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SENSITIVITY EVALUATION OF WELL-TYPE IONIZATION CHAMBER: A TOOL TO MANAGE SPENT RADIOACTIVE SEALED SOURCES

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ABSTRACT

Spent radioactive sealed sources (SRSS), after used in medicine, industry and research, are sent as radioactive waste to one of the National Nuclear Energy Commission (CNEN) Institutes. Radioactive Waste Management Laboratory (RWML) of the Nuclear and Energy Research Institute – IPEN-CNEN/SP, among its functions, is responsible for receiving, treating and storing radioactive wastes generated in all research centers of the IPEN-CNEN/SP, as well as from other Brazilians institutions. The process of treatment adopted for SRSS is the withdraw the source from its original shield and transfer it to a standard shield. An important step of this process is the characterization of the radioactive source. Generally, dose calibrators, commonly used in nuclear medicine services (NMS), are used to carry out this task. Considering that the radionuclides and the geometries of the sources to be characterized are different from those used in NMS, it is necessary to evaluate the sensitivity of this equipment for these kinds of SRSS activity measurements. This study was developed using commercial standards sources and sources with known activities under responsibility of the RWML, amongst those, ^{241}Am and ^{147}Pm sources were studied. The results indicate that the sensitivity of the chamber follows typical standard of punctual sources geometry. However, for other sources there are differences due to the effect of the source geometry. In such a way what one can find is the regions of higher sensitivity for those kinds of sources, with acceptable error and confidence level for this end.

1. INTRODUCTION

Activities involving the use of radioactive material generate in some stage of the process radioactive wastes which can be classified by diverse criteria. In Brazil the National Nuclear Energy Commission (CNEN) defines radioactive wastes as being “any material that contains radionuclides at concentrations levels greater than the exemption limits, established by the “CNEN - NE - 6.02 Licenciamento de Instalações Radiativas” [1] and for which no use is foreseen”.

Radioactive Wastes are frequently classified in: “low level”, “intermediate level” and “high level”. Although the values that involve these classifications are distinct in some countries, they follow the same concepts, that is: low level does not require shield for handling and transport; intermediate level requires shield for handling and transport and they are not heat generators; high level requires shield and cooling because they generate heat.

In Brazil this classification is based on the physical form, activity concentration and on the type of radionuclides present and it is described in regulatory document “CNEN - NE - 6.05 Gerência de Rejeitos Radioativos em Instalações Radiativas” [2].

SRSS generated by the medicine, industry and research activities, are sent to the institutes of CNEN for treatment and storage. Although the SRSS represent a small fraction of the radioactive wastes volume received by the Radioactive Waste Management Laboratory - RWML, they contribute with around 90% of the total radioactive activity.

Nuclear and Energy Research Institute, IPEN - CNEN/SP is the main reception center of these wastes in Brazil, receives, on average, 300 sources per year with activities between GBq and TBq. Table 1 presents the characteristics of the received sources and their main applications.

An important step in the management of the SRSS is the characterization. The goal of this step is the verification of the data supplied by the generators, as well as the identification and quantification of the activity of the radionuclides, mainly in the case of orphan sources.

The equipment to be used to carry out the SRSS characterization is a dose monitor commonly used in nuclear medicine services (NMS), which commonly is calibrated by the manufacturer using standard solutions of the radionuclides used in NMS, even though the competent authority establishes [3] that only the use of accurate tests with reference sources of ^{57}Co, ^{133}Ba or ^{137}Cs must be valid, and should not be done with radionuclide sources used in the NMS.

Therefore, it is possible that significant errors may occur in the measurements of SRSS activity using the dose calibrator under their operational conditions. To avoid those errors and considering that the SRSS under IPEN's responsibility have various geometries the first task was the evaluation of the sensitivity of the equipment used for their identification, which is presented in this paper.

Table 1: Characteristics of the used sources in diverse applications [4].

