CONTAMINATED SCRAP METAL-DIFICULTIES TO DETECT

Paulo Fernando Lavalle Heilbron Filho
Nerbe J. Ruperti Junior

Abstract

The objective of this article is to evaluate the difficulties that could involve the detection of contaminated scrap with radioactive materials in trucks through the check in radiation detector portals in order to develop a common protocol to be apply in all Brazilian melting Companies including the establishment of the best alarm set up level as well as the development of some procedures in order to increase the probability of detection.

The article takes in consideration the following point source radionuclides: Am-241, Co-60 and Cs-137in order to investigate the probability of detection of high, medium and low gamma radioactive source emissions by monitors portals.

Some others important radionuclides will be investigated further, especially those related to NORM radioactive materials (non point sources).

INTRODUCTION

Radioactive substances can become associated with scrap metal in various ways and if not discovered they can be incorporated into steel and non-ferrous metals through the melting process with a great probability of causing health hazards to workers and to the public as well as to the environment. It also can cause a lot of economic and commercial problems if, for example, a hot furnace is contaminated inside with radioactive material.

One–third of contaminated material with radionuclides produced in industries results from industrial activities involving NORM and TENORM that is brought to surface with a material resource product, such as petroleum or phosphate. But in this article will only take into consideration others important radionuclides, such as Am-241, Co-60 and Cs-137, low, high and medium gamma emissions respectively (see Table 1)

Table 1- Co-60, Cs-137 and Am-241 gamma energies

Radionuclide	Gamma energies (Mev)	Percentage of emission per decay
Co-60	1.17 1.33	100% 100%
Cs-137	0.66	100%
Am-241	0.014 0.018 0.060	13% 18% 36%

Am-241 is usually founded in lightning rods while Co-60 and Cs-137 in nuclear gages and teletherapy equipments.

The most famous accident related to scrap metal contamination in a melting company occurred in Mexico many years ago and was only detected in United States due to an alarm located at Los Alamos. Since this accident a lot of new incidents have occurred in recent years around the world involving the discovery of radioactive substances in scrap metal before they enter in the melting process.

In Brazil the main melting companies has radiation fixed portals for the detection of radioactive material in scrap metal and order to avoid it mixture in the furnace.

Usually the radioactive material detected in Brazil involves NORM materials (Naturally Occurring Radioactive Materials) but one incident occurred in 2004 involving the detection of two Co-60 sources (figure 1), orphan sources, that due to the existence of a portal in a melting company avoid the contamination of the furnace and consequently radiological damages.

Figure 1- Radioactive sources detected in the fixed portal

These sources, usually when detected, are storage in a special safety storage building belonging to the company.

Table 2 provides a general summary of the notifications relating to events involving the radioactive material detected in alarm gate, excluded NORM and TENORM from 2002 to 2007, in the main melting Brazilian Companies Alarm Gate Detector (Fixed portals).

Shipments of contaminated scrap metal are not easy to be detected even if the company performed a regular check using a fixed radiation detector portal, as will be shown in this article, especially if the radioactive source is a low gamma radiation emission such as americium or if the source is located at the centre of the truck and if the load has a high density material with little void fraction.

A programme in “Mathematica Platform” was developed in order to evaluate these difficulties and to help the Brazilian Nuclear Energy Commission to develop and harmonize in the country a monitoring strategy related to the detection of scrap metal in order to prevent the release of sealed radioactive sources and other radioactive material from regulatory control.

Table 2- List of the main events involving the detection of contaminated scrap metal in Brazil

Date	Radiation Levels	Material Detected	Picture	Obs
14/10/2002.	15 μSv/h 200 μSv/h at the contact with the radioactive material	I-131		Portal Exploranium. 4.000 cps
12/08/2004	>10.000 cps 30 μSv/h on the truck	Mo-99.	No picture was taken	Portal Exploranium. 4.000 cps
14/07/2005	>10.000 cps 40 μSv/h. on the truck	Lightning rod with Ra-226	No picture was taken	Portal Exploranium 4.000 cps.
25/10/2005	>8000 cps 0,3 μSv/h on the truck	Rocks	No picture was taken	Portal Exploranium 4.000 cps
03/08/2007.	>10.000 cps 0,5 – 1 μSv/h in the portal 10 μSv/h on contact	Th-232 in powder inside a 200l drum		Portal Exploranium 4.000 cps

THE MODEL AND DATA

In order to analyse the possible detection situations the arrange shows in figure 3 was used. Three main radioactive materials were considered (Am-241, Co-60, Cs-137).

