22NRM07 GuideRadPROS

D3 Report on training course for calibration of dosimeters, including cost effective procedures and guidance, with respect to actual quantities according to ISO 4037 standard series and ICRU Report 95 quantities

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Deliverable Cover Sheet

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1 Introduction

Radiation protection is an international field that relies on a harmonized approach to dosimetry. This means that common standards and publications are needed so that laboratories around the world can follow the same procedures and produce comparable results. These standards must reflect both user requirements and technological progress, which is why they are regularly reviewed and updated. Calibration laboratories must then acquire suitable equipment and train their staff according to the requirements described in these publications. This is a gradual and continuous process that ensures consistency and reliability of dosimetry data on a global level.

In recent years, ISO 4037 standard series has been updated and ICRU Report 95 on radiation protection quantities was published, which prompted an international effort to assess their implications and to develop practical guidelines for the calibration community. The goal of this work is to support laboratories in making a smooth and coordinated transition to the new standards. This is why the 22NRM07 GuideRadPROS project was launched — as a joint international effort to study the implications of the new standards and to publish guidelines for their adoption. Work Package 2 (WP2) of the project focuses on developing cost-effective procedures and guidance for the calibration of dosimeters. The aim is to support metrology institutes, particularly smaller ones, in implementing the recent standardization changes.

As part of WP2, a three-day practical training course on the calibration of dosimeters was organized in May 2025 by the project consortium at the Greek Atomic Energy Commission (EEAE) in Athens, Greece. This report provides a summary of the planning and organization of the course and, in particular, presents the participants' feedback on the quality and content of the training.

1.1 ISO 4037

Radiation protection dosimeters are tested and calibrated in photon reference fields according to the ISO 4037:2019 standard series. The latest revision introduced several important changes that require significant financial and human resources. As a result, some smaller laboratories and emerging metrology institutes face challenges in fully implementing the new standard.

The standard defines the procedures and requirements for setting up X-ray and gamma-ray reference fields. This is an area where many laboratories need additional guidance and support. The topic of spectrometry is also included in the standard, but it is only briefly described. Given that spectrometry techniques are becoming more accessible and increasingly used, further practical guidance and clarification would help laboratories apply this part of the standard more effectively.

Although ISO 4037:2019 provides a solid framework, some sections could be expanded or clarified to support harmonized international implementation. One effective way to identify areas for improvement is to collect feedback from end-users or to organize workshops that encourage open discussion and the exchange of practical experiences.

1.2 ICRU 95

Radiation protection is based on non-measurable protection quantities estimated by operational quantities defined by the International Commission on Radiation Units and Measurements (ICRU). ICRP, international commission for radiation protection, and ICRU launched the working group 26 leading to the publication of the ICRU Report 95 which introduced new operational quantities intended to replace the existing ones. The goal of these operational quantities is to overcome the difficulties in estimating the protection quantities by updating a operational system lasting for 40 years without changes while the protection quantities evolved toward a better protection of workers and public. Adopting the operational quantities proposed by ICRP and ICRU in the ICRU report 95 will to partly revised the related type test standards. This change will also have a significant impact on calibration laboratories, many of which will require clear guidance on the implications and on adapting their calibration procedures.

The main goal of the newly proposed quantities is to bring operational and protection quantities closer together, improving consistency between measurement and protection practices. However, these changes would also introduce new

requirements for dosimeters and calibration methods. Since the adoption of ICRU Report 95 would also require updates to national regulations and may have broad implications across the radiation protection community, it is important to encourage open discussion on its implementation and to involve policymakers and standardization bodies in this process.

2 Work package 2 “Training on requirements of ISO 4037 and calibration in reference fields”

The aim of WP2 “Training on requirements of ISO 4037 and calibration in reference fields” within the project is to identify the training needs related to the implementation of the ISO 4037 standard for establishing new X-ray reference fields, as well as to prepare for possible future changes resulting from the ICRU Report 95. As a first step toward achieving this goal, a comprehensive survey was conducted, covering topics such as the setup of reference calibration fields and spectrometry measurements.

Based on the survey results, which are summarized in section 2.1, an online workshop was developed and organized. This workshop focused on the setup of reference radiation fields in accordance with the ISO 4037 standard series, the process of performing calibrations, and the expected changes related to the ICRU Report 95. The workshop also served as an opportunity to test the newly developed theoretical training materials, which were later used in the hands-on workshop.

