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## From the Editor

Dear reader of the SSDL Newsletter, my name is Ms Paula Toroi, I am a medical physicist and have been working many years in the SSDL of Finland. I started my work as the new IAEA SSDL Officer in December 2015 and therefore I am also the current Editor of this Newsletter. I look forward working with you in the future. The IAEA's Dosimetry and Medical Radiation Physics Section (DMRP) also welcomes our new Dosimetrist Mr Pavel Kazantsev, a medical physicist from Russia and Ms Giorgia Loreti, a medical physicist from Italy who is the new Training Officer. Ms Loreti contributes to the implementation of medical physics training activities, supports the development of new educational material and helps monitor the effectiveness of training provided.

The first article of the current SSDL Newsletter (No.64) summarises the results from a pilot comparison study for diagnostic level air kerma measurement standards of SSDLs. Based on this data, the IAEA comparison program in x-ray diagnostic radiology has been approved and will be available for SSDL members. The second contribution is a report from a 2nd research coordination meeting held in autumn 2015 related to the coordinated research programme entitled "Development of Quality Audits for Advanced Technology in Radiotherapy Dose Delivery". An overview of the new IAEA publications is presented in the third part. The fourth contribution is dedicated to the current revision progress of the TRS 398 Code of Practice. The last issue is a short description of IAEA's activities for the celebration of the International day of Medical Physics.



*Participants and observers of the Research Coordination Meeting "Development of Quality Audits for Advanced Technology in Radiotherapy Dose Delivery"  
Vienna, October 2015 (see page 8)*

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# Services provided by the IAEA in Dosimetry and Medical Radiation Physics

The IAEA's Dosimetry and Medical Radiation Physics Section focuses on services provided to Member States through the IAEA/WHO SSDL Network and on a system of dose quality audits. The measurement standards of Member States are calibrated, free of charge, at the IAEA's Dosimetry Laboratory. The audits are performed through the IAEA/WHO postal dose assurance service for SSDLs and radiotherapy centres by using thermoluminescent and optically stimulated luminescent dosimeters (TLDs and OSLDs).

The Dosimetry Laboratory's Quality Management System has been reviewed and accepted by the Joint Committee of the Regional Metrology Organizations and the BIPM (JCRB). The IAEA Calibration and Measurement Capabilities (CMCs) have been reviewed and published in Appendix C of Comité International des Poids et Mesures (CIPM), Mutual Recognition Arrangement (MRA).

The IAEA CMCs can be found at the following web site: <http://kcdb.bipm.org/AppendixC/search.asp?met=RI>

The range of services is listed below.

<i>Services</i>	<i>Radiation quality</i>
Calibration of ionization chambers (radiotherapy, diagnostic radiology including mammography*, and radiation protection including environmental dose level)	X rays (10–300kV) and $\gamma$ rays from $^{137}\text{Cs}$ and $^{60}\text{Co}$
Comparison of therapy, protection and diagnostic level ionization chamber calibrations coefficients for SSDLs	$\gamma$ rays from $^{60}\text{Co}$ and $^{137}\text{Cs}$ and X rays
TLD Dose quality audits for external radiotherapy beams for SSDLs and hospitals	$\gamma$ rays from $^{60}\text{Co}$ and high energy X ray beams
OSLD Dose quality audits for radiation protection for SSDLs	$\gamma$ rays from $^{137}\text{Cs}$
Reference irradiations to dosimeters for radiation protection	X rays (40–300 kV) and $\gamma$ rays from $^{137}\text{Cs}$ and $^{60}\text{Co}$ beams

\* The IAEA CMCs for diagnostic calibrations have been modified. In the updated list, new quantities of kerma-length and kerma-area product were added and the radiation qualities for mammography calibrations were modified. Additional information will be published in the upcoming SSDL Newsletter.

Member States interested in these services should contact the IAEA/WHO SSDL Network Secretariat, for further details, at the address provided below. Additional information is also available at the web site:

<http://www-naweb.iaea.org/nahu/dmrp/SSDL/default.asp>

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### Note to SSDLs using IAEA calibration and audit services:

1. To ensure continuous improvement in IAEA calibration and audit services, SSDLs are encouraged to submit suggestions for improvements to the Dosimetry Contact Point.
2. Complaints on IAEA services can be addressed to the Dosimetry Contact Point.

# Pilot Comparison for Diagnostic Level Air Kerma Measurement Standards of SSDLs

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## Introduction

The IAEA signed the Mutual Recognition Arrangement (MRA) under the auspices of the International Committee of Weights and Measures (CIPM) in 1999. The MRA provides the formal recognition of national measurement standards and calibration and measurement capabilities (CMCs) among the Member States of the CIPM. The main objective of the SSDL Network is to ensure traceability of measurements for those Member States that do not have access to PSDLs, by providing the link between the end users and the international measurement system. The appropriate traceability of SSDLs and their calibration practices needs to be verified periodically through comparisons organized by the IAEA or Regional Metrology Organizations. By linking to its National Metrology Institute (NMI), any SSDL can take part in these comparisons. However, their results cannot be included in the BIPM key comparison database (<http://kcdb.bipm.org/>) unless their NMI is a signatory to the MRA and the SSDL has Designated Institute status for ionizing radiation measurements.

The IAEA Dosimetry Laboratory (IAEA), as the central laboratory of the IAEA/WHO SSDL Network [1], performs calibrations of diagnostic level air kerma measurement standards of Member States. The IAEA maintains secondary standards for the determination of air kerma for X ray beam qualities used in diagnostic and interventional radiology. It consists of Exradin A3, A4 and Radcal 10X5-6M type ionization chambers and Keithley 6517 electrometers for the conventional and mammography beam qualities. The IAEA maintains a peer reviewed quality management system complying with the ISO 17025 and published its revised diagnostic dosimetry CMC claims in 2013 in the key comparison database (KCDB) of the CIPM MRA including the RQR, RQR-M, RQA, RQA-M and RQT beam qualities specified in the IEC 61267 standard [3]. The ionization chambers and their ionization charge measurements used for calibration of SSDL reference dosimeters are traceable to the appropriate primary standards of the PTB and BEV, respectively.

## Purpose of the comparison program

This pilot phase of diagnostic comparison program of the IAEA, in line with the objectives of the IAEA/WHO SSDL

Network Charter, was triggered by the recommendation of the 15<sup>th</sup> meeting of the SSDL Scientific Committee. The comparison program aims to verify that SSDLs can carry out calibrations in terms of air kerma within acceptable limits, as well as verifying the traceability of the participants' diagnostic standards. Comparison result, like other IAEA audit report, is confidential. However, if an SSDL requires in advance, detailed comparison report will be published as an annual summary report on the IAEA/SSDL bilateral comparisons, and it can be used as supporting evidence for the eligible SSDLs to publish or maintain their relevant CMCs in the KCDB of the CIPM MRA. The aim of this pilot program is to evaluate the new arrangement of the IAEA-SSDL bilateral comparison program and the selected acceptance limit.

*Note that key or supplementary comparisons for the conventional diagnostic beam qualities (RQR, RQA, RQT) have not been organised yet, except the [EURAMET.RI\(I\)-S9](#) comparison. The IAEA has participated in this first regional supplementary comparison organised for air kerma and kerma-area product measurements for diagnostic beam qualities. Its final report is published in the *Tech. Suppl. of Metrologia* 52 (2015).*

## Participants

For the pilot phase one PSDL and 5 SSDL participants were invited based on their diagnostic measuring capabilities, see Table 1.

Table 1. List of participants and their diagnostic CMC claims.

Participant	Uncertainty of published CMCs (% , k = 2)
IAEA	1.1
1	---
2	---
3	2.2
4	2.8
5 (PSDL)	0.8
6	---

## Course of comparison

Each bilateral IAEA-SSDL comparison was conducted through the calibration of a transfer chamber in terms of air kerma according to the laboratory procedure and in the respective X-ray beams of the participant. For the purpose of a constancy check, the IAEA repeated the calibrations after return of the transfer chambers.

An excel worksheet was prepared and sent together with the Technical Protocol of the comparison to each participant for reporting on the required data about the laboratory and the calibrations performed. The comparison parameters were the calibration coefficients of the transfer chambers in units of  $mGy/nC$ , normalized to standard conditions of air temperature and pressure of  $T = 293.15$  K and  $P = 101.325$  kPa.

