period of 30 minutes in a calibration.

### 3.3 Preparation of the new calibration source

The Radiochemistry Laboratory of Government Laboratory (GL) adjacent to HKO’s Radiation Laboratory at King’s Park has long provided support to the Observatory’s environmental radiation monitoring program (Wong et al., 2003), including sample preparation and preparation of calibration sources for other types of detectors. It undertook the preparation of the new calibration source from a NIST traceable Eu-152 standard.

The Eu-152 standard was first diluted with 0.1 mol hydrochloric acid (HCl) to form a mother solution. The addition of HCl also helped to reduce biological contamination. The diluted solution was then distributed uniformly into 336 vials (Figure 5 (right)) with the activity of each vial being determined by the weight of solution in it. The vials were then tightly closed and wrapped with paraffin. The homogeneity of radioactivity among the vials was checked and the variation in radioactivity between different vials was found to be within one percent.
4. CALIBRATION RESULTS AND WORK STREAMLINING

4.1 Calibration results

With the new calibration source, full calibration (i.e. energy, FWHM and efficiency calibration) for the LCMS at Lok Ma Chau Livestock Monitoring Station and Man Kam To Animal Inspection Station were performed during October 2003 to January 2004. A total of five efficiency calibrations were performed at each station, one for each of the five animal geometries for the phantom. A set of five efficiency curves was thus obtained. These curves were then re-applied onto the calibration spectra to check whether or not the computed Eu-152 activities agreed with the certified activities.

As an independent test, a similar measurement was made at each of the two stations using the set of Cs-137 vials with a configuration in the phantom befitting that of a cow. The computed Cs-137 activity was then compared with the certified activity.

The results of calibration are summarized in Table 1. They showed that the computed activities were all within two standard deviations (95% confidence level) of the certified activities.

4.2 Reducing the amount of calibration work

Hitherto, the system calibration as described in Chapter 2 was done once every year at each of the three sites. At each site, the phantom had to be set up every time with five configurations of the vials to represent the different animal geometries.

Taking advantage of the calibration results described in the above section, it is possible to reduce the amount of calibration work by using a box of 120 vials of Eu-152 for checking the energy and efficiency calibration parameters, instead of setting up a phantom every time at each of the three sites. Measurements conducted to corroborate this are described below.

First, in ensuring accurate measurement resulting from the use of the box of Eu-152 vials, the measured activities corresponding to three Eu-152 peaks, namely 344 keV, 779 keV and 1408 keV which spanned a wide range of energies for the present application, were selected as performance indicators of the LCMS. As an example, the activity corresponding to the 344-keV peak, as measured by the LCMS at Man Kam To Animal Inspection Station, is shown in Figure 6 in the form of a control chart. Description of control charts in quality
assurance can be found in common textbooks, for instance, Practical Gamma-Ray Spectrometry, Gilmore et al., 1995 (Sections 15.4.2 and 15.4.3). The performance of the LCMS in respect of the three energy peaks can be assessed by re-measuring with the box of Eu-152 vials at regular intervals and monitoring the measured activities on the control charts.

Another performance indicator of the LCMS is the position of energy peaks on the MCA. The high yield and its relative isolation from other peaks make the 1408-keV peak of Eu-152 a good candidate. By re-measuring the box of Eu-152 vials at regular intervals, the channel number on the MCA corresponding to the 1408-keV peak is monitored by means of another control chart. As an example, the control chart for the position of the 1408-keV peak on the MCA, as measured by the LCMS at Man Kam To Animal Inspection Station, is shown in Figure 7.

The above indicators are used to monitor the performance of the LCMS over time. If the re-measured activities or the re-measured channel number of the reference energy peaks fall outside the control limits, which are set at the 2-standard deviation levels, the system performance is questionable and an investigation is required. The investigation would include: checking for physical damage of the equipment, general performance of the equipment itself, leakage in the Eu-152 vials and any error in the positioning of the box of Eu-152 vials, followed by re-measurement of the box of Eu-152 vials. If the re-measurement result confirms the earlier deviation from the control limits, the system performance is reckoned to have drifted and it would be necessary to re-calibrate the LCMS.