APPLIANCE	SOURCE	ACTIVITY
	RESEARCH AND DEVELOPMENT	
Calibration	^{60}Co, ^{90}Sr, ^{137}Cs, ^{241}Am	< 0.1 GBq
Irradiator	^{60}Co	1 – 1,000 TBq
	MEDICINE	
Teletherapy	^{60}Co	50 – 500 TBq
Brachitherapy	^{226}Ra	100 – 500 GBq
	INDUSTRY	
Industrial Radiology	^{192}Ir	0.1 – 5 TBq
	^{60}Co	0.1 – 1 TBq
Gauge Level	^{137}Cs	0.1 – 20 GBq
	^{60}Co	0.1 – 10 GBq
Sterilization and Food Preservation	^{60}Co	0.1 – 400 TBq
Well Logging	^{241}Am-Be	1 – 500 GBq
	^{137}Cs	1 –100 GBq

2. MATERIALS AND METHODS

A dose calibrator was used, similar to the ones utilized in the NMS, however with a bigger radionuclides library and the possibility of increase it. The used equipment is a CRC 15-BT model with ionization chamber well-type, manufactured by Capintec, which is the manufacturer of about 60% of the dose calibrator in use at São Paulo city [5, 6].

A set of standard sources establish on CNEN - NN - 3.05 [3], were used in the tests demanded for the national regulatory agency, being made in accordance with the quality control of the NMS; including test of linearity, reproducibility, etc. The local conditions satisfied all manufacturer recommendations.

A Lucite™ (PMMA) made support was used for sources positioning, in such a way that it guaranteed that the axis of the support was parallel to the axis of symmetry of the well of the ionization chamber, having still a millimeter scale in its depth and another one on the chamber top, allowing to know the exact position of the sources in the chamber. In this manner, it was possible to map each 10 X 10 mm of the interior of chamber, in both the radial and axial directions, taking into account some radionuclides of interest of RWML and with reliable level adjusted for this end (95%) [7, 8, 9].

Measurements of sources other than the ones recommended by the regulatory document and the cited above were made, enabling the evaluation of the chamber sensibility for the SRSS measurements and estimate the activity of ones found in RWML inventory source models.

The same tests had been executed for gamma emitting sources, for instance: ^{241}Am (γ_1 = 26.3 keV and γ_2 = 59.5 keV), ^{147}Pm (γ_1 = 121.2 keV and γ_2 = 197.3 keV), ^{192}Ir (γ_1 = 316.5 keV and γ_2 = 468.1 keV) and ^{60}Co (γ_1 = 1173 keV and γ_2 = 1332 keV) [10].

In some cases the SRSS cannot be considered punctiform, but they possess similar dimensions to that ones in the ionizing chamber. For these cases the interest is not by the positioning of the source, but the region where the standard deviation is lower (this fact can determine the dimensional limits for the measurements of the sources).

An ^{192}Ir disk-shaped source was used, and it was considered punctiform for its dimensions (Φ = 2.7 mm and thickness = 0.15 mm), on a X-54 source stand.

Three additional sources had been used. They were not considered punctiform in accordance with their dimensions as follows:

- ^{147}Pm - (L x W x H) = (62 x 13.5 x 10) mm,
- ^{241}Am - (Φ x L) = (3.0 x 32) mm,
- ^{60}Co - (Φ x L) = (20 x 50) mm, containing two small anisotropic sources in the edges.

During the data acquisition, the sensitivity evaluation was made under an helical ascendant geometry, to prevent significant variation in measurement in relation to a possible rotation of the chamber through its vertical axis.

It was made the evaluation of the position variation related to the central axis of the chamber for the ^{192}Ir source changing the source symmetry axis, parallel or perpendicular to the chamber axis, as illustrated in Fig. 1 below.

