IAEA Review of Safety-Related Aspects of Handling ALPS-Treated Water at TEPCO's Fukushima Daiichi Nuclear Power Station

Corroboration of Internal Exposure Monitoring

Performance of In-Vitro and In-Vivo Radiobioassay

IAEA
International Atomic Energy Agency

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EXECUTIVE SUMMARY

In 2021, the International Atomic Energy Agency (IAEA) started its review of safety-related aspects of handling Advanced Liquid Processing System (ALPS)-treated water at Tokyo Electric Power Company Holdings' (TEPCO's) Fukushima Daiichi Nuclear Power Station (FDNPS). Consistent with the request from the Government of Japan, the IAEA statutory functions and the mandate of the Task Force, the scope of the IAEA review is tailored to assessing safety related aspects of the implementation of Japan's *Basic Policy on Handling of ALPS-Treated Water at the Tokyo Electric Power Company Holdings' Fukushima Daiichi Nuclear Power Station* against the IAEA Safety Standards. The current approach outlined in the Basic Policy is to conduct a series of controlled discharges of ALPS-treated water into the sea ('batch discharges') over a period of decades.

Consistent with the relevant IAEA Safety Standards, TEPCO bears the responsibility for the protection of workers against occupational exposure to ionizing radiation. An individual monitoring programme was arranged with approved dosimetry services that operate under a quality management system to assess radiation doses to workers arising from exposure to external sources of radiation and from exposure due to intakes of radionuclides. The IAEA's data corroboration focuses on assessment of the capabilities of dosimetry service providers who are monitoring external and internal radiation exposure of workers involved in handling ALPS-treated water at FDNPS.

To conduct its safety review, the IAEA has organized the work of the Task Force into three main components: the assessment of protection and safety; regulatory activities and processes; and sampling, independent analysis and data corroboration. The latter activities include three elements:

- sampling, analysis and interlaboratory comparison for ALPS-treated water from the FDNPS;
- sampling, analysis and interlaboratory comparison for environmental samples (e.g., seawater, fish) from the surrounding environment of FDNPS; as well as
- assessment of the capabilities of dosimetry service providers involved in the monitoring of internal and external radiation exposure of workers at FDNPS.

The latter activities also include a review of analytical methods used by TEPCO and its contractors. The corroboration of external and internal radiation exposure monitoring is based on an extensive proficiency testing scheme, which involves interlaboratory comparisons for the determination of laboratory performance, assessment of the quality of measurement results and identification of potential improvements. Proficiency testing involves the evaluation of performance against pre-established criteria whereas interlaboratory comparisons comprise the organization, performance, and evaluation of measurements on the same or similar items by two or more laboratories in accordance with predetermined conditions.

This report presents the results and findings from an extensive proficiency testing scheme organized by the IAEA in 2023/24 to corroborate the capabilities of individual monitoring services for the assessment of internal radiation exposure of workers involved in handling ALPS-treated water). The scheme aimed to improve harmonization of individual monitoring and to evaluate the performance against pre-established criteria from international standards, in particular *Radiation Protection — Performance Criteria for Radiobioassay* (ISO 28218:2010) and *Statistical Methods for Use in Proficiency Testing by Interlaboratory Comparison* (ISO 13528:2022).

While Phase I was concerned with strontium and tritium bioassay in urine (*in-vitro* or indirect monitoring), Phase II regarded body activity measurements (*in-vivo* or direct monitoring). For the purpose of *in-vitro* radiobioassay interlaboratory comparison, aliquots of urine, which had been spiked with radionuclides prepared by dilution from certified reference materials, were distributed for analysis among participating laboratories. The *in-vivo* radiobioassay interlaboratory comparison circulated a unified brick phantom consisting of rectangular bricks made from polyethylene, which were set up to resemble the average weight of workers measured in a whole-body counting laboratory operated by TEPCO, for measurement among participating laboratories in a round-robin style experiment. The bricks contain holes, which were filled with certified rod sources of known activities. Its versatile components allowed the phantom to be set up in different postures such as lying in a stretcher geometry, sitting in a chair, or standing. Radionuclides and activities were selected to allow for evaluation of accuracy and the relationship of the participants' results to a certified reference or assigned value, considering the associated uncertainties:

<u>*In-vitro* radiobioassay</u>

- Radionuclides: ^{3}H (HTO), ^{90}Sr
- Activity concentration: < 10 kBq/L (HTO), < 20 Bq/L (^{90}Sr)

<u>*In-vivo* radiobioassay</u>

- Radionuclides: ^{134}Cs, ^{137}Cs
- Total activity: < 10 kBq

The participating laboratories met the performance limits regarding relative bias, z-score and zeta-score for all samples and test items analysed, providing evidence for their high level of competence and the technical validity of monitoring results. No inconsistencies could be identified. The methods of analysis were found to be effective and comparable between the IAEA and TEPCO. Evaluation concluded that the assessment of associated uncertainties was realistic.

The key findings of the reported interlaboratory comparisons are:

- The TEPCO laboratory has demonstrated a high level of accuracy in its measurements and technical competence.
- Analytical procedures follow the appropriate methodological standards required to obtain technically valid results.

The IAEA notes that these findings provide confidence in Japan's capability for accurate measurement of activity in excreta and the human body due to radionuclide intakes by workers.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

In 2021, the International Atomic Energy Agency (IAEA) started its review of safety-related aspects of handling Advanced Liquid Processing System (ALPS)-treated water at Tokyo Electric Power Company Holdings' (TEPCO's) Fukushima Daiichi Nuclear Power Station (FDNPS). Consistent with the request from the Government of Japan, the IAEA statutory functions and the mandate of the Task Force, the scope of the IAEA review is tailored to assessing safety related aspects of the implementation of Japan's *Basic Policy on Handling of ALPS-Treated Water at the Tokyo Electric Power Company's Holdings' Fukushima Daiichi Nuclear Power Station* against the IAEA Safety Standards. The current approach outlined in the Basic Policy is to conduct a series of controlled discharges of ALPS-treated water into the sea ('batch discharges') over a period of decades.

According to the requirements of *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards* [1], the responsibility for the protection of workers against occupational exposure resides with employers, registrants and licensees who shall ensure that protection and safety are optimized and that the dose limits for occupational exposure to ionizing radiation are not exceeded. Furthermore, appropriate arrangements shall be made with authorized or approved dosimetry services that operate under a quality management system for assessment and recording of the occupational exposure of workers. For workers who usually work in controlled areas, or who occasionally work in controlled areas and may receive a significant dose from occupational exposure, individual monitoring shall be undertaken where appropriate, adequate, and feasible. For workers who regularly work in supervised areas or who enter controlled areas only occasionally, the occupational exposure shall be assessed based on the results of workplace monitoring or individual monitoring, as appropriate. Employers shall ensure that workers who could be subject to exposure due to contamination are identified, and arrangements are made to assess intakes of radionuclides and committed effective doses.

The IAEA's data corroboration focuses on assessment of the capabilities of dosimetry service providers who are monitoring external and internal radiation exposure of workers involved in handling ALPS-treated water at FDNPS, and contains three distinct elements which have been implemented in a phased approach:

- corroboration of external exposure monitoring;
- corroboration of internal exposure monitoring; and
- review of analytical methods in external and internal dosimetry applied by the relevant dosimetry services.

This report presents the results and findings from an extensive interlaboratory comparison (ILC) programme organized by the IAEA in 2024 to corroborate the capabilities of TEPCO for the assessment of internal radiation exposure of workers involved in handling ALPS-treated water. A report focusing on external radiation exposure monitoring has been published separately.

In March 2024, the IAEA has initiated an extensive proficiency testing scheme to corroborate the capabilities of TEPCO for the assessment of internal radiation exposure of workers involved in handling ALPS-treated water. This scheme involved ILCs for the determination of laboratory performance, assessment of the quality of measurement results from *in-vitro* and *in-vivo* radiobioassay, and identification of potential improvements. Proficiency testing comprises the

evaluation of performance against pre-established criteria, whereas ILCs involve the organization, performance, and evaluation of measurements on the same or similar items by two or more laboratories in accordance with pre-determined conditions [2].

The IAEA also conducted a review of analytical methods relevant to internal dosimetry used by TEPCO. The results of this review contribute to ensuring the validity of the data generated as part of proficiency testing, provide for an independent demonstration of the reliability and robustness of individual monitoring, and serve the following purposes:

- evaluation of the performance of laboratories for specific measurements;
- identification of inconsistencies in results among laboratories;
- establishment of the effectiveness and comparability of analytical methods;
- provision of additional confidence to interested parties; and
- validation of uncertainties.

1.2. OBJECTIVE

The objective of the proficiency testing scheme was to assess the performance of internal dosimetry methods, which are employed to quantify internal contamination of workers involved in handling ALPS-treated water at FDNPS. Radionuclides and activities were selected to allow for evaluation of the relative bias with respect to the reference activity and, as applicable, the z-score and the zeta-score according to the international standards ISO 28218:2010 [3] and ISO 13528:2022 [4]. Further explanation of performance criteria is provided in Section 2.1.

A particular objective of the ILCs was to present all the results promptly and clearly (with graphical and numerical information) to all participating laboratories in terms of compliance with the ISO performance requirements. The presentation of the information was designed to explain the results within the context of the ISO requirements to make the ILCs understandable and accessible to both technical and non-technical readers.

1.3. SCOPE

Phase I was concerned with strontium and tritium bioassay in urine (*in-vitro* or indirect monitoring). Aliquots of urine, which had been spiked with radionuclides prepared by dilution from certified reference materials, were distributed for analysis among participating laboratories. Radionuclides and activities were selected to allow for evaluation of accuracy and the relationship of the participants' results to an assigned value, considering the associated uncertainties:

- Radionuclides: ^{3}H (HTO), ^{90}Sr
- Activity concentration: < 10 kBq/L (HTO), < 20 Bq/L (^{90}Sr)

Phase II regarded body activity measurements (*in-vivo* or direct monitoring). A unified brick phantom consisting of rectangular bricks made from polyethylene, which were set up to resemble the average weight of workers measured in a whole-body counting laboratory operated by TEPCO, was circulated for measurement among participating laboratories in a round-robin style experiment. The bricks contain holes, which were filled with certified rod sources of known activities. Its versatile components allowed the phantom to be set up in different postures such as lying in a stretcher geometry, sitting in a chair, or standing.

Radionuclides and activities were selected to allow for evaluation of accuracy and the relationship of the participants' results to a certified reference value, considering the associated uncertainties:

- Radionuclides: ^{134}Cs, ^{137}Cs
- Total activity: < 10 kBq

1.4. STRUCTURE

This publication reports on all aspects of the *in-vitro* and *in-vivo* radiobioassay ILCs to corroborate capabilities of radiobioassay laboratories at FDNPS, including the ILC design and participating laboratories (Section 2); the methods employed for sampling and for the distribution of samples among the participating laboratories (Section 3). The analytical methods used by each participant to determine activity or activity concentration of radionuclides in the test items, the methodology employed for statistical evaluation of data, and the results for *in-vitro* and *in-vivo* radiobioassay are presented in Sections 4 and 5, and conclusions in Section 6. The Appendix contains anonymised examples of the "Certificate of Participation".

Organizer

IAEA Radiation Safety Technical Services Laboratory
International Atomic Energy Agency
E-mail: RSTSU.Contact-Point@iaea.org

The organizer was responsible for sponsoring, planning, organisation, and logistics.

Co-ordinator

Claude Guichet
Medical Biologist, Secretary of PROCORAD
E-mail: claude.guichet@cea.fr
The co-ordinator was responsible for ensuring confidentiality during the reporting phase and drafting the final analysis and reports.

Collaborating Organizations

In-vitro radiobioassay: Association for the Promotion of Quality Control in Radiotoxicological Analysis (PROCORAD), France

In-vivo radiobioassay: Federal Office for Radiation Protection (BfS), Germany

2. DESIGN AND PARTICIPATING LABORATORIES

2.1. INTERLABORATORY COMPARISON PROCEDURE

2.1.1. In-vitro Radiobioassay

Instructions for handling ILC samples have been provided through the website http://www.procorad.org/. A technical questionnaire to be completed by the participating laboratories enabled the coordinator, in collaboration with the subject matter experts on the PROCORAD Scientific Board, to properly interpret the results. The samples were shipped by an external service provider at ambient temperature. Proof of receipt had to be provided to the PROCORAD secretariat. No special conditions were applied to storing of the samples before analysis. The storage conditions routinely used in the laboratory for similar samples were considered sufficient. Laboratories were requested to use their routine procedures for measurement and analysis.

Measured activity (concentration) and expanded uncertainty ($k = 2$) had to be reported for each radionuclide for a reference date of 15 March 2024 through the PROCORAD website via a secure login. Atomic and nuclear data required for analysis had to be attained from the Tables of Radionuclides (Monographie BIPM-5) published by the Laboratoire National Henri Becquerel (LNHB), Centre CEA Paris-Saclay, Gif-sur-Yvette Cedex, France, which can be accessed through the website http://www.lnhb.fr/home/nuclear-data/. The results were discussed at the 2024 PROCORAD Annual Meeting in Bordeaux, France, from 19 to 21 June 2024. After confirmation of the results, a Certificate of Participation was awarded to each participant including information on the reference values and overall uncertainties.

2.1.2. In-vivo Radiobioassay

Instructions for assembly of the reference phantom have been provided to the participating laboratories. A technical questionnaire to be completed by the participating laboratories enabled the coordinator to properly interpret the results. In compliance with the *Regulations for the Safe Transport of Radioactive Material* [5], the phantom was shipped with inserted rod sources as excepted package (UN 2910) by an external service provider. Proof of receipt had to be provided to the organizer. No special conditions were applied to storing of the phantom before measurement. The storage conditions routinely used in the laboratory for similar items were considered sufficient. Laboratories were requested to use their routine procedures for measurement and analysis.

Measured activity and standard uncertainty ($k = 1$) had to be reported for each radionuclide for a reference date of 18 March 2024 along with the detection limit of the method, using a standardized form provided by the coordinator. As soon as all participants had submitted their results, the relative bias with respect to the reference activity and the zeta-score were provided to each participating laboratory. Amendment of results after disclosure of these data was only possible in case of technical or administrative errors made by the coordinator. However, participating laboratories were granted a two-week period from issue of the provisional results by the coordinator to highlight any problems. After confirmation of the results, a Certificate of Participation was awarded to each participant including information on the reference values and overall uncertainties.

2.2. DESIGN

Proficiency testing on *in-vitro* and *in-vivo* radiobioassay was comprised of quantitative comparisons of the results of analyses using statistical methods to assess the performance of radiobioassay laboratories at the IAEA and TEPCO.

The 2024 PROCORAD ILC on determination of ^{90}Sr and ^{3}H in urine served as performance indicator to corroborate the capabilities of *in-vitro* radiobioassay monitoring carried out by the participating laboratories. Samples of urine, intentionally spiked with radionuclides obtained by dilution from certified reference materials, were distributed for measurement among participants, along with detailed instructions for reporting through a secure web-interface.

A reference phantom equipped with certified rod sources, which were produced by BfS with support from the European Commission Directorate-General Energy, Luxemburg, under contract ENER/2019/NUCL/SI2.811157, was circulated for measurement among participating laboratories in a round-robin style experiment.

2.3. PERFORMANCE CRITERIA

Statistical exploitation of results and performance evaluation for each measurement compared the relative bias, the zeta-score (for *in-vivo* radiobioassay) and the z-score (for *in-vitro* radiobioassay) against the performance limits of ISO 28218:2010 [3], $-0.25 < B_r < 0.5$, and ISO 13528:2022 [4], $|\zeta| \leq 2$ and $|z| \leq 2$. Further guidance is provided by Thompson *et al.* [6].

The relative bias, B_r, describes the deviation of the measured activity or activity concentration, a, from the assigned reference value, A:

$$B_r = \frac{a - A}{A} \quad \text{with} \quad -0.25 < B_r < 0.5$$

The assigned value, A, is the best estimate of the value of the measurand. It can be determined by one of the following methods [4, 6]:

- measurement by a reference laboratory,
- certified value(s) for a certified reference material (CRM) used as proficiency test item,
- direct comparison of the proficiency testing item with CRMs,
- consensus value from expert laboratories,
- consensus value from participants' results, or
- formulation (i.e., value assignment on the basis of proportions used in a solution or other mixture of ingredients with known analyte content).

Assigned values and estimates of their uncertainties have not been disclosed to the participants until after the reporting deadline for the results.

