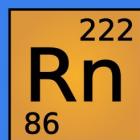


Laboratorio
Subterráneo
Canfranc



11.11.2024 - 13.11.2024
Laboratorio Subterráneo de Canfranc

Workshop I+D+i en Radón



SOCIEDAD ESPAÑOLA DE
PROTECCIÓN RADIOLÓGICA
Afilada a la I.R.P.A.



Laboratorio
Subterráneo
Canfranc

Metrología del radón: El Laboratorio de Radiación Natural (LRN)

Carlos Sainz Fernandez
Catedrático Universidad de Cantabria
Director LaRUC

LaRUC
Laboratorio de
Radiactividad Ambiental | Universidad
de Cantabria



Descripción del LRN

Actividades desarrolladas

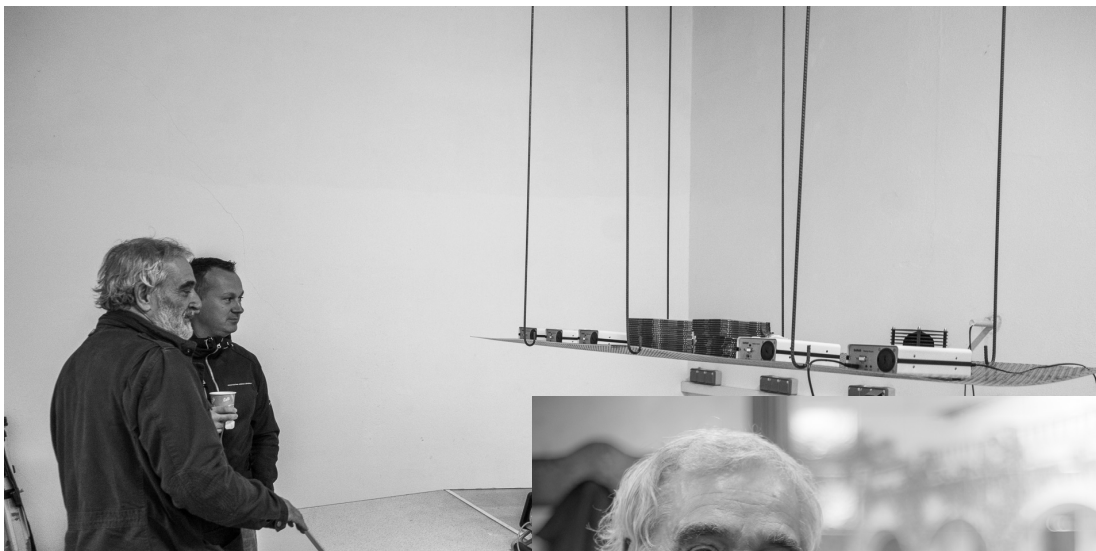
Intercomparación 2024

Perspectivas

LABORATORIO DE RADIATIVIDAD NATURAL (Plan Nacional de Radón)



**Mina de uranio de Saelices el
Chico (Salamanca), ENUSA
Industrias Avanzadas**





CAPACIDADES

Aula de formación

Salas de exposición

**Greens para verificación de
radiación gamma**

Rn en suelo

Casa Piloto

ACTIVIDADES

Cursos de formación

**Ejercicios de
Intercomparación**

Otras





NACIONALES

Teórico práctico de instrumentación de radón (2023, CSN)

Manejo de equipos radiométricos en campo (2018, 2019, 2021, 2023, CSN)





2011, 2013, 2016 (Curso workshop ERA e intercomparación), 2024

Basic Training Course in Radon Metrology and Control
and

IV ERA Radon workshop

Schedule and practical arrangements

25th - 29th April 2016

Ciudad Rodrigo (Salamanca, Spain)





INTERNACIONALES

Training Course “Radon for building professionals” (2017, 2018, IAEA)

Layout



- Day 1
 - Introduction: Basic radon knowledge and international requirements
- Day 2
 - Radon measurement techniques
- Day 3
 - Radon prevention methods
- Day 4
 - Radon remediation methods
- Day 5
 - Radon remediation exercise
 - Reporting of “take aways” and closing

**INTERNATIONAL INTERCOMPARISON EXERCISE ON NATURAL RADIATION MEASUREMENTS
UNDER FIELD CONDITIONS
2011**

42 LABORATORIOS DE 17 PAISES

RADÓN EN AIRE

EXHALACIÓN DE MATERIALES DE CONSTRUCCIÓN

RADÓN EN SUELO

RADÓN EN AGUA

RADIACIÓN GAMMA EXTERNA



Radon in water



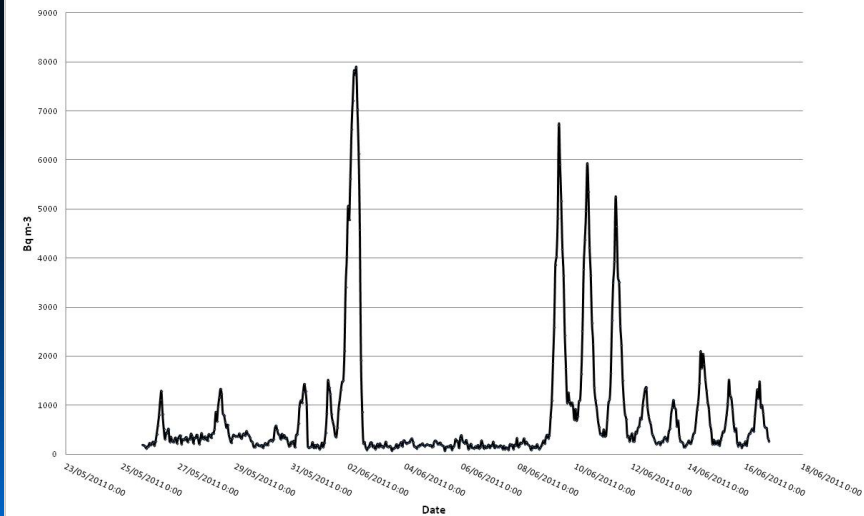
No standard solution
Radon diffusion - stable Rn in water
concentration
Range 300 - 400 Bq/l

Indoor radon



3 exposures/rooms- LOW/MEDIUM/HIGH
Reference Alphaguard/Atmos 12

Exposure 2



External dose rate

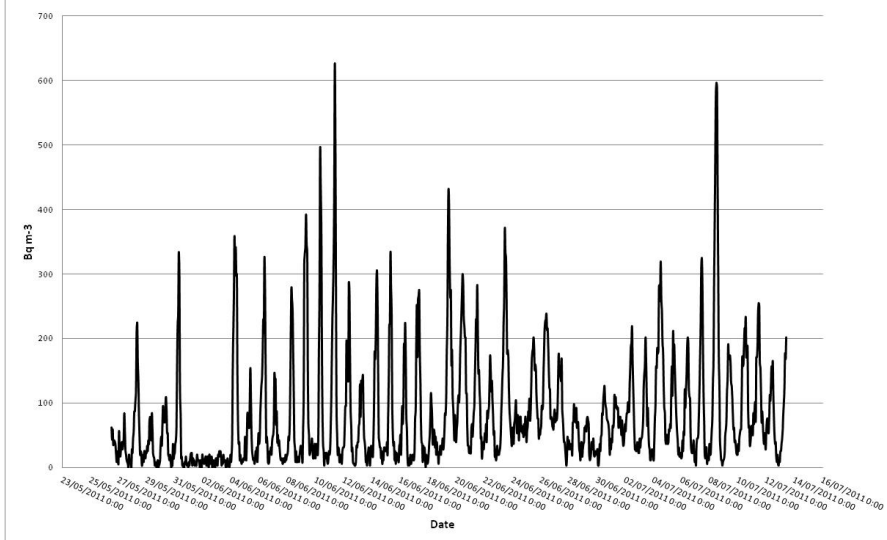
Easy to measure?



