*Topical Area 8 – Incidents and Accidents*

# *A Contribution to the Analysis of the Activity Distribution of a Radioactive Source Trapped Inside a Cylindrical Volume, Using the MCNPX Code*

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*Abstract.*

*Orphan sources, activated materials or contaminated materials with natural or artificial radionuclides have been detected in scrap metal products destined to recycling. The consequences of the melting of a source during the process could result in economical, environmental and social impacts. From the point of view of the radioactive waste management, a scenario of 100 ton of contaminated steel in one piece is a major problem. So, it is of great importance to develop a methodology that would allow us to predict the activity distribution inside a volume of steel.*
*In previous work we were able to distinguish between the cases where the source is disseminated all over the entire cylinder and the cases where it is concentrated in different volumes. Now the main goal is to distinguish between different radiuses of spherical source geometries trapped inside the cylinder. For this, a methodology was proposed based on the ratio of the counts of two regions of the gamma spectrum, obtained with a sodium iodide detector, using the MCNPX Monte Carlo simulation code.*
*These calculated ratios allow us to determine a function $r = aR^2 + bR + c$, where R is the ratio between the counts of the two regions of the gamma spectrum and r is the radius of the source. For simulation purposes six $^{60}Co$ sources were used (a point source, four spheres of 5 cm, 10 cm, 15 cm and 20 cm radius and the overall contaminated cylinder) trapped inside two types of matrix, concrete and stainless steel.*
*The methodology applied has shown to predict and distinguish accurately the distribution of a source inside a material roughly independently of the matrix and density considered.*

## *1. Introduction*

*Radioactive sealed sources are widely used for many industrial, health and research purposes and with far-reaching benefits. However, when these sources are lost, stolen or misplaced, they can also originate far deadly consequences on people's life and in the environment. One of the most important aspects related to the subject involves the increasing number of events involving orphan sources and contaminated or activated materials that have been detected, all over the world, in scrap metal cargos for recycling. If the radioactivity in the scrap metal is not detected beforehand, the resulting*

*molten products and by-products would be contaminated, with serious consequences for the company's economy, the environment and public health.*
*In Portugal, an average of 1500000 tonnes of scrap metal is recycled every year and about 50 incidents of radioactive materials in scrap metal were reported between 2000 and 2005 [1]. The increasing number of events reported about radiological incidents/accidents all over the world and involving contaminated scrap metal [2,3,4] have been the subject of concern by the European Community and the International Atomic Energy Agency [5]. Only the introduction of tough controlling mechanisms such as the alarm detectors systems in both scrap dealers and foundries as well as the implementation of radiological protection training of the workers can help to prevent serious accidents.*
*In a previous work [6] the Monte Carlo simulations [7] were used to predict and find correlations between the source distribution inside a specific material and the variations of the absorbed dose with the distance to the surface of that material. However, that only allowed to clearly distinguishing between the case where the material (in this case a cylinder was considered) is overall contaminated and the cases where the source is confined in a smaller volume inside the stainless steel cylinder.*
*Now, the main goal is to distinguish between different source volumes trapped inside two different matrices, using the gamma spectrum of the setup. This was done by using the Monte Carlo simulations. The proposed methodology is based on the ratio of the counts between two defined regions of the gamma spectrum obtained with a sodium iodide, NaI(Tl) detector and its relation with the source volume*
*The validation of the Monte Carlo simulations has already been performed in a previous work [6], using a pilot scale drum and $^{60}$Co sources. Dose measurements have been performed and a good agreement was achieved between experimental and simulation data.*

## *2. Methodology*

*MCNPX is a general Monte Carlo code that is widely used for a large number of situations involving radiation transport. In this study the MCNPX version 2.5 was used. The calculations were performed in a PC with a Pentium IV (1.7 GHz) processor and 512 Mb of RAM.*
*Conceptually, two cylinders of 1m x 0.5 m (height x diameter) were used (Fig. 1). One constituted only by stainless steel -AISI 304- and with the chemical composition (weight percentage): C=0.05%; Mn=1.5%; Si=0.5%; P=0.03%; S=0.2%; Ni=9%; Co=19% and Fe=69.9%. The other was constituted by concrete and the chemical composition (weight percentage) has been considered as an average value for the concrete materials: H=0.56 %; O=49.83 %; Na=1.71 %; Mg=0.24 %; Al=4.54 %; Si=31.52 %; S=0.12 %; K=1.92 %; Ca=8.26 % and Fe=1.22 %. The densities of the cylinders were, respectively, $7.92x10^3$ $kg.m^3$ and $2.01x10^3$ $kg.m^3$.*

