DISCUSSION ON SURFACE CONTAMINATION MONITORING USING PORTABLE ZINC SULFIDE SCINTILLATION DETECTORS

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ABSTRACT

Surface activity is an estimation of the radioactive surface contamination and, it is calculated using an expression that takes into account the instrument efficiency that is determined by its calibration. Such calibration is performed using sources that barely exhibit similar characteristics to the contaminated surface. Several factors such as humidity, dust, types of surface, source-to-detector distance, source geometry and efficiency affect the surface monitoring. On field conditions there are varieties of materials, equipment and types of contamination, so it is important to consider the effects of these factors on the measurements of surface activity and on the determination of the minimum detectable concentration. MDC is the smallest activity concentration that is practically achievable to be measured by a given instrument under a type of measurement procedure. MDC values must be smaller than the derived limits for surface contamination, so it is an important criterion to select appropriate instrumentation and measurement procedures. Special attention has to be paid when the radioactive contaminant is alpha emitter due to the short range of this kind of ionizing radiation. In this work it is discussed the influence of the factors mentioned above on the determination of the MDC for portable zinc sulfide scintillation monitors.

I. INTRODUCTION

The aim of all radiological protection operations is to prevent persons being needlessly exposed to harmful radiation. The radiological survey of a site can be performed for several purposes, such as for evaluation of working conditions, planning decontamination tasks or decommissioning objectives. One of the survey steps is the surface contamination monitoring. This monitoring can be done by indirect or direct methods. While indirect methods rely upon measuring the amount of radioactivity removed from a surface, by direct method the measurement of the amount of activity present is performed directly on that surface. Portable detectors are used for direct method of surface contamination monitoring. There are lots of possible radioactive contaminants with different characteristics. Among them, the more restrictive ones are the alpha emitters, due to the risk of ingestion or inhalation and the damage to the body that can be caused by this intake. The instrument chosen for the survey must be able to detect minimum detectable concentration, MDC, values lower than the permissible derived working limits, DWL [1]. The MDC corresponds to the smallest activity concentration measurement that is practically achievable with a given instrument and type of measurement procedure [2]. The MDC depends not only on the particular instrument characteristics (instrument efficiency, integration time, etc.), but also on the factors involved in the survey measurement process, which include surface type, source-to-detector geometry, source efficiency (backscatter and self-absorption) and background. The human performance on this survey has to be considered too [3].

The alpha radiation has a high linear energy transfer (LET) so it has a short range. Because of this, several conditions can affect the alpha contamination monitoring during a field survey using portable detectors. In the present work it is discussed some factors that affect the determination of the MDC of portable zinc sulfide scintillation detectors.

II. FACTORS THAT AFFECT MDC

MDC is a level of radioactivity, either on a surface or within a volume of material that is practically achievable by an overall measurement process. There are several statistical interpretations of MDC and Abelquist *et al.* [2] performed a sensitivity study about these interpretations. The measurements of that sensitivity study were obtained under ideal laboratory conditions with gas proportional detector. They found out from this limited MDC sensitivity study that the MDC expressions referenced in the literature produce very consistent results. The study also showed that, once demonstrated that the portable monitor possesses sufficient detection capabilities relative to the DWL for surface activity, there was no difference in the conclusions reached by each statistical interpretation of MDC.

The detector-related factors that may change the instrument MDC are detector size (probe surface area), geotropism, window density thickness and instrument response time. Environmental conditions such as temperature, pressure, and humidity also affects the MDC.

Zinc Sulfide Scintillation Detector. The measurement of residual radioactivity during surveys in support of decommissioning often involves measurement near-background levels [2]. Therefore, the detection limit of field survey instrumentation is an important criterion in the selection of appropriate monitor and measurement procedures. The commonly detection media used by alpha scintillation detectors is the silver-activated zinc sulfide, ZnS (Ag) [2, 4]. Alpha particles enter the scintillator through an aluminized Mylar window. Being thin enough to allow the penetration of alpha radiation without significant energy loss, this Mylar window prevents ambient light from reaching the photomultiplier. Light pulses from alpha radiation and ZnS interaction are amplified by a photomultiplier, converted to voltage pulses, and counted on a digital scaler/ratemeter with a set threshold value. The detector response is recorded as an integrated count or it is noted as a count rate, or both.

