Calibration verification by Monte-Carlo simulations of a total gamma counting tunnel for clearance purposes

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1. Introduction

Very low level radioactive materials aimed to be recycled, reused or disposed of can be released by JRC Ispra from regulatory control under the condition that the radionuclide concentrations content are below the specific clearance levels provided by the Italian Nuclear Safety Authority. JRC bought a commercial measuring system, the **Total Gamma Measurement Chain** (TGMC), to verify such condition on a group of containers statistically representative of the homogeneous group to be released and defined by a nuclide vector W.

2. TGMC system layout

- eight plastic scintillators with photomultiplier disposed to form a tunnel
- every scintillator shielded by lead plates
- each container through three measurement steps
- activity A_W average of A^d_W for d detectors.

- Calibration through standard calibration container (roughly homogeneous distribution):
    - density varying the number of steel plates
    - activity by ^{60}Co planar source and other mono-energetic point sources

3. Measurement method

A^d_W, determined by the d detector of the TGMC, are expressed by:

$$A^d_W = \left(\dot{R}^d_\Delta + z^d_{sta}\right)\frac{f^d_T}{r_W}$$

$\dot{R}^d_\Delta$ d detector net response

$\frac{f^d_T}{r_W}$ global transfer function for nuclide vector W

f^d_T and r_W are correction factors function of standard container geometry and material density:

$$f^d_T = \frac{1}{T_{1.17}\beta_{Co60,1.17} + T_{1.33}\beta_{Co60,1.33}}$$ for eleven densities;

$$r_W = \sum_w w_w r_w = \sum_w \sum_i \eta(E_i)\beta_{w,i}$$ only for 0.5 g/cm³ and 2.1 g/cm³.

It is defined:

$$\eta(E_i) = \frac{T(E_i)}{T_{1.17}\beta_{Co60,1.17} + T_{1.33}\beta_{Co60,1.33}}$$

and it is determined through interpolation of η_i values determined for k mono-energetic sources by:

$$\eta_i \beta_{i,k,mon} = \frac{\dot{R}_{k,mon} A_{Co60}}{\dot{R}_{Co60} A_{k,mon}}$$

where activities are known and detector responses measured.

f^d_T and r_W are factors obtained by mass attenuation coefficient of iron and apply to all types of material.

z^d_{sta} increases the activity value to have a true value with 95% probability.

4. In-homogeneity issue, safety factor

There is no safety factor for intrinsic non homogeneity of standard calibration container and measured ones.

We want to asses **the deviation introduced by the in-homogeneity, assumed as typical,** of the standard calibration container and extend it to all the measurements performed by the use of a safety factor .

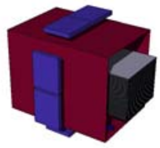
5. TGMC measurement method verification by Monte Carlo

Monte Carlo model simulates TGMC in two different configurations:

- actual standard calibration container
- ideal homogeneous calibration container

Model of the system

Structure of the model



Detail of the model

Determination of the energy threshold in the model

The energy threshold renders minimum the difference between the detector response experimentally determined and the one determined by the simulation:

Detector	1	2	3	4	5	6	7	8
E_s [keV]	318	302	330	272	290	250	252	194

Validation of the model

A comparison between a Monte Carlo simulation and an actual measurement on a homogeneous matrix and source of ^{40}K validated the model used:

Measurement	z[cps]	Δ[%]
TGMC	2372,455	/
Monte Carlo Model	2659,771	**+12,11**

Use of the model for the verification of the global transfer function

The average deviation of the correction factors f_T for the heterogeneous calibration standard container and the homogeneous ideal container is :

Density 0.5 g/cm³			Density 2.1 g/cm³		
$f_{T-Heterogeneous}$	$f_{T-Homogeneous}$	Δ[%]	$f_{T-Heterogeneous}$	$f_{T-Homogeneous}$	Δ[%]
155,0467925	135,1199731	+14,75	459,7014325	334,1076519	+37,21

The deviation curve at different energies is:

$$\Delta(E) = \frac{\eta_{inhomogeneous} - \eta_{homogeneus}}{\eta_{homogeneous}}$$

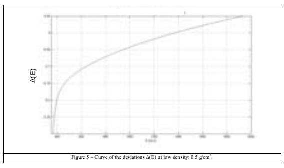


Figure 5 – Curve of the deviations Δ(E) at low density: 0.5 g/cm³.

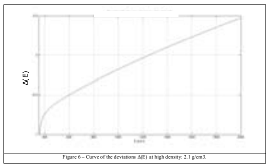


Figure 6 – Curve of the deviations Δ(E) at high density: 2.1 g/cm3.

Configuration	Density 0.5 g/cm³		Density 2.1 g/cm³	
	662 keV	1836 keV	662 keV	1836 keV
Deviation [%]	-9,56	+4,18	-4,46	+37,35

The deviation of the overall transfer function from its true value is:

Configuration	Density 0.5 g/cm³		Density 2.1 g/cm³	
	662 keV	1836 keV	662 keV	1836 keV
Deviation [%]	+11,20	-2,75	+8,50	-34,93

and the calibration performed by the calibration standard container is overestimating the fully homogeneous one only at low energies.

6. Conclusions

The activity measured by TGMC may underestimate the actual activity. Therefore, a **safety factor f_{mon} equal to 1.25** has been introduced in the system algorithm. This value has been determined by linear interpolation for the maximum density permitted in containers (about 1.6 g/cm³) at the energy of 1836 keV .

$$A^d_W = \left(\dot{R}^d_\Delta + z^d_{sta}\right)\frac{f^d_T \cdot f_{mon}}{r_W}$$

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