The theoretical content was later expanded with practical, hands-on sessions during the training course held at the EEAE, Greece. A questionnaire was distributed to the course participants, and their feedback is summarized in this report. Finally, using the experience gained and the collected feedback, new open-access e-learning materials will be developed, focusing on the implementation of the ISO 4037 standard series in calibration laboratories.

2.1 Initial questionnaire

Initially, a questionnaire was drafted to help identify the educational needs of the calibration laboratories. The survey was sent out to NMIs (National Metrology Institute), DIs (Designated Institute) and SSDLs (Secondary Standard Dosimetry Laboratory) through several networks such as EURAMET TC-IR, EMN for Radiation Protection and IAEA SSDL network. A total of 40 responses was collected, mostly from Europe, but also some from Asia. Most of the responses were from secondary standard laboratories.

The questions used in a survey (total of 9) focused on the process of setting up and performing calibrations according to the ISO 4037 standard and ranged from basic measurements such as HVL (half-value layer) to advanced techniques such as spectrometry. Most laboratories indicated needs for both theoretical and hands-on training in spectrometry and high voltage measurements. Other needs are presented in more detail in the following figure (Figure 1).

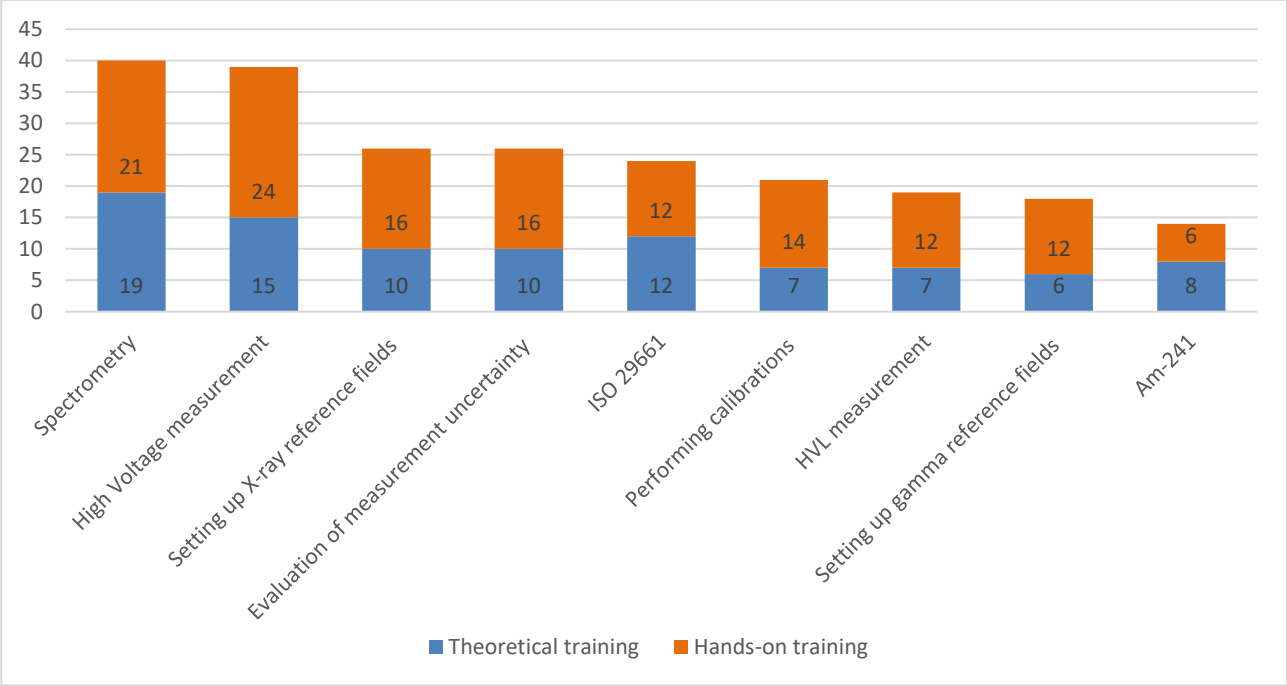

Figure 1. Answers to the question on training needs regarding the ISO 4037 standard sent to calibration laboratories

The laboratories were also asked for their input on the completeness of the ISO 4037 standard, more specifically which topics they feel are adequately covered. Most of the users think that setting up gamma reference fields is adequately explained, so there is no ambiguity in that topic. Most of the problems once again appeared in the topics of spectrometry and high-voltage measurements, with Am-241 reference field being the least covered topic. Am-241 part was actually solely mention in an informative appendix in the new version of the standard due to lack of data availability and is one of the topics covered within the project. More detailed statistics of the answers to this question are presented in the following figure (Figure 2).

