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ACPSEM POSITION PAPER

ACPSEM guideline regarding the adoption of the IAEA TRS-398 Code of Practice Revision 1

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Abstract
The IAEA Technical Report Series 398 Code of Practice for the determination of absorbed dose in external beam radiotherapy was endorsed at the Engineers and Physical Scientists in Medicine (EPSM) conference in 2001 and has been widely adopted in Australia and New Zealand. This guideline provides recommendations from the Australasian College of Physical Scientists and Engineers in Medicine (ACPSEM) following the recent publication of TRS-398 Revision 1. It is jointly authored by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), the Reference Dosimetry Advisory Group (RDAG) and the ACPSEM Radiation Oncology Specialty Group (ROSG). In addition to recommendations, the guideline discusses the implications of TRS-398 Revision 1 for the dosimetry of megavoltage photons, electrons and protons. TRS-398 Revision 1 is recommended for adoption in accordance with the recommendations provided in this guideline, including for FFF beams. For specialised FFF machines such as CyberKnife® and TomoTherapy®, and for Gamma Knife®, the ACPSEM recommends the use of IAEA TRS-483 Code of Practice. MR linacs are covered by the *ACPSEM position paper: dosimetry for magnetic resonance imaging linear accelerators* and in AAPM TG-351. For kilovoltage photons, the recommendation to use the AAPM TG-61 protocol for radiotherapy sources is retained and now specifically also includes cabinet irradiators used in radiobiology.

Keywords TRS-398 Revision 1 · ACPSEM, guideline, megavoltage photon dosimetry · megavoltage electron dosimetry

Introduction

The IAEA Technical Report Series 398 *Code of Practice for the determination of absorbed dose to water in external beam radiotherapy* [1] has been widely adopted in Australia and New Zealand since its introduction in 2000. In March 2024, the IAEA released a new version of TRS-398: Revision 1 Code of Practice (CoP) [2].

The revision of TRS-398 was motivated by advances in radiotherapy and dosimetry since the first edition was published in the 1990s. These include the introduction of new treatment modalities and beam types, the availability of new detectors, updated fundamental dosimetric data and measurement standards, widespread adoption of Monte Carlo calculations, improved data for kilovoltage X-ray dosimetry, developments in small-field dosimetry, and extensive clinical experience gained from the application of the original protocol. The updated code of practice incorporates these developments to provide more accurate and comprehensive guidance for contemporary radiotherapy dosimetry.

It is the intent of the ACPSEM to establish a set of evidence-based recommendations for best practice external beam radiotherapy determination of absorbed dose.

The Board of Directors of the Australasian College of Physical and Engineering Sciences in Medicine (ACPSEM) endorsed publication of this Guideline on 31 July 2026.

Extended author information available on the last page of the article

Methodology

A working party comprised of experts from the ACPSEM ROSG and ARPANSA RDAG has reviewed this new version, identified and assessed differences and formulated these recommendations regarding the adoption of TRS-398 Revision 1. The recommendations were developed and refined through iterative discussion within the multidisciplinary working party until consensus was reached. A formal consensus methodology was not used. For megavoltage photons and megavoltage electrons the assessments included comparing results when the two protocols were used to determine D_w using chamber types commonly in use in Australia and New Zealand.

Some of the changes that may require consideration are discussed.

The original TRS-398 underwent minor changes until version 12, and our comments here refer to this 2006 version as the "previous TRS-398". TRS-398 Revision 1 is the first official update from the IAEA. Despite being very similar to the previous versions it nevertheless may result in small changes to dosimetry results, documented below. All symbols and terms are as defined in TRS-398 Revision 1.

Recommendations regarding the codes of practice for determination of absorbed dose

The ACPSEM recommends that all radiotherapy clinics in Australia and New Zealand adopt TRS-398 Revision 1 for megavoltage photons, electrons, and protons, and continue to use AAPM TG-61 protocol [8] for kilovoltage photons [9].