To simulate the many possible situations (a truck full of void fractions and a truck fully load with high density materials including that the source has a shielding material) eight different densities were considered (from 1 g/cm^3 until 8 g/cm^3 simulating iron) and that the radiation source was a point source.

The positions of the source vary from the centre of the truck (the worst situation) to the edge of the truck (most favourable detection position), which means distances from 0 to 1 meter.

A distance of 30 cm from the edge of the truck to the portal was considered and an iron thickness of 1 cm was considered for the truck.

Build-up constants, attenuation and absorption coefficients for iron can be seen on Table 3 and Table 4 respectively.

Table 3– Iron build-up constants

Energy (MeV)	C	$\alpha 1$	$\alpha 2$
E>0.01 and E <=0.5	16	- 0.095	0.038
E>0.5 and E<=1.0	16	- 0.095	0.038
E>1.0 and E<= 1.5	11	-0.085	0.045
E>1.5 and E<= 2.0	8	-0.080	0.060
E>2.0 and E<= 2.5	6.5	- 0.075	0.072
E>2.5	5.25	- 0.076	0.081

Table 4– mass absorption and attenuation coefficients

Energy of gamma (MeV)	*Air mass absorption coefficients* cm^2/g	*Iron mass attenuation coefficients* cm^2/g
0.010	4.61	26.25
0.015	1.27	8.175
0.02	0.511	3.626
0.03	0.148	1.225
0.04	0.0668	0.624
0.05	0.0406	0.4022
0.06	0.0305	0.3027
0.08	0.0243	0.2169
0.10	0.0234	0.1816
0.15	0.025	0.1451
0.2	0.0268	0.1287
0.3	0.0287	0.1093
0.4	0.0295	0.09733
0.5	0.0296	0.0866
0.6	0.0295	0.08188
0.8	0.0289	0.07169
1.0	0.0278	0.06443
1.5	0.0254	0.05247
2.0	0.0234	0.04526
3.0	0.0205	0.03685

The exposure rate in R/h at a certain distance x of a point source radioactive material shielding by many materials can be calculated as follows:

$$\dot{D} = f_c . A . 3{,}7x10^{10} . \frac{3600}{1000} . \{\sum_{j=1}^{n} E_j \%_j . (\frac{\mu abs}{\rho})_j \frac{e^{-\sum_{i=1}^{n}\mu_i r_i}}{4\pi[\sum_{i=1}^{n} r_i]^2} . \prod_{i=1}^{n} B(\mu_i r_i)\}$$

Where:

- A is the activity of the source in Ci and E_i is the gamma energy of the i photon;
- f_c = constant factor= 1,6 * 10^{-8} g.R/MeV (10^6 ev/MeV/ (34 ev/ions pair *1,61*10^{12} pair ions/R);
- $\sum r_i$ is the distance in cm between the source to the detector;
- $\%_j$ is the percentage of gamma emission per disintegration of the gamma of energy Ei
- μ_i is the linear attenuation coefficient of the shielding I, in cm^{-1}, function of the energy Ei and type of shielding material and $\mu abs/\rho$ is the mass absorption coefficient of the air in cm^2 /g, function of the gamma energy E_j;
- r_i is the thickness of the medium I and
  - $B(\mu_i,r_i)$ is the build-up coefficient of the medium i, function of the gamma energy E_j; (in our case only the build-up factor of the scrap metal was considered.)