Five different Exradin A3 chambers were used for this comparison and one of them was sent to each laboratory. The technical details, photo and energy responses of the selected transfer chambers are given in Table 2, Figure 1 and Figure 2. The X-ray beam qualities selected from the RQR and RQT series are listed in Table 3. The participants may have decided how many beam qualities were used for the comparison, noting that to support conventional diagnostic and computed tomography CMC claims all the RQR, RQT, beam qualities listed in Table 3 need to be involved.

Table 2. Technical data of the transfer chamber

Type	Reference point	Nominal volume	*Polarizing voltage	Wall thickness	Outer diameter
Standard Imaging Exradin spherical chamber	chamber centre	3.6 cm <sup>3</sup>	+300 V	0.25 mm	19.5 mm

\*Positive polarity is applied to the collector. If an arrangement is used in which the collector is at virtual ground potential, then negative polarity should be applied.



Figure 1. Exradin A3 chamber

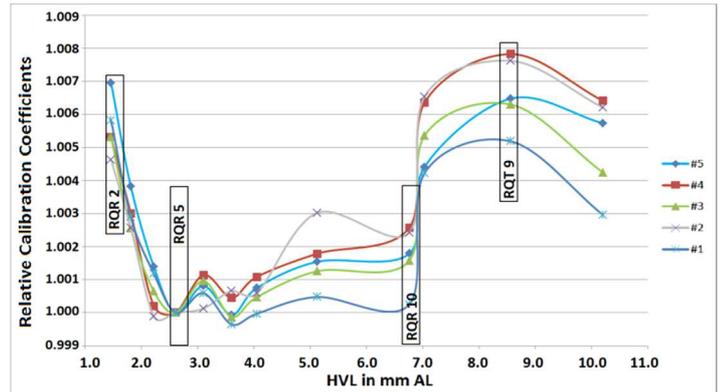


Figure 2. Calibration points of the Exradin A3 transfer chambers normalized to RQR-5 beam quality.

Table 3. Specification of the beam qualities

Radiation beam quality *	Tube voltage (kV)	Air kerma rate IAEA (mGy/min)	1 <sup>st</sup> HVL IAEA (mm Al)	1 <sup>st</sup> HVL IEC 61267 (mm Al)
Conventional diagnostic qualities				
RQR-2	40	50	1.42	1.42
RQR-5	70	50	2.59	2.58
RQR-10	150	50	6.74	6.57
Computed tomography				
RQT-9	120	50	8.49	8.4

\* see IEC 61267 [3]

The recommended focus to chamber distance (FCD) and beam diameter were 100 cm and 10 cm, respectively, to ensure the uniform irradiation of the transfer chambers. No corrections for polarity, saturation, HVL differences of the participants, were required due to the same collecting potential, applying less than 200 mGy/min dose rate and reasonably flat energy response curve of the transfer chambers, see Figure 2. However, if any additional correction factors were applied by the participants they shall be stated in the excel worksheets for data record and evaluation of comparison measurements.

The participants had four weeks to complete the calibrations and send the finalized worksheets back to the IAEA. The comparison reference values,  $N_{K,ref}$ , of each transfer chamber were established using the average of IAEA calibration coefficients,  $N_{K,(IAEA)}$ , from the calibrations performed just before it was sent to and after received from each participant. The stabilities of the five transfer chambers during the four months of pilot comparison period were within their 0.05% statistical calibration uncertainty.

All dosimetry standards of the SSDL participants are traceable to the PTB, and even if there are no available internationally accepted reference values for calculation of the degree of equivalences of the participants, one can calculate how far they are from the PTB primary realization of the air kerma using the published results of the PTB-

IAEA bilateral comparison [6] EURAMET.RI(I)-S10. The relevant PTB/IAEA ratios can be seen in Table 4. In case of the PSDL (Participant 5) the results can be interpreted as an indirect comparison between that PSDL and PTB primary standards.

Table 4. Results of PTB-IAEA diagnostic comparison performed in 2012.

Beam quality	R= PTB/IAEA	$u_R$ (relative standard uncertainty in %)
RQR-2	1.0021	0.2
RQR-5	1.0002	0.2
RQR-10	1.0008	0.2
RQT-9	0.9992	0.2

When the comparison results ( $R = N_{K, \text{part}} / N_{K, \text{ref}}$ ) were consistent with unity (within the expanded uncertainty of  $R$ ) and were within the  $\pm 2.5\%$  acceptance limit, the IAEA asked the participant to send back the transfer instruments together with the signed hard copy of excel data evaluation sheet. If one or more results were not consistent or outside of the acceptance limit, the IAEA informed the participant, without disclosing any details of the deviations. In this case additional two weeks were available for the participant to investigate the measurements (setup, calculations, uncertainties etc. or repeat the measurements again).

Note that the acceptance limit of  $\pm 2.5\%$  is established, taking into account the uncertainty budget example of the substitution method calibration practice, Table 6.8 of IAEA TRS 457 [4] as well as the reasonable achievable uncertainty of the comparison reference value determination. This acceptance limit enables the end-users to measure the air kerma with a diagnostic dosimeter, in compliance with the requirement of the IEC 61674 ed.2.0 [5] standard and calibrated at SSDL, with an expanded uncertainty of less than  $\pm 12\%$ .

Uncertainty calculations for the calibrations were done according to the GUM [7], and included all the components related to the specific calibration method and the environment at each SSDL. As an example, the uncertainty budget of participant 4 can be seen in Table 5.

Since all SSDL participants are traceable to the PTB, the uncertainty components of the physical constants (0.15 %) and the correction factors (0.2 %) of the primary standard free air chamber at the PTB are fully correlated. They were taken into account in the uncertainty calculation of  $R$  values. In case of the PSDL (Participant 5) only the uncertainty components of the physical constants are fully correlated and removed from the uncertainty budget.

Table 5. Uncertainty calculation of the diagnostic chamber calibration at the SSDL of participant 4.

Uncertainty component	Type A	Type B
<b>1. K-rate measurement with reference meter</b>	%	%
Calibration coefficient of Exradin A3		0.39
Long term stability of Exradin A3		0.29
Ionization current measurement	0.05	0.17
Difference in radial non-uniformity of the beam		-
Spectral difference between PTB and SSDL		0.06
Leakage current		0.06
Pressure and temperature correction		0.10
Recombination		-
Polarity		-
Stem effect		0.01
Short term stability of x-ray output during measurement	0.05	
Square sum	0.07	0.53
<b>1. Relative combined standard uncertainty of K-rate k=1</b>		0.53
<b>1. Relative combined standard uncertainty of K-rate k=2</b>		1.06
<b>2. K-rate measurement with meter to be calibrated</b>		
Positioning of the chamber at calibration distance		0.23
Ionization current measurement	0.05	0.17
Difference in radial non-uniformity of the beam		-
Leakage current		0.06
Pressure and temperature correction		0.10
Recombination		-
Polarity		-
Stem effect		-
Short term stability of x-ray output during measurement	0.05	
Stability of x-ray output between measurements		0.29
Square sum	0.07	0.42
<b>2. Relative combined standard uncertainty of K-rate k=1</b>		0.43
<b>2. Relative combined standard uncertainty of K-rate k=2</b>		0.86
<b>1.+2. Relative combined standard uncertainty of Nk k=1</b>		0.68
<b>1.+2. Relative combined standard uncertainty of Nk k=2</b>		1.37

## Results and conclusion

Except for the Participant 1, the applied calibration parameters of the participants approached the values recommended in the Technical Protocol, as shown in Table 6.

Table 6. Calibration parameters of the participants

Participant	RQR-2 HVL (mm Al)	RQR-5 HVL (mm Al)	RQR-10 HVL (mm Al)	RQT-9 HVL (mm Al)	FDD/Beam diam (cm)	Kair rate (mGy/min)	**u(Nk)
IAEA	1.42	2.59	6.74	8.49	100/10	50	0.55
1	1.45	2.66	6.69	---	100/5x5	12-110	2
2	1.5	2.6	6.5	8.6	100/10	50	0.63
3	1.44	2.58	6.61	8.41	100/27	19-52	1.14
4	1.42	2.62	6.6	8.68	100/14	32-50	0.7
5	1.41	2.59	6.58	8.43	*90/15	50	0.5
6	1.39	2.54	6.44	8.51	100/10	24-52	0.6

\*only the results measured by "setup 1" were used for the comparison  
\*\* as they were stated in the individual uncertainty budgets

The IAEA evaluated the comparison measurements and reported the results to the participants having used a restricted standard form. Figure 3 shows the graphical representation of the final comparison results anonymously. As can be seen, all results are consistent (expanded uncertainty bars of  $R$  values cover the unit) and don't exceed the 2.5% acceptance limit.