ARPANSA changed to TRS-398 Revision 1 on 1 July 2024, affecting both the Primary Standards Dosimetry Laboratory (PSDL) and the Australian Clinical Dosimetry Service (ACDS). The largest change will be seen in the PSDL calibration service for plane-parallel chambers calibrated in a high-energy electron beam. The ACDS has been performing audits against TRS-398 Revision 1 since 1 July 2024. Because of this, explanatory notes accompany audit findings that relate to differences in the protocol used at the clinic.

Implementation considerations

Direction of shifts

We define the change in absorbed dose to water D_w, as positive if this value increases under TRS-398 Revision 1. Note that the dose to patients will subsequently *decrease* if the value assigned to the reference dose D_w increases for the same amount of radiation delivered.

Megavoltage photons

TRS-398 Revision 1 continues to recommend the use of measured k_Q factors, where available. We note that ARPANSA measured k_Q factors will not change as a result of TRS-398 Revision 1.

Published k_Q factors from the original TRS-398 have changed by a small amount in TRS-398 Revision 1. The shift is energy and chamber-dependent, but in most cases is in the range 0.1% to 0.5% for clinical photon beams from radiotherapy linacs, with the new k_Q factors and measured D_w values being lower. The new consensus k_Q values are derived from a fit to measured and calculated values [3]. The uncertainty of the published k_Q factors in TRS-398 Revision 1 is 0.6% (k = 1), which is an improvement over the 1.0% (k = 1) uncertainty of the published factors in TRS-398.

TRS-398 Revision 1 contains an option to use $k_{Q,\,Qint}$ for photon beams (for example if the standards laboratory provides a calibration only at 6 MV, this factor could be used to calculate the chamber response at 18 MV). This approach is not necessary where measured k_Q factors are obtained from ARPANSA as they cover the range from ^{60}Co to 18 MV and can be interpolated to the individual clinical beam qualities.

For clinics using measured k_Q factors, the ACPSEM recommends that field chambers be calibrated at each clinical beam quality. Using measured k_Q factors reduces the uncertainty of this component of the dose calculation to approximately 0.4% (k = 1), as per the specific chamber calibration certificate. Any approaches in which measured k_Q factors are used with other chambers of the same type are discouraged.

Both TRS-398 and TRS-398 Revision 1 are silent on dosimetry for Gamma Knife®. The ACPSEM recommends the use of IAEA TRS-483 Code of Practice [4] for Gamma Knife®. Likewise, TRS-398 Revision 1 does not address MR linacs. For these linacs the ACPSEM refers to their corresponding position paper [5] and AAPM TG-351 report [6].

For relative measurements ($TPR_{20,10}$, depth-ionization, profiles, output factors), TRS-398 Revision 1 makes various recommendations regarding recombination, polarity, effective point of measurement (EPOM) and volume averaging effects. These recommendations can be adopted; however, we recommend that users commission their equipment for relative measurements with the following considerations.

There is evidence that effective point of measurement in cylindrical chambers is less than $0.6r_{\text{cyl}}$ and varies by chamber [7]. For consistency ACPSEM recommend continuing to use $0.6r_{\text{cyl}}$ for the cylindrical chamber effective point as given in TRS-398 Revision 1. However, users are

Table 1 Representative example of differences between D_w obtained from TRS-398 Revision 1 and TRS-483, calculated for measurements obtained with a PTW 30013 ionisation chamber.[a]

	Varian 6 FFF		Varian 10 FFF		Elekta 6 FFF		Elekta 10 FFF	
	TRS-398 R1	TRS-483	TRS-398 R1	TRS-483	TRS-398 R1	TRS-483	TRS-398 R1	TRS-483
$TPR_{20,10}$	0.631	0.634	0.706	0.710	0.678	0.681	0.723	0.727
k_Q	0.9882	0.9876	0.9716	0.9706	0.9785	0.9779	0.9675	0.9665
k_{SPR}	1.0000	0.9990	1.0000	0.9963	1.0000	0.9973	1.0000	0.9955
k_{vol}	1.0016	1.0020	1.0037	1.0047	1.0030	1.0037	1.0043	1.0052
Product	0.9898	0.9886	0.9752	0.9716	0.9814	0.9789	0.9717	0.9672
Change	0.12%		0.37%		0.26%		0.46%	