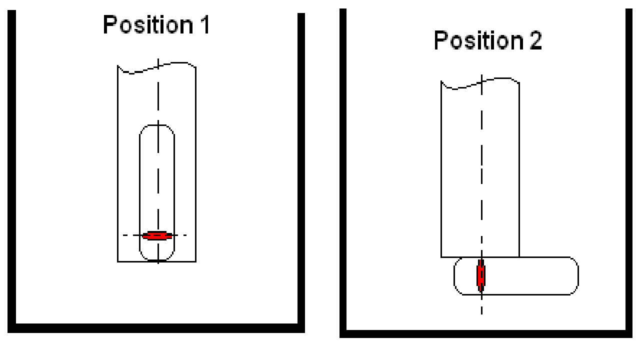

Figure 1: Source positioning (^{192}Ir) in relation to the axis of symmetry of the chamber.

3. RESULTS

In the sensitivity assessment, we can notice this ionization chamber behavior tends towards the typical behavior for punctiform sources, as observed in the "Good Practice Guide 93" [11], by the "National Physical Laboratory" (NPL), presented in Figure 2. Figure 3 represents the distribution obtained [12] in the chamber, associated to the dose calibrator CRC 15 – BT.

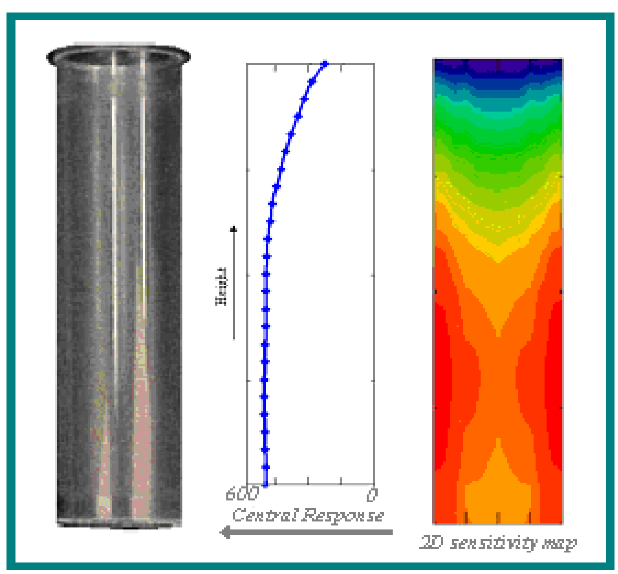

Figure 2: Spatial sensitivity of a typical ionization chamber [11].