The primary idea of scoring is to make all proficiency test results comparable, so that the significance of a score is immediately apparent, no matter what the concentration or identity of the analyte, the nature of the test material, the physical principle underlying the analytical measurement, or the organization providing the proficiency testing scheme. The zeta-score, ζ,

provides an indication of whether the participant's estimate of uncertainty is consistent with the observed deviation from the assigned value. It is calculated as follows:

$$\zeta = \frac{a - A}{\sqrt{u_a^2 + u_A^2}} \quad \text{with} \quad |\zeta| \leq 2$$

where u_a and u_A are the respective standard uncertainties of the measured activity and the assigned value. Zeta-scores outside ±2 are often regarded as questionable, while values outside ±3 are indicating a need for action. The cause might be underestimation of the uncertainty u_a, but might also be due to gross error causing the deviation $a - A$ to be large. Persistently low zeta-scores over a period of time might indicate over-estimation of uncertainty.

The z-score, *z*, is a standardized measure of performance. It provides an appropriate scaling of the difference between a participant's result and the assigned value. It is calculated as follows:

$$z = \frac{a - A}{\sigma_A} \quad \text{with} \quad |z| \leq 2$$

where σ_A is the standard deviation for proficiency assessment. The z-score cannot be calculated if the number of participants is less than seven. The interpretation of z-scores is *not* generally based on summary statistics that describe the observed participants' results. Instead, it uses an assumed model based on the proficiency testing scheme provider's fitness-for-purpose criterion, which is represented by the standard deviation for proficiency assessment, σ_A. A z-score of zero implies a perfect result. This will happen rarely even in the most competent laboratories. Approximately 95% of z-scores will fall between –2 and +2. Scores in this range are commonly designated acceptable or satisfactory. A score outside ±3 would be very unusual and is taken to indicate that the cause of the event should be investigated and remedied. Scores in this class are indicating a need for action.

To present the different performance parameters in a concise graph, Naji2 plots can be used which combine the z-score and the zeta-score with the uncertainties provided by the participants. This intuitive graphical tool allows a comprehensive assessment of the laboratory performance and enables to identify the need for corrective actions. Assuming that the zeta-score is smaller than a certain performance limit, *p*, as defined in ISO 28218:2010 [3], and using the definitions of the zeta- and z-score, respectively, the following relation can be derived:

$$p \geq \zeta = \sigma_A \cdot z / \sqrt{u_a^2 + u_A^2}$$

which further transforms into:

$$(u_a/\sigma_A)^2 \geq z^2/p^2 - (u_A/\sigma_A)^2$$

This equation describes the Naji2 plot parabolas, when plotting $(u_a / \sigma_A)^2$ (y-axis) over *z* (x-axis), as illustrated in Figure 1. Two lines distinguish between the three cases of performance (realistic, under-estimated or over-estimated uncertainty), as described in Table 1.

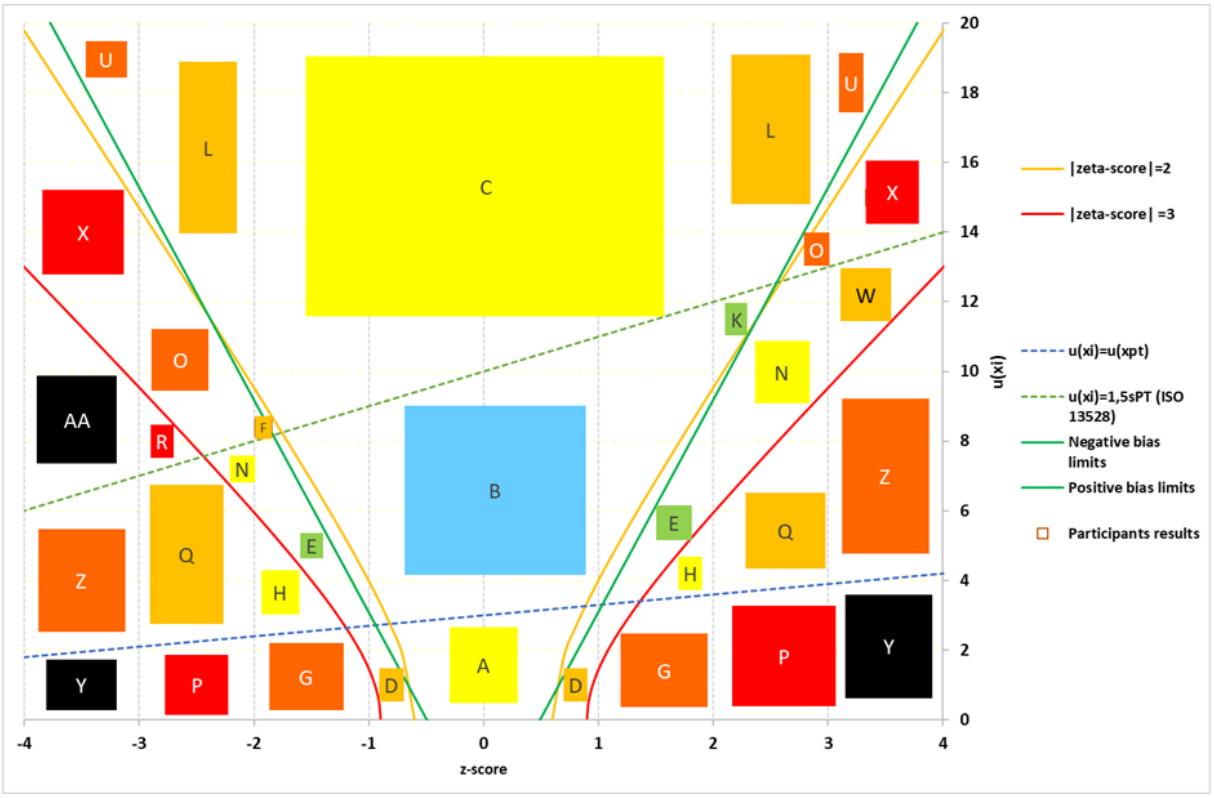

Figure 1. Naji2 plot presenting the uncertainty, u_a, reported by a participant versus the z-score, after Cordeiro et al. [7]. Orange parabolas delimit $|\zeta| = 2$, while red parabolas delimit $|\zeta| = 3$. The dotted blue and dotted green lines delimit the realistic uncertainty range, while the two green lines define the bias boundaries ($z = 0$). Letters denote various Naji plot areas further described in Table 1.

Table 1: Naji2 plot areas identified by letters defining cases of satisfactory, questionable, and unsatisfactory performance. An asterisk marks an unrealistic scenario.

z	***ζ***	**Uncertainty**	**Naji plot area**
Satisfactory	Satisfactory	Underestimated	A
		Realistic	B
		Overestimated	C
	Questionable	Underestimated	D
		Realistic	E
		Overestimated	F
	Unsatisfactory	Underestimated	G
		Realistic	H
		Overestimated	I*

Table 1 (cont.): Naji2 plot areas identified by letters defining cases of satisfactory, questionable, and unsatisfactory performance. An asterisk marks an unrealistic scenario.

z	ζ	Uncertainty	Naji plot area
Questionable	Satisfactory	Underestimated	J*
		Realistic	K
		Overestimated	L
	Questionable	Underestimated	M*
		Realistic	N
		Overestimated	O
	Unsatisfactory	Underestimated	P
		Realistic	Q
		Overestimated	R
Unsatisfactory	Satisfactory	Underestimated	S*
		Realistic	T*
		Overestimated	U
	Questionable	Underestimated	V*
		Realistic	W
		Overestimated	X
	Unsatisfactory	Underestimated	Y
		Realistic	Z
		Overestimated	AA

2.4. PARTICIPATING LABORATORIES

2.4.1. In-vitro Radiobioassay

Commissariat à l'énergie atomique et aux énergies alternatives, Centre CEA Paris-Saclay
DG/CEA PSAC/DSPS/LBM
BP 2 - Bâtiment 601
91191 Gif-sur-Yvette, France

Commissariat à l'énergie atomique et aux énergies alternatives, Centre CEA Valduc
DSTA/LBM
BP 14 - Bâtiment 105
21120 Is-sur-Tille, France

International Atomic Energy Agency
Radiation Safety Technical Services Laboratory
Division of Radiation, Transport and Waste Safety
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Tokyo Electric Power Company Holdings Inc
Fukushima Daiichi Decontamination and Decommissioning Engineering Company
Fukushima Daiichi Nuclear Power Station
22 Kitahara, Ottozawa, Okuma-machi, Futaba, Fukushima 979-1301, Japan

The IAEA Radiation Safety Technical Services Laboratory is accredited to ISO/IEC 17025:2017 [8] for *in-vivo* radiobioassay monitoring.

Further laboratories attending the 2024 PROCORAD ILC, which were used for comparison with the results submitted by IAEA and TEPCO, are presented in Table 2. Of those, 34 laboratories were registered for strontium bioassay in urine, and 47 laboratories were registered for tritium bioassay in urine.

Table 2: Laboratories participating in the 2024 PROCORAD interlaboratory comparison on in-vitro radiobioassay monitoring.

Laboratory	**Country**
Bayerisches Landesamt für Umwelt	DEU
Brazilian Nuclear Energy Commission, Poços de Caldas Laboratory	BRA
Bundesamt für Strahlenschutz	DEU
Cavendish Nuclear	GBR
CEA Military Applications Division	FRA
Centers for Disease Control and Prevention, NCEH Radiation Analytical Toxicology Laboratory	USA
Central Laboratory for Radiological Protection	POL
CHUV Chemical Radioanalytical Group IRA	CHE
CIEMAT Radiation Protection Laboratory	ESP
Dosimetry Services	GBR
Drace Geocisa	ESP
Electricité de France	FRA
ENEA	ITA
ENEA Radiation Protection Institute	ITA
ENEA CR Frascati	ITA
ENEA CR Saluggia	ITA
ENUSA Industrias Avanzadas, S.A., S.M.E.	ESP
European Commission JRC	ITA
Forschungszentrum Jülich GmbH	DEU
Greek Atomic Energy Commission	GRC
Health Canada Radiation Protection Bureau	CAN
Institute for Nuclear Research	ROU
IRE	BEL
Istituto Zooprofilattico Sperimentale della Puglia e della Basilicata	ITA
Japan Atomic Energy Agency, Nuclear Fuel Cycle Engineering Laboratories	JPN
Karlsruher Institut für Technologie	DEU

Table 2 (cont.): Laboratories participating in the 2024 PROCORAD interlaboratory comparison on in-vitro radiobioassay monitoring.

Laboratory	**Country**
Kinectrics Inc.	CAN
LABM CEA Cadarache	FRA
LABM CEA Marcoule	FRA
Laboratoire de biologie médicale Orano La Hague	FRA
LBM CEA Grenoble	FRA
LBMA IRSN	FRA
Medicinsk strålningsfysik	SWE
National Centre for Nuclear Research	POL
National Institutes for Quantum Science and Technology, Physical Dosimetry Group	JPN
NRCN-Radiotoxicologic Laboratory	ISR
NRS Dounreay	GBR
Nuclear Research & Consultancy Group	NLD
Radiation Protection, National Health Authority	DNK
SN Nuclearelectrica SA, Cernavoda NPP, Dosimetry Laboratory	ROU
SN Nuclearelectrica SA, Cernavoda NPP, Environmental Control Laboratory	ROU
Savannah River Nuclear Solutions	USA
SCK•CEN	BEL
Seibersdorf Labor GmbH	AUT
Service de Protection Radiologique des Armées	FRA
Soreq Nuclear Research Center	ISR
South African Nuclear Energy Corporation	ZAF
UK Health Security Agency	GBR
U-Series Srl	ITA

2.4.2. In-vivo Radiobioassay

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Tokyo Electric Power Company Holdings Inc
Fukushima Daiichi Decontamination and Decommissioning Engineering Company
Fukushima Daiichi Nuclear Power Station
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The IAEA Radiation Safety Technical Services Laboratory is accredited to ISO/IEC 17025:2017 [8] for *in-vivo* radiobioassay monitoring. TEPCO is certified following the ANSI N13.30 standard [9].

The IAEA Radiation Safety Technical Services Laboratory's standard operating procedures require a follow-up measurement being performed using two high-purity germanium detectors (high-energy setup) if the initial measurement with a scanning NaI(Tl) scintillation detector indicated a radionuclide intake. Although the final result would be assigned from the follow-up measurement, the results obtained from the NaI(Tl) scintillation detector were also reported to facilitate comparison with the FASTSCAN™ high-throughput whole-body counter operated by TEPCO.

2.5. CONFIDENTIALITY OF DATA

The participating laboratories were assigned codes only known to the coordinator and separately announced to each laboratory upon registration. All published reports refer to these codes and the identities of the laboratories are protected.

2.6. UNCERTAINTIES

2.6.1. In-vitro Radiobioassay

The expanded uncertainty ($k = 2$) of the assigned value, U_A, was calculated in accordance with *Evaluation of Measurement Data: Guide to the Expression of Uncertainty in Measurement* (GUM) [10] under consideration of the main sources of uncertainty when preparing the CRM or the CRM dilution.

Wherever the assigned value was obtained from the robust mean of participants' results, the expanded uncertainty was calculated as follows:

$$U_A = 2 \times (1.25 \cdot s)/\sqrt{n}$$

where s is the robust standard deviation of results and n is the number of participating laboratories.

These uncertainties were increased to take into account any non-homogeneity and/or instability according to a method described in ISO 13528:2022 [4], based on the inter-sample standard deviation.

2.6.2. In-vivo Radiobioassay

The relative standard measurement uncertainties ($k = 1$) of the assigned reference value for the ^{134}Cs and ^{137}Cs certified rod sources used in the unified brick phantom were specified by BfS as 3%.

2.7. CERTIFICATES OF PARTICIPATION

Anonymized examples of Certificates of Participation are presented in the Appendix. These certificates were designed as stand-alone documents to be understandable and accessible to technical and technical and non-technical readers.

3. SELECTION AND PREPARATION OF REFERENCE MATERIALS

3.1. REFERENCE URINE SAMPLES

Reference urine samples were prepared from urine collected from workers not exposed to artificial radionuclides. The absence of ^{3}H or ^{90}Sr contamination was verified by liquid scintillation counting before the samples were acidified using hydrochloric acid. The pH was reduced to 2 to 2.5 after overloading and before distribution into the sample bottles to meet the transport regulations. 1 g/L of sodium benzoate was added to avoid bacterial and fungal contamination during shipment. Calculation of the overload activity as well as performance of homogeneity, stability and batch verification tests were documented internally.

Sample 24HTOA was composed of blank urine. Two samples (24HTOB and 24HTOC) were spiked with solutions of mineral tritium prepared from a certified reference solution. One sample (24HTOD) was composed of a dilution from marked urine during occupational exposure, and one sample (24HTOE) was obtained by dilution from the source used for spiking. The total activity of spikes is < 10 kBq/L for mineral tritium. The overload is prepared by dilution from CRMs.

For determination of ^{90}Sr in urine, samples 24SRA and 24SRB were spiked with a certified solution of $SrCl_2$ in 0.1 M HCl solution, with approximately 30 µg/g Sr and Y carriers. Sample 24SRC was composed of blank urine. Calculation of the final activities was obtained by mass.

PROCORAD ensured that the samples were sufficiently homogeneous and stable to guarantee the validity of the results, following the procedures described in Annex B to ISO 13528:2022 [4]. Homogeneity and stability tests were carried out on a sample of entities subjected to the test. The evaluation criteria for checking homogeneity and stability were based on a robust standard deviation estimate from previous campaigns.

The certified reference values, X_c, were checked according to the procedure described in ISO 13528:2022 [4]. If the difference between the certified reference value and the robust mean, $\hat{\mu}_{rob}$, calculated from the participants' results was less than the expanded uncertainty ($k = 2$), the certified reference value was considered the assigned value:

$$\hat{\mu}_{rob} - X_c < 2 \cdot \sqrt{u_{\hat{\mu}_{rob}}^2 + u_{X_c}^2}$$

with $u_{\hat{\mu}_{\mathrm{rob}}}$ and $u_{X_{\mathrm{c}}}$ denoting the uncertainties of the robust mean and the certified reference value, respectively. Otherwise, the assigned value was considered the robust mean.

The certified reference value was used as the assigned value for samples 24HTOB, 24HTOC, 24SRA and 24SRB. The robust mean was considered the assigned value for samples 24HTOD and 24HTOE.

3.2. REFERENCE PHANTOM

The intercomparison was carried out using an UP-02T unified brick phantom consisting of rectangular bricks made from polyethylene, which can be set up in different shapes (F1–F6) resembling persons of weight 12 kg to 110 kg. The bricks contain holes, which were filled with certified rod sources of known activities. These phantoms are an unofficial *de facto* standard that is used worldwide by many laboratories for their calibrations and that is considered an appropriate method for calibration also by the International Commission on Radiation Units

and Measurement (ICRU) [11]. With its larger number of components, it is also more versatile to be set up in different postures such as lying in a stretcher geometry, sitting in a chair, or standing. For the ALPS ILC on *in-vivo* radiobioassay, the F4 size of phantom (adult, 70 kg, 170.5 cm) composed of 69 1-kg bricks and two 0.5-kg bricks has been chosen to correspond to the average weight of workers measured in whole-body counting laboratories operated by TEPCO (Figure 2). The phantom features tissue-equivalent properties regarding the attenuation of photon radiation in an energy range of at least 150 to 3000 keV.