3 points - LOW/MEDIUM/HIGH dose rate
Reference CIEMAT (Spain) Reuter Stokes



Exposure 3



Radon exhalation from building materials



Value near
detection limit

$$C_{eq} \approx C_{out}$$

Low leakage

Long time

Radon in soil



Inhomogeneous
field

Discrepancies point to
point

Comparison of
"radon index"
estimation





METRORADON: INTERCOMPARISON ON INDOOR RADÓN AND GEOGENIC RADON MEASUREMENTS UNDER FIELD CONDITIONS 2018

Introduction

Maximum participants number was reached: 20

Activity	Participant number	No. of Results
Rn in Air (Passive)	19	23
Rn in Air (Active)	8	22
Rn in soil	5	5
Exhalation	3	3

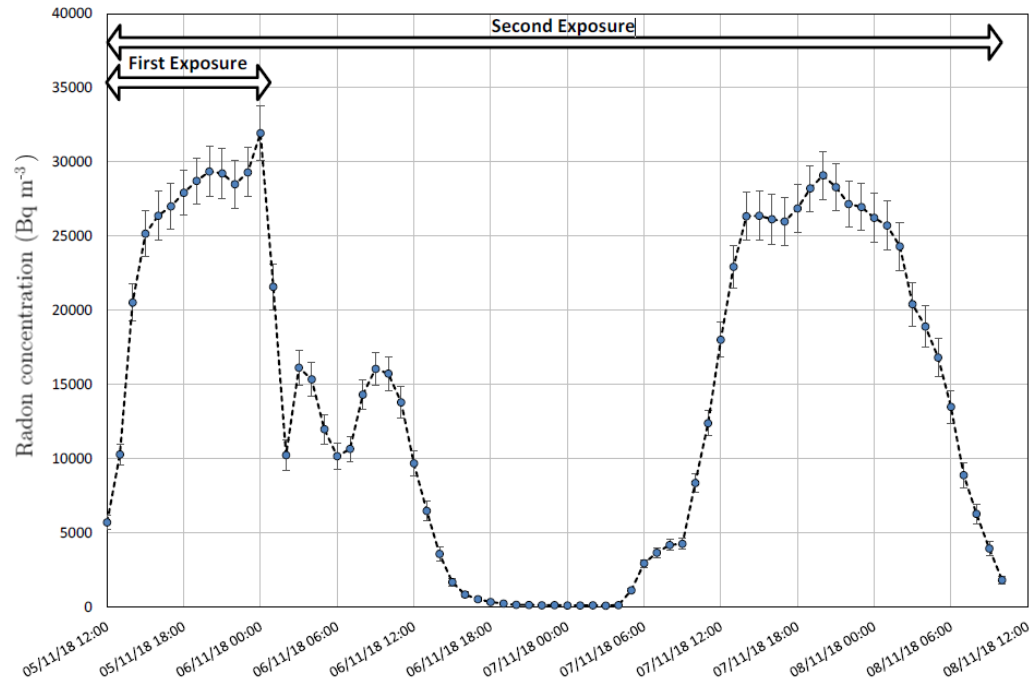


Acronym	Institution	Country
CIEMAT	Centro de investigaciones energéticas, medioambientales y tecnológicas	Spain
CLOR	Central Laboratory for Radiological Protection	Poland
ENEA	ENEA Radon Service	Italy
INAIL	Italian National Institute for Insurance against Accidents at work	Italy
IRSN	Institut de Radioprotection et de Sûreté Nucléaire	France
JRC	Joint Research Centre	Italy
LaRUC (UC)	Laboratory of environmental radioactivity, University of Cantabria	Spain
LRAB - UEX	LRAB - Universidad de Extremadura	Spain
LRG	Laboratorio de Radón de Galicia	Spain
LRN-UC	Laboratorio de Radioatividade Natural - Universidade de Coimbra	Portugal
NRCN	Nuclear Research Center Negev	Israel
PUCP	Pontificia Universidad Católica Del Perú	Peru
RADONOVA	Radonova Laboratories AB	Sweden
Radosys	Radosys / Radosys Atlantic	Portugal/Hungary
RERA-CIEMAT	Centro de investigaciones energéticas, medioambientales y tecnológicas	Spain
STUK	Radiation and Nuclear Safety Authority	Finland
SUBG	Sofia University "St. Kliment Ohridski"	Bulgaria
SUJCHBO	National Institut for NBC Protection	Czech Republic
TR	TECNO RAD s.u.r.l.	Italy
UBB	Babes-Bolyai University	Romania

Monitor	Detection technology	Sensitivity (cpm at 1 kBq m ⁻³)
AlphaGUARD	Ionisation chamber	50
ATMOS12 DPX	Ionisation chamber	20
SARAD EQF 3120	Silicon detector	7
Radon Scout	Silicon detector	1.8
Radon Scout Home	PIN photo diode	0.1



Detector	Diffusion chamber
CR-39 RSKS 100 mm ² (Radosys)	Diameter 26 mm, height 55 mm 29 cm ³ volume
CR-39 24.7×36.7×1.40 (mm) (Mi-Net)	ENEA patent
CR-39 Radout 25×25×1.5 (mm) (Mi.am)	Diameter 50 mm, height 20 mm
CR-39 TASTRAK 13×37×1 (mm) (Tasl)	Diameter 58 mm, height 20 mm NRPB/SSI
CR-39 Duotrack (Radonova)	Diameter 58 mm, height 40 mm
CR-39 Radtrak2 (Radonova)	Diameter 58 mm, height 20 mm NRPB/SSI
CR-39 Rapidos (Radonova)	Diameter 58 mm, height 40 mm
ST Electret Teflon (E-PERM)	L-OO Chamber 58 mL
ST Electret Teflon (E-PERM)	S Chamber 210 mL
LR-115 type2 400 mm ² (DOSIRAD)	Diameter 60.4 mm, height 27.6 mm Own design
LR-115 (KODAK) RAMARN device 0.012 mm film of cellulose nitrate, and coated on 0.1 mm thick polyester base	Polypropylene chamber 700 cm ³ volume
Makrofol 75.7 mm ² STUK design "Radonpurkki"	Diameter 20 mm, height 71 mm 79 cm ³ volume
DVD half made of polycarbonate and two thin Makrofol N foils	Thin CD case



	Start date	End date
1st exposure E1:	05/11/2018 12:00	06/11/2018 1:00
2nd exposure E2:	05/11/2018 12:00	08/11/2018 10:00

Article

Intercomparison of Indoor Radon Measurements Under Field Conditions In the Framework of MetroRADON European Project

Daniel Rabago ¹, Ismael Fuente ¹, Santiago Celaya ¹, Alicia Fernandez ¹, Enrique Fernandez ¹, Jorge Quindos ¹, Ricardo Pol ¹, Giorgia Cinelli ^{2,*}, Luis Quindos ¹ and Carlos Sainz ¹

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* Correspondence: giorgia.cinelli@ec.europa.eu

Received: 30 January 2020; Accepted: 3 March 2020; Published: 9 March 2020

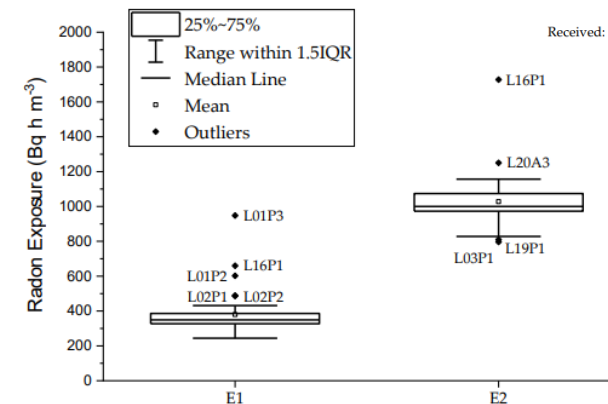
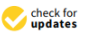


Figure 4. Boxplot diagram of the participant's results for exposures E1 and E2. Outliers are identified.