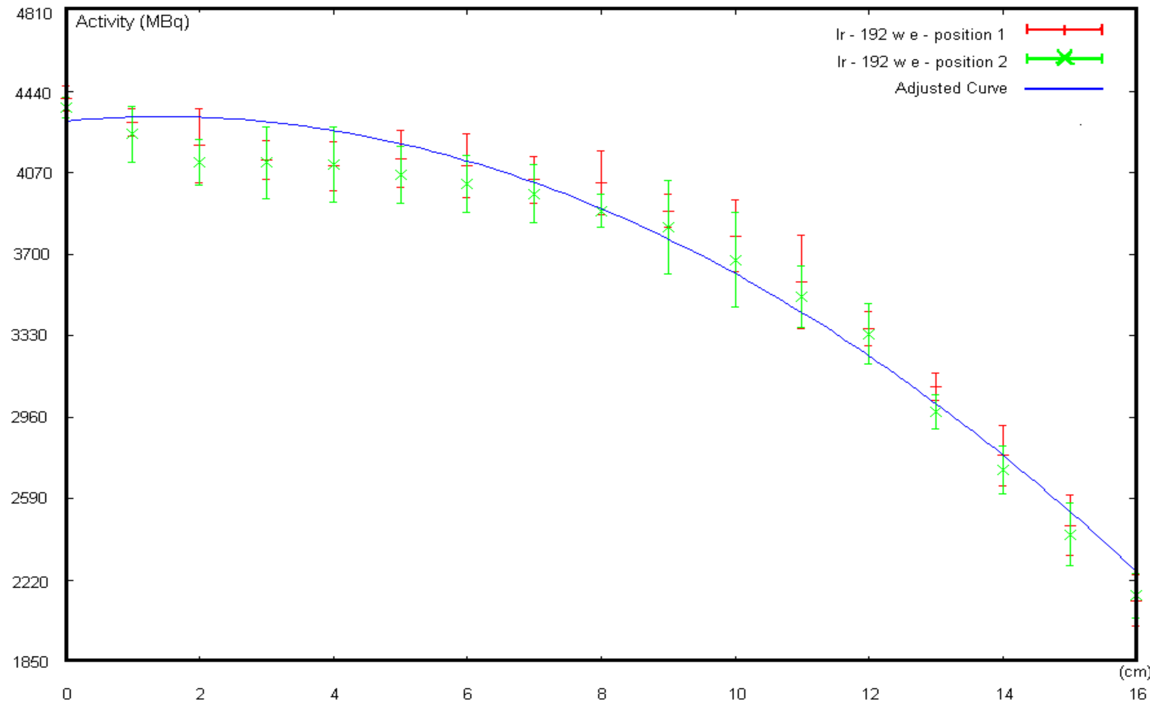

Figure 2: Obtained curve for the ionizing chamber associated with dose calibrator CRC 15-BT.

The regions of higher sensitivity of the well for the radionuclides ^{241}Am, ^{60}Co, ^{147}Pm and ^{192}Ir are presented in Fig. 4, 5, 6 and 7, respectively [13].

A region of interest to SRSS activity evaluation was selected from those results. It was chosen the 90 mm height from the chamber base, because it is the maximum source length observed in the RWML inventory that contains adequate activity to the equipment used in this study (maximum 444 GBq or 12 Ci). Besides, it is the region where we got the lower percentual error with the confidence level considered.

The evaluation of the ionization chamber sensitivity in the helical direction of the well, as it was verified during the experimental procedure, does not present significant variation, being possible to assume that the transversal section of the chamber is homogeneous in any reference.

It was made 10 measurements for each 100 mm^2 of the chamber section for the both cases where the source can be considered punctiform and for the other one. The results are presented in Table 2. For the purpose of higher statistical accuracy, all correction factors of radionuclides have been determined five times.

Table 2: Activity measurements in several positions and their respective standard deviations, for sources of ^{241}Am, ^{60}Co, ^{147}Pm and ^{192}Ir; with 95% confidence level.

Height (mm)	^{241}Am Mean (MBq)	Standard Deviation (MBq)	^{60}Co Mean (MBq)	Standard Deviation (MBq)	^{147}Pm Mean (MBq)	Standard Deviation (MBq)	^{192}Ir Mean (MBq)	Standard Deviation (MBq)
0	251	10.6	585	64	1513	151	4407	58
10	256	10.5	587	78	1591	156	4299	64
20	254	9.8	581	77	1386	123	4193	169
30	256	12.5	571	49	1421	304	4124	89
40	253	10.3	592	61	1184	79	4099	110
50	253	10.6	569	40	1332	151	4132	129
60	254	10,5	565	103	1288	240	4100	143
70	257	10.7	598	100	1240	289	4036	108
80	250	10.5	575	55	1220	217	4023	145
90	245	10.8	555	97	1034	135	3896	75
100	227	13.8	515	81	953	121	3780	162
110	209	11.1	501	70	923	101	3575	210
120	185	13.3	492	41	859	192	3365	76
130	155	12.4	451	100	755	180	3098	61
140	124	13.4	436	104	703	342	2787	138
150	94	13.1	407	74	640	88	2469	138
160	67	12.4	373	75	612	48	2126	113

Despite slight variations, which can be derived from the effect of geometry, energy and activity, the results with respect to accuracy satisfy the 20% limit specified by the manufacturer's manual [14].