The certified rod sources were produced by BfS with support from the European Commission Directorate-General Energy, Luxemburg, under contract ENER/2019/NUCL/SI2.811157. Each rod source is a capsule of polyethylene and radioactive filling made from epoxy resin, with a length of approximately 16.5 cm and a diameter of 6 mm (Figure 3) [12].

Figure 2. The F4-size UP-02T unified brick phantom consisting of rectangular polyethylene bricks set up in a stretcher and standing geometry.

Figure 3: Rod sources used in the ALPS interlaboratory comparison on in vivo radiobioassay.

4. RESULTS AND DISCUSSION: IN-VITRO RADIOBIOASSAY

4.1. ANALYTICAL METHODS

4.1.1. Tritium in Urine

The analytical methods applied by the participating laboratories for determination of tritium in urine are compiled in Table 3. The methods align with international best practice. Different types of liquid scintillation counters were used: TriCarb, Hidex 300 SL and AccuFLEX LSC-LB7. One laboratory used the triple-to-double coincidence ratio (TDCR) method with the Hidex 300 SL.

Table 3: Analytical methods used by the laboratories participating in the in-vitro radiobioassay ILC for determination of tritium in urine.

Laboratory	Scintillation cocktail	Sample volume	Scintillation cocktail volume	Counting time for total tritium	Chemical quenching	Colour quenching
11	Revvity Ultimagold®	1 mL	15 mL	1200 s	Yes	No
21	Revvity Ultimagold®	2 mL	15 mL	6000 s	Yes	Yes
35	Revvity Ultimagold®	1 mL	13 mL	6000 s	Yes	No
60	Revvity Ultimagold®	1 mL	15 mL	600 s	Yes	Yes

4.1.2. Strontium in Urine

The analytical methods applied by the participating laboratories for determination of ^{90}Sr in urine are summarized in Table 4. The methods used vary in the type of chemical treatment of samples, the use of chromatographic separation and measurement techniques, the counting times, the isotopes measured and the use of tracers. One laboratory used the Čerenkov effect for measurement.

Table 4: Analytical methods used by the laboratories participating in the in-vitro radiobioassay ILC for determination of strontium in urine.

Laboratory	Sample volume	Chemical treatment	Chromatography	Measurement technique
11	250 mL	Oxalate	No	Proportional beta gas counting
21	500 mL	Calcium phosphate	Extraction	Liquid scintillation counting
35	200 mL	Calcium phosphate	Strontium resin	Proportional beta gas counting
60	250 mL	Oxalate	Strontium resin	Liquid scintillation counting

Table 4 (cont.): Analytical methods used by the laboratories participating in the in-vitro radiobioassay ILC for determination of strontium in urine.

Laboratory	Scintillation cocktail	Counting time	Measured isotope	Tracer
11	None	3600 s	^{90}Sr	No
21	None	6000 s	^{90}Y	No
35	None	10200 s	^{90}Sr	^{88}Sr
60	Instagel	1800 s	^{90}Sr	No

4.2. BIAS AND Z-SCORE

4.2.1. Tritium in Urine

24HTOA urine was comprised of non-spiked urine collected from workers not exposed to tritium. The expected result for this sample is the absence of tritium, which was consistently confirmed by all four laboratories.

The reference values and results obtained for samples 24HTOB, 24HTOC, 24HTOD and 24HTOE from the in-vitro radiobioassay ILC on determination of tritium in urine are presented in Tables 5 to 8. For samples 24HTOB and 24HTOC, the assigned value was the certified reference value. For samples 24HTOD and 24HTOE, the robust mean was considered the assigned value. The z-score was calculated for the total number of participants $n = 44$. Uncertainties are provided for a coverage factor $k = 2$.

Table 5: Reference values and results for sample 24HTOB of in-vitro radiobioassay ILC on determination of tritium in urine.

Laboratory	Measured activity (Bq/L)	Assigned value (Bq/L)	B_r	z
11	2150 ± 328	2220 ± 90	−0.03	−0.60
21	2250 ± 393		0.01	0.26
35	2070 ± 158		−0.07	−1.28
60	2040 ± 367		−0.08	−1.54

Table 6: Reference values and results for sample 24HTOC of in-vitro radiobioassay ILC on determination of tritium in urine.

Laboratory	Measured activity (Bq/L)	Assigned value (Bq/L)	B_r	z
11	5900 ± 900	5910 ± 228	−0.00	−0.03
21	5990 ± 958		0.01	0.25
35	5650 ± 362		−0.04	−0.81
60	5580 ± 596		−0.06	−1.03

Table 7: Reference values and results for sample 24HTOD of in-vitro radiobioassay ILC on determination of tritium in urine.

Laboratory	Measured activity (Bq/L)	Assigned value (Bq/L)	B_r	z
11	8960 ± 1370	8628 ± 170	0.04	0.73
21	9050 ± 1360		0.05	0.93
35	8300 ± 515		−0.04	−0.73
60	8740 ± 709		0.01	0.25

Table 8: Reference values and results for sample 24HTOE of in-vitro radiobioassay ILC on determination of tritium in urine.

Laboratory	Measured activity (Bq/L)	Assigned value (Bq/L)	B_r	z
11	9850 ± 1500	9439 ± 173	0.04	0.90
21	9820 ± 1470		0.04	0.83
35	9090 ± 564		−0.04	−0.76
60	8850 ± 716		−0.06	−1.28

The results from all laboratories comply with the performance limits of ISO 28218:2010 [3] and ISO 13528:2022 [4]. The biases were < 10 %. To complement the results, graphs of the relative bias and the z-score are presented in the Appendix, along with the corresponding Naji2 plots.

4.2.2. Strontium in Urine

24SRC urine was comprised of non-spiked urine collected from workers not exposed to ^{90}Sr. The expected result for this sample is the absence of ^{90}Sr, which was consistently confirmed by all four laboratories.

The reference values and results obtained for samples 24SRA and 24SRB from the in-vitro radiobioassay ILC on determination of strontium in urine are presented in Tables 9 and 10. The assigned value was the certified reference value. The z-score was calculated for the total number of participants n = 34. Uncertainties are provided for a coverage factor k = 2.

Table 9: Reference values and results for sample 24SRA of in-vitro radiobioassay ILC on determination of strontium in urine.

Laboratory	Measured activity (Bq/L)	Assigned value (Bq/L)	B_r	z
11	4.32 ± 0.48	4.78 ± 0.23	−0.10	−0.92
21	5.18 ± 1.10		0.08	0.80
35	5.01 ± 0.37		0.05	0.46
60	4.28 ± 0.38		−0.11	−1.00

Table 10: Reference values and results for sample 24SRB of in-vitro radiobioassay ILC on determination of strontium in urine.

Laboratory	Measured activity (Bq/L)	Assigned value (Bq/L)	B_r	z
11	2.72 ± 0.32	2.95 ± 0.10	−0.08	−0.69
21	2.99 ± 0.66		0.01	0.12
35	2.94 ± 0.28		−0.00	−0.03
60	2.49 ± 0.25		−0.16	−1.38

The results from all laboratories comply with the performance limits of ISO 28218:2010 [3] and ISO 13528:2022 [4] The biases were < 20 %. To complement the results, graphs of the relative bias and the z-score are presented in the Appendix, along with the corresponding Naji2 plots.

5. RESULTS AND DISCUSSION: IN-VIVO RADIOBIOASSAY

5.1. ANALYTICAL METHODS

The analytical methods applied by the laboratories participating in the *in-vivo* radiobioassay ILC are compiled in Table 11. The methods align with international best practice. Different detector types were used: electrically-cooled broad-energy (BE) high-purity (HP) Ge and NaI(Tl) scintillators.

Table 11: Analytical methods used by the laboratories participating in the in-vivo radiobioassay ILC.

Laboratory	Shielding	Detector(s)	Energy range/ channels	Analysis software
1	10.5 cm steel (4π)	Electrically-cooled HPGe (2)	10~2100 keV 8192	Apex-InVivo™ Genie™ 2000
2	10.5 cm steel (4π)	LED temp.-stabilized scanning Na(Tl) (1)	100~2100 512	Apex-InVivo™ Genie™ 2000
3	10 cm steel	Two NaI(Tl) (2)	88~1836 512	Apex-InVivo™ Genie™ 2000

Table 11 (cont.): Analytical methods used by the laboratories participating in the in-vivo radiobioassay ILC.

Laboratory	Calibration date (efficiency)	Calibration nuclides	Calibration phantom
1	10-2023	^{40}K, ^{60}Co, ^{88}Y, ^{133}Ba, ^{134}Cs, ^{137}Cs, ^{152}Eu	UP-02T unified brick phantom
2	10-2023	^{40}K, ^{60}Co, ^{88}Y, ^{133}Ba, ^{134}Cs, ^{137}Cs, ^{152}Eu	UP-02T unified brick phantom
3	06-2023	^{57}Co, ^{60}Co, ^{88}Y, ^{109}Cd, ^{113}Sn, ^{137}Cs, ^{139}Ce, ^{203}Hg	Mirion model 2257 phantom

5.2. BIAS AND ZETA-SCORE

The reference values and results obtained for *in-vivo* radiobioassay monitoring of ^{134}Cs and ^{137}Cs activity in the UP-02T unified brick phantom are presented in Tables 12 and 13. The assigned value was the certified reference value. Because of the low number of participants, $n < 7$, the z-score could not be calculated. Uncertainties are provided for a coverage factor $k = 2$.

Table 12: Reference values and results for in-vivo radiobioassay monitoring of ^{134}Cs in whole-body phantom.

Laboratory	Measured activity (Bq)	Assigned value (Bq)	B_r	ζ
1	2149 ± 106	2069 ± 124	0.04	0.98
2	1981 ± 82		−0.04	−1.19
3	2230 ± 700		0.08	0.45

Table 13: Reference values and results for in-vivo radiobioassay monitoring of ^{137}Cs in whole-body phantom.

Laboratory	Measured activity (Bq)	Assigned value (Bq)	B_r	ζ
1	4614 ± 260	4686 ± 282	−0.02	−0.38
2	4350 ± 188		−0.07	−1.99
3	4910 ± 1520		0.05	0.29

The results from all laboratories comply with the performance limits of ISO 28218:2010 [3] and ISO 13528:2022 [4]. The biases were < 10 %.

6. CONCLUSIONS

An extensive proficiency testing scheme was implemented to corroborate the capabilities of TEPCO's radiobioassay laboratory for the assessment of internal radiation exposure of workers involved in handling ALPS-treated water at FDNPS. This scheme aimed to determine laboratory performance, assess the quality of measurement results from *in-vitro* and *in-vivo* radiobioassay and identify opportunities for potential improvement. The performance was evaluated against pre-established criteria from the international standards ISO 28218:2010 [3] and ISO 13528:2022 [4].

6.1. IN-VITRO RADIOBIOASSAY

Interlaboratory comparisons were carried out for determination of tritium and strontium in urine. The participating laboratories met the performance limits regarding relative bias and z-score for all samples analysed, providing evidence for their high level of competence and the technical validity of monitoring results. No inconsistencies could be identified. The methods of analysis were found to be effective and comparable between the IAEA and TEPCO. Evaluation of the Naji2 plots concluded that the assessment of uncertainties for determination of tritium and strontium activity concentration in urine was realistic.

6.2. IN-VIVO RADIOBIOASSAY

An interlaboratory comparison was carried out for determination of ^{134}Cs and ^{137}Cs activity in a simulated human body. The participating laboratories met the performance limits regarding relative bias and zeta-score, providing evidence for their high level of competence and the technical validity of monitoring results. No inconsistencies could be identified. The methods of analysis were found to be effective and comparable between the IAEA and TEPCO. Evaluation of the zeta-score concluded that the assessment of uncertainties for determination of ^{134}Cs and ^{137}Cs activity in the whole body was realistic.

6.3. KEY FINDINGS

The key findings of the reported interlaboratory comparisons are:

- The TEPCO laboratory has demonstrated a high level of accuracy in its measurements and technical competence.
- Analytical procedures follow the appropriate methodological standards required to obtain technically valid results.

The IAEA notes that these findings provide confidence in Japan's capability for accurate measurement of activity in excreta and the human body due to radionuclide intakes by workers involved in handling ALPS-treated water.

APPENDIX I.

IN-VITRO RADIOBIOASSAY CHARTS FOR TRITIUM IN URINE

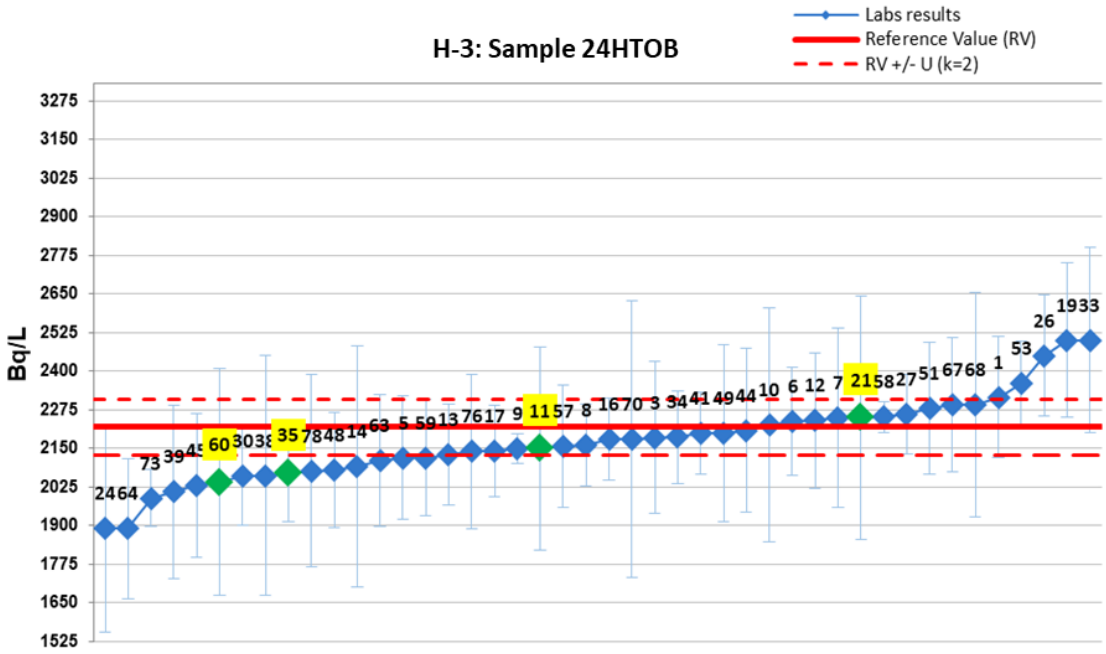

Figure 4. Relative bias and expanded measurement uncertainty of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOB). Red lines indicate the assigned value and associated uncertainty. Laboratories are identified by anonymized codes. Vertical axis refers to activities in Bq/L.

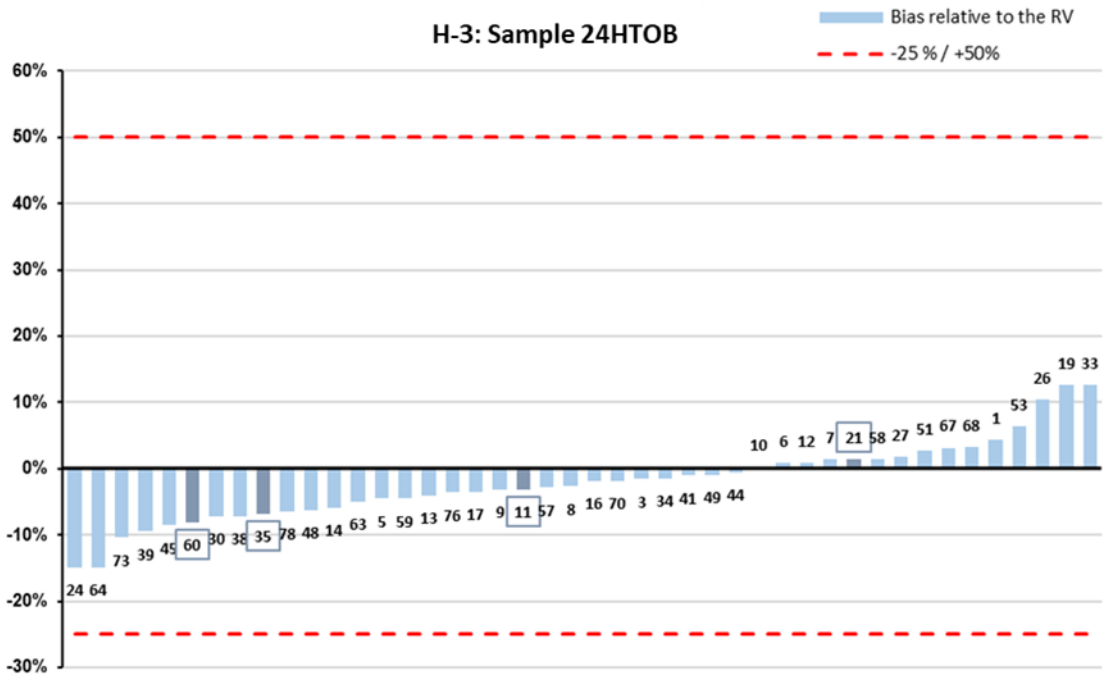

Figure 5. Relative bias of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOB). Dashed red lines indicate the performance limits of ISO 28218:2010 [3]. Laboratories are identified by anonymized codes. Vertical axis refers to relative bias.