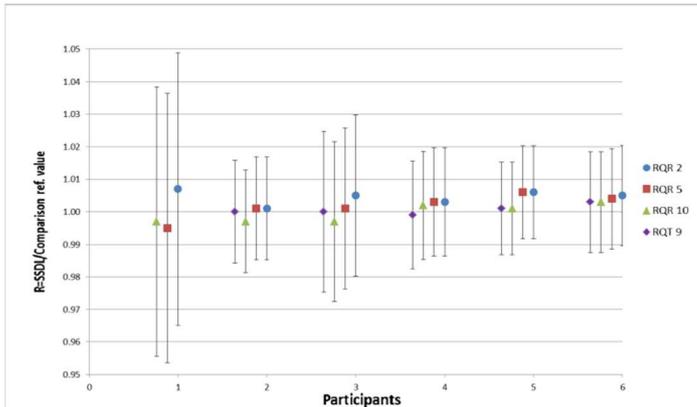


Figure 3. Pilot comparison results of participants in 2013-2014. The error bar is the expanded ( $k=2$ ) uncertainty of each participant.

Taken into account the results of this pilot study, SSDLs 3 and 4 may reduce their published CMC claims uncertainties. In case of Participant 5 the expanded uncertainty of R is slightly higher than the uncertainty of the published claim, see Table 1.

This pilot comparison exercise confirmed the 2.5% acceptance limit and the new arrangement of the IAEA-SSDL bilateral comparison program. Detailed comparison protocol, high quality IAEA transfer chambers, scheduled comparison time window, and standardized reporting form will be used for the comparisons. The Technical Protocol and the excel report template of the IAEA diagnostic comparison program can be downloaded from the [SSDL network website](#).

*Note that when eligible participants intend to use the IAEA-SSDL bilateral comparison results to support their CMC claims, the confidential IAEA reports and the excel worksheets for data record and evaluation need to be disclosed for the yearly publication of the bilateral*

*comparisons in open literature. The publication should include sufficient technical details and uncertainty calculations to enable judgements on whether the comparison results can support the specified CMC claims [8].*

## References

- [1] IAEA/WHO Network of Secondary Standard Dosimetry Laboratories, [SSDL Network Charter IAEA](#), Vienna (1999).
- [2] DOLP 013 [Appendix to IAEA Calibration Certificate for Diagnostic Radiology Ionization Chamber Calibration Procedures at the IAEA Dosimetry Laboratory](#)
- [3] IEC 61267:2005 Medical diagnostic X-ray equipment - Radiation conditions for use in the determination of characteristics
- [4] IAEA Technical Report Series no. 457, [Dosimetry in Diagnostic Radiology: An International code of Practice](#), 2007
- [5] IEC 61674 ed.2.0 Dosimeters with ionization chambers and/or semiconductor detectors as used in X-ray diagnostic imaging
- [6] Comparison of air kerma measurements between the PTB and the IAEA for x-ray radiation qualities used in general diagnostic radiology and mammography, *Metrologia* 2013, **50**, Tech. Suppl., 06008
- [7] ISO/IEC [Guide to the Expression of Uncertainty of Measurement](#), 2008
- [8] Measurement comparisons in the context of the CIPM MRA CIPM MRA-D-05 [http://www.bipm.org/utls/common/CIPM\\_MRA/CIPM\\_MRA-D-05.pdf](http://www.bipm.org/utls/common/CIPM_MRA/CIPM_MRA-D-05.pdf)

# Development of Quality Audits for Advanced Technology in Radiotherapy Dose Delivery

Report of 2nd RCM held in IAEA Headquarters,  
Vienna, 28 September – 2 October 2015

Joanna Izewska, Dosimetry and Medical Radiation Physics Section, IAEA

**RCM participants:** Victor Gabriel Alves (Brazil), Suming Luo (China), Eduardo Larrinaga Cortina (Cuba), Daniela Ekendahl (Czech Rep.), Irena Koniarova (Czech Rep., observer), Vinatha Panyam (India), Wojciech Bulski (Poland), Krzysztof Chelminski (Poland, observer), Siri Srimanoroth (Thailand), Emelie Adolfsson (Sweden), Åsa Carlsson Tedgren (Sweden), Dietmar Georg (Austria), Wolfgang Lechner (Austria, observer), Milan Tomsej (Belgium), Mikko Tenhunen (Finland), Julie Povall (UK, observer), Andrea Molineu (USA, observer).

**IAEA participants:** Balazs Almady, Tomislav Bokulic, Tania Santos, Paulina Wesolowska.

**Scientific Secretary:** Joanna Izewska

The purpose of the 2nd Research Coordination Meeting (RCM) of the E2.40.18 Coordinated Research Programme (CRP) entitled “Development of Quality Audits for Advanced Technology in Radiotherapy Dose Delivery” was to review the research programme of the CRP, to discuss the results of scientific investigations in regards to methodology and procedures for national external audit groups (EAGs) for dose verification of advanced technology radiotherapy used for cancer treatment and to review the work plans for the remaining term of the CRP until its completion. Reports by participants on the status of national dosimetry audits and research relevant to the CRP were delivered and discussed. In addition to the RCM discussions, a practical ‘end-to-end’ audit session was conducted at the AKH hospital in Vienna, and a 1-day workshop on radiochromic film dosimetry took place at the IAEA Laboratories, Seibersdorf, supported by in-kind contribution by Ashland, USA.

Within the current CRP new methodology was developed for four audit steps (that were consecutively numbered following the previous audit steps 1–6 developed in the past series of CRPs dedicated to dosimetry audits in radiotherapy): (i) step 7a: remote verification of treatment

planning systems (TPS) calculation of small beam output factors (ii) step 7b: dosimetry audit of multileaf collimators (MLC) positional performance using radiochromic film, (iii) step 8: film audit of single clinical intensity modulated radiotherapy (IMRT) field dose delivery and (iv) step 9: ‘end-to-end’ dosimetry audit (imaging, planning, dose delivery) for multiple field IMRT techniques using TLDS and radiochromic films. Procedures and phantom designs developed within the CRP as well as instructions and data sheets for audited centres were reviewed and discussed. Results of testing these procedures through pilot studies involving a group of research agreement holders and multicentre studies involving all CRP participants were presented.



*Fig. 1. Workshop on radiochromic film dosimetry at the IAEA Laboratories, Seibersdorf, in-kind contribution by Ashland, USA.*

Dosimetry phantoms used in this CRP were designed in consultants’ meetings associated with the CRP; they were machined at the IAEA. Initial feasibility studies to test the phantoms were performed at the AKH hospital in Vienna by staff of the IAEA Dosimetry Laboratory (DOL) in Seibersdorf in cooperation with colleagues of the Vienna Medical University. All pilot and multicentre studies were organized by DOL. Phantoms were distributed by DOL

staff together with films and TLDs to the CRP participants for irradiation. Upon the return of irradiated detectors to DOL, they were evaluated and the global results were analyzed. Following the verification of CRP procedures in multicentre audit runs, national developments were initiated including trial audit runs with a selected number of radiotherapy centres in participating countries.

## Summary of CRP activities

### *Step 7a: Quality audits for dose rate dependence of small fields shaped with MLC*

The purpose of this audits step was to check dosimetric data in TPS for small fields shaped with MLC. This was done by calculating the number of monitor units (MU) in TPS for 5 MLC-shaped field sizes to deliver 10 Gy on axis at 10 cm depth at 100 cm source skin distance (SSD). The dose rate was calculated for fields  $2 \times 2 \text{ cm}^2$ ,  $3 \times 3 \text{ cm}^2$ ,  $4 \times 4 \text{ cm}^2$ ,  $6 \times 6 \text{ cm}^2$  and  $10 \times 10 \text{ cm}^2$  and normalized to that at  $10 \times 10 \text{ cm}^2$  field. Results were compared with the published data sets [1, 2].

