Implementation of an Intercomparison Exercise according to ISO/IEC 28218 in the Internal Dosimetry Services of Spanish Nuclear Power Plants

J. F. Navarro [1], B. Pérez [1], M. A. López [1], T. Navarro [1], I. Amor [2], M. L. Tormo [2], I. Sierra [1], C. Hernández [1]

[1] Internal Dosimetry Service - Radiation Dosimetry Unit - CIEMAT, Avda.Complutense 40, E-28040 Madrid, Spain.

[1]Consejo de Seguridad Nuclear, C/ Justo Dorado, 11, E-28040 Madrid, Spain.

E-mail: jf.navarro@ciemat.es

Abstract. The surveillance of workers occupationally exposed to internal contamination in Spanish nuclear power plants (NPP) has to be licensed and authorised by the National Regulatory Authority which establishes all the controls and technical requirements to be accomplished by internal dosimetry services. To fulfil this purpose, the Spanish Nuclear Safety Council (CSN) and the Whole Body Counting laboratory (WBC) of Internal Dosimetry Service of CIEMAT (centre of reference in Spain for internal dosimetry matters) have organised an intercomparison exercise for the in vivo measurements of gamma-emitting radionuclides in total body and radioiodine in thyroid. The objective of this exercise is to check the quality of the measurements realized in the whole body counters of the participating services in order to ensure the proper monitoring of workers in routine or emergency scenarios. To achieve this goal, the design of the intercomparison exercise is the main tool to check and validate the calibration methodology of the detection systems, measurements procedures and the gamma spectrometry software of the participants. This paper describes the methodology followed for implementing this exercise and the subsequent analysis of the results according to “Relative Bias” and “Repeatability” parameters performance criteria defined in ISO/IEC 28218. Technical recommendations and conclusions related to the intercomparison exercise were proposed by both WBC (IDS-CIEMAT) and CSN based on final results in order to promote improvements to ensure the quality of the measurements in the internal dosimetry services.

Key words: Intercomparison exercise, internal dosimetry, in vivo monitoring.

1. Introduction.

Since 1999, the Whole Body Counting of Internal Dosimetry Service (CIEMAT) and Nuclear Safety Council (CSN) are involved on organizing intercomparison exercises aimed to internal dosimetry services of Spanish nuclear power plants and nuclear emergency mobile units (TECNATOM) for the in vivo measurements of gamma-emmitting radionuclides in total body or radioiodine in thyroid. Main objective of this kind of exercises is to verify and validate the quality of the capabilities (measurement procedures, calibration methodology, gamma spectrometry tools, etc.) of the participating internal dosimetry services (IDS) according to international standards. ISO/IEC 28218 “Performance Criteria for Radiobioassay”[1], approved in 2010, established technical requirements and recommendations in this matter. Last intercomparison exercise was realized in 2009-2010 participating eight IDS belonging to NPP and TECNATOM. WBC laboratory of IDS (CIEMAT) was in charge of elaborating the measurements protocol sent to participants, manufacturing active phantoms and analyzing the results in order to propose actions to improve the capabilities of the services [2].

2. Methodology.

Intercomparison exercise considered two counting geometries to be analyzed in the detection systems of participants (QUICKY WBC Helgesson SS and DIYS WBC Helgesson SS): In vivo measurement of gamma-emitting radionuclides in total body and radioiodine in thyroid according to a measurement protocol sent to participants [3]. An anonymous code was assigned to each detection system. At least one technician of WBC-IDS (CIEMAT) and an inspector of Nuclear Safety Council were present in each exercise to ensure compliance with the protocol. Participants were requested to provide a description of their calibration and routine measurement procedures, technical specifications of detection systems, staff and responsibilities, etc.

Figure 1(a). Model Quicky WBC Helgesson SS

Figure 1(b). Model DIYS WBC Helgesson SS.

Figure 1(c). IDS of Spanish NPP(*)

Figure 1(d). Mobil unit TECNATOM.

(*) José Cabrera NPP is in decommissioning phase.

The measurement protocol also included the following issues to be checked:

(1) Daily quality control of the instrumentation prior to measurements.

(2) Environmental background check.

(3) Qualitative analysis of radionuclides in active phantoms: total body and thyroid neck phantom both simulating counting geometries.