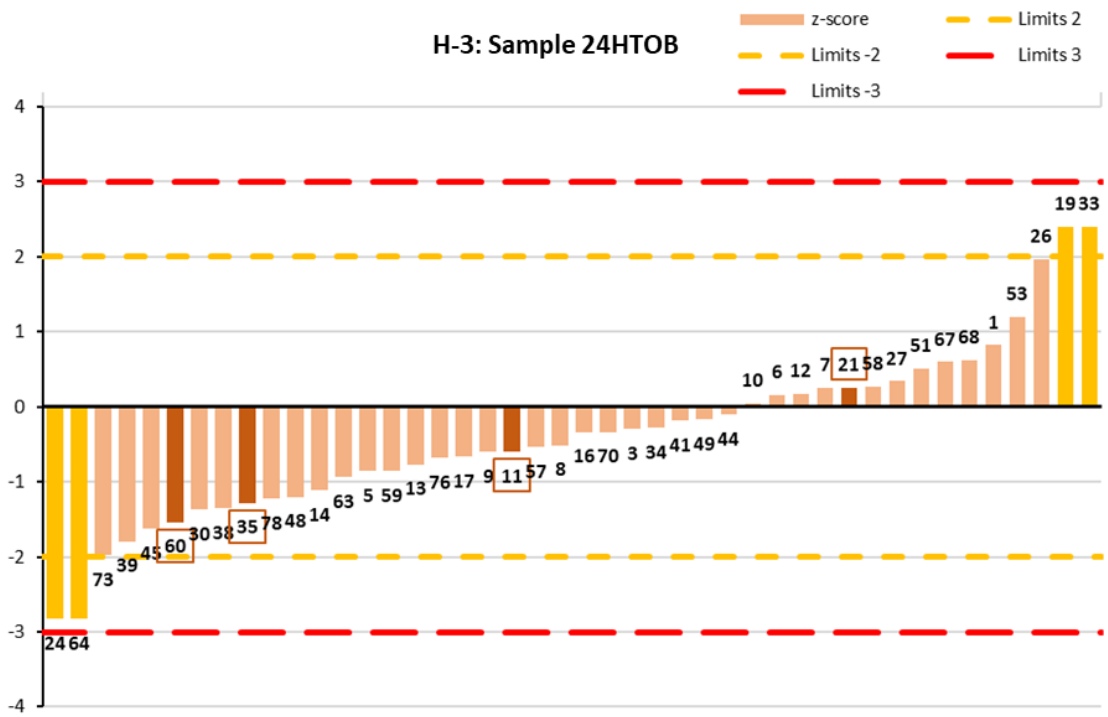

Figure 6. Z-score of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOB). Yellow and red lines indicate questionable (±2) and unsatisfactory (±3) performance, respectively. Laboratories are identified by anonymized codes. Vertical axis refers to z-score.

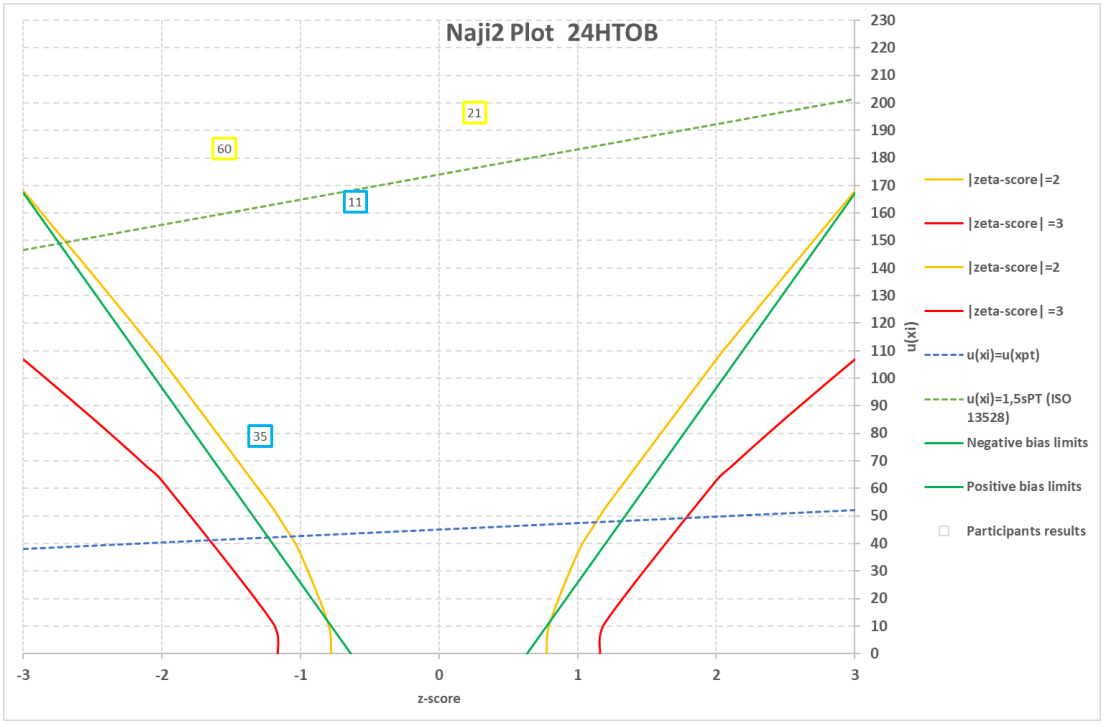

Figure 7. Naji2 plots of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOB).

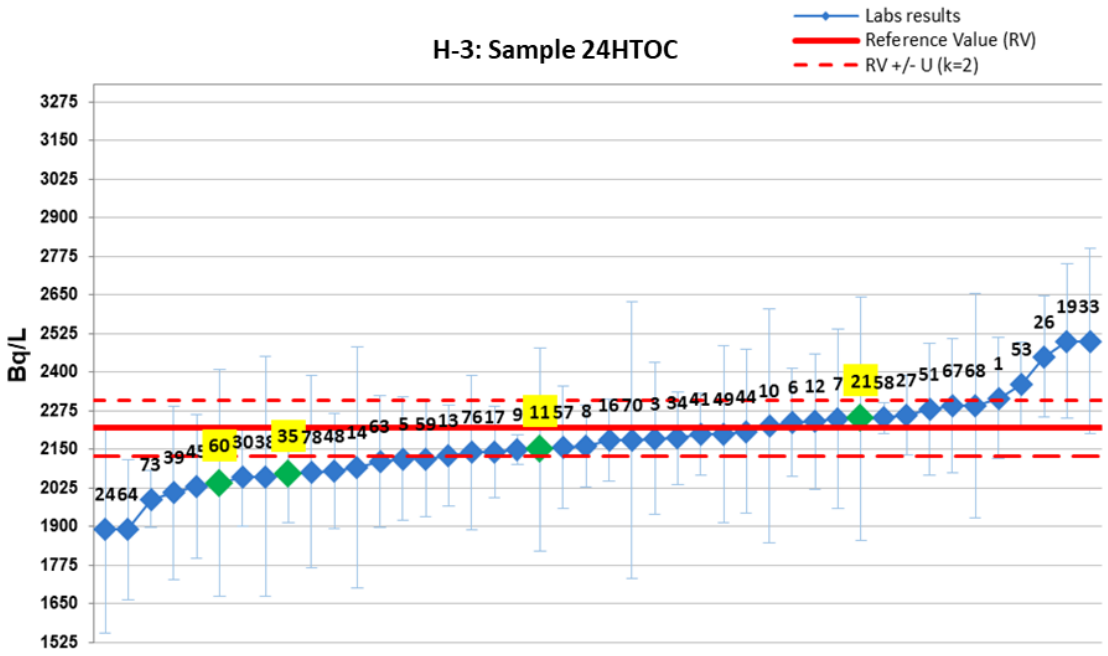

Figure 8. Relative bias and expanded measurement uncertainty of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOC). Red lines indicate the assigned value and associated uncertainty. Laboratories are identified by anonymized codes. Vertical axis refers to activities in Bq/L.

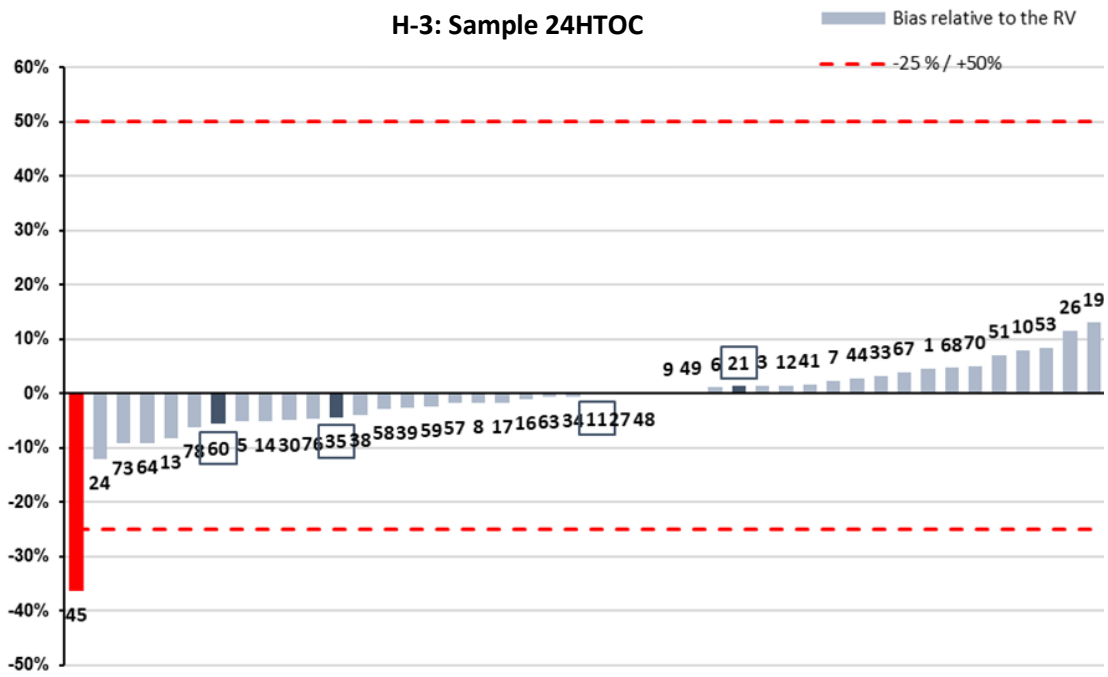

Figure 9. Relative bias of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOC). Dashed red lines indicate the performance limits of ISO 28218:2010 [3]. Laboratories are identified by anonymized codes. Vertical axis refers to relative bias.

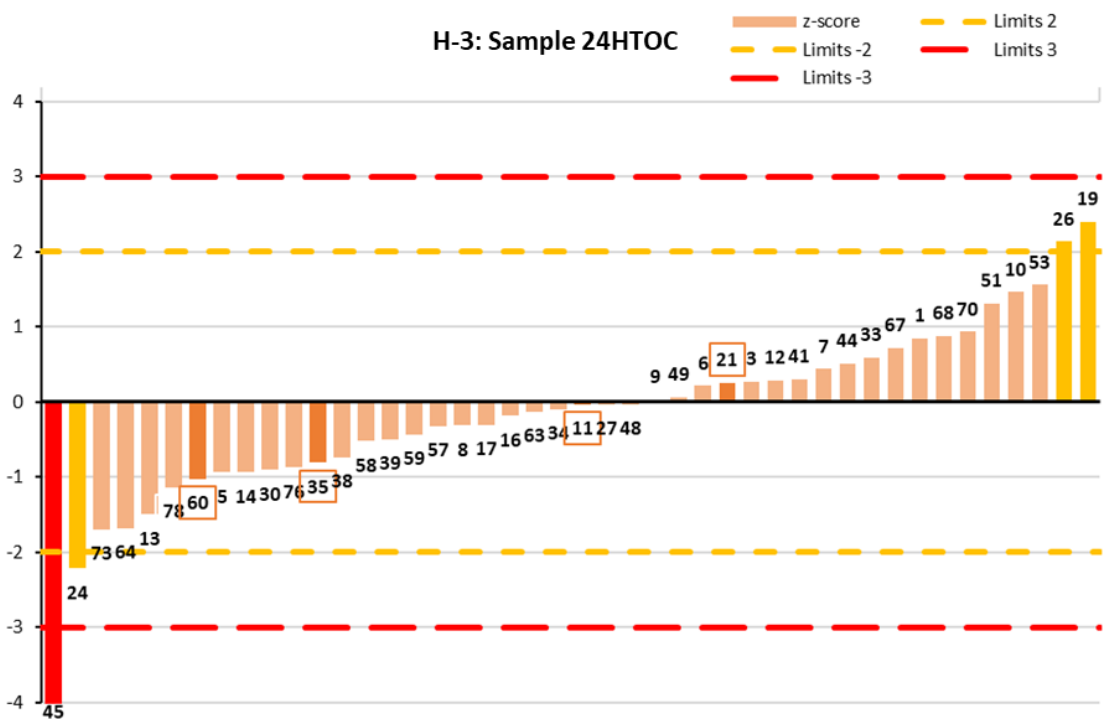

Figure 10. Z-score of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOC). Yellow and red lines indicate questionable (±2) and unsatisfactory (±3) performance, respectively. Laboratories are identified by anonymized codes. Vertical axis refers to z-score.

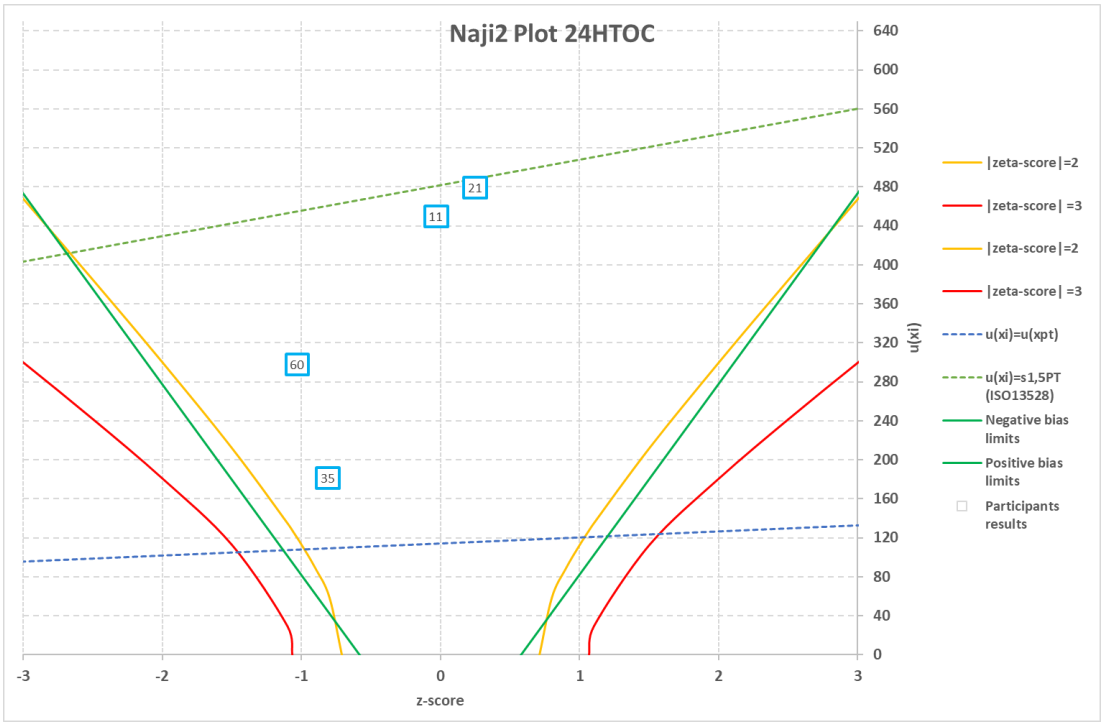

Figure 11. Naji2 plots of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOC).