Even though the response curves of the system presented coefficients of determination, R^2 - the square of the Pearson correlation coefficient, is above 90%, which is below the threshold of tolerance suggested by the TEC DOC 1151 [15] to the NMS, but it is acceptable to the characterization of SSRS. Then the determination of the response curves of the system allows to know the better region of the ionization chamber's response.

It is possible to observe in Tab. 2 that the maximum deviation obtained in the interest region is 5%, so the source is not punctiform (^{241}Am). To ^{60}Co, the maximum deviation obtained in the interest region is of 19% characteristic of an anisotropic and heterogeneous source. The maximum deviation obtained in the interest region of 21% can be observed in ^{147}Pm (betagamma emitting), source has dimensions next to the ones of the chamber. To punctiform radioactive sources it is possible to observe that the maximum deviation obtained in the interest region is of 4% (^{192}Ir).

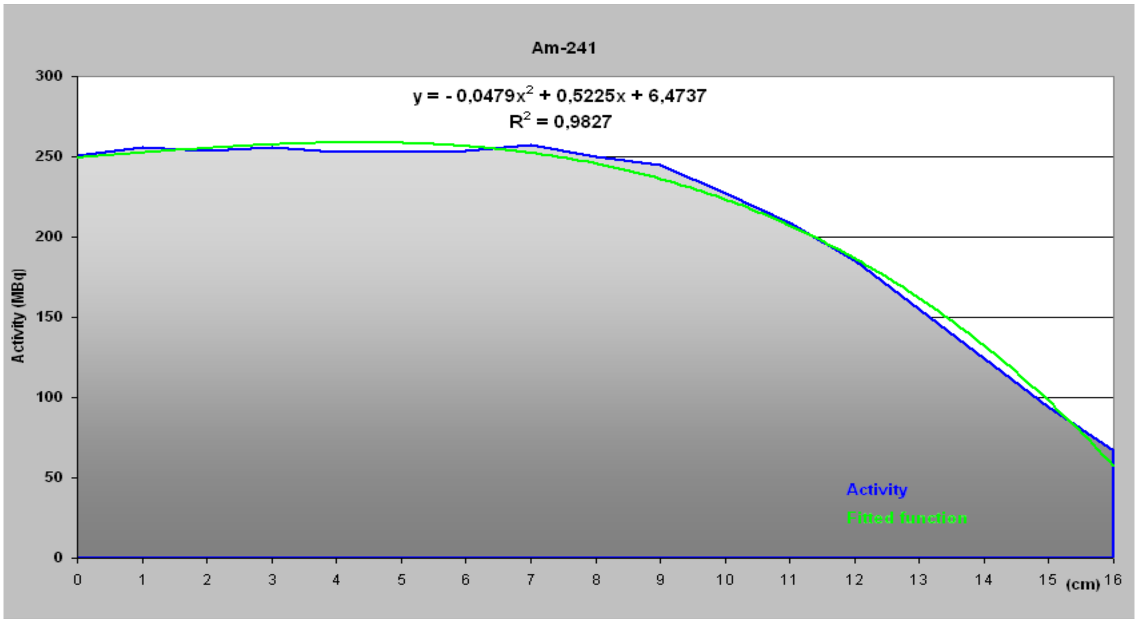

Figure 4: Representative curve of the sensitivity of the chamber for ^{241}Am and its function of adjust.