In total 140 TPS data sets from 14 countries participating in the CRP were collected (27 from pilot study, 16 from multicentre study and 97 from national trial audit runs); of these, the analysis was performed on 119 data sets. The remaining 21 data sets were not included in the analysis mostly because participants used flattening filter free (FFF) beams for which the reference data have not yet been published [1, 2]. A new publication on this topic is in press. The average ratios between the TPS calculated output factor (OF) and published OF [1, 2] showed that, in general, TPSs overestimate the dose for small fields. The mean value for  $2 \times 2 \text{ cm}^2$  field was 1.021 with 0.03 standard deviation (SD); for  $3 \times 3 \text{ cm}^2$  field it was 1.011 with 0.02 SD. The acceptance criteria of  $\pm 3\%$  for  $2 \times 2 \text{ cm}^2$  and  $\pm 2\%$  for fields  $\geq 3 \times 3 \text{ cm}^2$  were adopted. 35 of 119 data sets analyzed in this study did not meet the acceptance criteria. These were mostly Varian machines with older generation TPSs using the golden data sets. A follow up was organized to gather information on commissioning of TPSs for small fields (local measurements, detector, orientation, corrections, OF table). Once the deviations in TPS calculation for small fields have been confirmed by careful measurements, it will be necessary to correct them in order to improve the accuracy of the dose calculation for small segment sizes in the delivery of IMRT.

### *Step 7b: Film quality audit of MLC performance for IMRT dose delivery*

The aim of this study was to assess a picket fence test as an audit tool for verifying the positioning accuracy of MLC leaves. This was done by irradiating an MLC pattern consisting of 5 strips positioned at -6 cm, -3 cm, 0 cm, 3 cm, and 6 cm relative to the central axis on an EBT 3 film (for Varian machines, the central strip was shaped with the main jaws). Films were placed for irradiation in a solid phantom at the depth close to the depth of the dose maximum, at 100 cm source axis distance (SAD). In total 46 films from 14 countries were analyzed (6 from pilot study, 10 from multi-centre study and 30 from national trial runs). Nine different MLC models were checked: Agility, Beam Modulator and MLCi/MLCi2 from Elekta, Millennium 120, Millennium 80 and HD120 from Varian and MLC 160, MLC 82, MLC 58 from Siemens. The strips positioning bias, the opening width and the average strips position were checked. The acceptance criteria for the positioning bias were  $\pm 0.5 \text{ mm}$  between the individual pairs of leaves and the average of all pairs of leaves. For the opening width the acceptance limits were  $\pm 0.75 \text{ mm}$  and  $0.3 \text{ mm}$  standard deviation between the opening width of individual pairs of leaves and the average of all pairs of leaves. The average strips positions showed that for Varian machines the offset between the centre of main jaws and MLC can be up to  $0.7 \text{ mm}$ . The best results were achieved for Millennium 120 MLC. In total 9 from 46 films analyzed had unsatisfactory results; all 9 did not meet the criteria for the opening width and 6 of them of the opening bias. The centres with poor results were alerted of their MLCs sub-optimal performance.

### *Step 8: Film quality audit for relative dosimetry of photon beam single IMRT field*

The aim of this study was to verify the audit methodology for the transfer of an IMRT treatment field from the TPS to the treatment unit, the delivery of the treatment field and the agreement between the delivered relative dose distribution and that calculated by the TPS. A single highly modulated IMRT field chosen for a clinical patient treatment at the hospital was delivered to a film positioned at 100 cm SAD in a solid water phantom at 5 cm depth. Film was irradiated several times to reach the maximum dose of 6 Gy. Participants from 14 countries irradiated 16 films using 8 different accelerator models, 6 MLC models, 4 TPS models and 8 dose calculation algorithms. Comparison was performed between the TPS calculated and the film measured dose distributions using a gamma analysis tool by FilmQA Pro, Ashland. The gamma acceptance criterion of  $3\%/3\text{mm}$  over all pixel values exceeding 20% of the maximum dose was adopted, with 90% of pixels passing the criterion. Agreement of the

profiles through the maximum dose region was also checked with the criteria of 7% of the maximum dose for low gradient regions and 4 mm position error for high gradient regions. All participants achieved the minimum passing level of 90% with the actual passing rate between 95.4% and 100%. The average result of gamma analysis for Varian machines was 99.0% (12 participants) and for Elekta machines 97.7% (4 participants). Comparison of dose profiles showed that the largest differences occur in the high dose gradients regions, where precise positioning of the MLC leaves has the greatest impact on the accurate dose delivery; 4 mm error in such regions can bring more than 20 % difference in the dose.

#### *Step 9: “End-to-end” dosimetric quality audit for IMRT including imaging, treatment planning and delivery*

The aim of performing this “end-to-end” exercise was to verify the audit methodology of the dose delivery for IMRT treatment including all phases from CT images acquisition to the final beam delivery. For this audit, a polystyrene phantom was designed containing an IMRT QA insert with solid water structures representing a planning target volume (PTV) and an organ at risk (OAR).



*Fig. 2. Solid phantom for ‘end-to-end’ dosimetric quality audit for IMRT including imaging, treatment planning and delivery.*

Each participant received a phantom loaded with a piece of EBT film and 4 TLDs (2 in PTV and 2 in OAR); extra TLDs for imaging were also sent. Participants were asked to scan the phantom, contour the structures, create the treatment plan and irradiate the phantom. The plan was generated as per the standard hospital procedures for head and neck to deliver 4 Gy to PTV in 2 fractions and limit the dose to OAR to 2.8 Gy (additional target objectives were provided). Feasibility study was performed to initially test the audit methodology. Additional measurements were done to determine corrections needed for TLD evaluation due to imaging procedures. Several CT scans of the phantom were performed at the AKH hospital in Vienna in

order to check the extra signal on TLDs. For this, two TLDs were placed outside the phantom and two TLDs in the target volume inside the phantom. The results showed that the signal from the outside TLDs is approximately 0.6% of the signal from the TLDs irradiated to the dose of 2 Gy. The signal of inside TLDs was about 20% higher than from the outside TLDs. Ion chamber measurements were also performed for TLD positions in PTV and OAR to verify if the TLD dose is in agreement with the ion chamber measurements. To-date the pilot study results were obtained for 6 participants using 6 different accelerator models, 4 MLC models, 3 TPS models and 5 dose calculation algorithms.

All 6 participants created the TPS plans fulfilling the criteria provided; the range of the mean dose for OAR TLD was large with the minimum of 0.63 Gy and the maximum of 2.12 Gy; they were well below the 2.8 Gy limit. Gamma analysis using FilmQA Pro, Ashland, was performed to compare TPS calculated and film measured dose distributions. Similarly to Step 8, the gamma acceptance criterion of 3%/3 mm over all pixel values exceeding 20% of the maximum dose was adopted, with 90% of pixels passing level. TLD results were presented as ratios of the TLD measured dose and the participant stated dose ( $D_{TLD}/D_{stat}$ ).

All participants achieved the minimum gamma passing level of 90% with the actual passing rates between 93.5% and 100%. TLD results were in good agreement with TPS doses in the PTV region with the mean ratio of  $D_{TLD}/D_{stat}=0.991$  and the standard deviation of 1.3%. Results in OAR gave the mean value of  $D_{TLD}/D_{stat}=1.007$  with the standard deviation of 5.6%. OAR TLDs were located in a high dose gradient region, where a 1 mm positional shift could cause a difference up to 12% for specific treatment plans.

### **National contributions**

In addition to the global results of pilot and multicentre audit runs, developments at the national level by CRP participants were reported. Summaries provided by a few participants are given below.

#### *Brazil*

The methodology of the current CRP extends the external audit activities to advanced techniques which are becoming increasingly used in modern radiotherapy in Brazil. There are around 250 radiotherapy services and some new institutions are already implementing volumetric arc therapy (VMAT) as their first and main technique. It is important to establish a comprehensive methodology to

evaluate the performance of these modern radiotherapy techniques.

An independent verification of the output factor calculated by treatment planning systems was carried out in 7 radiotherapy services with 8 Varian machines. The majority of MLC models were Millennium 120, the only exception was a True Beam machine with HD 120 MLC. Large deviations were found on the smallest field size ( $2 \times 2 \text{ cm}^2$ ) and the main reason for that was the use of too large ionization chamber for the measurements.

An ‘in house’ software was developed in order to provide a flexible tool to perform gafchromic film dosimetry. The Python programming language was used. The methodology implemented is optical density based using scanned film images to perform dose measurements. EBT3 films were scanned in a color mode RGB (red, green and blue) 16 bits per channel and spatial resolution of 72 dpi. Calibration curves were obtained for each channel using the least squares polynomial fitting. The uncertainty parameterization for each calibration curve was implemented based on literature [3] for type A uncertainty. A methodology to perform multichannel weighted dosimetry was adapted from Alves et al [4] and Mendez et al [5] and it was possible to estimate Type B uncertainty.