Radioactive Sources for Calibration. Appropriate calibration of the field instruments is necessary for accurate measurements of total surface activity [1, 2, 5]. The selection of calibration sources is one of the parameters that the MDC of an instrument depends on. Calibration sources should be selected choosing alpha radiation emitters with energies similar to those expected of the contaminant in the field. For instance, both uranium and thorium series emit a complex decay scheme of alpha, beta and gamma radiations, so calibration to a single radionuclide must carefully be assessed to ensure that it is representative of the detector's response to these decay series [2].

Source-to-Detector Distance. Another factor that may affect the instrument efficiency and, thus, the MDC is the distance between a source and the detector. The deviation in instrument response that results when the source-to-detector distance during calibration is only slightly different from the detector-to-surface spacing maintained during field measurements of surface activity. This means that small changes in detector-to-surface distance produce significant changes in detector response, especially for alpha and low-energy beta radiation. To minimize the effects of source-to-detector distance on MDCs, it is recommended that the detector be calibrated at a source-to-detector distance that is similar to the expected detector-to-surface spacing in the field [2]. The International Electrotechnical Commission recommends, for the measure of surface sensitivity of the probe to alpha radiation, that the source shall be placed at a distance from the sensitive surface of the probe following manufacturer's indication, but which should in no case exceed 10 mm [6]. To ensure the detection of alpha contamination by direct monitoring, IAEA recommends that the probe should not be more than about 5 mm from the surface under examination [5]. Goles *et al.* [7] performed their study using a quarter of inch spacing.

Source Geometry Factors. The detector's response may be influenced, in part, by the distribution of the contaminant on the surface being assessed. If relatively large uniform areas of activity can characterize the contamination, then the detector should be calibrated to a distributed or extended source. Similarly, if the surface can be characterized by localized spots of surface contamination, which may be approximated by a point source, then the calibration source should be similar to point source geometry. Because of the time consuming task to determine the contaminant geometry during field survey measurements, it may be appropriate to use the instrument efficiency obtained from distributed source geometry for all surface activity measurements locations, except for those of elevated direct radiation [2].

III. SURFACE CONTAMINATION

In the field, variables such as surface types and coatings, including painted, scabbled, or wet surfaces can affect the sensitivity of the instrument. Surface contamination is evaluated in terms of surface activity.

Surface Activity. Estimates the radioactive surface contamination, which is calculated using the Eq. (1) [1]:

$$A_s = \frac{N - N_0}{E_i . E_s . W . 60} \tag{1}$$

where:

A_s = surface activity in Bq.cm^{-2}

N = gross count rate of the measurement in cpm

N_0 = background count rate in cpm

E_i = instrument efficiency in count per emission

E_s = source emission efficiency in emission per Bq

W = area of the detector window in cm^2

60 = time conversion factor in s per min

E_i is defined as the ratio between the net count of the instrument and the surface emission rate (q_{2p}) of a source for a specified geometry. q_{2p} is the particle fluency that incorporates both the absorption and the scattering processes that affect the radiation emitted from the source. E_i is determined during calibration by obtaining a static counting with the detector over a calibration source that has a traceable activity or surface emission rate.

E_s is defined as the ratio between the number of particles of a given type emerging from the front face of a source and the number of particles of the same type created or released within the source per unit time. E_s takes into account the particle emission increase due to backscatter effects, as well as the decrease to self-absorption losses.

The product of the instrument efficiency and source efficiency yields the total efficiency, which is used to assess the surface contamination. Total efficiencies are determined with a clean, stainless steel source and, then are used to assess contamination on a dust-covered concrete surface. Several factors should be considered when using an instrument in the field. These factors involve the background count rate for the particular surface and any surface coatings. A particular field condition may significantly affect the usefulness of a determined instrument, as wet surfaces for alpha measurements or scabbled surfaces for low-energy beta measurements [2].