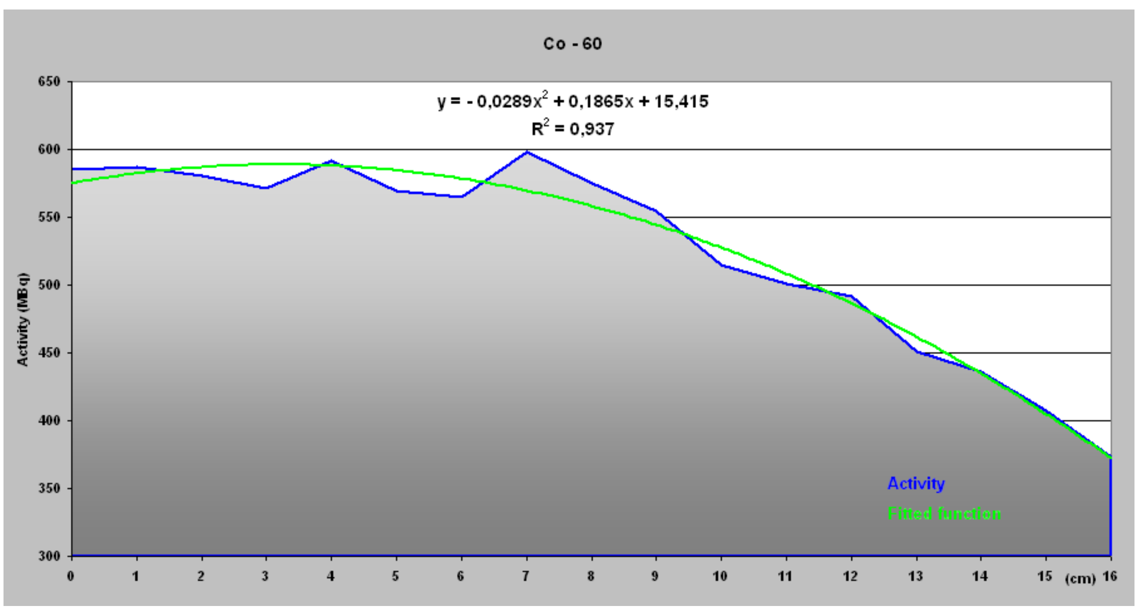

Figure 5: Representative curve of the sensitivity of the chamber for ^{60}Co and its adjusted function.

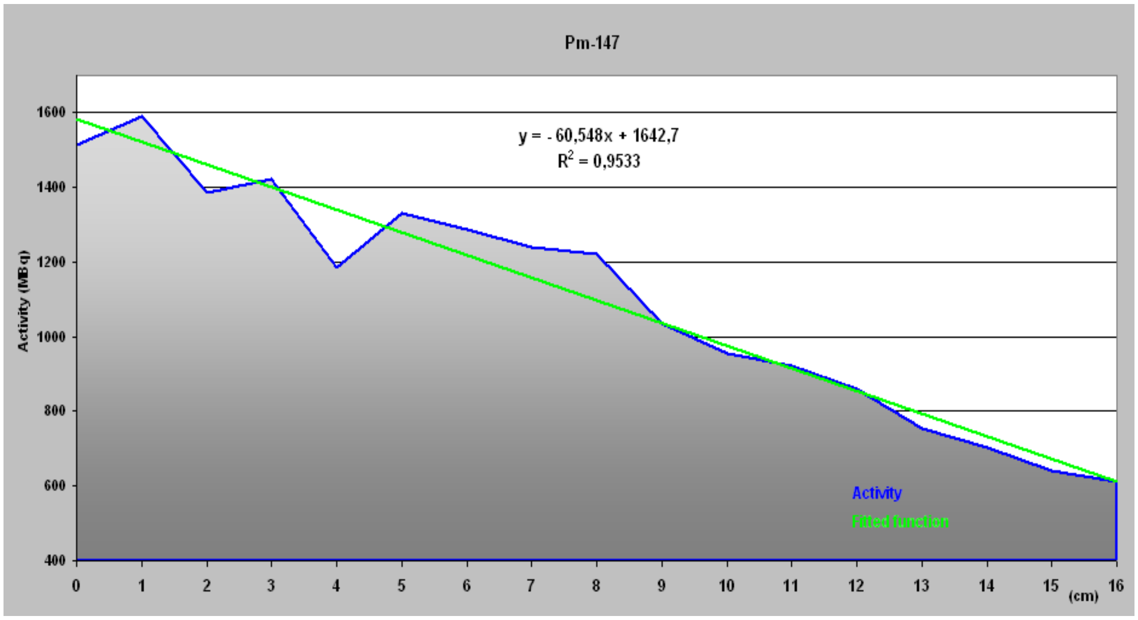

Figure 6: Representative curve of the sensitivity of the chamber for ^{147}Pm and its adjusted function.