Exposure	E_{ref}	$u(E_{ref})$	σ_p	s^*	p
E1	356	8	71	43	45
E2	1014	13	101	68	41

Referencia: Valor de consenso según ISO 13528:2015.

There are p items of results denoted as:

$$E_i = E_1, E_2, E_3, \dots, E_p$$

Calculate initial values for E_{ref} and s^* as:

$$E_{ref} = \text{median of } E_i$$

$$s^* = 1.485 \text{ median of } |E_i - E_{ref}|$$

Update the values of E_{ref} and s^* as follows. Calculate:

$$\delta = 1.5 s^*$$

$$E_i^* = \begin{cases} E_{ref} - \delta & \text{when } E_i < E_{ref} - \delta \\ E_{ref} + \delta & \text{when } E_i > E_{ref} + \delta \\ E_i & \text{otherwise} \end{cases}$$

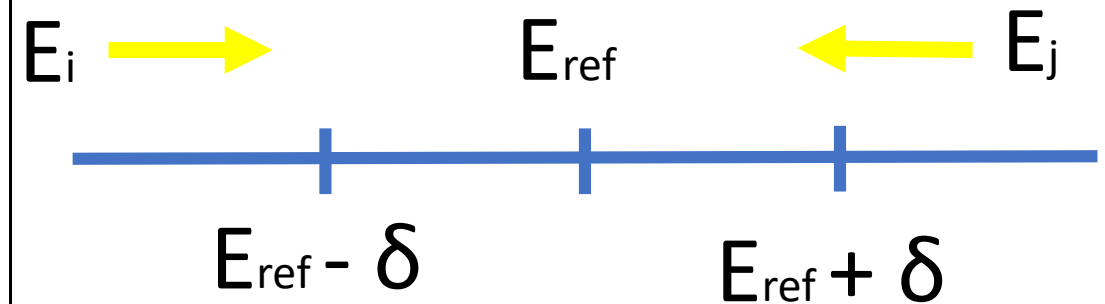
Calculate the new values of E_{ref} and s^* from:

$$E_{ref} = \text{mean of } E_i^*$$

$$s^* = 1.134 \cdot \text{SD}(E_i^*)$$

The robust estimates E_{ref} and s^* are derived by an iterative calculation, i.e. by updating the values of E_{ref} and s^* several times until the process converges.

ITERATIVE PROCESS



$$u(E_{ref}) = 1.25 \frac{s^*}{\sqrt{p}}$$

Data analysis - Metrics

$$D_i(\%) = 100 \cdot \frac{E_i - E_{ref}}{E_{ref}}$$

$$\zeta_i = \frac{E_i - E_{ref}}{\sqrt{u^2(E_i) + u^2(E_{ref})}}$$

$$Z_i = \frac{E_i - E_{ref}}{\sigma_p}$$

| ζ |; | z | ≤ 2.0 result is considered satisfactory
2.0 < | ζ |; | z | < 3.0 result is considered to give a problem
| ζ |; | z | ≥ 3.0 is considered not satisfactory

ζ score	z-score	Action to take
Satisfactory	Satisfactory	Participant's result is good. No action is required.
Not satisfactory	Satisfactory	Participant's claimed uncertainty is too low, but the result fulfils the intercomparison requirements.
Satisfactory	Not Satisfactory	Participant's uncertainty assessment is accurate but the results do not fulfil the intercomparison requirements.
Not Satisfactory	Not Satisfactory	Participant's result is biased in excess. A complete reevaluation should be performed.

Radon in air: 1st exposure E1

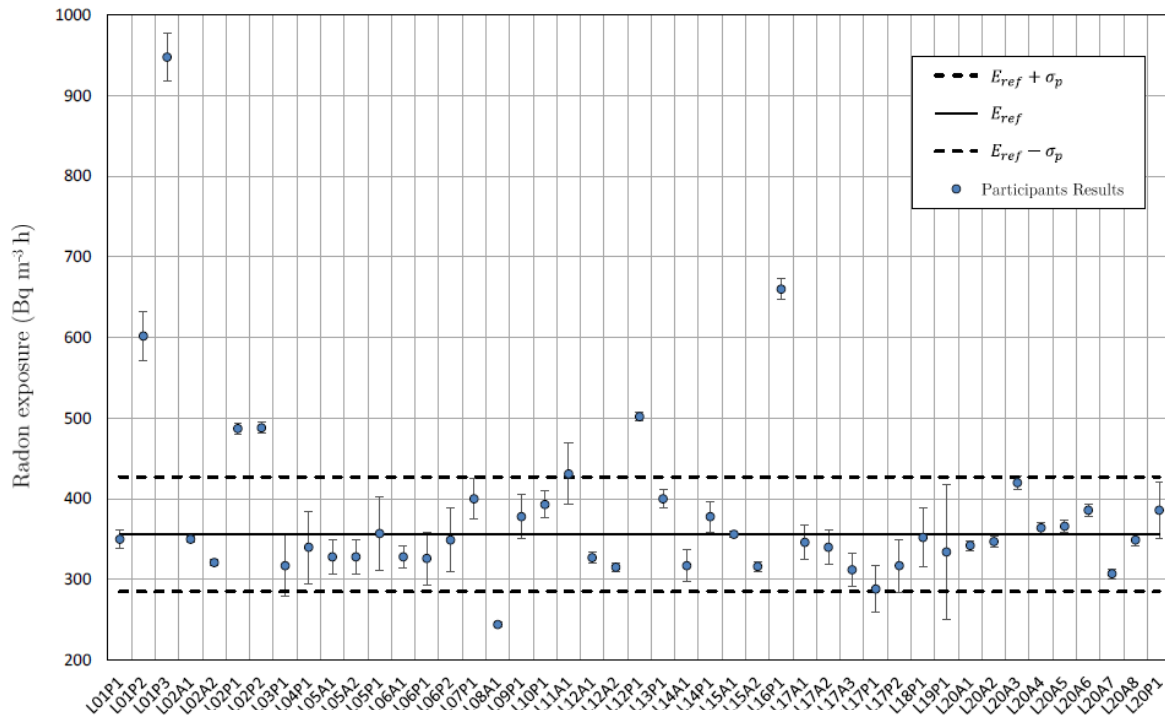
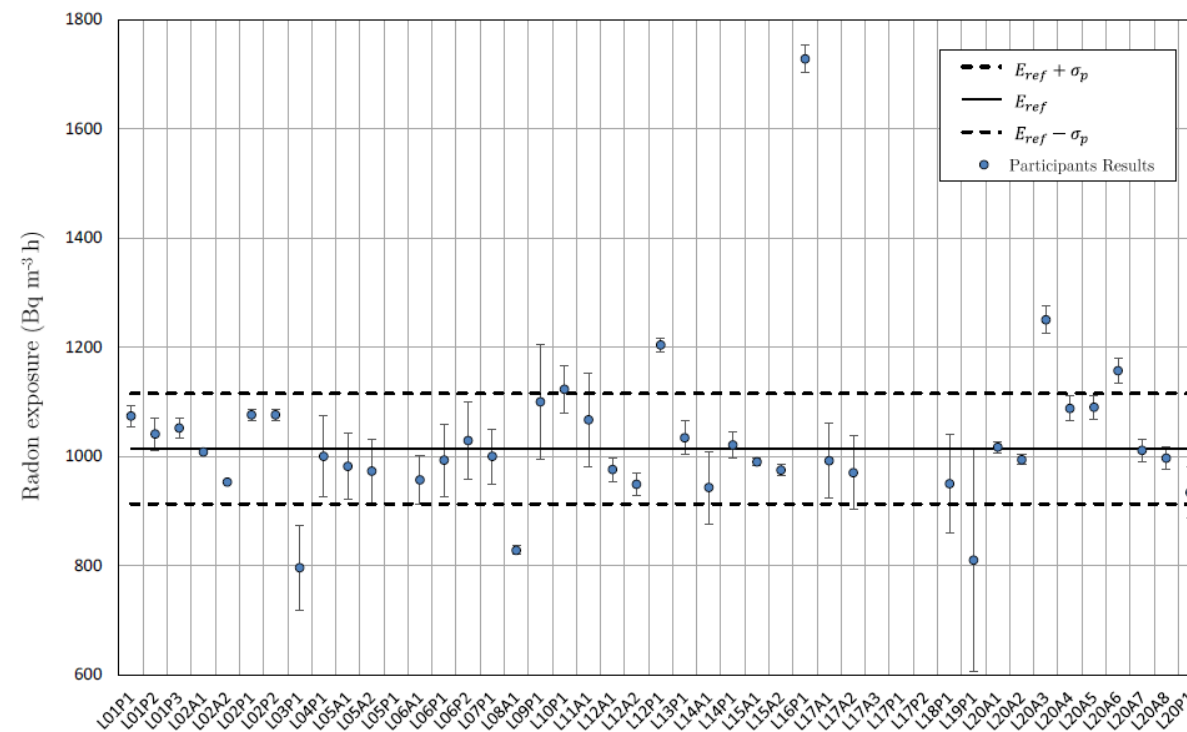