[a] The chamber measurements, including corrections for influence quantities, are identical for both protocols and have therefore been omitted

Table 2 Previous and new values of k_Q for common Farmer-type chambers for ARPANSA 15 MeV and 18 MeV electron beams

Reference chamber make and model	TRS-398 v12 (2006) k_Q		TRS-398 Revision 1 k_Q		Correction factor	
	15E R_{50}=5.89 cm	18E R_{50}=7.13 cm	15E R_{50}=5.89 cm	18E R_{50}=7.13 cm	15E R_{50}=5.89 cm	18E R_{50}=7.13 cm
PTW 30013	0.9045	0.9006	0.9118	0.9083	1.0081	1.0085
IBA FC65-G	0.9132	0.9096	0.9148	0.9111	1.0018	1.0017
NE 2571	0.9114	0.9087	0.9122	0.9089	1.0009	1.0002

encouraged to consult the literature or evaluate the performance of individual dosimeters to ensure their use in this manner is acceptable.

Relative measurements incorporating different depths will have varying dose per pulse and so a depth-dependent recombination correction should be applied. The polarity effect should also be evaluated, as large values can indicate problems with cable irradiation or the chamber behaviour. Recombination and polarity effects should be evaluated when the chamber is commissioned over the range of dose-rates, field-sizes and beam qualities. Depending on the accuracy sought, these corrections may not need to be re-measured or applied every time the chamber is used.

FFF beams

Specialised FFF beams such as CyberKnife® and TomoTherapy® are explicitly excluded from TRS-398 Revision 1. For these beams, the ACPSEM recommends the use of IAEA TRS-483 Code of Practice [4].

FFF beams at 10 MV and below are included in TRS-398 Revision 1, and the ACPSEM recommends that Revision 1 be used for these beams noting that there are minor differences as compared to the TRS-483 (see Table 1 for an example). These differences arise because TRS-483 includes an additional stopping power correction for FFF beams, it requires an adjustment to the field size for beam quality measurement and it includes slightly different generic volume-averaging corrections. We also note that k_{vol} is included in k_Q in TRS-483.

As for the published k_Q factors in TRS-398 Revision 1, ARPANSA's measured k_Q factors may be interpolated to FFF beams using $TPR_{20,10}$, even though they are measured only for conventional beams.

For relative measurements, the considerations described in the preceding section on megavoltage photon beams also apply to FFF beams. In particular, a depth-dependent recombination correction should be applied to FFF depth-ionisation curves and $TPR_{20,10}$ measurements [7]. The influence of the correction k_{vol} should be evaluated at different depths.

The $TPR_{20,10}$ determination from $PDD_{20,10}$ equation was not designed for FFF beams and local validation is recommended.

Megavoltage electrons

TRS-398 Revision 1 continues to recommend chambers be calibrated directly in electron beams if such a calibration service is available. While ARPANSA does provide a calibration service for plane-parallel chambers, this is a cross-calibration against a thimble chamber calibrated in ^{60}Co and is equivalent to performing this cross-calibration in a clinic. This means that radiotherapy clinics can choose either route and neither approach is preferred.

In TRS-398 Revision 1 the electron k_Q factors have been recalculated and include some changes. Notably, the k_Q factors for the PTW 30013 chamber have increased by as much as 1%. This change will apply to electron cross-calibrations provided by ARPANSA (Table 2) and those performed in the clinic.

When using a cross-calibrated plane-parallel chamber, small changes in $k_{Q,\,Qint}$ for the plane-parallel chamber combine with change for the reference thimble chamber. The result may be an increase in D_w in the clinic of up to 1.4% at the lowest energies (4 MeV and 6 MeV).