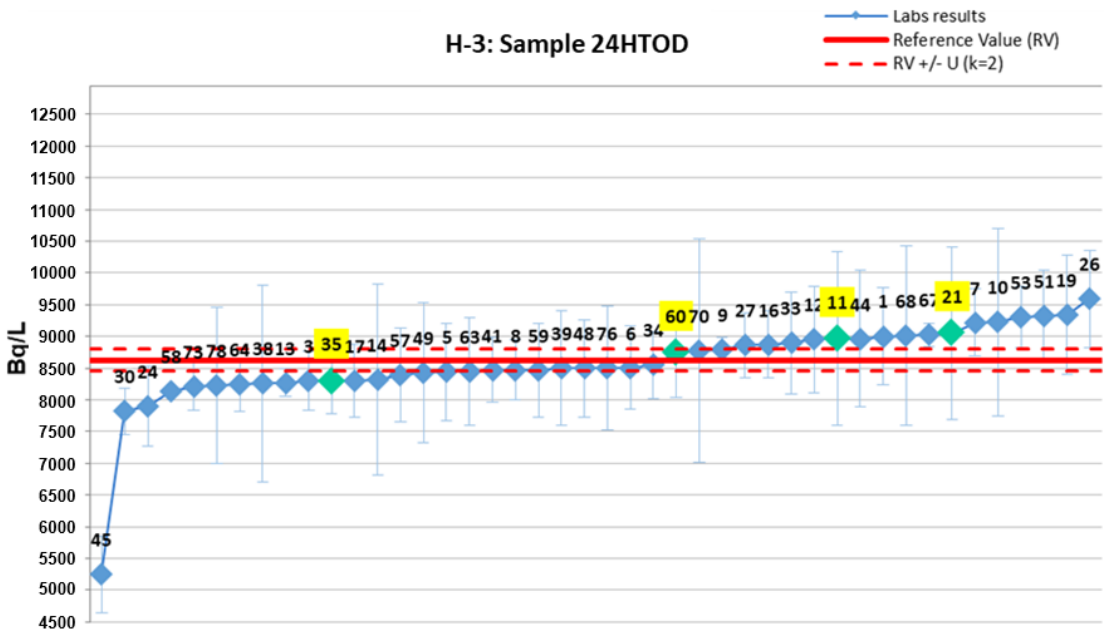

Figure 12. Relative bias and expanded measurement uncertainty of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOD). Red lines indicate the assigned value and associated uncertainty. Laboratories are identified by anonymized codes. Vertical axis refers to activities in Bq/L.

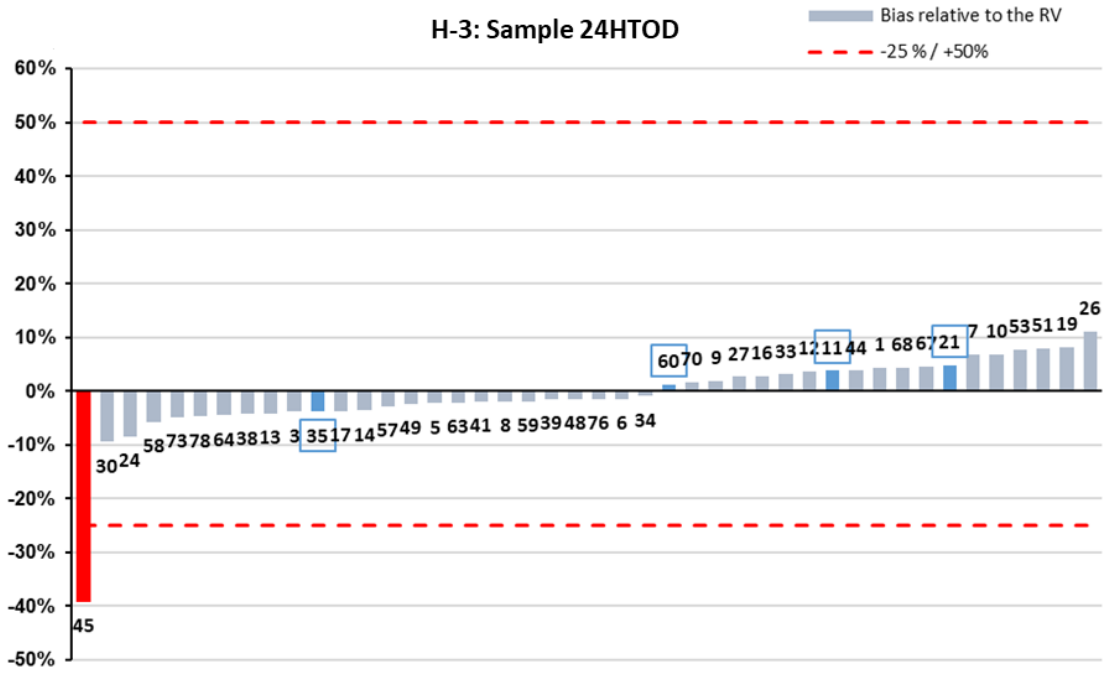

Figure 13. Relative bias of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOD). Dashed red lines indicate the performance limits of ISO 28218:2010 [3]. Laboratories are identified by anonymized codes. Vertical axis refers to relative bias.

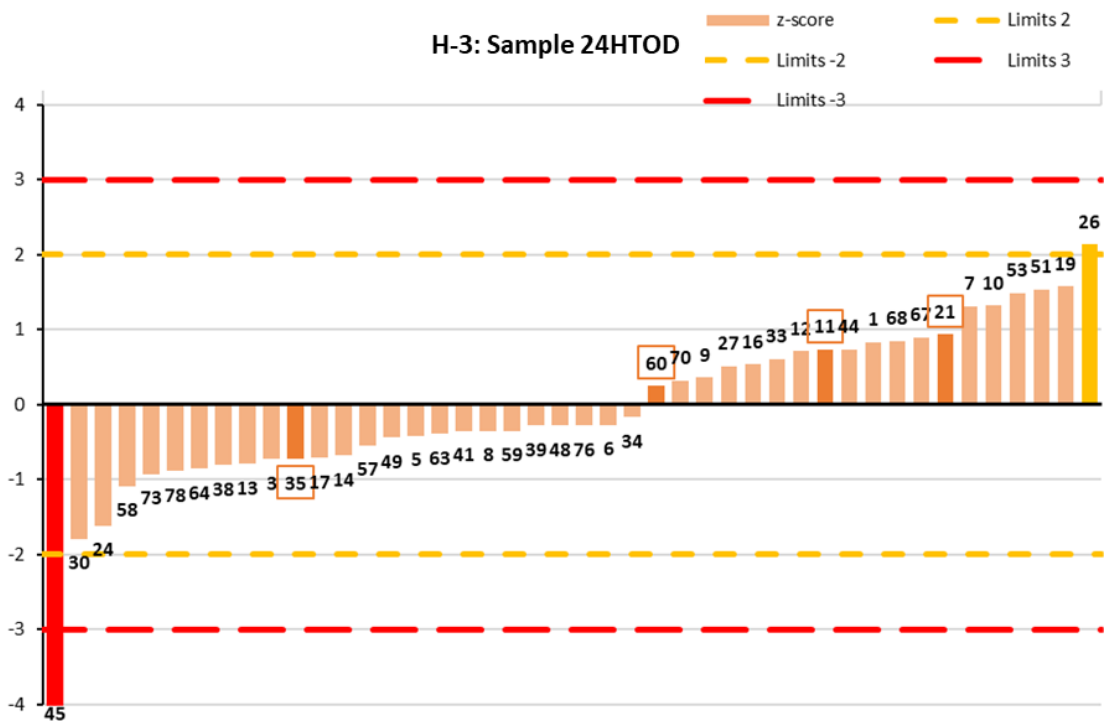

Figure 14. Z-score of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOD). Yellow and red lines indicate questionable (±2) and unsatisfactory (±3) performance, respectively. Laboratories are identified by anonymized codes. Vertical axis refers to z-score.

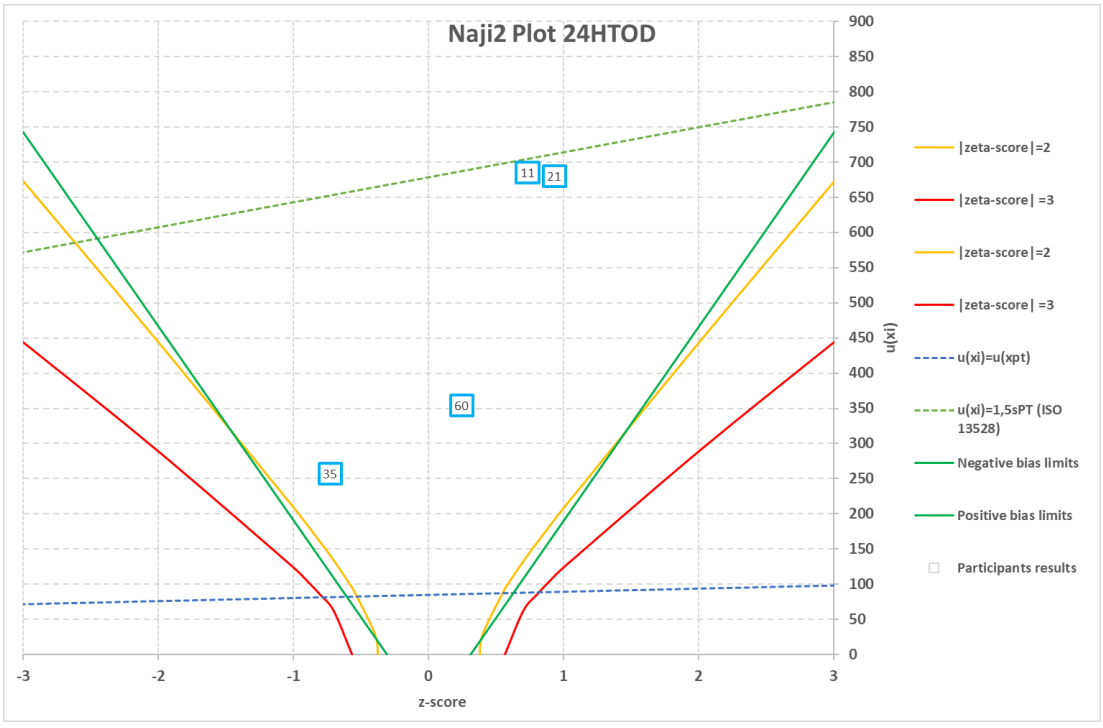

Figure 15. Naji2 plots of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOD).

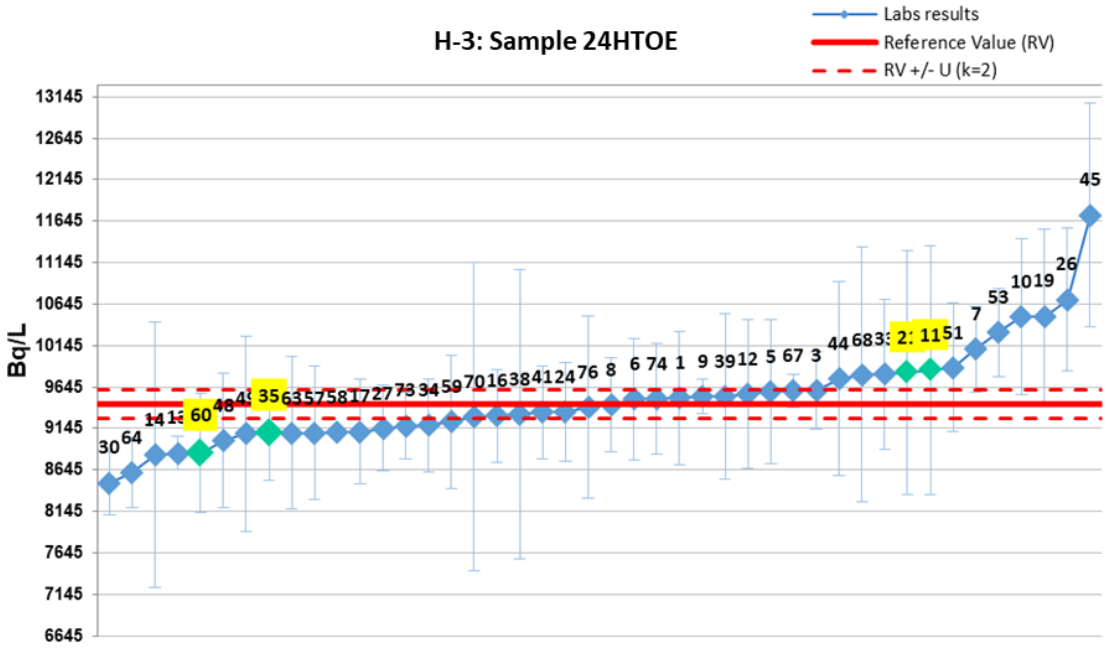

Figure 16. Relative bias and expanded measurement uncertainty of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOE). Red lines indicate the assigned value and associated uncertainty. Laboratories are identified by anonymized codes. Vertical axis refers to activities in Bq/L.

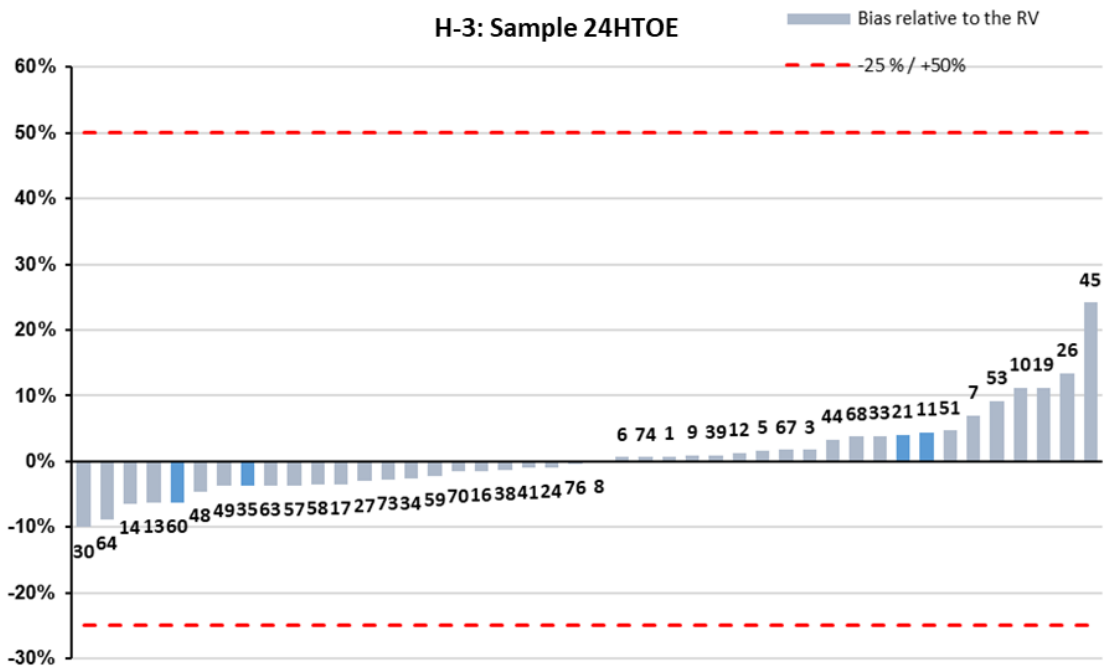

Figure 17. Relative bias of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOE). Dashed red lines indicate the performance limits of ISO 28218:2010 [3]. Laboratories are identified by anonymized codes. Vertical axis refers to relative bias.

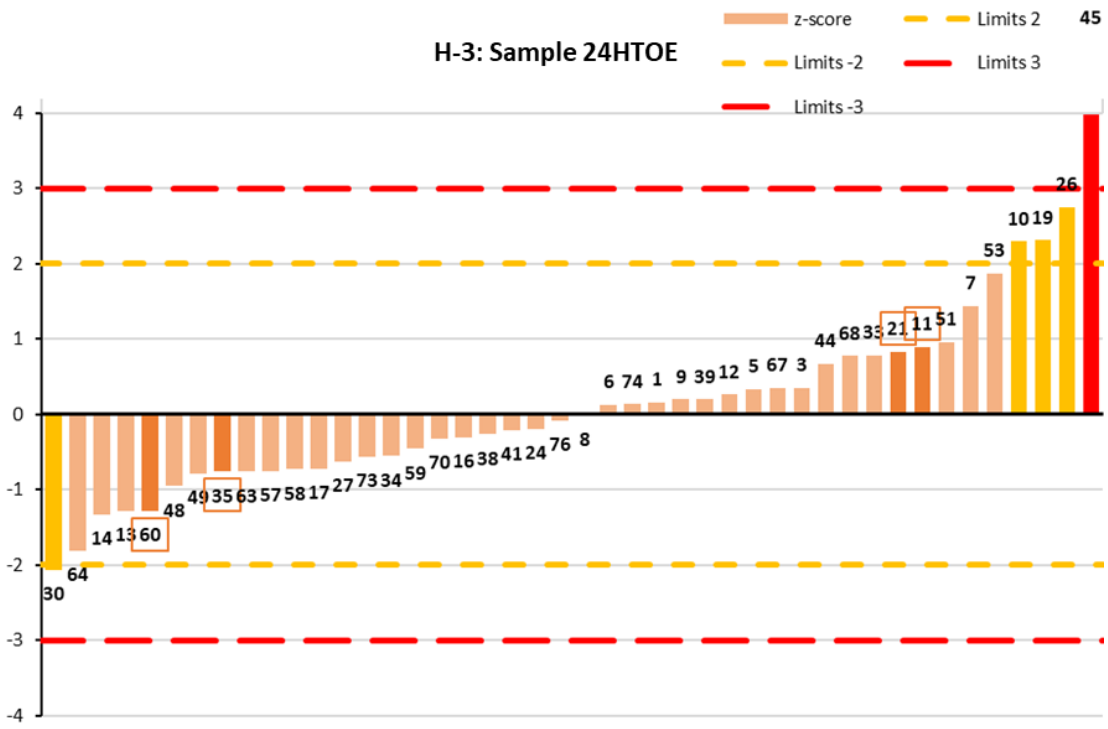

Figure 18. Z-score of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOE). Yellow and red lines indicate questionable (±2) and unsatisfactory (±3) performance, respectively. Laboratories are identified by anonymized codes. Vertical axis refers to z-score.