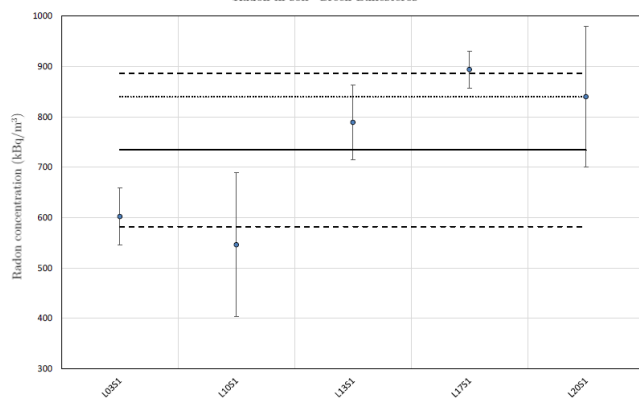
Table 9. Percentage of the results that are within the limits for Zeta score (ζ) and z-score (z).

	Results of E1 (%)	Results of E2 (%)
$ D(\%) \leq 10\%$	56	80
$ D(\%) \leq 20\%$	82	90
$ \zeta \leq 2.0$	62	63
$2.0 < \zeta < 3.0$	9	17
$ \zeta \geq 3.0$	29	20
$ z \leq 2.0$	91	90
$2.0 < z < 3.0$	2	7
$ z \geq 3.0$	7	2

Radon in air: 2nd exposure E2



Radon in soil *Green Ballesteros*





Article

The Metrological Traceability, Performance and Precision of European Radon Calibration Facilities

Thomas R. Beck ^{1,*}, Andrei Antohe ², Francesco Cardellini ³, Alexandra Cucos ⁴, Eliska Fialova ⁵, Claudia Grossi ⁶, Kinga Hening ⁴, Jens Jensen ⁷, Dejan Kastratović ⁸, Matej Krivošik ⁹, Patrick Lobner ¹⁰, Aurelian Luca ², Franz Josef Maringer ¹⁰, Nathalie Michielsens ¹¹, Petr P. S. Otahal ⁵, Luis Quindós ¹², Daniel Rábago ¹², Carlos Sainz ¹², László Szűcs ¹³, Constantin Teodorescu ², Cathrin Tolinsson ⁷, Cornel Liviu Tugulan ², Tuukka Turtiainen ¹⁴, Arturo Vargas ⁶, Josef Vosahlik ⁵, Goran Vukoslavovic ⁸, Hannah Wiedner ¹⁰ and Katarzyna Wołoszczuk ¹⁵

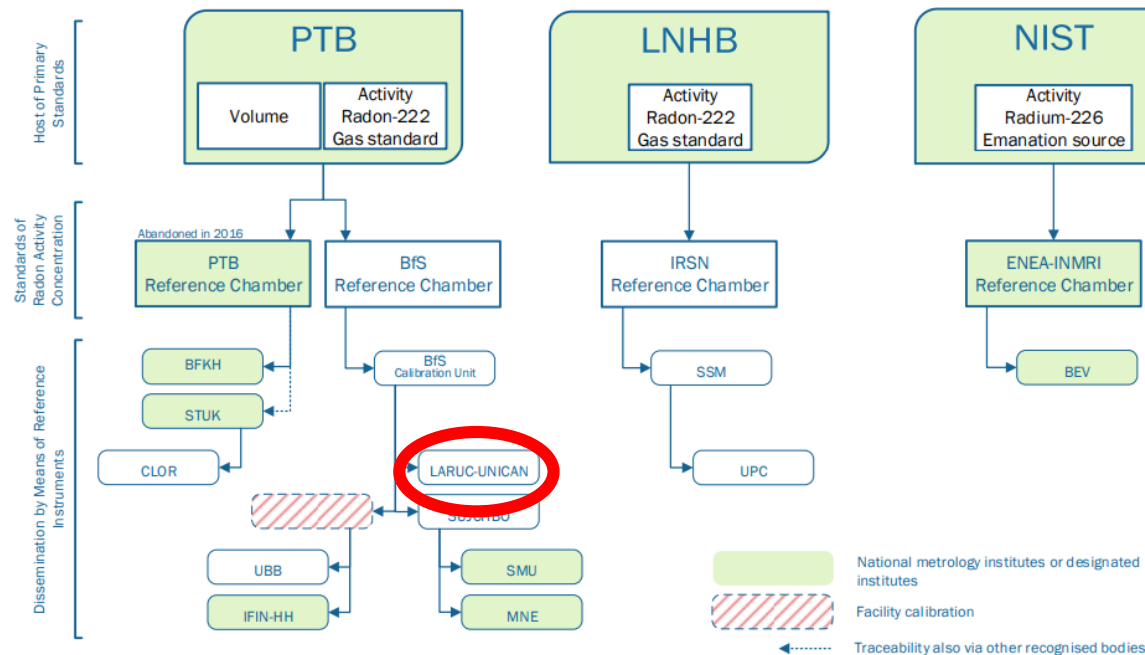
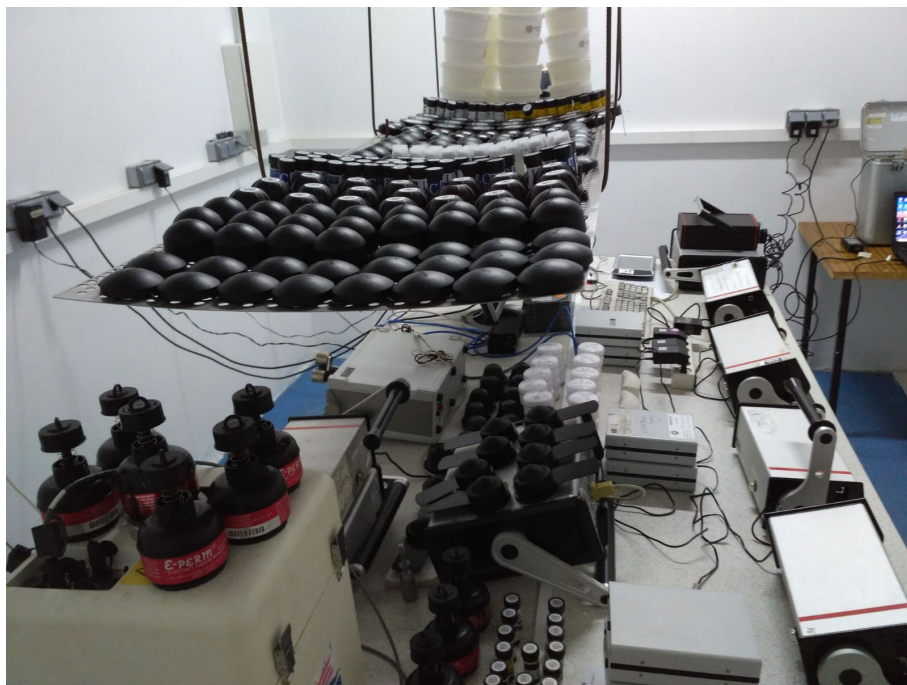


Figure 4. Chart of metrological traceability of European calibration facilities for radon: status at the start of the interlaboratory comparison (2018).