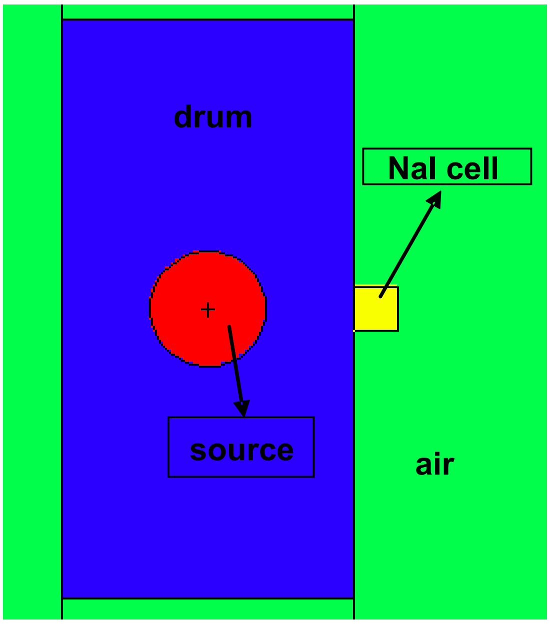


*FIG. 1 - Schematic representation of the conceptual model.*

*Six different distributions for the gamma source, $^{60}Co$, centred with the cylinder, were considered: a point source (ps); four spherical source distributions with radius of 5 cm (sph5), 10 cm (sph10), 15 cm (sph15) and 20 cm (sph20) and finally, a source distribution filling the overall cylindrical volume (cyl).*
*Energy distribution of pulses created in the simulated detector by radiation has been calculated using F8 specific MCNPX tally card.*
*Calculations were performed in a NaI, 3''×3'' detector cell placed into contact with the surface of the cylinder. The detector cell was centred with the source as shown in Fig. 1. On the gamma spectrum two regions were selected: between the energies of 30 and 400 keV, where the scintillation efficiency is higher [8], designated by region 1, and the region of the characteristic photons of the source, between the energies of 1100 and 1400 keV, designated by region 2.*
*The gamma sources were modelled as isotropic sources and to minimize the computing running time the electron transport was not considered.*

## *3. Results*

*In order to study the variation of the ratio between the two regions of the gamma spectrum with the source distribution in both matrices, gamma spectra was obtained in the detector cell for each source volume. Figures 2 and 3 show the spectra obtained for each matrix.*

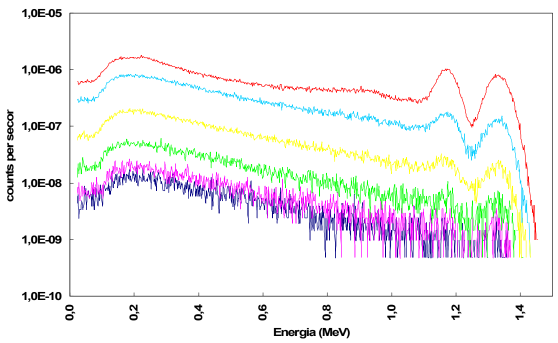


*Figure 2 - Gamma spectra for the six source distributions inside a stainless steel cylinder: cyl (red), sph 20 (cyan), sph 15 (yellow), sph 10 (green), sph 5 (magenta), ps (blue).*

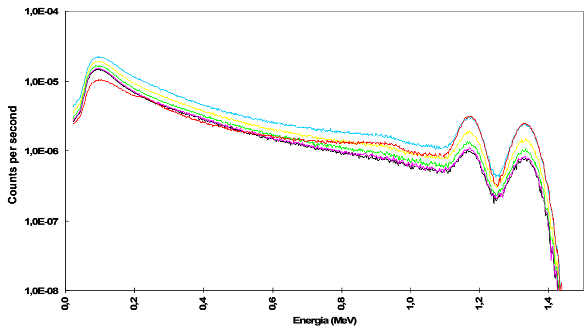


*Figure 3 - Gamma spectra for the six source distributions inside a concrete cylinder: cyl (red), sph 20 (cyan), sph 15 (yellow), sph 10 (green), sph 5 (magenta), ps (blue).*