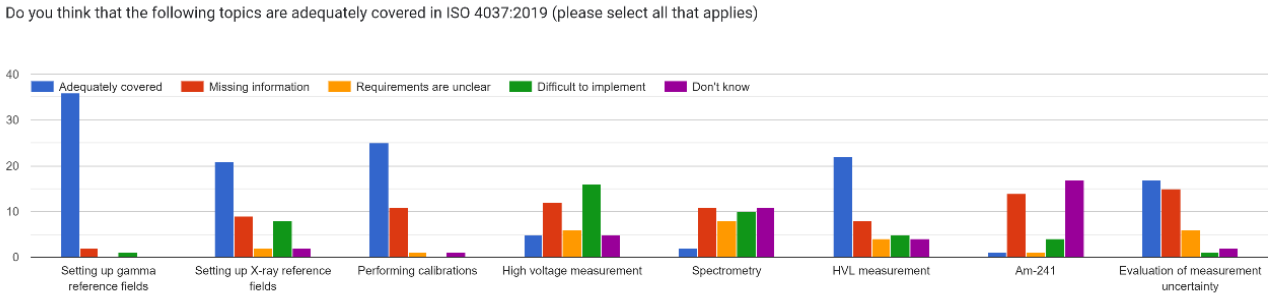

Figure 2. Answers to the question of which topics within the ISO 4037 standard are adequately covered

The following survey questions explored the specific procedures used by the participating laboratories, such as X-ray tube high-voltage determination and the preparation of measurement uncertainty budgets. The results of this part of the survey were summarized in an internal project report, and a peer-reviewed publication is currently in preparation. These findings provide valuable insights into the level of knowledge, compliance with standards, and differences in procedures across a wide range of international calibration laboratories.

For the purposes of this report, it is important to note that most of the surveyed laboratories (around 90%) are aware of the newly proposed operational quantities introduced by the ICRU Report 95, but fewer than half indicated that they fully understand these quantities and their practical implications.

The survey also included open-ended questions where participants could describe their most urgent training needs. Once again, the topics of high-voltage measurements and spectrometry dominated the responses, followed by determination of measurement uncertainty budgets. Respondents expressed a clear preference for hands-on training rather than purely theoretical lectures. Interestingly, even for topics that had already been covered in previous training programs, such as evaluation of measurement uncertainty, participants still emphasized the value of practical exercises.

Based on the survey analysis, the most urgent training needs were identified, confirming a strong demand for both theoretical and practical educational materials to support laboratories in implementing the relevant standards and recent developments in radiation protection dosimetry.

2.2 Online theoretical workshop

Based on the identified training needs, the project consortium developed theoretical training materials focused on the implementation of the ISO 4037 standard series. Most of the lectures addressed the setup of reference radiation fields and the execution of type testing and calibrations, with particular emphasis on spectrometry techniques and the requirements introduced by the new ICRU Report 95 operational quantities.

Since the training materials were still in the theoretical stage at this point in the project, it was decided to organize an online workshop to make the content more accessible to a broader audience. The workshop was initially intended for project participants only, and to evaluate whether the contents of the workshop lectures are adequate and if the topics of interest are addressed appropriately. Also, the invitation was later extended to project stakeholders and other TC-IR members as well as policymakers and regulatory authorities to encourage wider engagement. To promote the event, a flyer was prepared, and the announcement was published on the project website and shared via different networks.

The 2-day workshop was held online on September 30th and October 1st 2024. Approximately 30 participants have attended the workshop, the majority comprised of project partners and stakeholders from Europe.

Ten lectures were given at the workshop, mainly by the members of the consortium, with a few lectures given by the project's chief stakeholder from the ISO TC85 SC2 WG2 which oversees the developments regarding the ISO 4037 standards. During the workshop, feedback on presentations was collected, and active discussions and dialogue were used to improve the presentations for the future training course and for the potential use in e-learning material. In particular, the level and coverage of presentations as well as the general course structure were adjusted based on the participants' feedback and the anticipated expertise profiles of the target audience.