Figure 32 shows how the situation was theoretically modelled

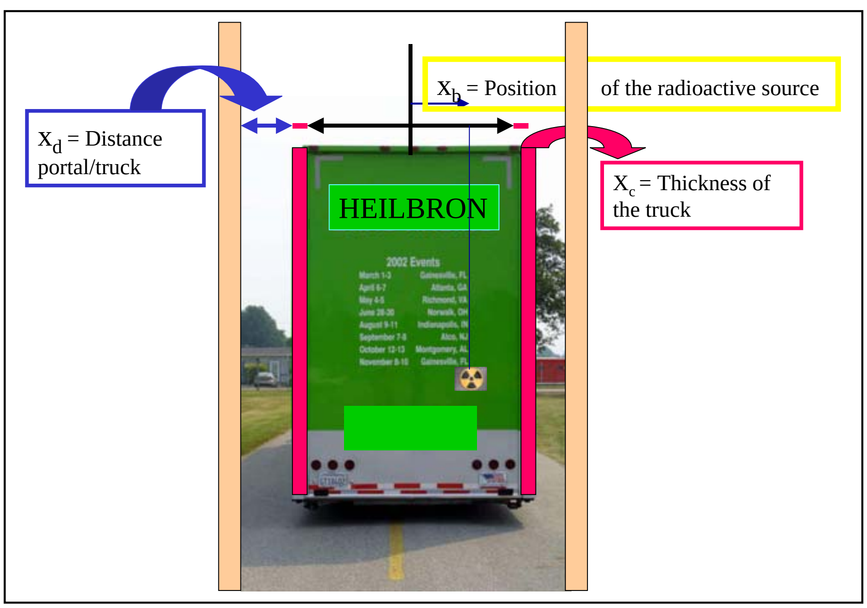

Figure 2 – Modelling situation

The following hypothesis and data was considered in the analysis:

x_d=distance from the truck to the portal equal to 30 cm of air;
x_c=thickness of the truck equal to 1 cm of iron ;

x_b=distance from the source to the wall of the truck varying from 10 cm to 100 cm
x_s=thickness of the shielding of the source equal to 1 cm of lead
ρ_{scrap}= density of the scrap metal varying from 1 g/cm^3 to 8 g/cm^3 to simulate different void fractions inside the truck;
ρ_s=density of the shielding source equal to 11,35 g/cm^3 (lead)
ρ_c= density of the wall of the truck equal to 7,87 g/cm^3 (iron)

It should be pointed out that natural radiation exposures in Brazil (excluding radon) are of the order of 1 mSv/year, equivalent to approximately 0.1 μSv/h ($\approx 10^{-5}$ R/h) and if the equipment has the capacity to detect 10% of this background typical value (levels of 10^{-6} R/h) the source will only be detected if the radiation levels in the detector is in this order of magnitude.

Figure 3, shows the dose rates expected at the detector for a Co-60 source of 1 mCi located in different positions on the truck (from the wall to the centre-orange points) as a function of the density of the scrap metal in comparison with the 10^{-6} radiation natural level (in dot).