INTERCOMPARACIÓN DE SISTEMAS DE MEDIDA DE GAS RADÓN EN AIRE BAJO CONDICIONES DE CAMPO 2024



Acronym	Institution	Country
CIEMAT SPR	CIEMAT SPR	Spain
AGQ LABS	AGQ LABS & TECHNOLOGICAL SERVICES	Spain
BBU	Babes - Bolyai University, "Constantin Cosma" Radon Laboratory	Romania
BM	BragaMetro, Lda.	Portugal
CRSL	CALIDAD RADIOLOGICA S.L.	Spain
CLOR	Central Laboratory for Radiological Protection	Poland
LMRn	CIEMAT Laboratorio de Medidas de Radón	Spain
CSN - ARAN	Consejo Seguridad Nuclear (Área de Radiación Natural)	Spain
CSN - AVRA	Consejo Seguridad Nuclear (Área de Vigilancia Radiológica Ambiental)	Spain
CyE	CYE CONTROL Y ESTUDIOS S.L.	Spain
DIRAD/IRD	Divisão de Radioproteção Ambiental do Instituto De Radioproteção e Dosimetria	Brazil
EDM (TD)	EDM - Empresa de Desenvolvimento Mineiro S.A. (Technical Dept.)	Portugal
EDM (ERD)	EDM - Empresa de Desenvolvimento Mineiro S.A. (Environmental Remediation Dept.)	Portugal
Eurofins	Eurofins Radon Testing Sweden AB	Sweden
IMROH	Institute for Medical Research and Occupational Health - Division of Radiation Protection	Croatia
INTA	Instituto Nacional de Técnicas Aeroespaciales	Spain
ISIRYM	Instituto Universitario de Seguridad Industrial, Radiofísica y Medioambiental	Spain
ISS	Italian National Institute of Health	Italy
LRA-UPV	LABORATORIO DE RADIATIVIDAD AMBIENTAL-UNIVERSITAT POLITECNICA DE VALENCIA	Spain
LRA-UDC	Laboratorio de Radiactividad Ambiental de la Universidade da Coruña	Spain
LRN	Laboratório de Radioatividade Natural da Universidade de Coimbra	Portugal
LRAB	Laboratorio Radiactividad Ambiental Badajoz - Universidad de Extremadura	Spain
LaRUC	Laboratory of Environmental Radioactivity, University of Cantabria	Spain
LARUEX	LARUEX, University of Extremadura	Spain

NORM Consulting	NORM Technology Consulting S.L.	Spain
POLIMI	Politecnico di Milano	Italy
Radiansa	Radiansa Consulting S.L.	Spain
Radolab	Radolab OU	Estonia
RADONOVA	RADONOVA LABORATORIES AB	Sweden
RSP	RADONSPAIN	Spain
Radosys	Radosys	Hungary
LABOF-TF	Servicio de Laboratorios y Calidad de la Construcción. Gobierno de Canarias	Spain
SXXI	SIGLO XXI CONSULTORES SL	Spain
ULPGC	UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA	Spain
US	Universidad de Sevilla (CITIUS)	Spain
Unimi	Università degli Studi di Milano	Italy
LARAM-UV	UNIVERSITAT DE VALÈNCIA	Spain
URV	Universitat Rovira i Virgili (Unidad de Física Médica)	Spain
USC-LRG	University of Santiago de Compostela. Galician Radon Laboratory	Spain

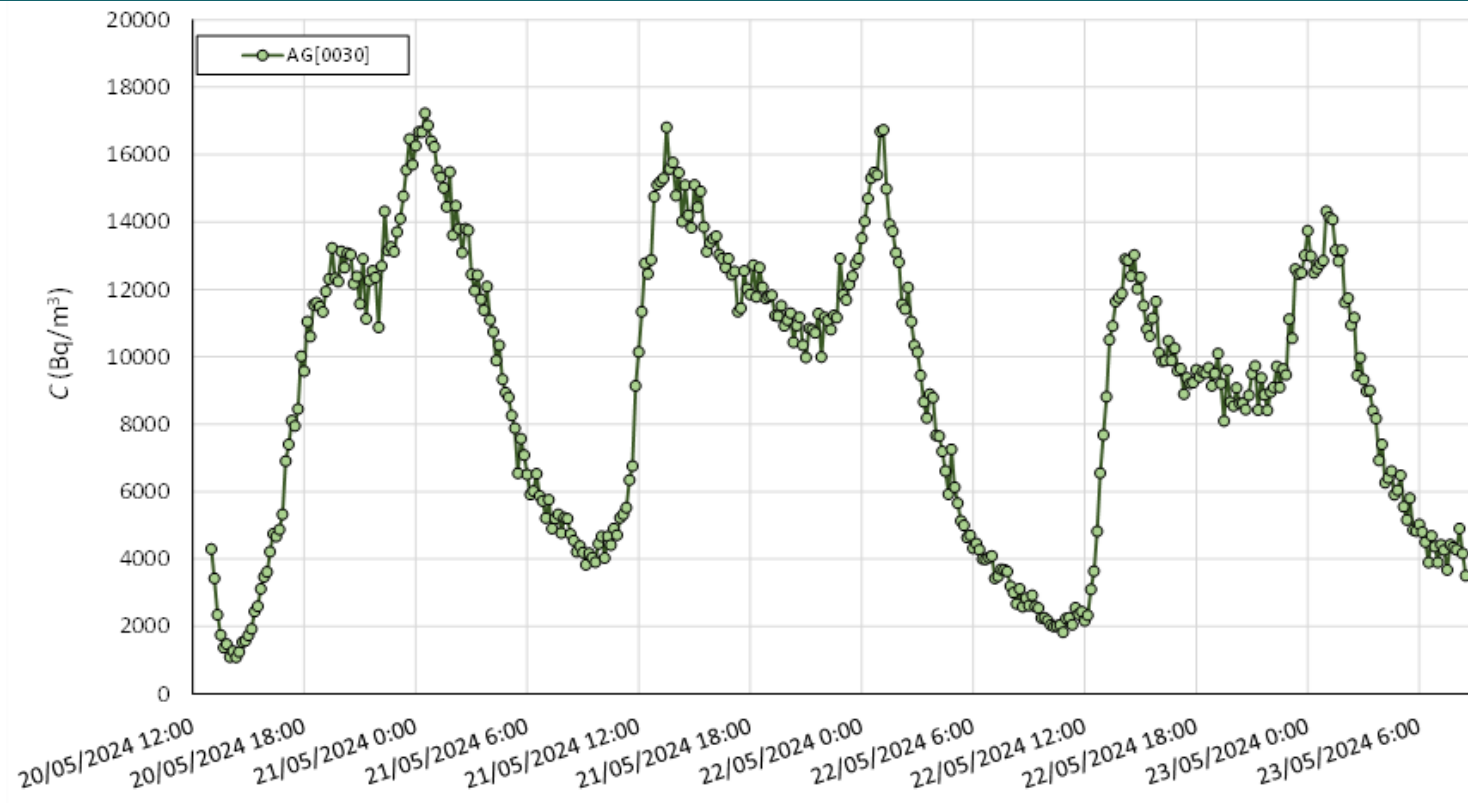
**39 PARTICIPANTES (laboratorios,
empresas, centros de investigación)
24 nacionales**