2.3 Practical training course

Using the knowledge gained during the preparation and implementation of the online workshop, the need for practical training topics was confirmed as previously identified by consortium and the survey. This was further supported by the input from EURADOS WG2, which has extensive experience in organizing workshops in the field of radiation protection.

A workshop was then organized to test the developed practical training course content. The original plan was to conduct the workshop as a two-day training course, repeated three times in groups of 10 participants. For practical reasons, it was later decided to hold one extended workshop, with practical lectures delivered in smaller groups, but the target number of participants did not change.

The workshop was initially intended only for the project consortium, but was later expanded to include additional participants such as project stakeholders and personnel of other respective laboratories. The flyer and invitation were promoted through several channels, including the project website, the EMN for Radiation Protection, and the IAEA SSDL network. Policymakers were also invited in order to raise their awareness and encourage support for education, training, and capacity building.

In total, 61 applications were received for the course. Ultimately, 36 persons participated in the workshop, including 5 from the project consortium and 5 from the project stakeholder committee. This means that the majority of participants

had not been involved in the project beforehand, demonstrating the course's impact beyond the project itself. Of the total, 22 participants came from the European Union and 6 from outside of Europe. The course was delivered by 12 lecturers, most of whom were from the project consortium, with one lecturer representing the project's chief stakeholder from ISO TC85 SC2 WG2, as was also the case for the online workshop. Radiation protection authorities and regulator bodies were represented by several consortium partners.

The training course was held over three days, from 20th to 22nd May 2025, at the Greek Atomic Energy Commission (EEAE) in Athens. The main objective of the course was to provide participants with practical skills for the implementation of the ISO 4037 standard series and ICRU Report 95, with a particular focus on the topics identified in the earlier survey and online workshop.

The program combined theoretical and practical lectures, complemented by dedicated sessions for round-table discussions. For the practical exercises and discussion sessions, participants were divided into four groups of up to 10 people each. This was done based on the interests and previous knowledge of the participants to ensure balanced and effective group discussions. For example, not everyone attended the spectrometry sessions which were considered an advanced topic. The detailed program is presented in the following table (Table 1).

Table 1. The practical training course program. Theoretical lectures are highlighted in green and practical sessions and round table discussions held in smaller groups are marked with red.

	Tuesday, 20th May		Wednesday, 21st May		Thursday, 22nd May		
09:00 - 09:15	Registration (9:00-9:15)		Wrap-up of last day all		Wrap-up of last day all		
09:15 - 09:30	Welcome & Opening EK		HVL Measurements SK	HV Divider & HVL HZ	New RP quantities OH		
09:30 - 09:45	Introduction: EEAE PF		by dosimetry	Group 3 & Group 4 Training	Concept and Impact of ICRU 95		
09:45 - 10:00	Scope of TC AB		Group 1 & Group 2 Lecture		Discussion on ICRU 95 implementations		
10:00 - 10:15	Introduction of lecturers All		HV Divider & HVL HZ	HVL Measurements SK	System of Intercomparison AS		
10:15 - 10:30	Standardization landscape OH		Group 1 & Group 2 Training	by dosimetry	CMC and Interlaboratory		
10:30 - 10:45	ISO & IEC			Group 3 & Group 4 Lecture	Coffee Break		
10:45 - 11:00	Coffee Break		Coffee Break				
11:00 - 11:15					Spectrometry- Part I LCM	Training Session- Calib Groups	
11:15 - 11:30	ISO 4037 OH		Field Homogeinity HZ		Spectrometer and set-up	in lab AB	
11:30 - 11:45	Concept & Requirements				Spectrometry - Part II LCM	NK	
11:45 - 12:00	Setting up Reference Fields AB		Performing Calibrations NK		Determination of Response function	MZ	
12:00 - 12:15	X-ray and gamma-ray units		Traceablity		Training Session-Spec Groups	MC	
12:15 - 12:30	"Ice Breaker" - Part I P		Type Testing NK		practical set-up in lab LCM		
12:30 - 12:45	Short presentations by participants						
12:45 - 13:00	Lunch		Lunch		Lunch		
13:00 - 13:15							
13:15 - 13:30			Team Photo Before the Afternoon Lectures		Visit to the calibration laboratory in groups of 10		
13:30 - 13:45	"Ice Breaker" - Part II P		Round Table P		Round Table P		
13:45 - 14:00	Short presentations by participants		Discussion with all lecturers		Discussion with all lecturers		
14:00 - 14:15	Setting up Reference Fields AB	High Voltage Dividers HZ	Uncertainties in Measurements MZ		Spectrometry - Part III JT	Training Session-Calib Groups	
14:15 - 14:30	Group 1 & Group 2 Training MC	Group 3 & Group 4 Lecture	Theoretical concepts		Unfolding, tube voltage, calculation	in lab AB	
14:30 - 14:45		Forum for practical experience All	Training Session Uncertainty Groups		conversion coefficients	or Paper work	
14:45 - 15:00		Group 3 & Group 4 Lecture	Uncertainty calculation (laptop) PA		Tea break		
15:00 - 15:15	High Voltage Dividers HZ	Setting up Reference Fields AB	Uncertainty - using MC (laptop) NK		Feedback form	OH	
15:15 - 15:30	Group 1 & Group 2 Lecture	Group 3 & Group 4 Training MC	Tea break		Spectrometry- Part IV JT	Training Session-Calib Groups	
15:30 - 15:45	Forum for practical experience All				Uncertainty	in lab AB	
15:45 - 16:00	Group 1 & Group2 Lecture		Training Session Uncertainty Groups		Training Session Groups	or paperwork NK	
16:00 - 16:15	Tea break		(laptop) PA		Work at Computer JT	Calibration & intervals MZ	
16:15 - 16:30	Round Table P		Example Type testing MZ		LCM	MC	
16:30 - 16:45	Discussion with all lecturers		defining tests and result interpretation NK				
16:45 - 17:00					Closure		