An automated picket fence image processing was developed for two MLC models, Varian Millennium 120 and Elekta MLCi. At the step 8a, gamma index parameters were 3%/3mm and threshold of 20% and image registration between film and TPS doses was made automatically through normalized cross correlation method. The average pass rate found for 7 beams audited was 96.8% with 4.7% standard deviation.

#### *China*

Within the current CRP, trial quality audits for IMRT dose delivery in 30 radiotherapy centres having Elekta, Varian and Siemens accelerators in 4 provinces of China were carried out. For the audit step 7a, output factors were calculated by TPSs in participating centres and compared to the published data [1, 2]. Overall, 70% results were found acceptable. Output factors calculated by TPSs were outside the  $\pm 2\%$  and  $\pm 3\%$  limits for  $3 \times 3 \text{ cm}^2$  and  $2 \times 2 \text{ cm}^2$  fields, respectively, for 7 Varian and 2 Siemens machines. As a follow-up, local measurements performed with the ion chamber showed very good agreement between the measured and published output factors.

Following the methodology of the CRP step 7b, a trial study of the MLC positioning accuracy was performed for 30 accelerators. Strips and individual leaf positions were

analyzed and 24 of 30 picket fence tests achieved satisfactory results.

For the audit step 8, a large homogenous solid phantom was used for a single IMRT field irradiation in 28 centres. Analysis of films was done with FilmQA software using gamma acceptance criteria of 3%/3mm and 20% threshold. 25 of 28 (89.3%) IMRT fields had the gamma passing rate above 90% acceptance limit. This exercise was accompanied by a TLD audit using the IAEA’s  $15 \times 15 \times 15 \text{ cm}^3$  solid phantom. Together with TLDs, a set of EBT3 films was irradiated by participating centres in the same phantom in the range of 50 cGy – 800 cGy for calibration purposes. In total, 25 of 30 TLD results (83.3%) were within the  $\pm 5\%$  acceptance limit.

#### *Cuba*

The project was conceived for four participating hospitals: Instituto de Oncología y Radiobiología (INOR), Hospital Clínico Quirúrgico Hermanos Ameijeiras (HHA), Hospital Oncológico Conrado Benitez (HOGB), Centro de Investigaciones Médico Quirúrgicas (CIMEQ). The first three hospitals have the technical capacity to implement the IMRT technique and CIMEQ is planned to implement it in the coming year. Currently the IMRT technique is only implemented and licensed clinically at INOR. For this reason INOR has not acted as EAG (trial run) but as audited center by the IAEA on the steps performed within the multicentre pilot runs.

The methodology implemented at INOR for IMRT QA was the patient-specific QA through the dose maps field by field checks by measurements with 2 D ion chamber arrays in a regular phantom of solid water slabs. In some cases, the composite plan is checked with an octagonal phantom. Eventually checks have been performed using redundant programmes and radiochromic films.

In this part of the project INOR performs steps 7, 8 and 9. The results are within the limits of accepted tolerances. For the next period it is expected that two of the centers will start IMRT treatments, so it is planned to use the audit methodology tested in INOR as a mandatory test for licensing these techniques before the clinical use. This will also constitute the performance evidence within the Cuban National Quality Audit Program in Radiotherapy.

A newly acquired glass dosimetry system (RPLD) would allow INOR to assess the replacing of TLD in the audits. This development would bring more flexibility and independence with the postal audits logistics.

### *The Czech Republic*

The Czech Republic's population is about 10 million, while the number of cancer patients undergoing radiotherapy reaches about 26 thousand per year. The radiotherapy is provided by 34 radiotherapy centers. Independent national dosimetry audits are carried out by laboratories of the National Radiation Protection Institute in Prague. The audits exist in two forms, as on-site and postal TLD audits. Their purpose is to contribute to improvement of clinical dosimetry in the scope of the general quality assurance programme in radiotherapy, and consecutively to maintenance of good practices.

The postal TLD audits started in 1997. At present, a few methodologies differing in extent of dose measurement are available. They include dose measurements both under reference and non-reference conditions of external photon beam radiotherapy. In practice, however, the most applied is basic TLD audit for beam calibration check. In accordance with the Czech national recommendations, each clinically used beam must undergo this basic audit every two years. The results are provided to the State Office of Nuclear Safety (SONS), which is responsible for radiation safety in the Czech Republic. The benefit of these checks is unquestionable. Major deviations have been very scarce lately, and they usually are connected with random errors. The more advanced versions of the TLD audit have been realized as trial runs in the frame of both international and national research projects. However, for SONS's purposes, a national run of the TLD audit for photon beams in the presence of heterogeneities has been launched this year.

The on-site audits have been performed since 1996 after commissioning of each treatment unit. Absorbed dose to water (or RAKR for brachytherapy), beam quality, output and wedge factors, PDD, MLC positioning, MLC transmission, and dosimetric leaf gap (where applicable) are checked. Mechanical parameters (isocentre stability, radiation field size, treatment couch parameters, etc.) are verified as well. The audits have revealed several significant errors that might have potentially lead to an accident if not remediated. Checks of non-dosimetric parameters and imaging functions of TPS with QUASAR phantoms can be performed on request. Moreover, end-to-end audits for IMRT prostate treatment are available from 2013. Doses delivered to PTV and rectum are measured with ionization chambers in 3 planes. Planar dose distribution is verified with EBT2 film. It allows making DVHs analysis and evaluating the common practice in IMRT prostate treatment planning in the Czech Republic.

During the current CRP, new methodologies were tested. A national trial run revealed discrepancies in calculations of output factors related to small IMRT fields. Deviations of 6% (for 6 MV beams) and 11% (for 18 MV beams) were found for Eclipse treatment planning system with Pencil Beam Convolution algorithm and v8.6 Progressive Resolution Optimizer algorithm. The degree of a possible influence of these deviations on clinical outcomes has not been quite clarified for this particular case. However, pencil beam algorithms are substituted progressively with algorithms that better count changes in the lateral electron transport. Most of the Czech hospitals having Eclipse treatment planning system have already introduced a more advanced AAA algorithm into clinical practice. Trial audit runs of other methodologies (picket fence test, dose distribution for a single beam IMRT field) did not expose any particular issues.

### *India*

The SSDL at the Bhabha Atomic Research Centre (BARC) has conducted TLD postal dose quality audits under reference conditions for radiotherapy centres in India. Out of the 100 institutions contacted, 78 had expressed their willingness to participate in the recent audit run. The results of the audits show 66 institutions having their results within  $\pm 5\%$ , 10 within 5-10% and 2 greater than  $\pm 10\%$ . The discrepancies in dosimetry that occurred in 12 institutions with poor TLD results were resolved and the repeat audit run is under implementation.

Under the development of quality audit for advanced technology in IMRT in India, SSDL-BARC conducted audits for twenty two radiotherapy beams for dose rate dependence of small fields shaped with MLCs (step 7a). Six radiotherapy centres participated in a trial run for film quality audit of MLC performance for IMRT dose delivery (step 7b).

In step 7a, 10 Varian, 7 Elekta and 2 Siemens machines were included. Of the 10 institutions participating with Varian machines, three had results outside the acceptable limits. It was noted that some institutions were making use of 0.6 cc chambers for small beam dosimetry. One of the institutions was making use of Pencil Beam Convolution algorithm whereas the others were using Analytical Anisotropic Algorithm. These are known issues contributing to deviations in small beam output factors both resulting from TPS commissioning and from the limitations of calculation algorithms. For the seven Elekta machines included in the audit, none showed any deviations. Out of the two institutions that were having Siemens machine, one showed the deviation of 7.5% for  $2 \times 2 \text{ cm}^2$  field size and 3%

for 3×3 cm<sup>2</sup> field. The institutions with discrepancies were advised to re-commission their treatment planning systems.

For the audit step 7b, films were scanned using EPSON 10000XL and evaluated using ImageJ software package. The picket fence pattern showed that of the six institutions that were audited one had a difference of 2.1mm between the planned and evaluated leaf width opening. The results for the remaining five institutions showed differences of less than 1mm between the planned and evaluated leaf width opening.