Background Count Rates for Various Materials. Several different types of surface materials may be encountered in a facility undergoing decommissioning. The background count rates vary depending on the local area background radiation levels. Commonly, among the construction materials, the lower background count rates are verified for linoleum, carbon steel, and wood, and higher for the brick and ceramic materials. Since the detector MDC varies directly with the background count rate, it is expected that the lower MDCs for ZnS detector are obtained for linoleum, carbon steel, and wood, while the higher MDCs are for brick and ceramic materials [2]. While the minimum detectable level will be roughly proportional to the background over a small range of background levels (such as those indicated by a particular type of detector at different locations), this will not be the case over wide ranges (such as those produced by different types of detectors).

Effects of Surface Condition on Detection Sensitivity. Calibration sources invariably consists of a clean, smooth surface and, as such, do not reproduce the self-absorption characteristics of surfaces in the field. The conversion of the surface emission rate to the activity of the contamination source is often a complicated task that may result in significant uncertainty if there are deviations from the assumed source geometry. For instance, the measurement error associated to an alpha surface activity measurement on a rough surface, such as scabbled concrete, would be substantially greater compared to the measurement performed on the smooth surface of a calibration source. This happens because the source efficiency varies widely depending on the amount of self-absorption and backscatter provided by the surface [1, 2]. Depending on the surface conditions in the field the total efficiency can change affecting MDCs levels. It was observed, by Abelquist *et al.,* that ZnS detectors efficiencies for uranium traceable sources dispensed on various surface materials are lower compared to the ones obtained from electroplated calibration sources. The possible reason was that the uranium source deposition did not constitute a source with virtually no self-absorption. This source deposition was likely more realistic to the uranium contamination measured in the field [2].

Effects of Overlaying Material. Normally, in field conditions, materials such as dust, humidity and oil can be found deposited over the contaminated surface. The evaluation of various thicknesses of paint, dust, and water between the detector and the source, has shown that the source efficiency is reduced as the density thickness of the material on the surface increases. The alpha radiation presents a large variability in attenuation with different materials. Abelquist *et al.* observed that the source efficiency decreases with increasing density thickness in the same manner for water, dust, and paint [2].

IV. HUMAN PERFORMANCE

In the case of scanning surface alpha contamination in large areas, commonly, the first thing to be done is to locate where the measurements are higher than background level using beta-gamma contamination detectors, then the ZnS scintillator detector is used to measure the surface contamination [8].

Field survey operation can be done in static or scanning modes. Scanning is performed during radiological surveys to identify the presence of any locations of elevated direct radiation. Not only the sensitivity of the survey instrumentation when used in the scanning mode, but also the surveyor's ability affects the probability of detecting residual contamination in the field [2]. The amount of radiation reaching the probe is affected by the source-to-detector geometry, which is a function of their dimensions and the distance of the probe from surface, as well as the speed at which the surveyor moves it over the surface. The information reaching the surveyor depends on the audibility and visibility of the instrument's display [3]. Also, the surveyor must decide whether the signals represent only the background activity, or whether they represent residual contamination in excess of background [2].

The MDC of a scan survey depends on the intrinsic characteristics of the detector (efficiency, window area, etc.), the nature of the contaminant (type and energy of emissions), relative distribution of the contamination (thickness of the overlaying material, point or distributed source), scan rate and other characteristics of the surveyor. The detection of a signal in a noise background is determined not only by the magnitude of the signal relative to the background, but also by the willingness of the surveyor to report that a signal is present. In practice, surveyors do not make decisions on the basis of a single indication. Instead of that, upon noting an increased number of counts, they pause briefly and then decide whether to move on or take further measurements [2]. IAEA recommends that the probe transit velocity across the surface should not exceed about 150 mm/s [5]. Goles *et al*. [7] scanned the surface at 50 mm/s.