On Day 1, the setting up of reference fields was presented to the workshop participants, in both radionuclide and X-ray radiation fields, according to ISO 4037. Practical implementation specifics were discussed with the participants. On Day 2 practical exercise on performing the HVL measurements was done, as well as an exercise regarding the use of high voltage dividers. For some of the practical sessions the groups were combined for convenience. The training sessions on measurement uncertainty were held for all four groups at the same time, and they included exercises which were prepared in Python and executed in Jupiter Notebook, while the input files were shared by using the GitHub platform. The focus of Day 3 practical exercises was on spectrometry. During the spectrometry practical session, an example of the setup with some of the specific considerations which should be taken were demonstrated to the participants. One of the exercises was focused on the implementation of the method to estimate the maximum peak X-ray tube voltage from the X-ray spectrum by linear extrapolation. Last practical session was related to the documentation used for reporting the calibration coefficient and the associated measurement uncertainty.

3 Training course questionnaire

Prior to the training course, the consortium prepared a questionnaire to be distributed among the participants. Its purpose was to evaluate the usability of the practical training sessions as well as the accompanying theoretical lectures. The results of the participants' feedback will be presented in the following sections.

3.1 Questionnaire results

The questionnaire was designed to be straightforward, asking participants to rate the level and demand of the lectures held each day. They were asked to choose one of four options indicating how difficult the lectures were to follow. Additional questions addressed their prior level of knowledge and overall satisfaction with the course. Participants were also invited to provide written remarks and suggestions for future courses.

In total, 35 completed questionnaires were collected during the training course. Most respondents reported having more than five years of experience in the field of radiation protection, while only six participants had less than two years of experience. The distribution of working experience among participants is presented in the following figure (Figure 3).