*Due to the photon high absorption and the computing running time used (3000 minutes), the counting statistics for the smaller volumes trapped inside the stainless steel matrix are poor. Nevertheless, the error of the overall counts in each region is acceptable. From the analysis of the Figures 2 and 3, it stands out that the contribution of the two peaks of $^{60}$Co (region 2) increases with the increasing source volume. This is also true for the region 1. However these two zones of the spectrum do not increase in the same way. When the source volume increases, the counts in region 2 increases faster than in region 1, as it was expected. This fact is emphasized if the ratio between the overall counts in each region of the spectrum is considered (the counts in region 1 divided by the counts in region 2). The fitting of a unique quadratic function for the overall results of both matrices reveals a good agreement. The plot is presented in Figure 4.*

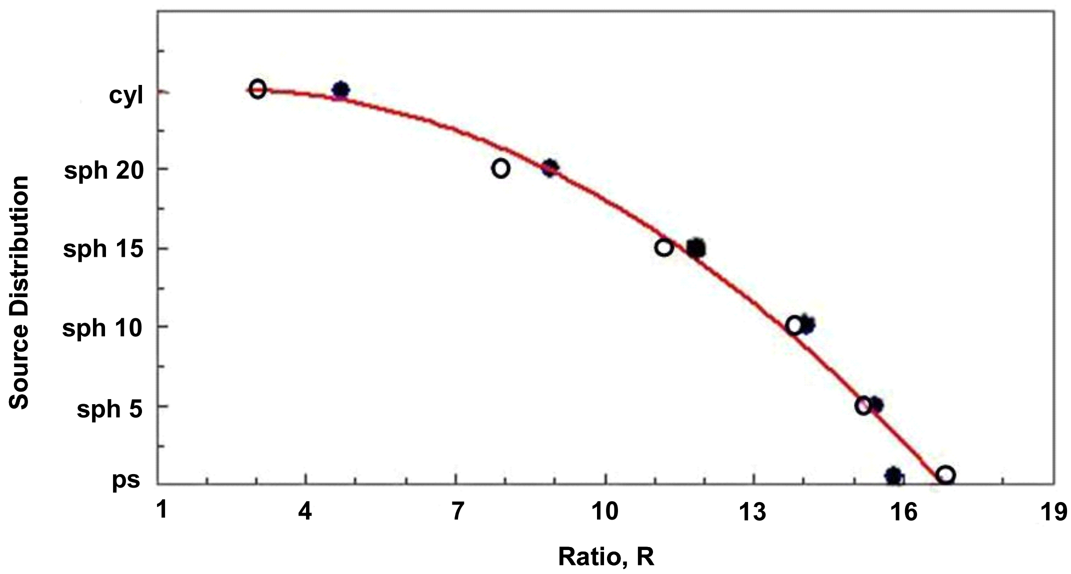


*Figure 4 - Plot of the ratios for both matrices (● for concrete values and ○ for the stainless steel values) for the six source distributions, and the fit for the overall values (-).*

*The fitting function is:*

$$r = -0.12R^2 + 0.58R + 24.36,$$

*where r (in centimeters) is the radius of the source distribution and R is the ratio between the two regions of the spectra. The correlation coefficient for this fit is 0.99.*
*The analysis of these results shows clearly that although the densities and composition of the matrices are quite different, the variation of the ratios have an identical behaviour for both matrices. This could indicate that, at least in a restrict range of densities, the ratio variation with the source distribution is roughly independent of the matrix.*
*The obtained data shows that this methodology can be used to predict the distribution of a source inside a material. In fact, there is a significant variation of the ratio with the source distribution.*
*Experimentally, a gamma spectrum acquired with a portable spectrometer is not as "clean" as the one obtained through simulation. In particular, the spectrum data for energies below 60 keV is normally discarded. Thus using for region 1 only the counts between 100 and 400 keV, the plot of these ratios and quadratic fitting for both matrices are shown in Figure 5.*