Monitor	Detection technology	Sensitivity (cpm at 1 kBq m ⁻³)
AlphaGUARD	Ionisation chamber	50
AlphaE	Silicon diode	0.5
RadonEye	Silicon detector	14
Tesys MR-1	Lucas Cell	40
Rad7	Silicon detector	14
RTM 1688-2	Silicon detector	3
SPIRIT	Semiconductor detector	40
RPP-U	Semiconductor photodetector	4
Radon Scout	Silicon detector	1.8
Radon Scout Home	PIN photo diode	0.1
Interface Radon	Ionisation chamber	28

Detector (Manufacturer)	Diffusion chamber (Volume)
CR-39 (Radosys)	RSKS (29 cm ³)
CR-39 (Tasl)	TASTRAK (53 cm ³)
CR-39 (Radonova)	Radtrak ³ (40 cm ³)
CR-39 (RTP)	Radout (39 cm ³)
Electrete LT (E-Perm)	Chamber S (210 cm ³)
Electrete LT (E-Perm)	Chamber L-OO (58 cm ³)
Electrete ST (E-Perm)	Chamber L-OO (58 cm ³)

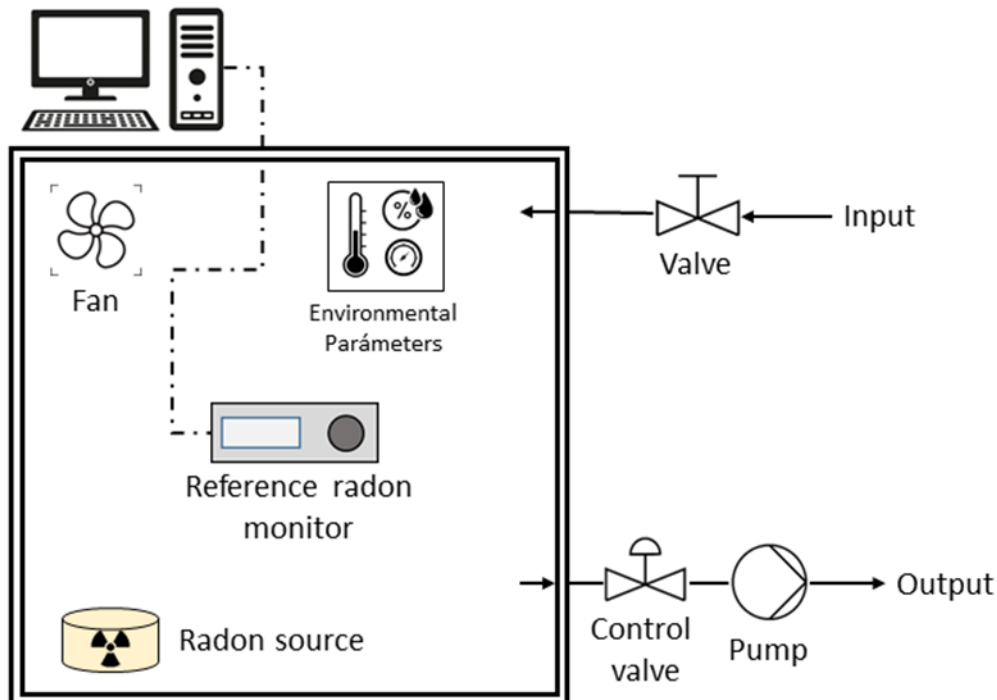




Fechas	t (h)	E_{ref} (kBq h m ⁻³)	$u(E_{ref})$ (kBq h m ⁻³)
20/05/2024 13:00 - 23/05/2024 8:30	67.5	621.4	4.5

	rH (%)	T (°C)	P (hPa)	$\dot{H}^*(10)$ (nSv/h)
Sala1	64.5	16.4	940.0	170
Exterior	73.4	10.9	940.4	250

REFERENCIA: Alphaguard calibrado en cámara de LaRUC



- Reference monitor traceable to international standards
- Radon sources (Bq/h)
- Air exchange with exterior controlled with a pump
- Environmental parameters monitored (P , rH , T)
- Keep the Rn concentration between:
 - 100 and 20000 Bq/m³

$$D_i(\%) = 100 \cdot \frac{E_i - E_{ref}}{E_{ref}}$$

$$\zeta_i = \frac{E_i - E_{ref}}{\sqrt{u^2(E_i) + u^2(E_{ref})}}$$

$zeta\text{-score} \leq 2$	Resultado Satisfactorio
$2 < zeta\text{-score} < 3$	Resultado Cuestionable
$zeta\text{-score} \geq 3$	Resultado insatisfactorio

<i>zeta-score</i> ζ	Acciones a tomar
Satisfactorio	El resultado del participante es bueno. No se requiere ninguna acción.
No Satisfactorio	La incertidumbre declarada por el participante es demasiado baja en relación con el error o sesgo obtenido.

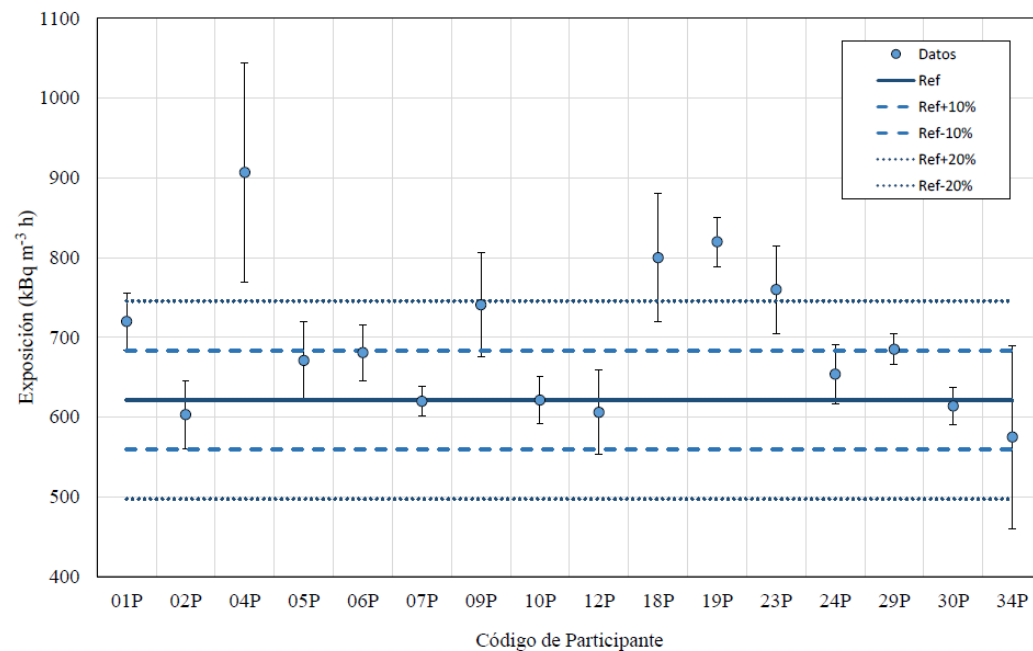


Figura 4. Exposición de radón con su incertidumbre asociada ($k=1$) para detectores pasivos. Se muestra el valor de referencia con una línea sólida y el rango $\pm 10\%$ y $\pm 20\%$ con líneas discontinuas.