#### *Poland*

The routine activities of the SSDL of Poland included the updating of the radiotherapy infrastructure database, dosimeter calibrations, country wide TLD postal audit runs for Polish radiotherapy centres, and the Polish SSDL TLD system verification by the IAEA via the blind check. Within the framework of the CRP E2.40.18, the audit steps 7 - 9 were followed.

The CRP Step 7a on quality audits for dose rate dependence of small fields shaped with MLC was implemented for 32 out of 35 Polish radiotherapy centres for different linacs, TPSs, MLC types and beam qualities. In total, 81 beams were checked (Varian 41, Elekta 24, Siemens 16). The beam qualities ranged from 4 MV to 20 MV. The results were evaluated and compared to the published data [1, 2]. Although comprehensive, the published dataset did not provide data for certain beam qualities, therefore the interpolation/extrapolation was performed fitting the second degree polynomials to the published data. When compared to the published values, the TPS calculated mean output factors by participating centres agreed for all field sizes and energies within 1% difference for Elekta machines. For Varian machines the average differences for 3×3 cm<sup>2</sup> and 2×2 cm<sup>2</sup> fields for 6 MV beams were 1.6% and 2.3%, respectively. For Siemens machines the differences for 2×2 cm<sup>2</sup> fields were 1.6% and 1.7% for 6 MV and 15 MV beams.

The picket fence test (CRP step 7b) is undergoing nationwide. The films were sent to 35 centres together with the MLC sequences prepared for different types of accelerators available in Polish radiotherapy centers. To-date 34 participants returned the films irradiated following the step 7b MLC sequence. The results are being analyzed.

The single IMRT field test was performed according to the IAEA instruction sheet for step 8: "Film quality audit for relative dosimetry of photon beam single IMRT field" for one of six Varian Clinac 2300 C/D accelerators installed at the Oncology Centre in Warsaw within the framework of a multicentre study. Also for the audit step 9, a nine beam

IMRT plan was prepared and delivered to the IAEA solid phantom using 'end-to-end' methodology. Using the experiences of the multicentre study results for the audit steps 8 and 9, national developments will be initiated.

#### *Thailand*

In Thailand, there are 61 linear accelerators installed in 32 radiotherapy centers, and 46 of them have IMRT capability. A complete radiotherapy audit system is not yet available, but the SSDL performs beam output calibration and provides TLD postal dose audit to all radiotherapy centers annually. The participation in the IAEA CRP Project on 'Development of Quality Audits for Advanced Technology (IMRT) in Radiotherapy Dose Delivery' is an opportunity for the Thai SSDL to gain experience in auditing radiotherapy treatment planning and performing 'end-to-end' audits. Three Thai radiotherapy centres participate in the CRP: Chulabhorn Hospital, King Chulalongkorn Memorial Hospital and Ramathibodi Hospital. They are all quipped with Varian Machines and Eclipse TPSs.

In the CRP Step 7a on quality audits for dose rate dependence of small fields shaped with MLC, results of two centres were outside the acceptable level (3.4%, 3.6%), and the third one was borderline (2.9%). These results are being followed out by the SSDL with measurements using a microdiamond and edge detectors.

In the CRP Step 7b on picket fence test, all three hospitals had satisfactory results for both MLC positioning bias and opening width evaluation.

In the CRP Step 8 on film quality audit for relative dosimetry of photon beam single IMRT field, the results of gamma analysis of three hospitals showed passing rate above the minimum passing level of 90%. Their data were of 99.4%, 99.9%, and 100% passing rate.

For the CRP Step 9, additional measurements are planned with small real time detectors to determine the dose inside the structures of the 'end-to-end' phantom during IMRT treatments.

#### *Remarks on gamma analysis: testing scanners and software tools*

A study of different flatbed scanners, software tools for radiochromic film analysis and handling protocols was performed at the IAEA Dosimetry Laboratory to better understand differences in gamma analysis results performed locally by different countries participating in this CRP.

A set of IMRT films were evaluated with three software tools (Ashland FilmQA Pro, PTW Verisoft,

Radiochromic.com) and three scanners (EPSON 11000XL, EPSON 4990 and EPSON 750 Pro). Gamma analysis was performed using the following set of parameters: 3% dose difference (DD), 3 mm distance-to-agreement (DTA) and 20% dose threshold. Both global and local gamma values were calculated.

A range of gamma results were obtained with FilmQA Pro for the same films scanned with three scanners above. For the global gamma setting the gamma pass rates from 96.2% to 99.6% were obtained and for the local gamma setting, the corresponding results ranged from 91.5% to 97.6%. Overall, the differences in the gamma pass rates for the same films scanned with different scanners were up to 3.4% and 6.1% for the global gamma and the local gamma settings, respectively. Different software tools used in analyzing the same film (scanned by the EPSON 11000XL) also affect the gamma pass value; the results ranged from 95.9% to 98.3% for the global gamma setting and from 95.1% to 98.2% for the local gamma setting. On the whole, the differences between the gamma values calculated by different software tools were up to 3.4% for the global gamma and up to 3.1% for the local gamma settings.

The results of this study show that different scanners and software tools can result in differences in the gamma passing rate. In particular, the use of different scanners can generate considerable differences. Comparing gamma analysis performed by national audit groups may not be straightforward due to the differences in hardware/software used for film analysis.

## RCM recommendations

The meeting participants formulated the following recommendations:

1. Experiences of the audit Step 7a for small fields shaped with MLCs relevant to IMRT treatments indicate that the TPSs calculate doses that are generally higher than the measured doses. The audits found that about 30% of the small field audit results were outside the acceptance limit. In particular, this is pronounced for algorithms that do not include lateral transport of secondary electrons, such as those utilizing pencil beam model. Due to the magnitude of deviations in small field results, the audit groups should recommend to the participating radiotherapy centres to commission their TPSs in accordance with the clinical applications used. The upgrade of outdated TPSs to the algorithms that account for lateral transport would be necessary, in particular for dose calculations in lung and breast as well as for head and neck treatments, where significant dose errors of 20-30% have been reported affecting the treatment outcome, especially for higher

photon beam energies. Literature on this topic is widely available.

2. In addition, the EAG should provide feedback to those radiotherapy centres which used ionization chambers with inappropriately large volume for small beam dosimetry, such as 0.6 cc chamber for  $2 \times 2$  cm<sup>2</sup> field output. Accidents were reported resulting in from the misuse of detectors for small beams.

3. The experiences of the CRP E2.40.18 indicate that gamma analysis comparison among centres is not trivial and careful attention should be paid to film dosimetry and results evaluation.

4. Interest was expressed for continuing the IAEA CRP series involving national audits for radiotherapy dosimetry. Suggestions for next CRP topics to be considered involve auditing dosimetry in brachytherapy, image guided radiotherapy (IGRT) as well as radiosurgery and stereotactic body radiation therapy (SBRT).



Fig. 3. RCM participants and observers.

## Acknowledgements

In-kind contribution by Ashland, USA, is acknowledged for delivering a workshop on Gafchromic film dosimetry and gamma analysis, and for providing user licenses for FilmQA Pro for the workshop participants.

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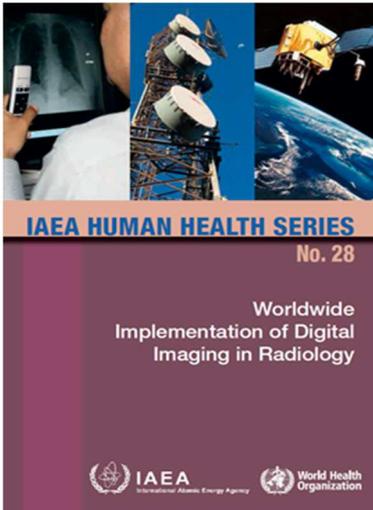
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## New IAEA Publications

### Worldwide Implementation of Digital Imaging in Radiology

Harry Delis



*IAEA Human Health Series No.28 on "Worldwide Implementation of Digital Imaging in Radiology"*

Until the end of the last century, the majority of medical imaging examinations used film as a medium for image capture, display and storage. The digital image revolution in medical diagnostic imaging, however, began in the 1970s with the invention of the computed tomography (CT) scanner. This was followed by magnetic resonance imaging (MRI) in the 1980s and digital X ray acquisition systems (such as computed radiography (CR) and digital radiography (DX) in the 1990s. The momentum of digital medical imaging has grown to the extent that digital image management is currently the preferred method for medical imaging.