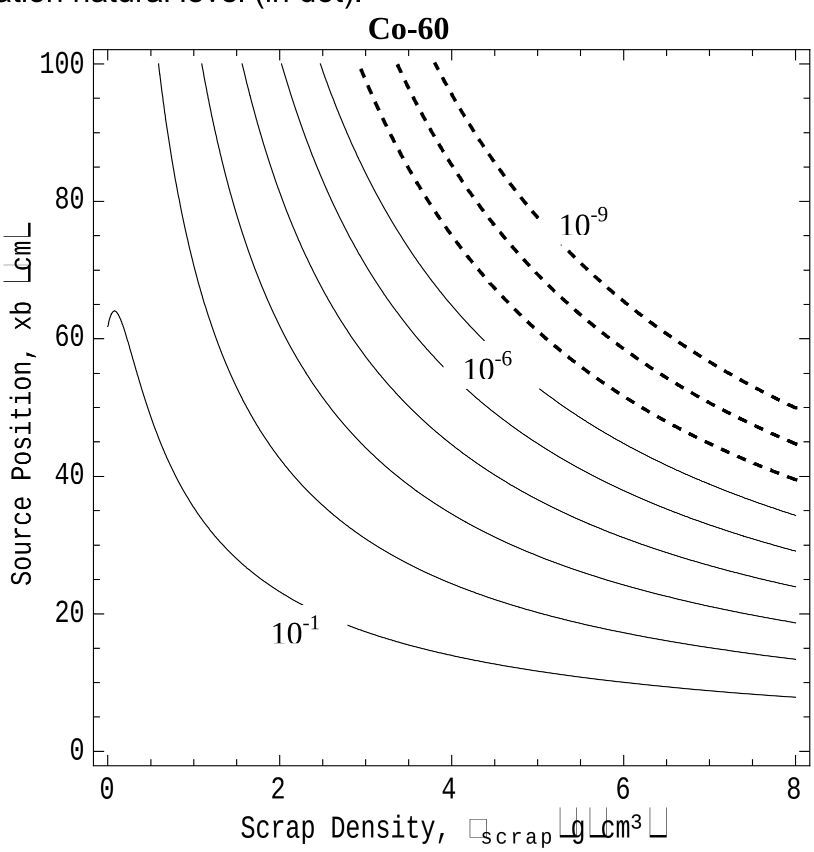

Figure 3- Comparison between the natural radiation level and the expected exposure rate at the portal for many different positions of a 1 mCi Co-60 source and as a function of the scrap density (isolines in R/h)

In can be seen from the graphic the shadow areas where the Co-60 source would have a great probability not to be detected by the portal. It is easy to see, as expected, that when the density of the scrap increases (very small amount of void fractions) the source would only be detected if it were located at a maximum position of 40 cm from the wall of the truck.

In the case of Cs-137, 1 mCi source, (figure 4) the area of the shadow increases and for a high density of the load the source would only be detected if it were located at approximately 22 cm from the wall of the truck.

In the case of an Am-241 lightning rod (figure 5), 1 mCi source, it can be seen that the shadow area increases very much which makes practically impossible to detect in portals this kind of radiation source.

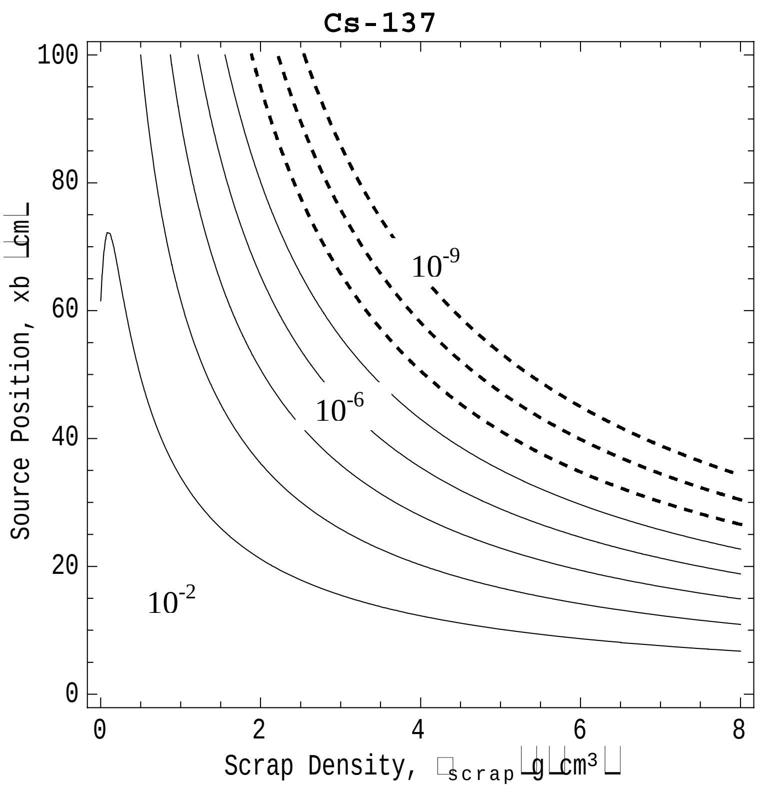

Figure 4- Comparison between the natural radiation level and the expected exposure rate at the portal for many different positions of a 1 mCi Cs-137 source and as a function of the scrap density (isolines in R/h)