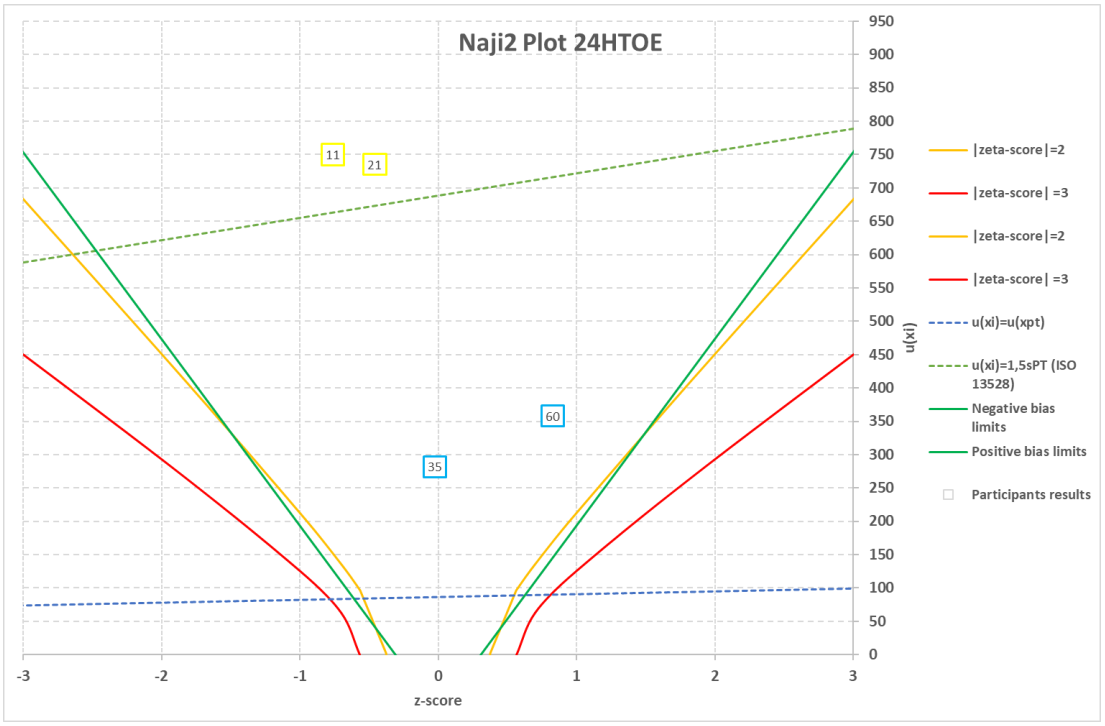

Figure 19. Naji2 plots of participants' results for in-vitro radiobioassay of tritium in urine (sample 24HTOE).

APPENDIX II.

IN-VITRO RADIOBIOASSAY CHARTS FOR STRONTIUM IN URINE

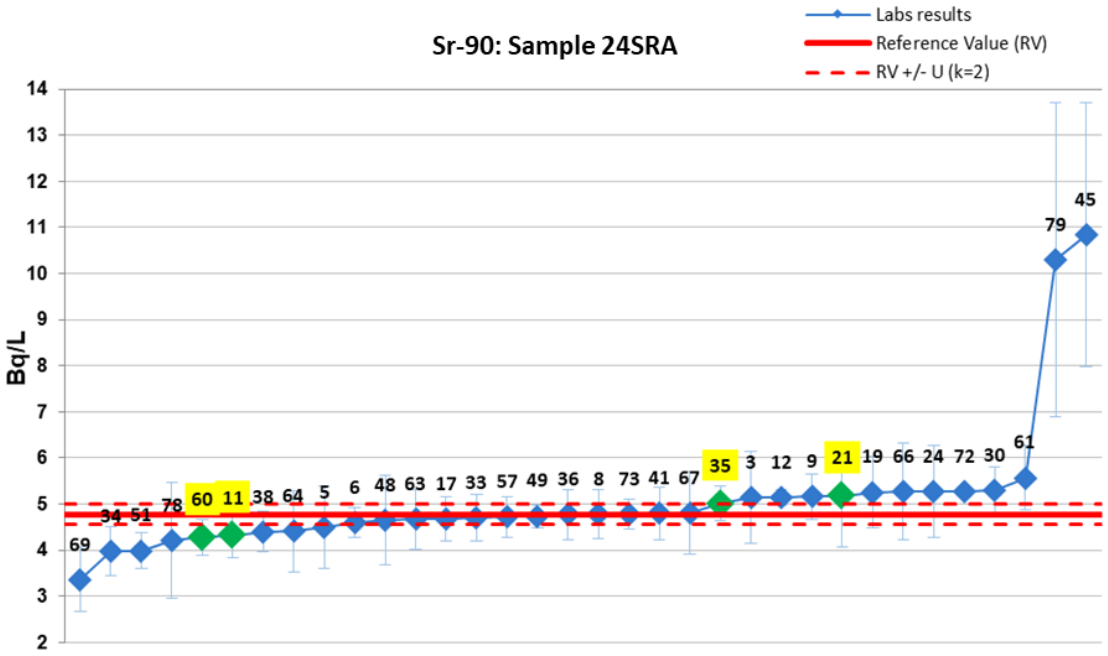

Figure 20. Relative bias and expanded measurement uncertainty of participants' results for in-vitro radiobioassay of strontium in urine (sample 24SRA). Red lines indicate the assigned value and associated uncertainty. Laboratories are identified by anonymized codes. Vertical axis refers to activities in Bq/L.

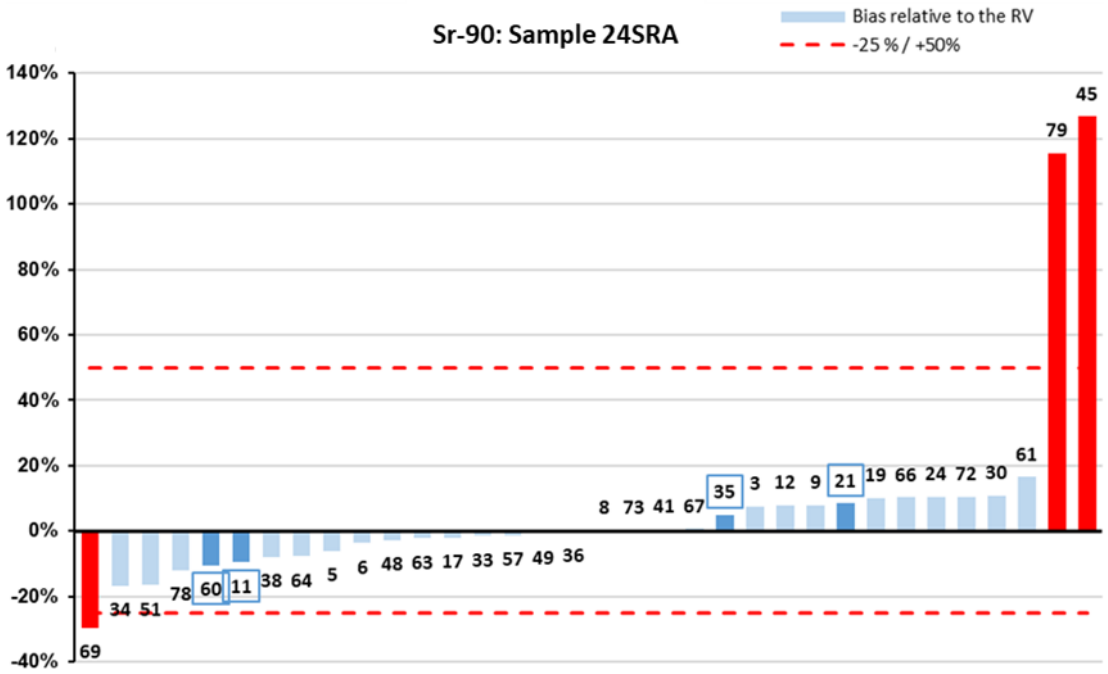

Figure 21. Relative bias of participants' results for in-vitro radiobioassay of strontium in urine (sample 24SRA). Dashed red lines indicate the performance limits of ISO 28218:2010 [3]. Laboratories are identified by anonymized codes. Vertical axis refers to relative bias.

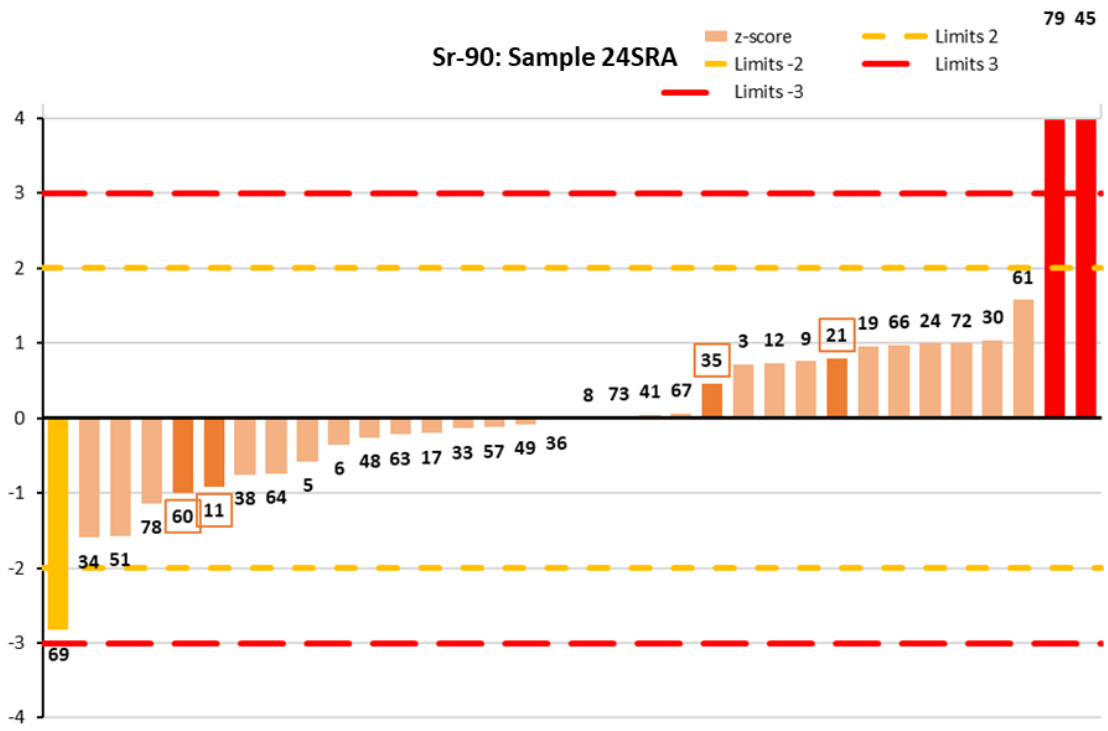

Figure 22. Z-score of participants' results for in-vitro radiobioassay of strontium in urine (sample 24SRA). Yellow and red lines indicate questionable (±2) and unsatisfactory (±3) performance, respectively. Laboratories are identified by anonymized codes. Vertical axis refers to z-score.

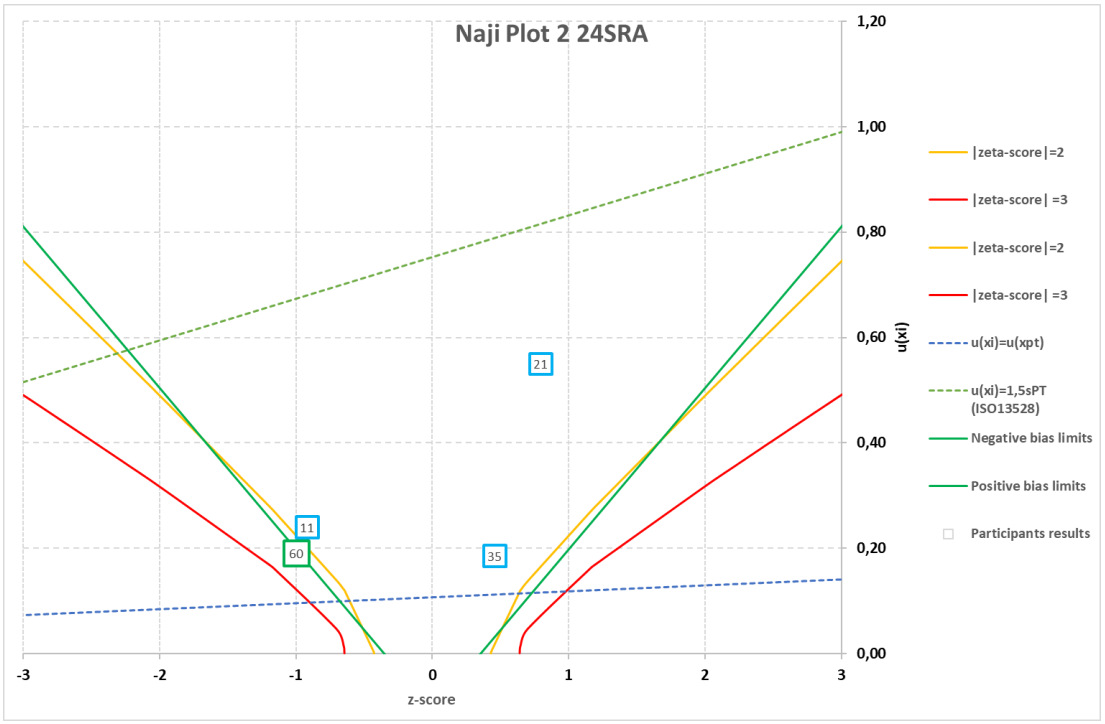

Figure 23. Naji2 plots of participants' results for in-vitro radiobioassay of strontium in urine (sample 24SRA).

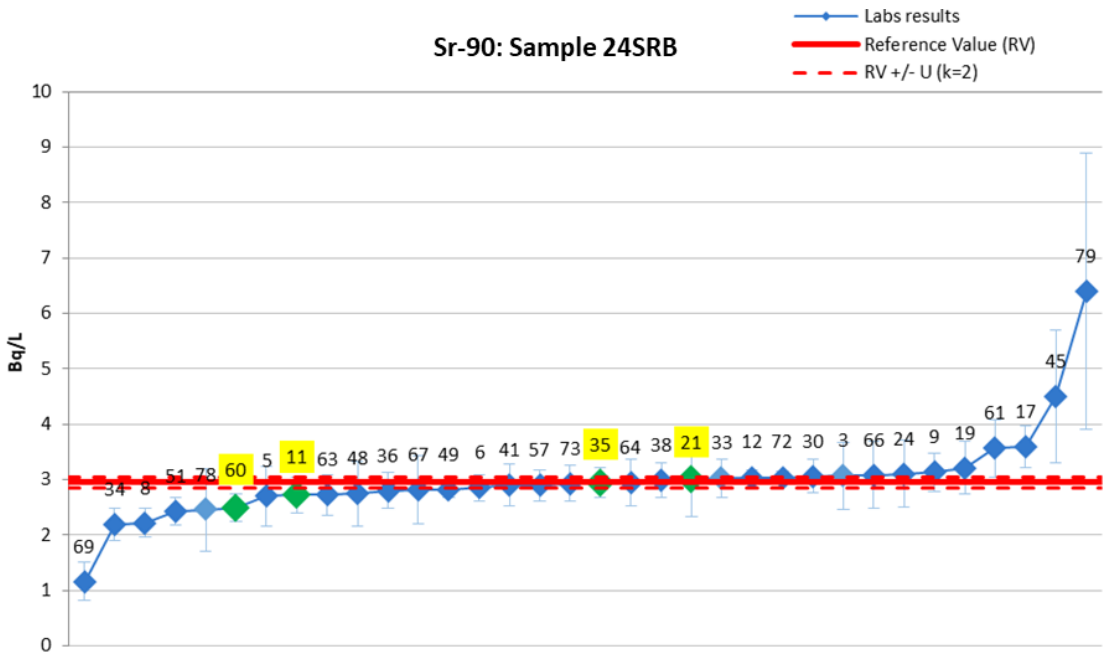

Figure 24. Relative bias and expanded measurement uncertainty of participants' results for in-vitro radiobioassay of strontium in urine (sample 24SRB). Red lines indicate the assigned value and associated uncertainty. Laboratories are identified by anonymized codes. Vertical axis refers to activities in Bq/L.