PASIVOS

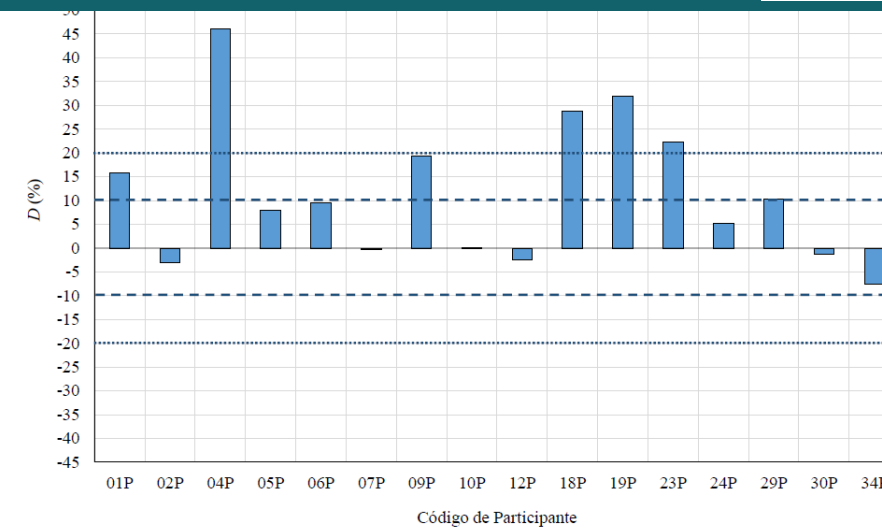


Figura 5. Diferencia porcentual D (%) respecto al valor de referencia de los detectores pasivos. Se muestra el rango $\pm 10\%$ y $\pm 20\%$.

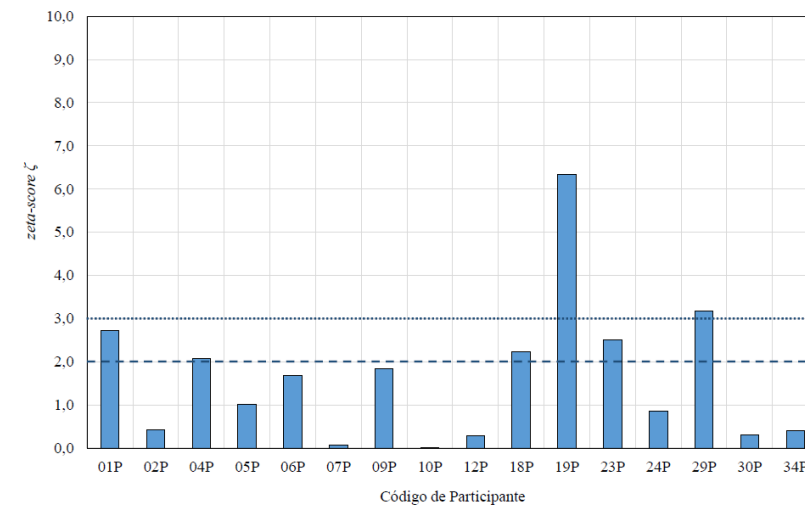


Figura 6. Parámetro *zeta-score* ζ de los detectores pasivos. Se muestra con una línea de puntos el valor $\zeta = 3$ y con una línea discontinua el valor $\zeta = 2$.

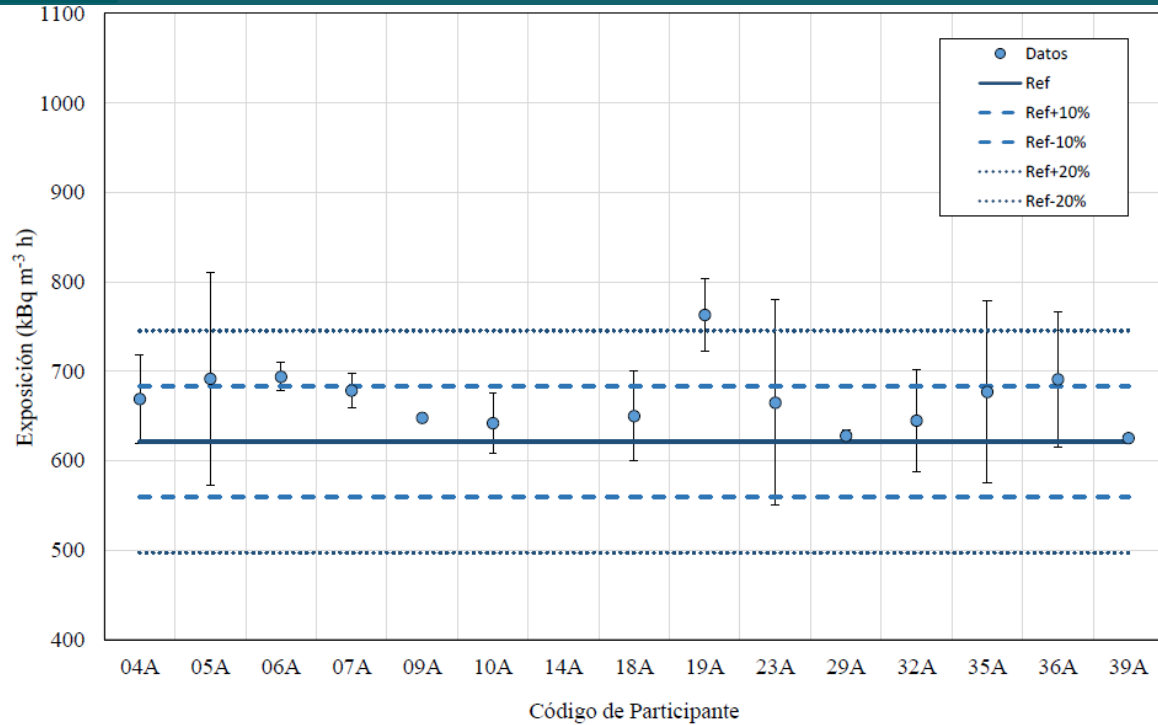


Figura 7. Exposición de radón con su incertidumbre asociada ($k=1$) para monitores en continuo. Se muestra el valor de referencia con una línea sólida y el rango $\pm 10\%$ y $\pm 20\%$ con líneas discontinuas.

ACTIVOS

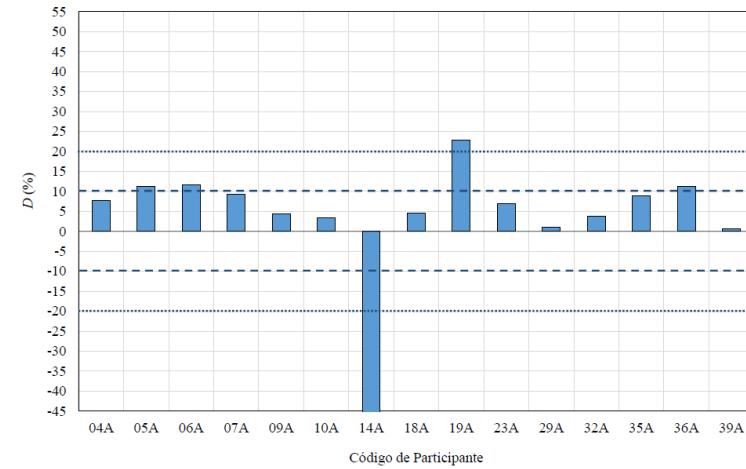


Figura 8. Diferencia porcentual D (%) respecto al valor de referencia de los monitores en continuo. Se muestra el rango $\pm 10\%$ y $\pm 20\%$.

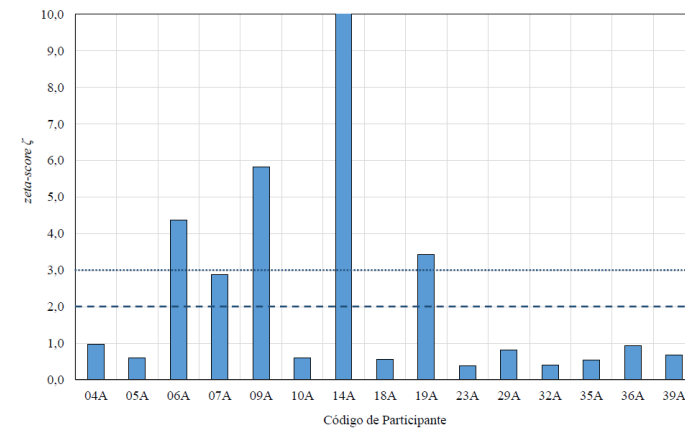


Figura 9. Parámetro ζ -score ζ de los monitores en continuo. Se muestra con una línea de puntos el valor $\zeta=3$ y con una línea discontinua el valor $\zeta=2$.