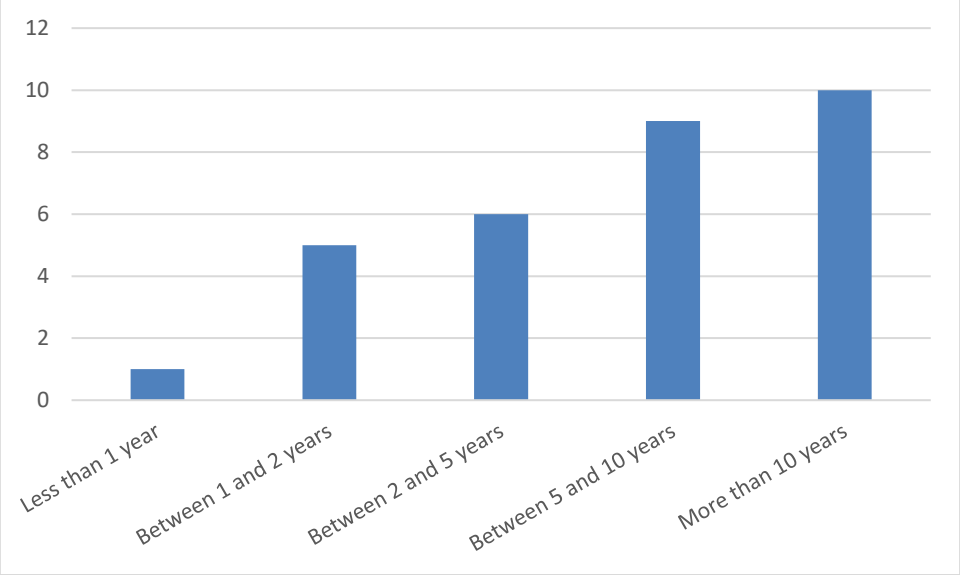

Figure 3. The distribution of the participant's level of experience in the field of radiation protection and calibration.

Participants were asked to separately rank the demand level of the lectures and practical sessions for each day. For both, they were given four possible response options. The results of this part of the survey are presented in Figure 4. Most participants reported that the lectures and practical sessions were at or slightly above their level of knowledge, but still manageable to follow. Only one or two participants found the sessions either too demanding or not demanding enough. For the first day's theoretical lectures, five participants indicated a relatively low demand level, which can be attributed to the introductory lessons on the ISO 4037 standard series and the setup of reference fields. Overall, the results demonstrate that the lectures were well aligned with the target audience, and suggest that a slight increase in the demand level could even be beneficial.

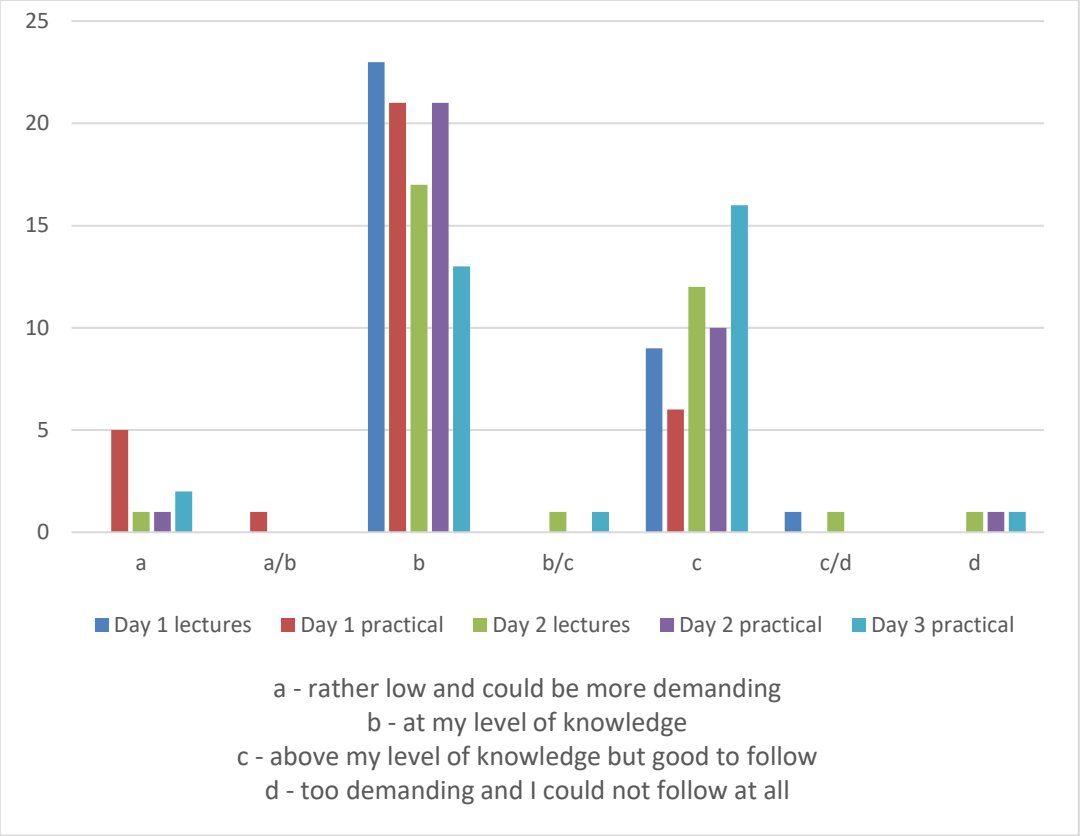

Figure 4. Participants feedback on the demand level of the given theoretical lectures and practical training sessions.