(4) Determination of accuracy (Relative bias and repeatability) of the measurements according to ISO/IEC 28218.

(5) Blank person measurement: Estimation of ^{40}K in human body. Testing measurement procedures in case of non-contaminated individuals.

(6) Sensitivity of detection systems: Calculation of detection limits. Harmonization.

Moreover, criteria of acceptance of parameters were defined according to ISO/IEC 28218 being adapted to the specific situation of this exercise.


INTERNATIONAL STANDARD

ISO 28218

Radiation protection — Performance criteria for radiobioassay

Relative Bias (Br).

$$B_{ri} = \frac{A_i - A_{ai}}{A_{ai}}$$

$$B_r = \sum_{i=1}^{n} \frac{B_{ri}}{n}$$

Ai .- Activity value provide by IDS participant in intercomparison
Aai.- Official activity value provide by WBC laboratory (IDS-CIEMAT)
n = number of measurements (al least five).

Repeatability (SBr).

$$s_{Br} = \sqrt{\frac{\sum_{i=1}^{n} (B_{ri} - B_r)^2}{(n-1)}}$$

Criteria of acceptance.

Relative Bias…………… [-0.25, + 0.50](a).
Repeatability…………… ≤ 0.4
(a) If Aai > MTL (Minimun Testing Level) according to Table 1. ISO/IEC 28218.

Figure 2. Criteria of acceptance according to ISO/IEC 28218 for evaluating results

Once each participant performed the intercomparison measurements, they were required to send results before a deadline established by WBC laboratory.

3. Materials.

To test proficiency of participants in direct measurements of internal contamination, WBC laboratory staff was in charge of preparing active phantoms simulating internal contamination of organs or total body (BOMAB and thyroid neck phantom).Validation of the process was required by National Safety Council (CSN) to ensure the proper preparation of the material. Therefore, prior to the beginning of intercomparison exercise, in vivo measurements of the phantoms were realized in the detection systems of WBC laboratory according to ISO/IEC 28218 in order to achieve this goal [4]. Laboratories of Internal Dosimetry Service of CIEMAT have implemented this standard in all calibration and measurement procedures [5] and are involved in an accreditation process in order to fulfill compliance with the requirements of ISO/IEC 17025 for testing and calibration purposes [6].

3.1 Description of BOMAB Phantom simulating internal contamination in total body.

A BOMAB (**BO**ttle **M**anikin **AB**sorption Phantom) was fabricated in the laboratories of the Internal Dosimetry Service of CIEMAT. This phantom simulates the ICRP 89 reference man [7]. It consists of ten tissue-equivalent plastic pieces filled with a radiactive material in an acidified distilled water solution. A mixed radionuclide gamma-emitting reference standard, consisting of an acid solution of radionuclides provided in five different certified ampoules, was distributed among the 10 phantom pieces proportionally to their inner volume to ensure a homogeneous distribution of the activity. The filling solution was acidified in order to avoid precipitation and/or absorption of the radionuclides in phantom walls. The In Vitro Bioassay Laboratory of IDS (CIEMAT) has developed a procedure for filling BOMAB Phantom according to ANSI/HPS N13.35 [8].

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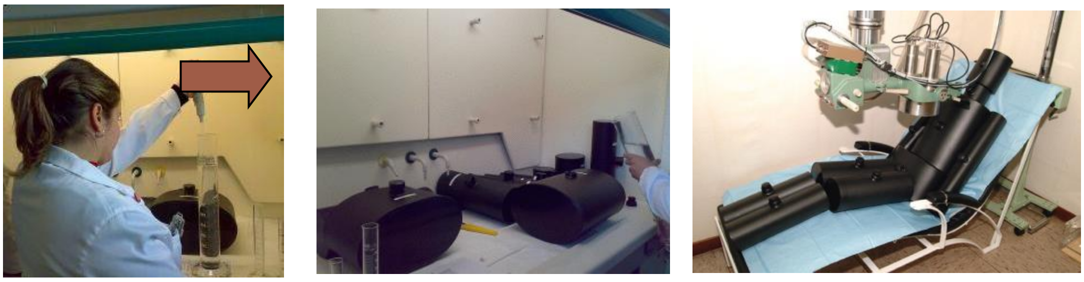

Figure 3. Filling and validation of BOMAB Phantom in IDS-CIEMAT laboratories

One of the main objectives of this exercise was to test gamma spectrometry software of IDS participants (complex spectra, multiplets, low and high levels of activity, etc.). To fulfil this goal, organizers proposed the cocktail of radionuclides described in table below with varied values of activity and complex energy spectrum in order to check the reliability of the calibration methodology and the capability of the spectrometry software to resolve energy lines very close. (^{54}Mn and ^{88}Y radionuclides have energy lines very close one to each other (835 KeV and 898 KeV respectively) creating a complex multiplet in the spectrum.