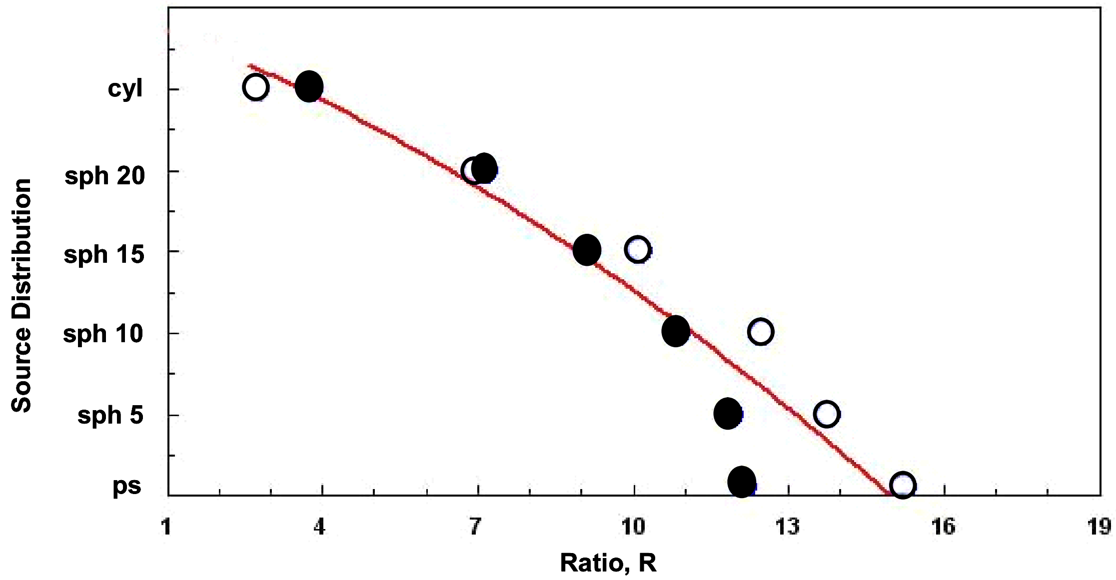


*Figure 5 - Plot of the ratios for both matrices (● for concrete values and ○ for the stainless steel values) for the six source distributions, and the fit for the overall values (-), using the range 100 to 400 keV for region 1.*

*The corresponding fitting function is:*

$$r = -0.05R^2 - 1.18R + 29.90,$$

*and the correlation coefficient for this fit is 0.95.*
*In this case the fitting for the overall data is not as good as the one obtained using the range 30 to 400 keV for region 1. This approach may give rise to some imprecision in predicting the source distribution, in particular for the*

*smaller source geometries. Fitting both matrices independently would lead to better results.*
*However, the error associated with the use of a unique correlation function for different matrices is not meaningful when compared with all the sources of error inherent to a real scenario: the accurate chemical composition and density of the matrix might not be known, the matrix might not be homogeneous, the source might have a non-homogeneous distribution, the interference of other sources of radiation (natural background, for example) need to be considered, among others. Nevertheless, the sensitivity, S, given by $S = \left|\frac{dr}{dR}\right| = \left|-0.1R - 1.18\right|$, shows that the different source distributions are easily distinguished using this approach.*

## *4. Conclusions*

*The results reported in this paper show that Monte Carlo simulations can be used as a predictive tool for activity distribution inside a cylinder as it is the case of a radioactive source trapped in a specific volume of molten metal during the recycling process.*
*The prospect of a matrix or density independent correlation is very useful in a real scenario once the geometry of the problem is the only important factor to be carefully considered.*
*The sensitivity results confirm that it is possible to easily distinguish between different source distributions.*
*In order to be able to apply this methodology it will be necessary to perform the simulation with a model corresponding to the real scenario (contaminated molten metal, for example), draw the corresponding function $r = f(R)$, obtain the ratio of the two regions from the experimental gamma spectrum of the setup and finally find the source distribution value corresponding to the experimental ratio.*
*The knowledge of the source distribution is of paramount importance to determine how the problem should be handled in a real scenario.*

## *References*


1. *Trindade, R., Paiva, I., Portugal, L., Radioactive Substances in Scrap Metal (Portuguese), Radioprotecção, Vol. I, N. 10, Vol. II, N. 1, May (2002).*
2. *National Radiological Protection Board, IRID: Ionising Radiations Incident Database, Chilton, Didcot (1999).*
3. *Consejo de Seguridad Nuclear, Meltdown of a Source of Cesium-137 at Acerinox Plant (Algeciras), Madrid (1998).*
4. *International Atomic Energy Agency, The Radiological Accident in Istanbul, Vienna(2000).*
5. *United Nations Economic Commission for Europe, Report on the Improvement of the Management of Radiation Protection Aspects in the Recycling of Metal Scrap, New York and Geneva (2002).*

6. *Oliveira, C., Portugal, L., Paiva, I., Trindade, R., Analysis of the Activity Distribution from an Orphan Source in Molten Scrap Metal, Using the MCNPX Code, 11th International Congress of the International Radiation Protection Association, Proceedings CD-Rom, May 2004, Madrid, Spain.*
7. *MCNPX™ User's Manual, Version 2.5.0, LA-CP-05-0369, Los Alamos Laboratory, April 2005.*
8. *Gilmore, G., Hemingway, J., Practical Gamma-Ray Spectrometry, ISBN: 0-471-95150-1, J. Wiley & Sons, Lda., March 1995*