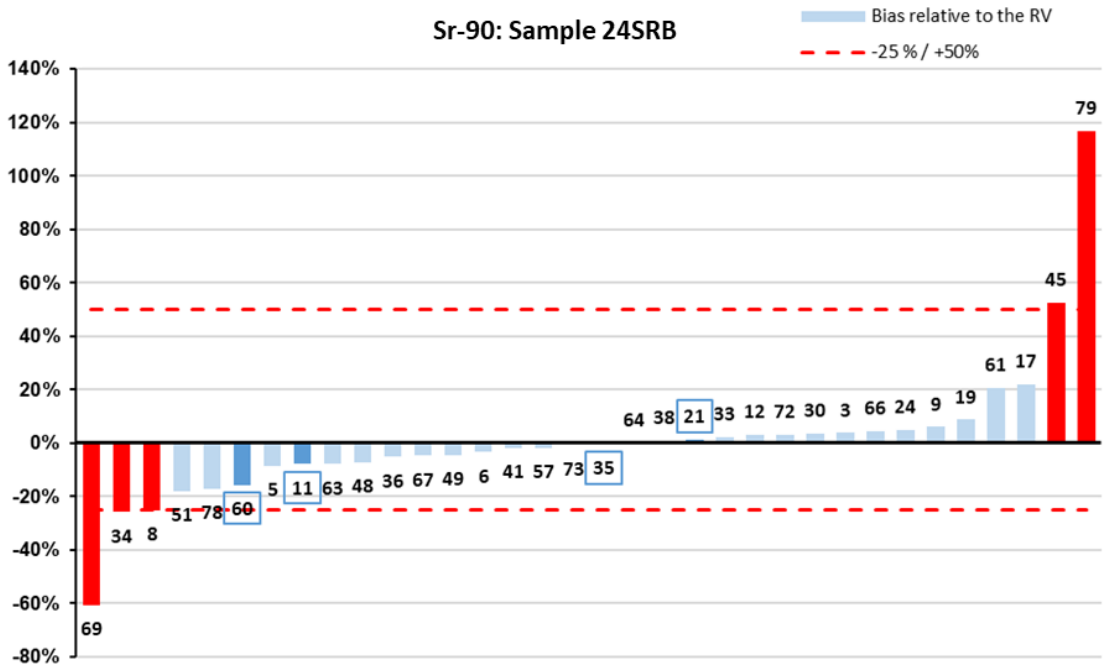

Figure 25. Relative bias of participants' results for in-vitro radiobioassay of strontium in urine (sample 24SRB). Dashed red lines indicate the performance limits of ISO 28218:2010 [3]. Laboratories are identified by anonymized codes. Vertical axis refers to relative bias.

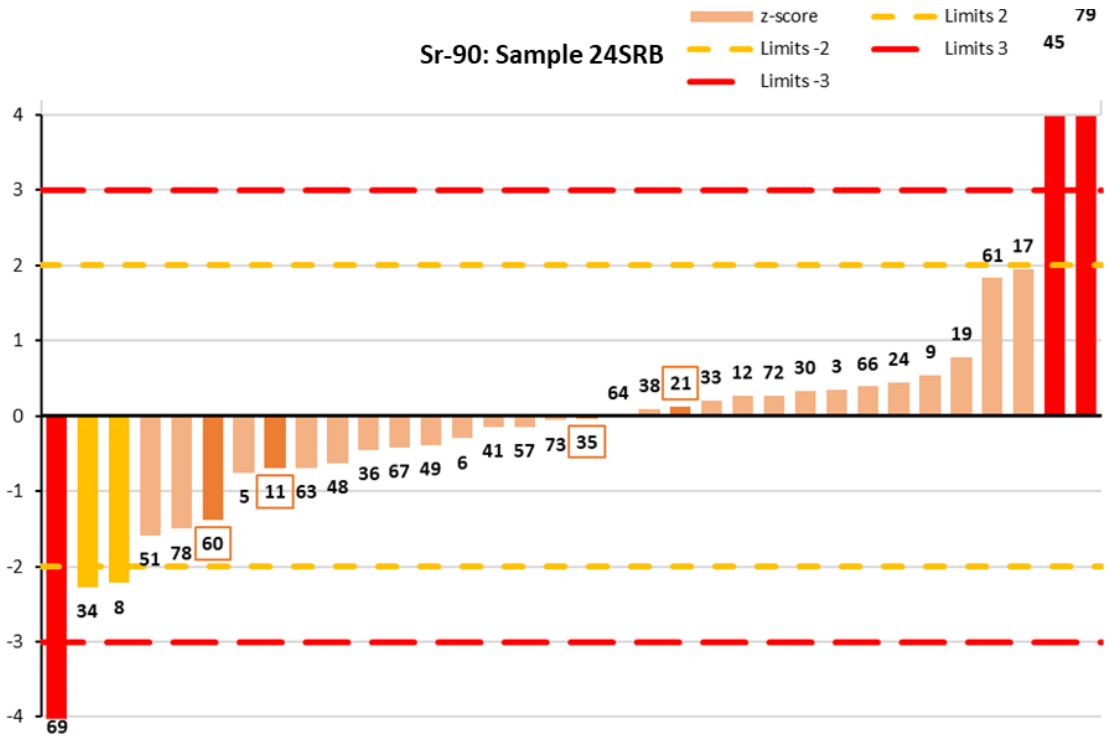

Figure 26. Z-score of participants' results for in-vitro radiobioassay of strontium in urine (sample 24SRB). Yellow and red lines indicate questionable (±2) and unsatisfactory (±3) performance, respectively. Laboratories are identified by anonymized codes. Vertical axis refers to z-score.

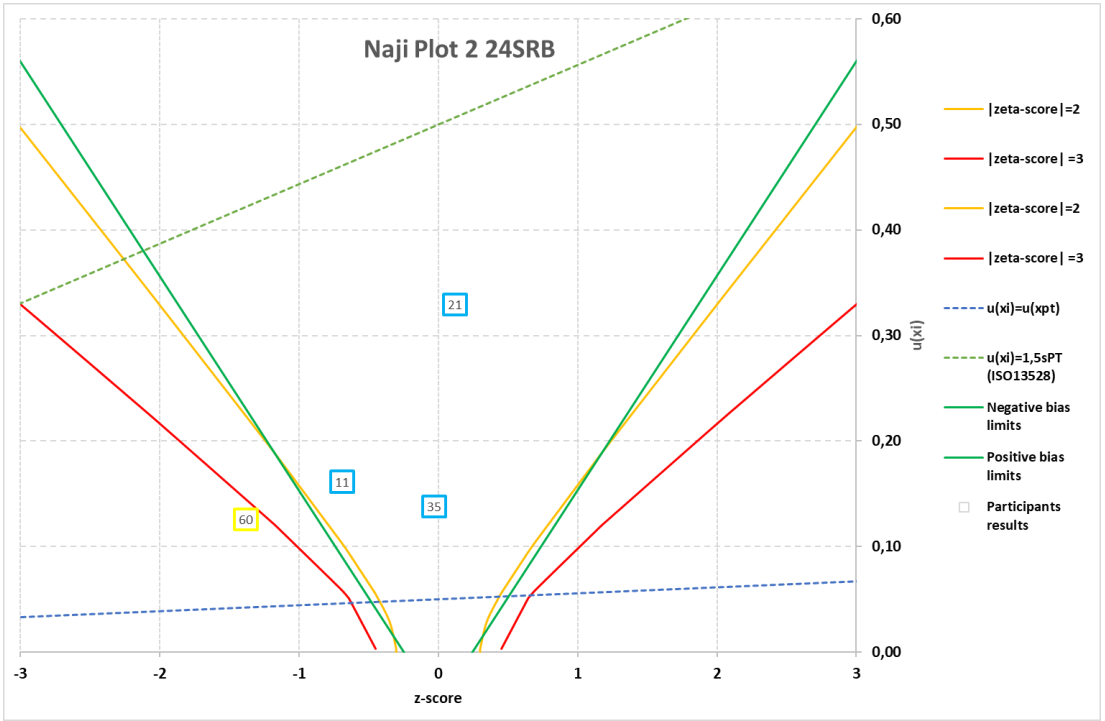

Figure 27. Naji2 plots of participants' results for in-vitro radiobioassay of strontium in urine (sample 24SRB).

APPENDIX III.

IN-VIVO RADIOBIOASSAY CHARTS FOR CAESIUM IN WHOLE BODY

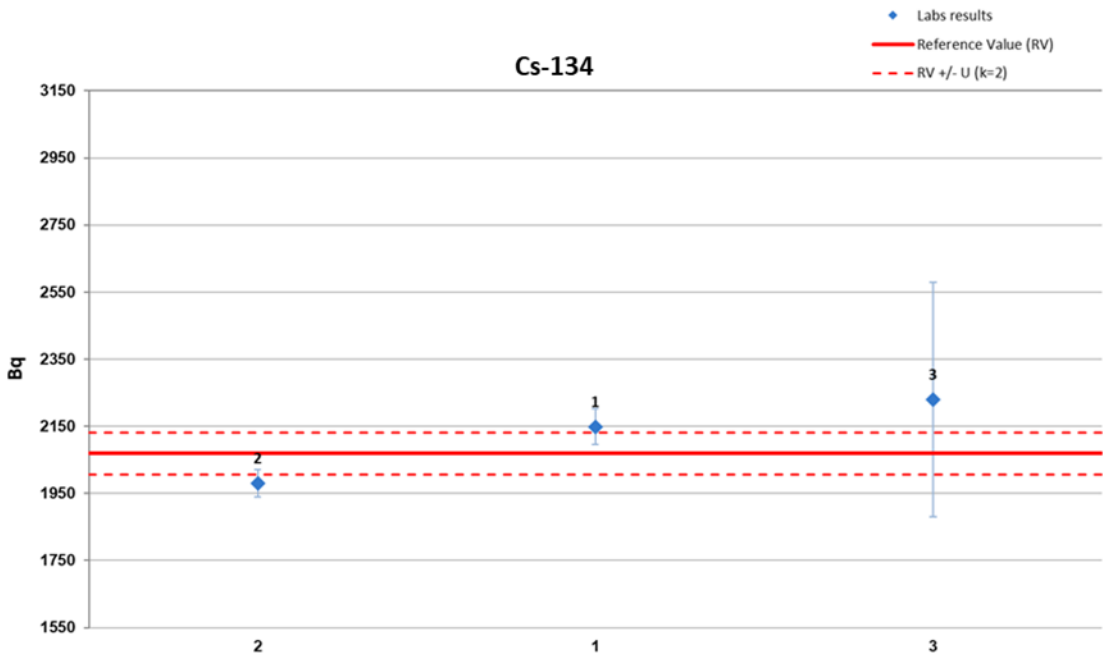

Figure 28. Relative bias and expanded measurement uncertainty of participants' results for in-vivo radiobioassay of ^{134}Cs in whole-body. Red lines indicate the assigned value and associated uncertainty. Laboratories are identified by anonymized codes. Vertical axis refers to activities in Bq.

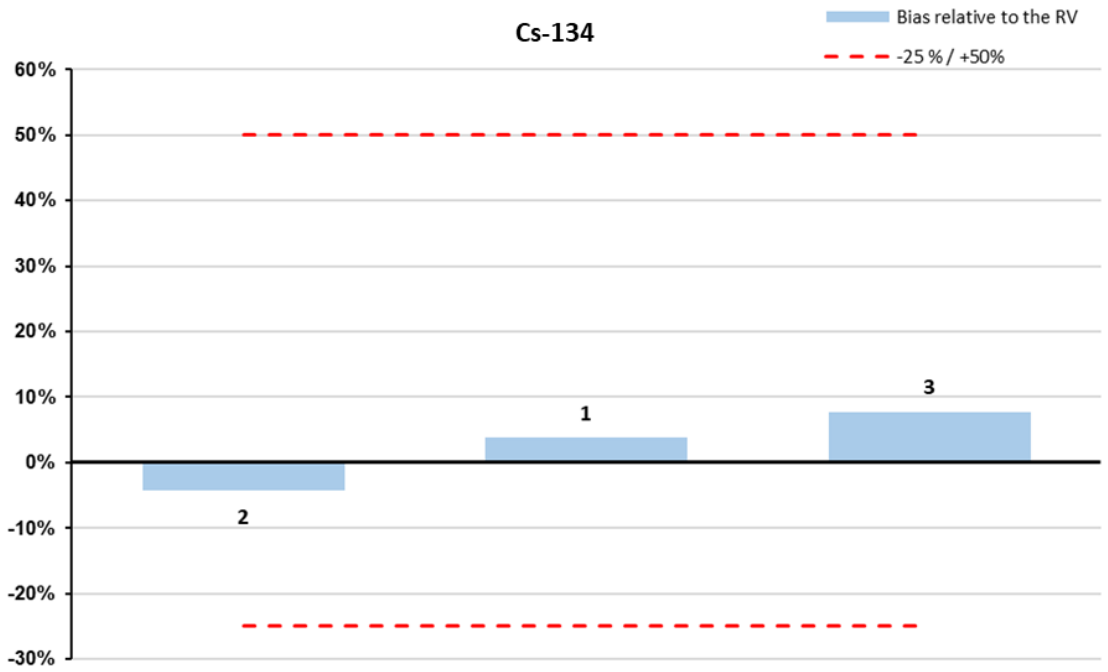

Figure 29. Relative bias of participants' results for in-vivo radiobioassay of ^{134}Cs in whole-body. Dashed red lines indicate the performance limits of ISO 28218:2010 [3]. Laboratories are identified by anonymized codes. Vertical axis refers to relative bias.

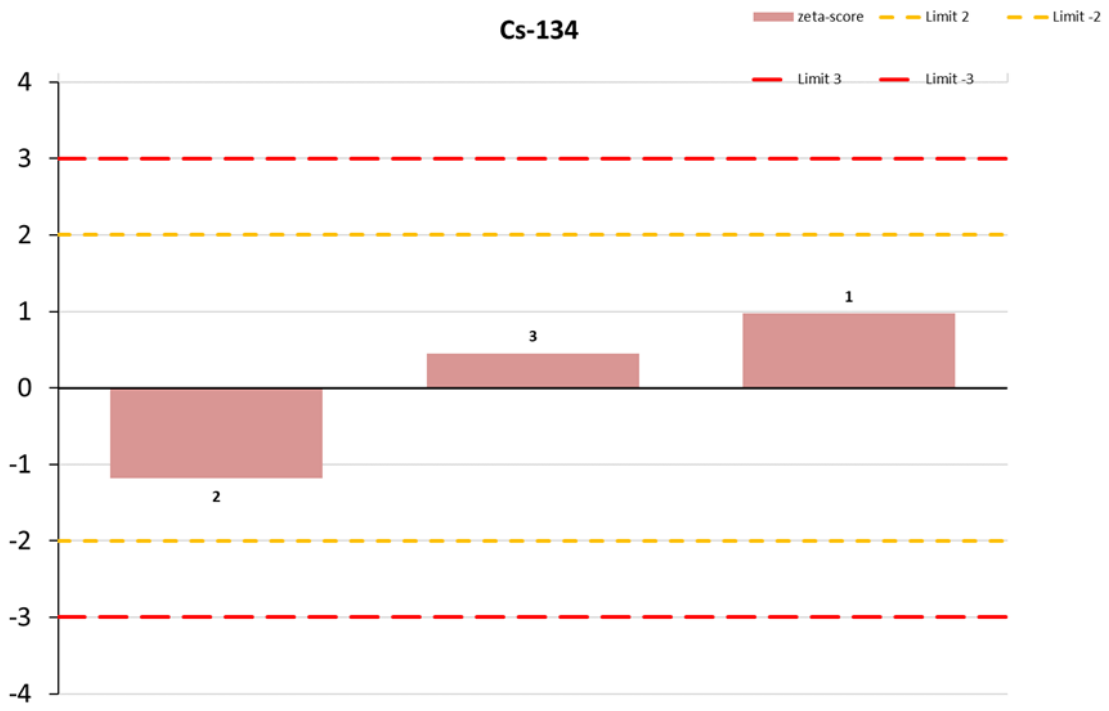

Figure 30. Zeta-score of participants' results for in-vivo radiobioassay of ^{134}Cs in whole-body. Yellow and red lines indicate questionable (±2) and unsatisfactory (±3) performance, respectively. Laboratories are identified by anonymized codes. Vertical axis refers to zeta-score.