Table 1. BOMAB Radionuclides: In vivo measurements in total body

Radionuclide	$T_{1/2}$	Energy (keV)	I_e (%)	A_{ai} (kBq)
^{57}Co	271.40 d	122.06	85.60	20
^{137}Cs	30.13 y	661.65	85.00	20
^{54}Mn	312.16 y	834.85	99.98	20
^{88}Y	106.63 d	898.04	94.00	15
^{60}Co	5.27 y	1173.24	99.90	20
^{60}Co	5.27 y	1332.50	99.98	20
^{88}Y	106.63 d	1836.06	99.33	15

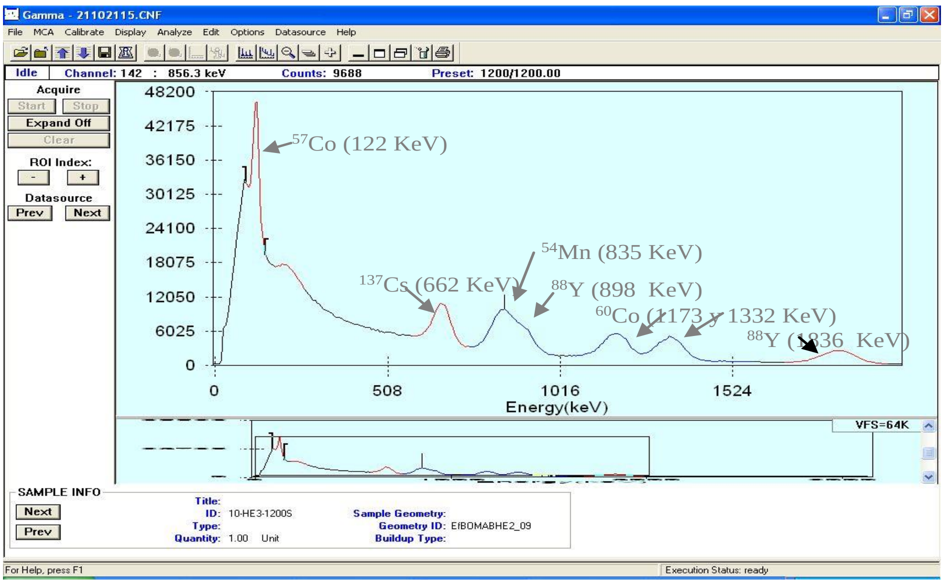

Figure 4. BOMAB radionuclides spectrum collected at WBC laboratory IDS (CIEMAT)

3.2 Description of Thyroid Neck Phantom simulating internal contamination in thyroid gland.

^{131}I is an important radionuclide in terms of occupational exposure in the nuclear field. In vivo measurement in thyroid is the best procedure to estimate internal contamination of this radionuclide. Due to the short half live of ^{131}I (8 days), ^{133}Ba is usually used for simulating ^{131}I in intercomparison exercises because of its long half live ($T_{1/2}$=10 years) and very close gamma emissions.

Table 2. ^{131}I and ^{133}Ba radionuclides data

Radionuclide	$T_{1/2}$	E (keV)	I_e (%)	Radionuclide	$T_{1/2}$	E (keV)	I_e (%)
^{131}I	**8 d**	**80.2**	**2.60**	**^{133}Ba**	**10.5 y**	**81.0**	**36.00**
		284.3	**6.10**			**276.0**	**7.00**
		364.5	**81.20**			**356.0**	**62.00**