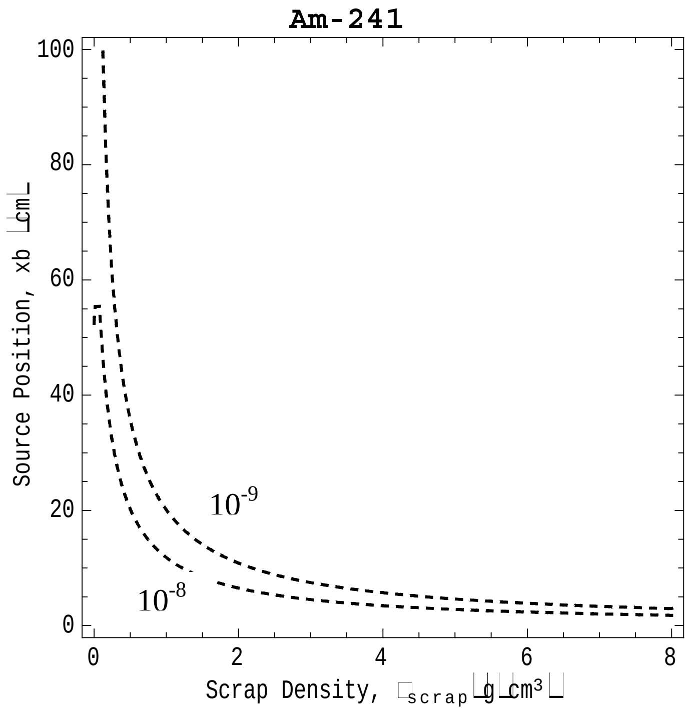

Figure 5- ***Comparison between the natural radiation level and the expected exposure rate at the portal for many different positions of a 1 mCi of Am-241 source and as a function of the scrap density (isolines in R/h).***

CONCLUSIONS

It can be seen from the results that if the radioactive source is shielded (say 1 cm lead) and the truck is very heavy (high density) it would be very difficult to detect a radioactive source even in the case of a cobalt source.

In order to increase the chance of detection of radioactive orphans sources in the portals it is strongly recommended that the weight of the scrap in the truck be so that the average density of the load be reduced to a maximum of 2 g/cm^3.

It should be pointed out that the calculations presented on this article considered only small activities spent sources (1 mCi for Co and Cs) and 5 mCi in the case of Americium, a typical activity of a lightning rod. If the activity of the sources increases the probability of detection linearly increases since the dose rates linear increases.

The Economic and Social Council also recommend in document ECE/TRANS/AC.10/2006/ that at a mean indication of 0.2 μSv/h, an alarm should be triggered when the dose rate is increased by 0.1 μSv/h for a period of 1 second.

The probability of detecting this alarm condition should be 99.9%, i.e. no more than 10 failures in 10 000 exposures. This requirement should be fulfilled in a continuous radiation field, with the incident gamma radiation ranging from 60 keV to 1.33 MeV (tested with 241Am, 137Cs and 60Co).

Related to the search region it also says that the volume in which efficiency of detection is maintained will vary according to the instrument. The following is a description of the geometrical region in which the performance characteristics for the given alarm levels should be applicable.

- Truck monitor (two pillars):

(i) Vertical: 0.7 to 4 m;
(ii) Horizontal, parallel to the direction of movement: up to 3 m (6 m between the two
pillars);
(iii) Speed up to 8 km/h.

And that false alarm rate during operation should be less than 1 per day for background dose rates of up to 0.2 μSv/h. If a high occupancy rate of say, 10 000 occupancies per day were expected, this would mean ensuring not more than 1 false alarm in 10 000, for which the recommended testing requirement is not more than 4 false alarms in 40 000 occupancies.