On the final day, special attention was given to the spectrometry sessions, reflecting the broad need for this topic identified in the initial survey presented at the beginning of the report. As spectrometry is one of the main objectives of the project and has only recently begun to gain wider application, participants were asked to rate their expectations for the lectures delivered that day. The results, shown in Figure 5, indicate that the majority of participants had their expectations fulfilled or even exceeded. No participant reported unmet expectations, while four indicated that they had no specific expectations. These findings confirm that the lectures were well aligned with the audience's needs. They also provide valuable feedback to the project consortium regarding the appropriate level of detail to be included in future lectures, as well as the extent to which spectrometry should be incorporated into the ISO 4037 standard series to ensure a harmonized approach among end-users.

The same question was posed to participants regarding the entire three-day course. The results, presented in Figure 6, again show that most participants felt their expectations were fulfilled or exceeded. One participant reported unmet expectations, but clarified that this was due to his/her professional background as a medical professional, which was not fully aligned with the course content.

Participants were also asked whether the course should be repeated. The majority expressed strong interest, with 30 out of 35 respondents stating that the course should definitely be offered again. Suggestions for potential improvements were also collected. Six respondents proposed changes to the course, while most felt it should be repeated in its current form.

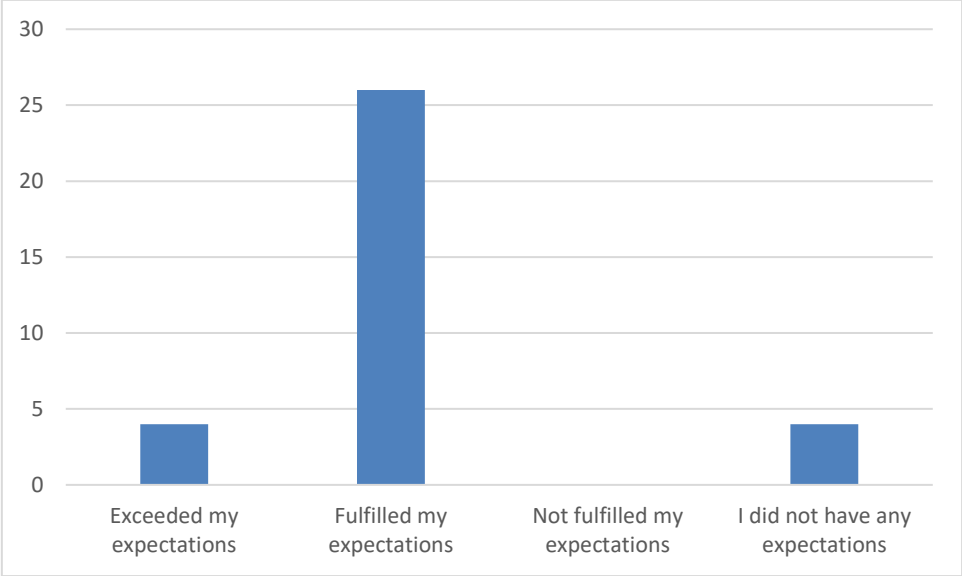

Figure 5. The participants feedback on their expectations for the lectures given on the last day with a large focus on spectrometry.