The peak width (FWHM) has not been selected as a performance indicator because a drift in this parameter would most likely be revealed by the re-measured activities of the three energy peaks described above (for example, Figure 6).

The new calibration practice results in a reduction in the number of full calibrations from once annually for each site to once every three years, depending on the stability of the LCMS over time as reflected in the quality assurance monitoring. Full calibrations for the three LCMS performed annually in three years require 54 man-days. The new practice of having one full calibration at each site every three years, coupled with quarterly checking using the box of Eu-152 vials during the 3-year period, would reduce the manpower by roughly a half, to 26 man-days. Furthermore, it reduces workers’ exposure to radiation and lowers the risk of accidental contamination of workers and working areas.
5. CONCLUSIONS

A new liquid Eu-152 calibration source at lower cost was identified as a replacement of the original Eu-152 source used for calibrating the LCMS. Liquid-based vials containing the Eu-152 source prepared with the assistance of the Government Laboratory were found suitable for the calibration work.

A new practice has been introduced for the calibration of the LCMS. Instead of a full calibration each year at each of the three sites, a full calibration will only be made once every three years at each site, augmented by quarterly checking of the system performance with a box of Eu-152 vials. This has resulted in reduced manpower requirement and workers’ exposure to radiation, and lowered risk of accidental contamination of workers and working areas.
# REFERENCES


2. International Commission on Radiological Protection (ICRP) 1978 Limits for Intakes of Radionuclides by Workers, ICRP Publication 30, Part 1, Chapter 3


4. International Commission on Radiological Protection (ICRP) 1994 Dose Coefficients for Intakes of Radionuclides by Workers, ICRP Publication 68, Sections 7 and 8

5. Gilmore, Gordon and John Hemingway 1995 Practical Gamma-Ray Spectrometry, Sections 15.4.2 and 15.4.3
Figure 1. Location of the Livestock Contamination Monitoring Systems

- Lok Ma Chau
  Livestock Monitoring Station
- Man Kam To
  Animal Inspection Station
- Sheung Shui Slaughterhouse
  Livestock Monitoring Station
- Guangdong Nuclear Power Station / Lingao Nuclear Power Station
Figure 2. Screening livestock at Man Kam To Animal Inspection Station: cow (left) and porker (right)
Figure 3. Configuration of the Livestock Contamination Monitoring System

The sodium iodide detector and control of the hydraulic platform of the animal constrainer

The workstation installed with signal analyzer, analysis software and alarms

Spectral analysis
Figure 4. Phantom with a livestock geometry for calibration of the LCMS
Figure 5. Old (left) and new (right) radioactive sources for insertion into the phantoms for calibration of the LCMS
Figure 6. Control chart used to monitor the activity of the 344-keV peak of the Eu-152 reference source set, as measured by the LCMS at Man Kam To Animal Inspection Station.
Figure 7. Control chart used to monitor the position (in term of channel number) of the 1408-keV peak of the Eu-152 reference source set, as measured by the LCMS at Man Kam To Animal Inspection Station.
<table>
<thead>
<tr>
<th>Location of the LCMS</th>
<th>Radionuclide in the source</th>
<th>Animal Phantom Configuration</th>
<th>No. of source vials used</th>
<th>Measurement Date</th>
<th>Certified Activity (Bq/kg)</th>
<th>Measured Activity ± Counting Uncertainty (95% confidence level) (Bq/kg)</th>
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</thead>
<tbody>
<tr>
<td>Lok Ma Chau</td>
<td>Eu-152</td>
<td>cow</td>
<td>336</td>
<td>15 Oct 2003</td>
<td>2899</td>
<td>2920 ± 21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>porker</td>
<td>240</td>
<td>20 Oct 2003</td>
<td>2893</td>
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<td>2929 ± 24</td>
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<td>88</td>
<td>29 Oct 2003</td>
<td>2902</td>
<td>2924 ± 23</td>
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<td></td>
<td></td>
<td>weaner</td>
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<td>21.42</td>
<td>22.30 ± 1.67</td>
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</tbody>
</table>

Table 1. Summary of verification of measurements against the certified activities, taken during the efficiency calibrations of the LCMS at Lok Ma Chau Livestock Monitoring Station and Man Kam To Animal Inspection Station.