V. USE OF ALPHA MEASUREMENTS TO ASSESS SURFACE ACTIVITY

A common practice has been to use beta measurements to demonstrate compliance with surface activity guidelines expressed as alpha activity [2]. The uranium and thorium decay series emit both alpha and beta radiation. If beta measurements are applied to assess compliance with uranium and thorium surface activity guidelines, consideration should be given to the energy of the radionuclide used to calibrate the detector.

At IPEN, it has been used the alpha measurements, from instruments calibrated with ^{241}Am electroplated standard source, and using Eq. (1) for surface activity assessment.

The minimum radioactivity is calculated in terms of activity (Bq) instead of concentration (dpm/cm^2), and the Eq. (2) has been used for the calculation of the minimum detectable activity MDA [8]:

$$MDA = \frac{2.71 + 4.65\sqrt{N_0}}{E_i . E_s .60} \qquad (2)$$

where:

$MDA =$ minimum detectable activity in Bq

$N_0 =$ background count rate in cpm

$E_i =$ instrument efficiency in count per emission

$E_s =$ source emission efficiency in emission per Bq

$60 =$ time conversion factor in s per min

VI. CONCLUSION

The factors that affect the determination of the MDC for portable zinc sulfide scintillation monitors must be considered when performing a radiological surface monitoring.

Depending on the surface conditions in the field, if the total emission efficiency is affected, the MDCs levels will change in an inverse manner.

The most representative calibration source would be one prepared from the radioactive material (e.g., uranium or thorium) that is being measured in the field.

The period that the activity is scanned determines the information available to the surveyor. Thus, if the probe is moved too quickly, or it is not held over the source for long enough, the distributions of activity obtained will not be sufficiently assessed to support acceptable performance of the surveyor. In practice, surveyor's criteria probably vary constantly as a function of the location being surveyed or the appearance of the surface. Historical data showing that the surveyed area is not expected to be contaminated, while the total time available for the survey is limited, represents a "worst case" for detecting potential contamination by scanning from a human performance perspective. So, it is necessary to consider how much these factors actually affect the surveyors.

In conclusion, every field monitoring planning should take into consideration the factors mentioned here, especially when using alpha portable monitors.

Studies have to be developed in order to analyze those variables that really affect the MDC of the portable monitors used at IPEN, therefore achieving more accurate results of surface contamination.

REFERENCES

[1] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, ISO-7503-1, **Evaluation of surface contamination – part 1: Beta-emitters (maximum beta energy greater than 0,15 MeV) and alpha-emitters,** 1988.

[2] Abelquist, E. W., Brown, W. S., Powers, G. E., Huffert, A M., **Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions**, NUREG-1507, Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Division of Regulatory Applications, USA, December 1997.

[3] Brown, W. S., Abelquist, E. W., **Human Performance in Radiological Survey Scanning**, NUREG/CR-6364, BNL-NUREG-52474, Office of Nuclear Regulatory Research, Division of Regulatory Applications, USNRC, USA, March 1998.

[4] Turner, J. E., **Atoms, Radiation, and Radiation Protection**, 2nd ed., John Willey & Sons, Inc., N. Y., 1995.

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, **Monitoring of Radioactive Contamination on Surfaces**, Technical Reports Series 120, Vienna, 1970.

[6] COMISSION ÉLECTROTECHNIQUE INTERNATIONALE, **Contaminamètres et Moniteurs de Contamination alpha, bêta, alpha-bêta**, Publication 325, Suisse, 1970.

[7] Goles R. W., Baumann B. L. and Johnson M. L. **Minimum Detectable Activities of Contamination Control Survey Equipment**, USA, August 1991.

[8] Kodama Y., Vasques F. M. F., Cambises P. B., Almeida C. C. **Radiation Survey of a Uranium Pilot Plant for Rebuilding Purpose,** 10th International Congress of the International Radiation Protection Association, Hiroshima, Japan, May 2000.