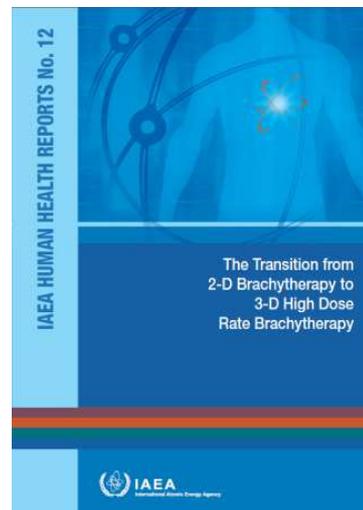
The reasons for this include the efficiencies inherent in digital capture, display and storage and the competitive cost structures of such systems when compared to alternatives involving film. Additionally, digital medical imaging also enables teleradiology (the remote review, consultation and interpretation of medical images) to become a practical and effective method to address the uneven geographical distribution and the local shortages of imaging specialists. The increasing role of technology may help to alleviate staff shortages, though other and new roles in technical infrastructure support will be necessary. Nevertheless, despite all these advantageous characteristics, implementing fully digital medical imaging systems, from request to report, remains a nontrivial exercise.

In response to the need to advise Member States, and as a result of a request from the World Health Organization (WHO), made through the Scientific Committee of the IAEA/WHO Network of Secondary Standards Dosimetry Laboratories, work was begun to investigate this topic. As a result in September 2015, the IAEA Human Health Series No. 28, entitled "Worldwide Implementation of Digital

Imaging in Radiology" was released, as collaboration between IAEA and WHO. This publication is aimed at administrative, clinical and technical staff who are faced with the introduction of digital technology to diagnostic radiology in their clinics.

This includes hospital administrators and managers, radiologists and radiographers, technologists, medical physicists and clinical engineers as well as information technology staff. The publication provides a basic introduction in digital technology and digital networks as well as an overview of the issues to consider when implementing such technology in diagnostic radiology.

### The Transition from 2-D Brachytherapy to 3-D High Dose Rate Brachytherapy



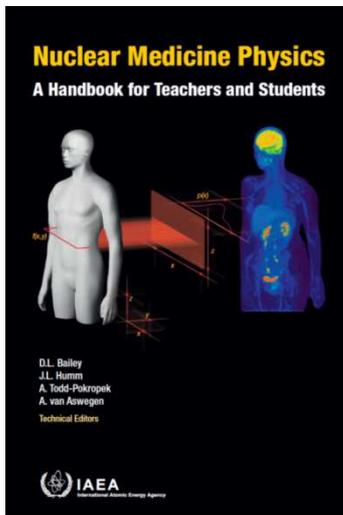
*IAEA Human Health Reports No. 12*

Brachytherapy is a major treatment modality in the treatment of common cancers including cervical cancer. This publication addresses the recent technological change in brachytherapy treatment planning with better access to 3-D volumetric patient imaging modalities including computed tomography (CT) and magnetic resonance (MR) as opposed to traditional 2-D planar images. In the context of 2-D and 3-D brachytherapy, the publication provides definitions, clinical indications, transitioning milestones, commissioning steps, quality assurance measures, and a related questionnaire. Staff training and resourcing are also addressed.

The publication will serve as a guide to radiotherapy departments in Member States who wish to make the transition from 2-D to 3-D brachytherapy. (*Information taken from [www.pub-iaea.org](http://www.pub-iaea.org)*)

# Nuclear Medicine Physics Handbook

Gian Luca Poli



*Nuclear Medicine Physics Handbook*

Nuclear medicine is the use of radionuclides in medicine for diagnosis, staging of disease, therapy and monitoring the response of a disease process. It is also a powerful translational tool in the basic sciences, such as biology, in drug discovery and in pre-clinical medicine. Developments in nuclear medicine are driven by advances in this multidisciplinary science that includes physics, chemistry, computing,

mathematics, pharmacology and biology.

The IAEA Nuclear Medicine Physics Handbook for Teachers and Students covers the physics of nuclear medicine and is the third in the series of books for Medical Physics education after the Radiation Oncology and Diagnostic Radiology handbooks. The intent of this hardcover volume is to provide a comprehensive overview of the knowledge required in physics, instrumentation and data processing for the practice of medical physics in modern nuclear medicine.

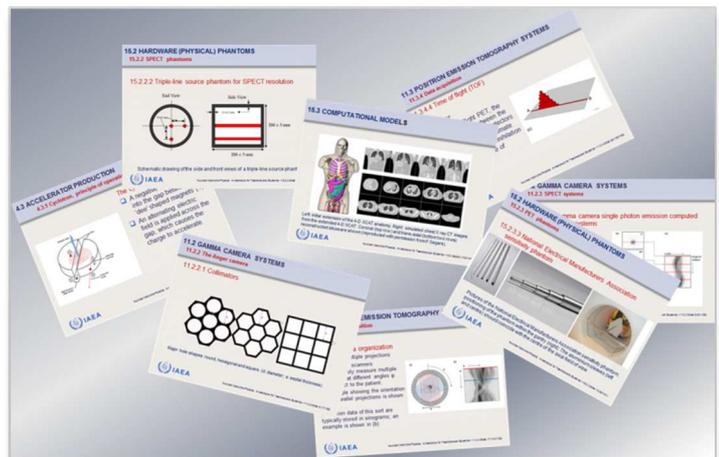
This handbook is intended for teachers, students and residents involved in medical physics programs, and it aspires to serve as primary text for academic education and clinical training of Nuclear Medicine Medical Physicists in the IAEA Member States.

It represents also a resource for interested readers from other disciplines, for example, nuclear medicine physicians, radiochemists and medical technologists, who would like to familiarize themselves with the basic concepts and practice of nuclear medicine physics.

The book is comprised of 20 chapters and one appendix, beginning with a general introduction to the basic physics for nuclear medicine and progressing logically through a series of chapters addressing radiobiology, radiation safety, radionuclide production, non-imaging and imaging instrumentation (including gamma cameras, SPECT and PET scanners, and multimodality devices), image processing and reconstruction, radiopharmacy, quantitative

nuclear medicine, internal dosimetry in clinical practice and radionuclide therapy. Each chapter concludes with a small number of references and suggested additional readings.

The technical editors and authors, selected for their experience and in recognition of their contributions to the field, were recruited from around the world and, thus, this book represents a truly international collaboration. The handbook was written to address an urgent need for a comprehensive, contemporary text on the physics of nuclear medicine and has been endorsed by several international and national organizations.



*Teaching slides for each chapter of the Handbook are available to teachers and students on the IAEA Human Health Campus website ([humanhealth.iaea.org](http://humanhealth.iaea.org))*

# The Revision of IAEA TRS 398 Code of Practice

A key step in the radiotherapy process is the requirement for consistent reference dosimetry traceable to metrological primary standards and to enable common procedures within a country to be followed for reference dosimetry. For conventional radiotherapy with external beams this has been achieved by adopting dosimetry protocols and Codes of Practice such as IAEA TRS 398. The data in IAEA TRS 398 was prepared in the mid-1990s, and since that date a number of new developments have taken place or will be implemented in the near future. Among them can be mentioned:

1. ICRU report committee 20 on key data for measurement standards in the dosimetry of ionizing radiation is ready to release a comprehensive set of new data for fundamental quantities that will impact radiation metrology standards and reference dosimetry for radiotherapy beams.
2. A number of new technologies for radiotherapy have been implemented in the field, mostly on MV photon beams, protons and heavier ions that require guidance and data for end users.
3. New detectors are now commercially available that require data in their clinical practice.
4. With regard to the dosimetry of kV x-rays, not only the provision of TRS 398 for having  $N_{D,w}$  calibrations in these beams are still pending from becoming a reality, but