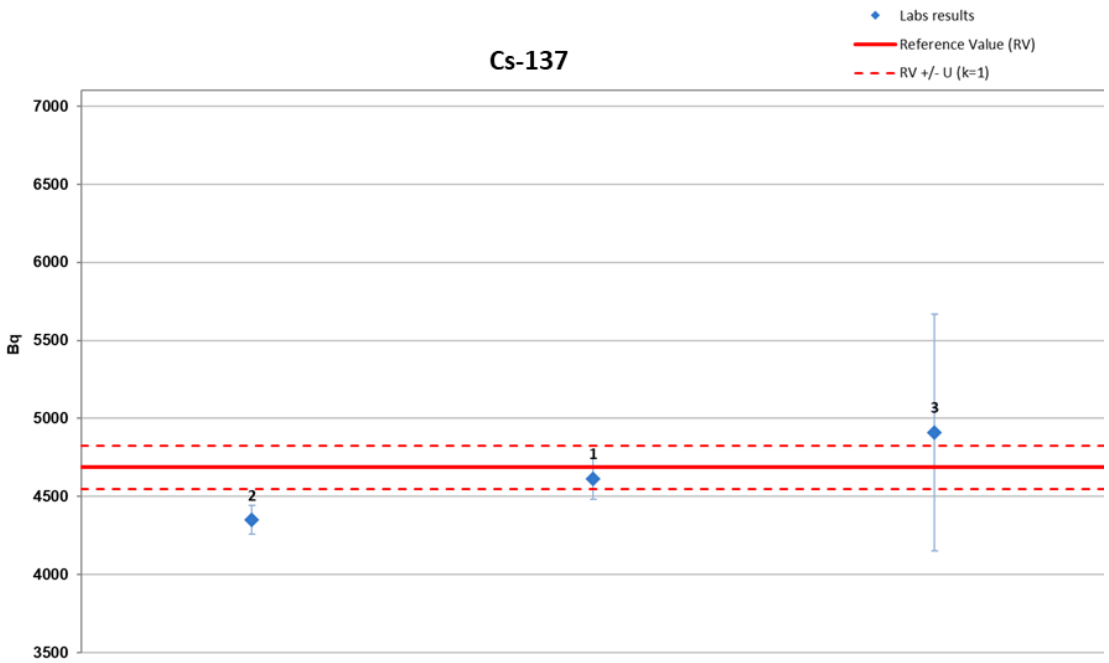

Figure 31. Relative bias and expanded measurement uncertainty of participants' results for in-vivo radiobioassay of ^{137}Cs in whole-body. Red lines indicate the assigned value and associated uncertainty. Laboratories are identified by anonymized codes. Vertical axis refers to activities in Bq.

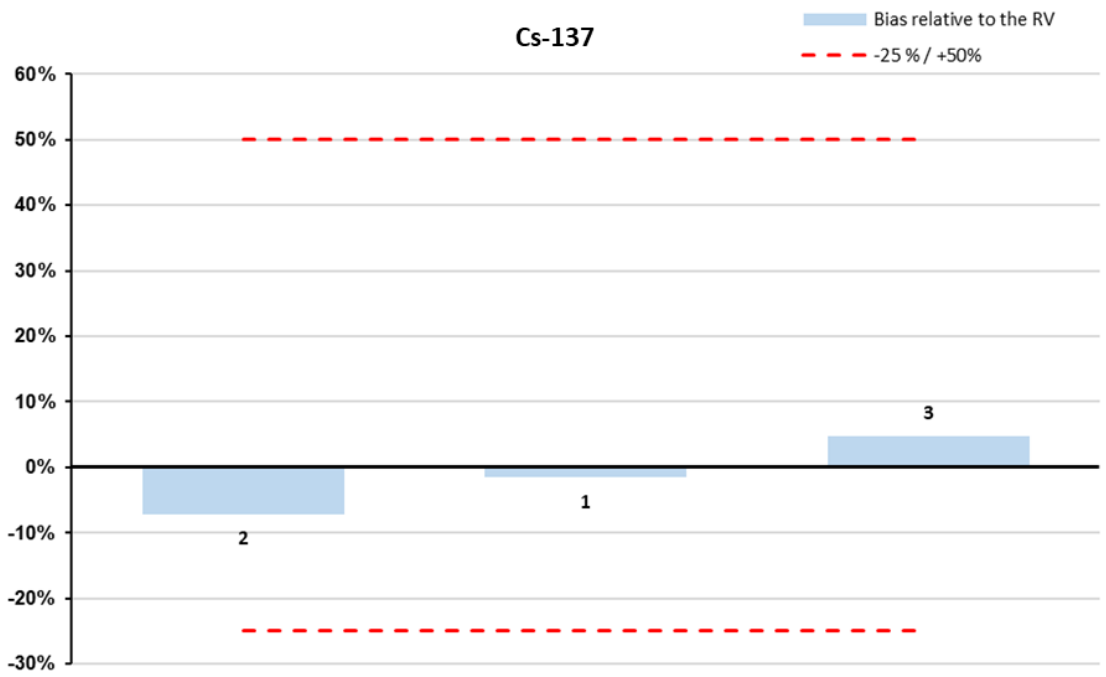

Figure 32. Relative bias of participants' results for in-vivo radiobioassay of ^{137}Cs in whole-body. Dashed red lines indicate the performance limits of ISO 28218:2010 [3]. Laboratories are identified by anonymized codes. Vertical axis refers to relative bias.

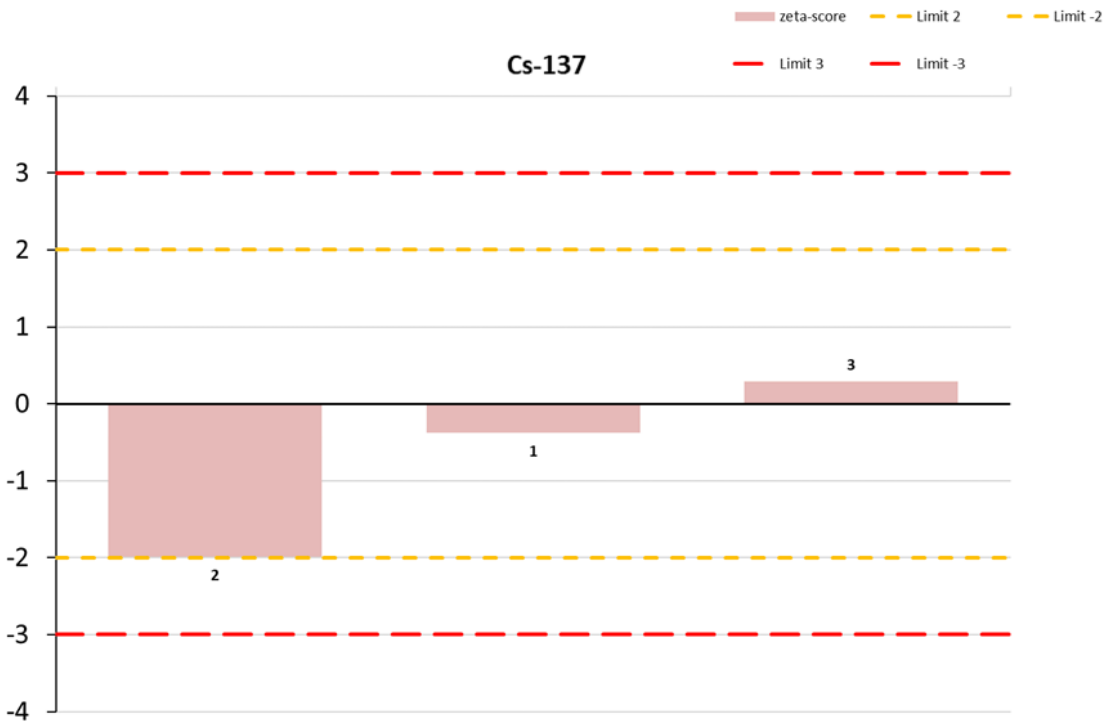

Figure 33. Zeta-score of participants' results for in-vivo radiobioassay of ^{137}Cs in whole-body. Yellow and red lines indicate questionable (±2) and unsatisfactory (±3) performance, respectively. Laboratories are identified by anonymized codes. Vertical axis refers to zeta-score.

APPENDIX IV.

CERTIFICATES OF PARTICIPATION

NOTE

SITE – DATE : CEA Paris Saclay Site de Saclay June 14th 2024

ADDRESSEES :

SUBJET : *In-vivo* Radiobioassay Monitoring certicate of participation

N/REF. : DG/CEA PSAC/DSPS/LBM 240628001

EMETTEUR : Claude Guichet

CERTIFICATE

The coordinator of the Internal Dosimetry Interlaboratory Comparisons *In-vivo* Monitoring mentioned hereafter certifies that:

has been participating in the *In-vivo* Radiobioassay intercomparisons organized in **2024** by the IAEA

The following exercises were carried out and evaluated using assigned values:

- Whole body counting 70 kg Cs-134 ☒
- Whole body counting 70 kg Cs-137 ☒

Claude GUICHET

ILC Coordinator

CEA

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claude.guichet@cea.fr
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Xxxxxxxx

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Association pour la Promotion du Contrôle de Qualité des Analyses de Biologie Médicale en Radiotoxicologie

A-1035

CERTIFICATE

The Secretary of the Association mentioned hereafter certifies that:

has been participating in the radiotoxicology intercomparisons organized in 2024 by the PROCORAD Association.
The following exercises were carried out and evaluated using assigned values:

- Free tritium in urine ☒
- Organically bound tritium in urine ☒
- 14 carbon in urine ☐
- 35 sulfur in urine ☐
- 32 phosphorus in urine ☐
- γ and X emitters in urine ☒
- Uranium in urine (activity) ☒
- Uranium in urine (mass) ☒
- Actinides in urine (except uranium) ☐
- Actinides in faecal ash ☒
- 90 strontium in urine ☒
- Total alpha emitters in nasal swabs ☐
- Actinides with DTPA in urine ☐
- 210 polonium in urine ☐

Gif sur Yvette June 30th 2024
Claude GUICHET
PROCORAD Secretary

Siège Social : Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA) Bureau du Conseiller Médical 18 route du panorama BP 16
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Téléphone : 01 69 08 65 30 Télécopie 01 69 08 42 51 E-mail : contact@procorad.org
www.procorad.org

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DEFINITIONS

The following definitions reproduced from [3], [4], [14] and [15] apply for the purposes of this report.

The symbol 'ⓘ' denotes an information note.
The symbol '!' denotes a cautionary note.
Notes do not constitute part of the definition.

assigned value

value attributed to a particular property of a proficiency test item.

bias

Systematic error of the indication of a measuring instrument.

certified reference material

Reference material, characterized by a metrologically valid procedure for one or more specified properties, accompanied by a certificate that provides the value of the specified property, its associated *uncertainty* and a statement of the metrological traceability.

coordinator

one or more individuals with responsibility for organizing and managing all of the activities involved in the operation of a proficiency testing scheme.

combined standard uncertainty

Standard measurement uncertainty that is obtained using the individual standard measurement uncertainties associated with the input quantities in a measurement model.

conventional quantity value

Quantity value attributed by agreement to a *quantity* for a given purpose.

dose

A measure of the energy deposited by radiation in a target.

dosimetry service

Organization that operates a personal and/or area dosimetry system which includes the evaluation of the reading of *dosemeters* after their use and includes:

- providing the user with *dosemeters*;
- recording the results;
- reporting the results to the user.

ⓘ The *dosimetry service* fulfils basic quality management and independency requirements if it fulfils the requirements stated in ISO/IEC 17025.

ⓘ The user includes not only external clients but also internal personnel who wear *dosemeters* provided by their organization and are engaged in radiation protection activities inside or outside the organization. The same quality of *dosimetry service* which is provided to external users is also provided to organizations' employees (internal users), in accordance with their own quality management system.

exposure

The state or condition of being subject to irradiation.

! *Exposure* should not be used as a synonym for *dose*. *Dose* is a measure of the effects of *exposure*.

ⓘ *Exposure* to ionizing radiation can be broadly divided into exposure categories according to the status of the individual(s) exposed; into exposure situations according to the circumstances of the *exposure*; and according to the source of the *exposure*.

external exposure

Exposure to radiation from a source outside the body.

ⓘ Contrasted with *internal exposure*.

indicated value

Value of the measurand given directly by a measuring instrument on the basis of its calibration curve.

ⓘ In this document, the indicated value is the one given by the dosimetry system as the final result of the evaluation algorithm (for example, display of the software, print out) in units of *dose equivalent* (Sv).

ⓘ It may be necessary that a measured *dose* (e.g., by *control dosemeters*) or a calculated transport and/or background dose be subtracted by the *dosimetry service* or by the evaluating organization.

indication

Quantity value provided by a measuring instrument or a measuring system.

individual monitoring

Monitoring using measurements by equipment worn by individuals, or measurements of quantities of radioactive substances in or on, or taken into, the bodies of individuals, or measurements of quantities of radioactive substances excreted from the body by individuals.

ⓘ Also called personal monitoring.

ⓘ For workers, usually contrasted with workplace monitoring.

individual monitoring service

Synonymous with *dosimetry service*.

interlaboratory comparison

Organization, performance and evaluation of measurements or tests on the same or similar items by two or more laboratories in accordance with predetermined conditions.

internal exposure

Exposure to radiation from a source within the body.

ⓘ Contrasted with *external exposure*.

***in-vitro* radiobioassay**

Measurements to determine the presence of, or to estimate the amount of, radioactive material in the excreta or in other biological materials removed from the body.

***in-vivo* radiobioassay**

Measurements of radioactive material in the human body utilizing instrumentation that detects radiation emitted from the radioactive material in the body.

measurand

Quantity intended to be measured.

monitoring

The measurement of *dose*, dose rate or activity for reasons relating to the assessment or control of *exposure* to radiation or exposure due to radioactive substances, and the interpretation of the results.

ⓘ 'Measurement' is used somewhat loosely. The 'measurement' of *dose* often means the measurement of a *dose equivalent* quantity as a proxy (i.e., substitute) for a *dose* quantity that cannot be measured directly. Also, sampling may be involved as a preliminary step to measurement.

ⓘ Measurements may actually be of radiation levels, airborne activity concentrations, levels of contamination, quantities of radioactive material or individual *doses*.

ⓘ The results of these measurements may be used to assess radiological hazards or *doses* resulting or potentially resulting from *exposure*.

ⓘ Monitoring may be subdivided in two different ways: according to where the measurements are made, into *individual monitoring*, workplace monitoring, source monitoring and environmental monitoring; and, according to the purpose of the *monitoring*, into routine monitoring, task related monitoring and special monitoring.

outlier

Observation in a set of data that appears to be inconsistent with the remainder of that set.

ⓘ An *outlier* can originate from a different population or be the result of an incorrect recording or other gross error.

participant

Laboratory, organization or individual that receives proficiency test items and submits results for review by the proficiency testing provider.

phantom

Surrogate person, or part of a person, used for calibration of *in-vivo* measurement systems.

ⓘ A *phantom* is constructed to allow placement of radionuclides in a geometry approximating internal depositions. A *phantom* could be used as an appropriate blank.

precision

Closeness of agreement between indications or measured *quantity values* obtained by replicate measurements on the same or similar objects under specified conditions.

proficiency testing

Evaluation of participant performance against pre-established criteria by means of *interlaboratory comparisons*.

proficiency testing scheme

Proficiency testing designed and operated in one or more rounds for a specified area of testing, measurement, calibration, or inspection.

quantity

Property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference.

quantity value

Number and reference together expressing magnitude of a *quantity*.

radiobioassay

Measurement of amount or concentration of radionuclide material in the body, or in biological material excreted or removed from the body (*measurand*), and analysed for purposes of estimating the quantity of radioactive material in the body.

reference material

Material, sufficiently homogeneous and stable with respect to one or more specified properties, which has been established to be fit for its intended use in a measurement process.

relative bias

Quotient of the *bias* divided by the expected value.

standard deviation for proficiency assessment

Measure of dispersion used in the evaluation of results of *proficiency testing*.

standard measurement uncertainty

Measurement *uncertainty* expressed as a standard deviation.

uncertainty

Non-negative parameter characterizing the dispersion of the *quantity values* being attributed to a measurand, based on the information used.

validation

Act of defining the method capability and determining whether it can be properly applied as intended, or a test to determine whether the overall implemented analysis fulfils specified requirements.

z-score

Standardized measure of performance, calculated using the participant's result, assigned value and the standard deviation for proficiency assessment.

zeta-score

Standardized measure of performance, calculated using the participant's result, assigned value and the *combined standard uncertainties* for the result and the assigned value.