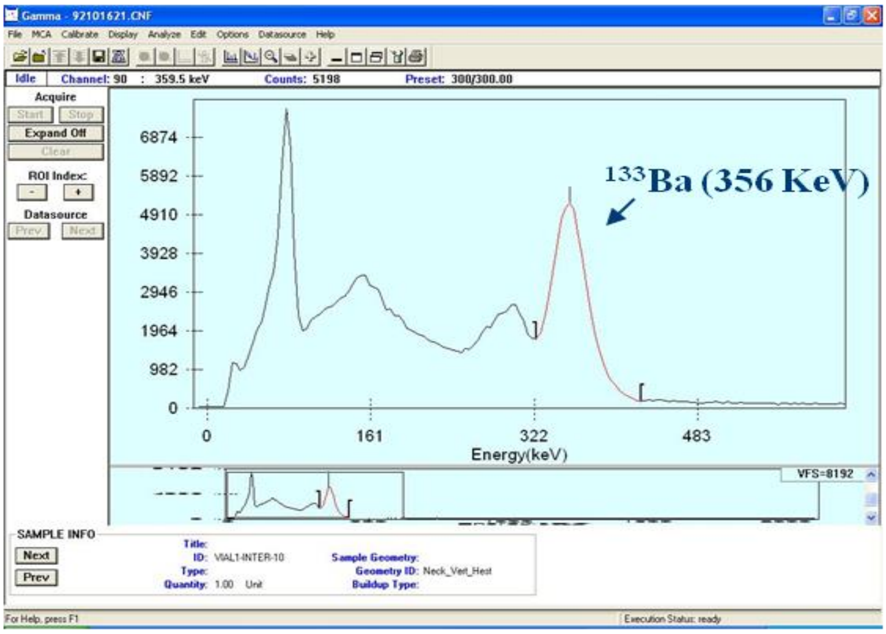

Figure 5. ^{133}Ba spectrum collected at WBC laboratory IDS – Ciemat

To test proficiency of thyroid measurements, the CIEMAT-ANSI standard thyroid uptake neck phantom with 20 ml vial simulating thyroid gland was used. Both 20 ml vials of standard liquid source of ^{133}Ba with unknown activity were prepared at IDS (CIEMAT) laboratories in order to ensure the technical capabilities of participants in different scenarios of measurement (low and high values of internal contamination).

4. Register and Results.

4.1. Register.

Following the intercomparison protocol, each participant received phantoms to be measured according to the period assigned taking into account their availability. WBC laboratory of IDS CIEMAT was in charge of organizing radioactive material transport throughout the facilities. To ensure compliance of protocol, intercomparison exercises were carried out in presence of both CIEMAT technicians and CSN inspectors. Once finished the exercise, participants delivered all reports associated with the measurements (daily quality control of instrumentation and environmental background, measurements of accuracy, blank measurements, etc.). Measurements were realized in routine conditions following official procedures of services. Each participant had two months after finishing the measurements to send the filled protocols with their results. In the table below detection systems of IDS and dates of intercomparison are described. It is noteworthy that all the exercises were carried out in only three months.

Table 3. Internal Dosimetry Services of NPP and TECNATOM mobile units

Facility	QUICKY WBC HSS	DIYS WBC HSS	Dates
NPP Almaraz	NaI (HSS)102 x 102 x 76	NaI (HSS)205 x 100	16-17/03/2010
NPP Garoña	NaI (HSS)102 x 102 x 76	NaI Canberra 5x5 NaI Canberra 5x5	23-25/04/2010
NPP Ascó	NaI (HSS)102 x 102 x 76	NaI (HSS)205 x 100	13-14/04/2010
NPP Vandellós II	NaI (HSS)102 x 102 x 76	NaI (HSS)205 x 100	15/04/2010
NPP Zorita	-	NaI (HSS)205 x 100	28/04/2010
NPP Cofrentes	NaI (HSS)102 x 102 x 76	NaI (HSS)205 x 100	4-5/05/2010
Mobil units Tecnatom	NaI (HSS)102 x 102 x 76	10 x 10 x 7.5 (4 detector)	27/04/2010 02/06/2010
NPP Trillo	NaI(HSS) 102 x 102 x 76		14/067/2010

4.2. Accuracy analysis according to ISO/IEC 28218.

Following the protocol, five measurements of BOMAB phantom were realized in routine conditions according to IDS's procedures (QUICKY WBC in stand up geometry and DIYS WBC in stretched geometry). Accuracy analyses of results sent by participants were carried out by WBC laboratory. Results were in compliance with acceptance criteria of ISO 28218 parameters used (Bias relative and Repeatability) for all radionuclides. Of special interest was the way of resolving complex multiplet between ^{54}Mn and ^{88}Y energy lines as it is shown in both figures below.