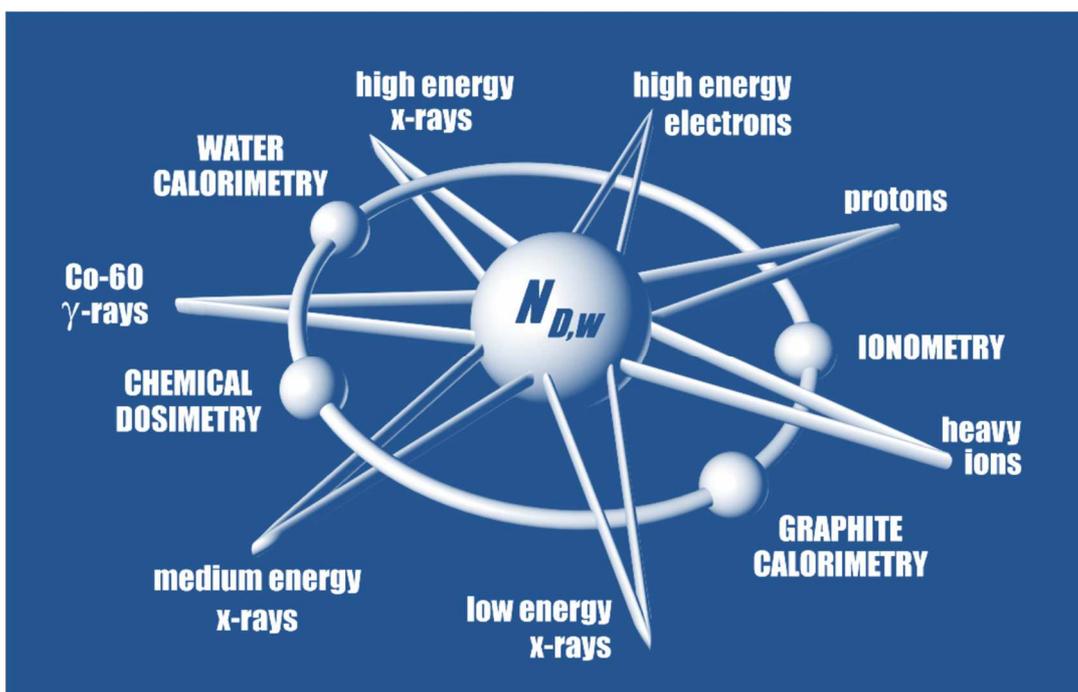
also there was no specific data recommended. Taking into account that a major key data change is due to cross sections for the photoelectric effect, a revision of TRS 398 should include this type of beams.

5. TRS 398 also included recommendations for the dosimetry of radiotherapy beams in non-standard conditions, i.e. for beams smaller than 10 cm \* 10 cm. Recent developments for small fields should also be taken into account, at least in a summarized perspective.

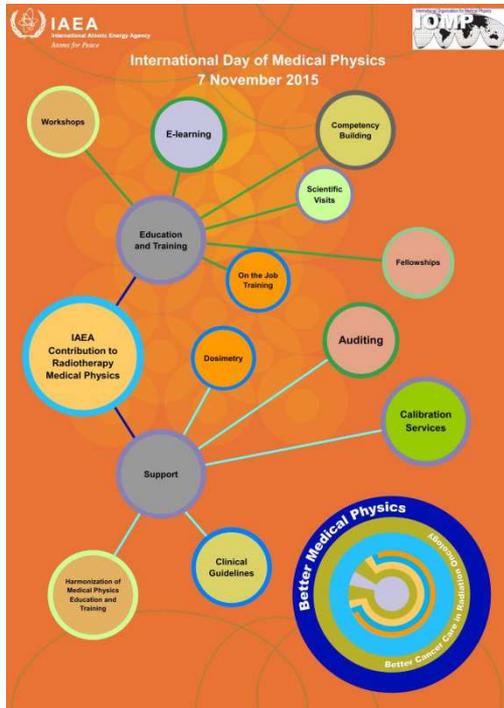
Based on these major elements it has been decided that IAEA TRS 398 should be updated to take into account the issues noted above along with other improvements.

*While we are updating TRS 398 we would like to take into account user experience of using the Code of Practice. If you would like to contribute, please complete the survey at*

<https://humanhealth.iaea.org/MedicalPhysics/UpdateTRS398.pdf>



# The International Day of Medical Physics 2015 at IAEA



November 7, is an important date for medical physics. On that day in 1867, Marie Sklodowska-Curie, known for her pioneering research on radioactivity, was born in Poland. The 3rd International Day of Medical Physics (IDMP) was celebrated on November 7, 2015. The 2015 IDMP was dedicated to radiotherapy. The slogan for the 2015 celebration was: **Better Medical Physics = Better Cancer Care in Radiation Oncology.**

The IAEA has supported radiotherapy medical physics and implementation of best medical physics practice by providing education, training and support to medical physicists in Member States. However, the general public is not well aware of the critical role medical physicists play in providing services in radiation oncology departments. To raise awareness about the role of medical physicists, the IAEA participated in this year's IDMP celebration on Friday November 6, 2015 at the IAEA Headquarters in Vienna. More than 50 professionals, mostly Medical Physicists from around the world were present to celebrate this special day along with the IAEA staff (<https://nucleus.iaea.org/HHW/Latest/IDMP/index.html>).



Celebration of the International Day of Medical Physics (IDMP) at IAEA

# Courses, Meetings and Consultancies in 2016 and 2017

## TC Courses and Workshops related to DMRP activities

- RAS6072 Regional Training course on Basics of IMRT, 7—11 March 2016, Jakarta, Indonesia
- Workshop for the Development of Harmonized QC protocols for Diagnostic Radiology, RER6032, 18—22 April 2016, Vienna, Austria
- Joint ICTP-IAEA Workshop on Computed Tomography: Quality Control, Dosimetry and Optimization, 2—13 May 2016, Trieste, Italy
- Regional Training Course on QA/QC and dosimetry in mammography, RAF6048, 22—26 May 2016, Algiers, Algeria
- 2<sup>nd</sup> Train-the-Trainer International Workshop on Medical Physics Support for Nuclear and Radiological Emergencies, Atlanta, Georgia, USA, 23—27 May 2016
- Regional Training Course on basic QC for radiographers working in diagnostic radiology [in Russian], RER6032, 13—17 June 2016 (tentative), Riga, Latvia
- Workshop on the Implementation QA program - QUAADRIL, RER6032, 29 August—2 September 2016, Athens, Greece
- Regional Training Course on QA/QC in Diagnostic Radiology in a digital era, RER6032, 19—23 September 2016 (tentative), Ljubljana, Slovenia
- Regional Training Course on QA/QC and dosimetry in Interventional Radiology, RER6032, November 2016 (tentative), Udine, Italy
- Joint ICTP-IAEA Workshop on “Internal Dosimetry for Medical Physicists Specializing in Nuclear Medicine”, 21—25 November 2016, Trieste, Italy

## DMRP Meetings and Consultancies

- Consultants Meeting to complete the draft of the document SPECT and SPECT/CT Atlas of Quality Controls and Image Artefacts, 22—26 February 2016, Vienna, Austria
- 17<sup>th</sup> Biennial Meeting of the SSDL Scientific Committee (SSC-17) on the Evaluation of and Recommendations on the Dosimetry Programme and the IAEA/WHO Network of SSDLs, 14—18 March 2016, Vienna, Austria
- RAS6077 mid-term review meeting, 21—24 March 2016, Mumbai, India
- 3<sup>rd</sup> Research Coordination Meeting of the CRP on Enhancing Capacity for early breast cancer detection and diagnosis through imaging”, E1.30.39, 4—8 April 2016, Istanbul, Turkey
- RAS6072 mid-term review meeting, 18—22 April 2016, Vienna, Austria
- Meeting of the drafting committee to develop Guidelines for remote/automated QC in diagnostic radiology, 5—9 September 2016 (tentative), Vienna, Austria
- 3<sup>rd</sup> Research Coordination Meeting of the Doctoral Coordinated Research Project (CRP) on Advances in Medical Imaging Techniques”, E2.40.19, 10—14 October 2016, Vienna, Austria
- Workshop on Dosimetry Comparisons for Secondary Standards Dosimetry Laboratories (SSDLs), 7-11 November 2016 (tentative), Vienna, Austria
- Workshop on Uncertainties in Radiation Dosimetry, 4<sup>th</sup> Quarter 2016, Vienna, Austria
- International Conference on Advances in Radiation Oncology (ICARO-2), 19—23 June 2017, Vienna, Austria

## ESTRO Courses

- Basic Clinical Radiobiology, 27 Feb—2 March 2016, Budapest, Hungary
- IMRT and other conformal techniques in practice, 3—7 April 2016, London, United Kingdom
- Dose modelling verification for external beam radiotherapy, 6—10 March 2017, Utrecht, The Netherlands
- Advanced treatment planning, 14—18 September 2017, Cambridge, United Kingdom

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 International Organization of Medical Physics (IOMP)

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