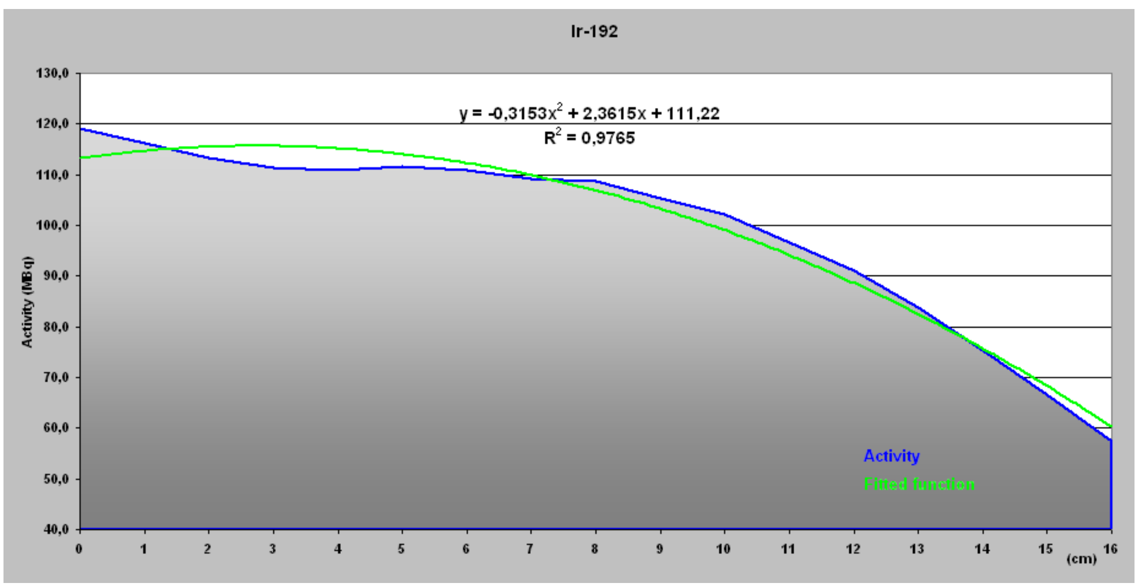

Figure 7: Representative curve of the sensitivity of the chamber for ^{192}Ir and its adjusted function.

Although the results obtained in tests recommended by CNEN [3] are within the limits indicated, the tolerance of 20% on the accuracy seems to be high when related to NMS measurements. To SRSS characterization these values are considered acceptable.

3. CONCLUSIONS

This work contributes for the characterization of orphan sources. Results showed that fixing the geometry of measurements of SRSS can be useful to characterize and quantify its activities, supplying conditions and values with confidence levels adequate to the final inventory of the SRSS that will be destined to the repository thus guiding policies that are necessary to its implementation and construction.

For SRSS that can be considered punctiform could be indicated a position considered excellent for the activity evaluation, obtaining the lower error in the activity measured and as consequence a more trustworthy value for the inventory of sources that will be destined to the national repository.

The axis of symmetry of the well is what it presents the lesser error and for this reason must be adopted, not only in the NMS, but also in the protocols of identification of the SRSS.

The SRSS that have bigger dimensions, present higher errors, however for the purpose to estimate the activities of the sources that will be disposed off, it is important to evaluate the region where this error will be minimized.

In the case of NMS, although the dose calibrators calibration is not demanded by CNEN [3], it could be carried out using the same radionuclides used for medical sources activities measurements purposes and it must be executed by staff and calibration laboratories that has the certification to perform this service.

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