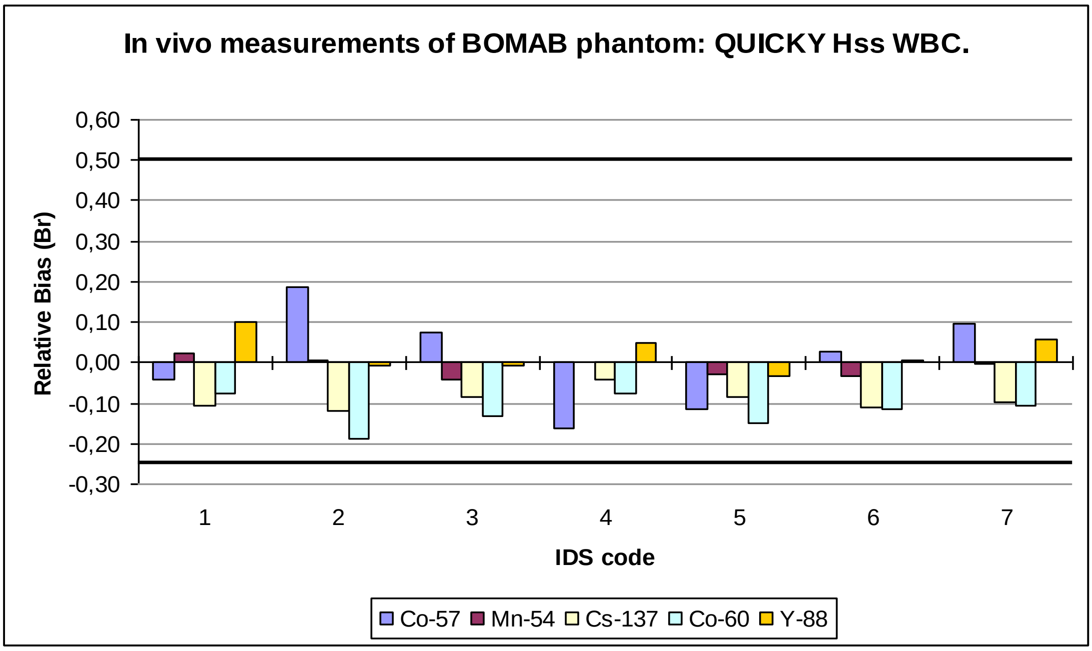

Figure 6. Accuracy analysis BOMAB measurements: QUICKY WBC

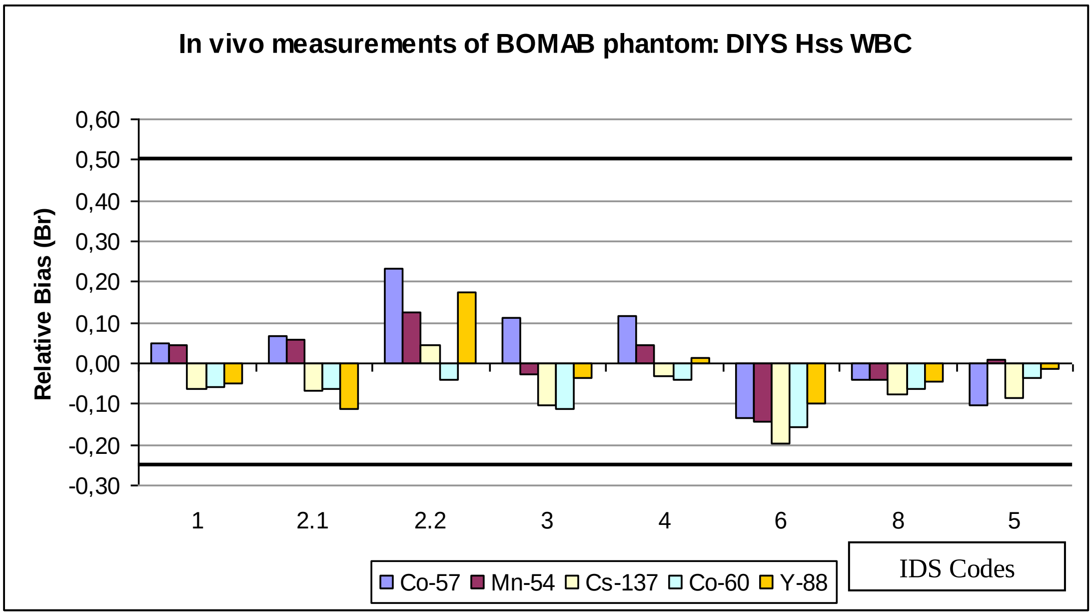

Figure 7. Accuracy analysis BOMAB measurements: DIYS WBC

In case of in vivo measurement of radioiodine in thyroid, five measurements of ANSI standard thyroid uptake neck phantom with 20 ml vials (^{133}Ba) simulating thyroid gland were realized in routine conditions according to procedures. Results sent by participants were in compliance with acceptance criteria of parameters used (Bias relative and Repeatability) although an overestimation of ^{133}Ba value was observed in most of the detection systems.