ACTIVOS: Tiempo de respuesta

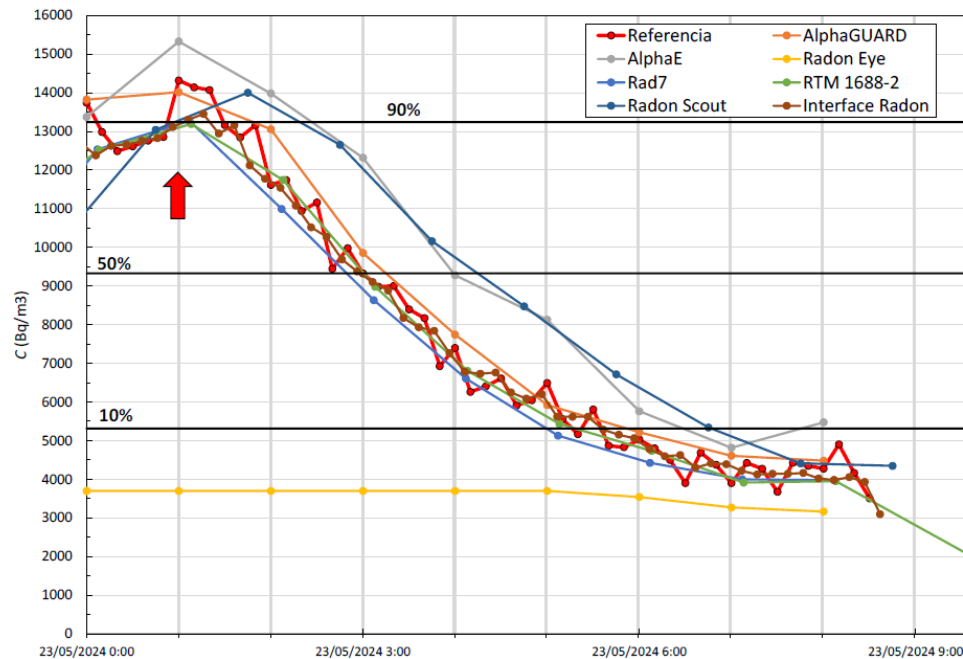
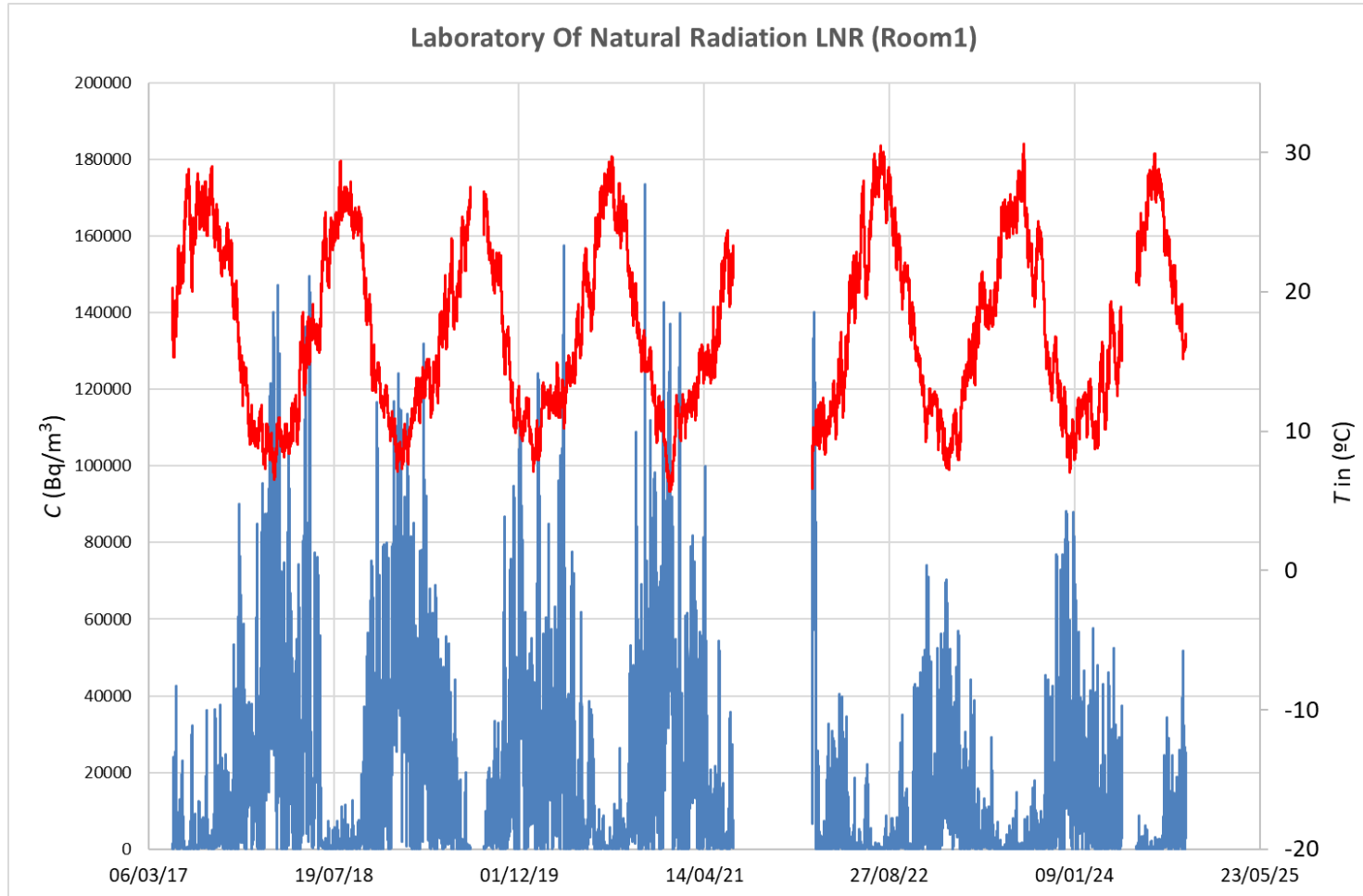


Figura 10. Evolución de la concentración de radón en la Sala1 medida por el dispositivo de referencia y los monitores para estudiar el tiempo de respuesta. La flecha roja indica el inicio considerado, y las líneas negras horizontales indican el 10%, el 50% y el 90% del valor neto del periodo.

Tabla 7. Tiempo de respuesta t_r indicado en horas que tarda para cada monitor en alcanzar los valores de concentración del 90%, 50% y 10% durante el periodo de disminución de la concentración de radón.

Monitor	t_r (h) [90%]	t_r (h) [50%]	t_r (h) [10%]
Referencia	0.5	2.16	4.5
AlphaGUARD	1	3	5
AlphaE	2	3	6
RadonEye	-	-	-
Rad7	<1	2	4
RTM 1688-2	<1	2	5
Radon Scout	1	3	5
Interface Radon	0.3	2.0	4.5



Modelización

Relación gamma/RnD

**Desarrollo de
remedio/control**

...

DOCENCIA

Protección Radiológica Ambiental
Radiación Natural
Radón, metrología, mitigación

INVESTIGACIÓN

Modelización
Relación gamma/RnD
Desarrollo de remedio/control

SERVICIOS

Ejercicios de intercomparación
Control calidad Unidades Móviles

...

GRACIAS POR VUESTRA ATENCIÓN