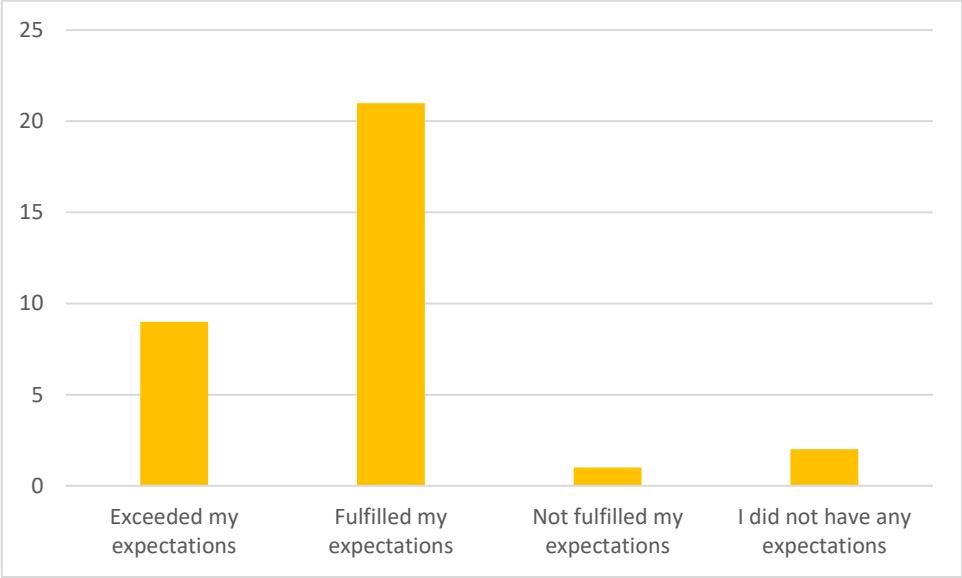

Figure 6. The participants feedback on their expectations for the whole three-day course.

3.2 Participants' remarks

Participants provided additional remarks on each of the survey questions, as well as general comments for future courses. Many offered compliments on the organization of the course, noting that the schedule was well structured and easy to follow. The round-table sessions, where participants could ask questions in smaller groups, were particularly well regarded. However, several participants encouraged the organizers to form even smaller groups and to increase the number of hands-on sessions. They suggested that introducing specific tasks for the practical sessions would help participants focus, while working through all necessary steps would allow them to encounter the challenges they might face when reproducing the measurements later in their own laboratories. Some participants felt that the hands-on training

was structured more as a demonstration, with limited opportunities to interact directly with the equipment and setup. A very common request was to extend the duration of the workshop, with a full-week training format seen as more suitable for in-depth practical sessions, smaller working groups, and additional time for discussion. Others proposed splitting the course into more specialized topics, such as setting up and commissioning a new X-ray reference field or focusing exclusively on spectrometry and spectra unfolding.

There were also requests for more detailed coverage of certain topics already addressed in previous workshops organized by EURADOS, IAEA or other organizations, including type testing and the determination of measurement uncertainty. Some participants expressed interest in additional training sessions dedicated to the newly proposed radiation protection quantities (ICRU Report 95), as the lectures on this topic were well received. Although spectrometry was a major component of the course, with both theoretical lectures and hands-on training, there was still demand for more detail. Several participants were new to Monte Carlo methods and had little prior experience with spectrometry equipment. Introductory lectures on these topics could be included in future courses, though care would be needed to be taken to avoid reducing overall demand level too much.

One practical suggestion was to share lecture slides in advance, enabling participants to prepare for topics where they lacked background knowledge. This aligns with requests for additional support and could be complemented by e-learning materials, which are planned as part of the final activities in WP2 of the project. Participants without prior experience in Monte Carlo simulations expressed appreciation for the prepared Python scripts provided by the lecturers, as these offered a clear and accessible starting point.

The visit to the calibration laboratory was highly valued, giving participants insight into different laboratory practices, equipment, and techniques. Many also appreciated the opportunity to network with peers, discuss ongoing challenges, and exchange ideas for future work. For this reason, it is recommended that future courses also include dedicated breaks and discussion periods, allowing participants to collaborate and support one another in understanding and applying the lecture content.

4 Implications for the future

The course was very successful, and most participants encouraged repeating it in the future. They also provided useful suggestions on how it could be improved.

Participants especially liked the question sessions and round-table discussions, as these gave them the chance to ask questions and exchange ideas. For the next course, it would be good to keep this format but have smaller groups and more hands-on training. Participants also suggested adding specific tasks or exercises to help them follow the practical sessions in a more structured way.

Many participants recommended extending the course to a full week. This would give more time for small-group work, practical exercises, and in-depth discussions. Most participants said that the difficulty level was suitable for them, either at their level or slightly above, but some did not have enough background knowledge in certain topics. To help with this, organisers could share the slides before the course and prepare e-learning materials so that participants can review the topics in advance.

Since most participants had more than five years of experience in the field, future courses could continue to focus on this group as the main audience. Introductory material could be offered separately as optional preparation, rather than as part of the main course, to keep the technical level high and focus on more advanced topics such as spectrometry.

Overall, the feedback shows that the course was well received, appreciated and organized. It provides a good base for future training. With more time, smaller groups, and better preparation materials beforehand, future courses can further improve learning outcomes and participant satisfaction.

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