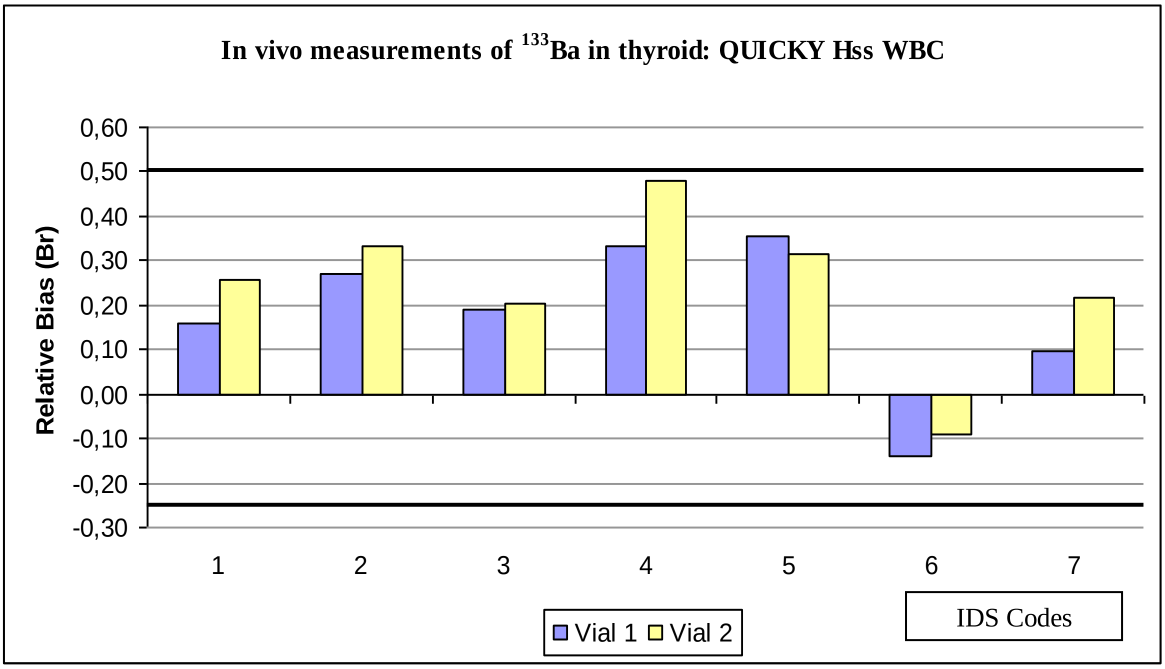

Figure 8. Accuracy analysis of Thyroid measurements: QUICKY WBC

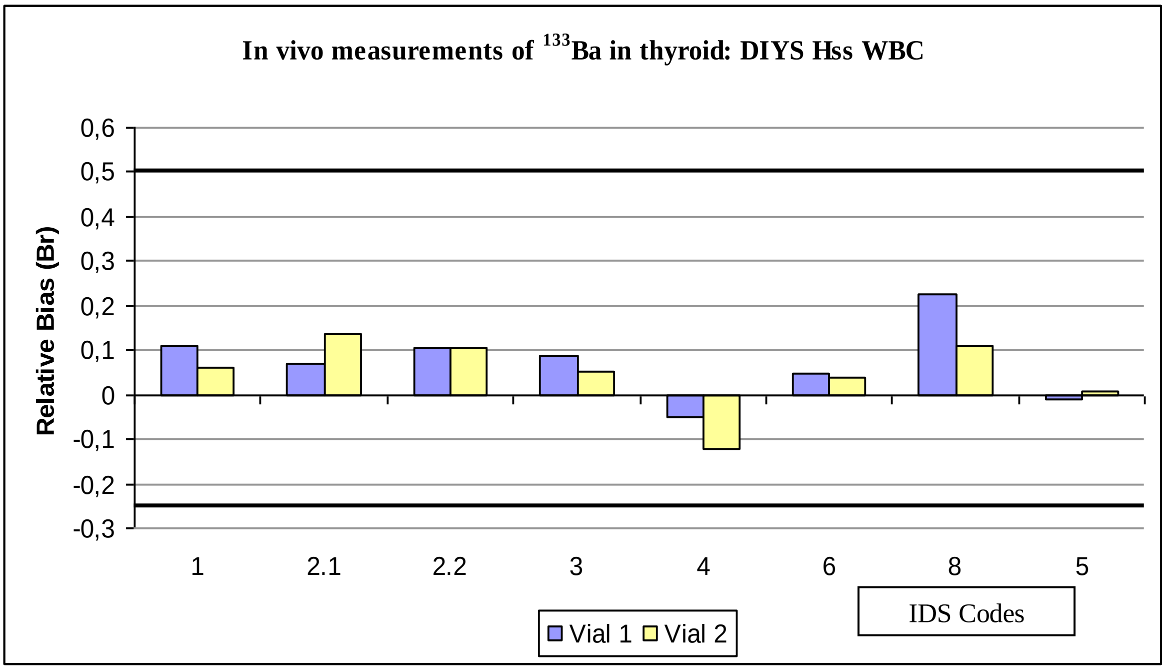

Figure 9. Accuracy analysis of Thyroid measurements: DIYS WBC

4.3. Estimation of ^{40}K in human body. Testing measurements in case of non-contaminated individuals.

The same blank person was measured in each detection system of participants to test the most common situation in routine monitoring non-contaminated individual measurement

Figure 10(a). ^{40}K measurement : Model Quicky WBC   Figure 10(b). ^{40}K measurement : Model DIYS WBC

Official ^{40}K activity value (4700 Bq) was adopted based on the measurement realized in the WBC laboratory of CIEMAT. To check values obtained by participants the Bias Relative parameter was used. An overestimation of ^{40}K values was observed in all the participating detection systems. Organizers proposed the participants to substract the contribution of daily environmental background to the individual measurement according to international recommendations (ICRU report 69) [9] and international standards.

4.4. Sensitivity of Detection Systems: Calculation of detection limits. Harmonisation

According to ISO/IEC 28218, the value of the "detection limit" indicates the ability of the service laboratory to detect a radionuclide in direct measurements of individuals. The "decision threshold" provides a way of distinguishing the difference between the count rate from the measure under analysis and the count rate from the appropriate blank. The detection limit is person dependent and can be used to estimate the sensitivity of the detection systems in a specific geometry of measurement taking into account routine conditions (specially the counting time). The organizers proposed to participants to implement the methodology followed in ISO/IEC 28218 to calculate these limits in order to achieve harmonization in Spanish internal dosimetry services and compliance with the state of the art in this matter.

5. Conclusions.

Most of the results reported by participants were in compliance with acceptance criteria. Technical recommendations related to results analysis were proposed by both WBC laboratory of IDS (CIEMAT) and Nuclear Safety Council (CSN), based on final results analysis in order to promote improvements to ensure the quality of the measurements. It is advisable to carry out some improvements in measurement procedures, daily quality controls and the determination of detection limits in order to achieve a better harmonization, to reduce discrepancies and to apply new international recommendations in this field. Final report of the intercomparison exercise was presented in a meeting celebrated in Nuclear Safety Council Head Office on 6th of April 2011. All issues proposed in the intercomparison exercise were checked by the organizers and the participants had the opportunity to exchange knowledge, experience and identify problems to be resolved.

6. References.

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