Radiotherapy clinics can re-calculate their electron dosimetry using revised values of k_Q and $k_{Q,\,Qint}$ from IAEA TRS-398 Revision 1 without conducting additional measurements. We note that checking and validation is essential – if the correction is made in the wrong direction, the clinical dose could be in error by up to 3%.

The uncertainty of the published k_Q factors in TRS-398 Revision 1 is 0.7% (k=1), both for thimble and plane-parallel chambers, used for beams of $R_{50}\geq 3$ g/cm^2 and $R_{50}\geq$ 2 g/cm^2, respectively. The uncertainty is 0.8% (k=1) for plane-parallel chambers for beams with $R_{50}<2$ g/cm^2. These uncertainties are improvements over those of the published k_Q factors in TRS-398, which were 1.2% (k=1) and 1.7% (k=1) for thimble and plane-parallel chambers, respectively.

ARPANSA electron cross-calibration reports issued prior to 1 July 2024 can be adjusted by multiplying the plane-parallel chamber $N_{D,\,w}$ calibration coefficient by the same correction using the factor given in the last two columns of Table 2. However, it is noted that such a correction is probably only worthwhile if the reference chamber was type PTW 30013.

We note that the use of plane-parallel chamber calibrated in ^{60}Co is no longer explicitly discouraged in TRS-398 Revision 1. This approach would remove the "highest-energy cross-calibration" step currently in use in most clinics, and hence save considerable effort, at the expense of a very small loss of precision (the k=1 uncertainty in D_w increases from 0.9% with the cross-calibration to 1.2% with plane-parallel chamber calibrated in ^{60}Co). However, TRS-398 Revision 1 still includes the statement *"Ideally, the chamber should be calibrated in an electron beam, either directly at a standards laboratory or by cross-calibration in a clinical electron beam."* Hence, ACPSEM recommends that the cross-calibration should continue. We hope that clinics and ARPANSA will explore the results of using the simpler approach with a view to changing this recommendation in the future.

There are several small practical changes to megavoltage electron dosimetry including explicitly noting the reference point for plane-parallel chambers should be the inner window surface, scaled for water equivalence; solid water phantoms may not be used for absolute calibration; R_{50} can be measured with 10 cm x 10 cm applicators or larger for all electron beam energies up to 22 MeV.

Megavoltage protons

Although there are currently no clinical proton units in Australia or New Zealand, the updates introduced in IAEA TRS-398 Revision 1 may still be of interest, as the previous version has been widely implemented in many clinics overseas.

TRS-398 Revision 1 has more focus on Pencil Beam Scanning (PBS) systems, which were included as a footnote in the original version but are now the most common modality in clinical use. The k_Q factors have been re-calculated with reductions of some 0.5% to 1.7% for Farmer-type chambers. The k_Q factors for plane-parallel chambers have changed in the range −0.2% to 0.4%.

Comments regarding Water Equivalent Thickness (WET)

The reference point of a plane-parallel chamber is defined in TRS-398 Revision 1 as the inside of the centre of the front window in Table 19 (electrons) and Tables 35 and 36 (protons). In the electron case TRS-398 Revision 1 clearly calls for the WET of the plane-parallel chamber to be taken into account when positioning the reference point at the reference depth. However, for protons this statement is missing, and Fig. 21 does not mention the WET of the chamber, only the tank window (if side-entry). We note that the original TRS-398 contained a statement that WET could be neglected in Section 4.2.5.2, but this comment has been removed in TRS-398 Revision 1.

In the case of electrons, the effect on reference dosimetry is negligible and therefore the ACPSEM recommends using the physical thickness. For example, the difference in the WET of a Roos chamber window (1.3 mm) and the physical thickness (1.1 mm) is 0.2 mm which affects the reference dosimetry by about 0.2% at the reference depth of around 12.5 mm for 6 MeV, less for higher energies. In the case of proton reference dosimetry, differences of order 0.2% to 0.5% are expected. We recommend reviewing the recent literature as we expect this issue to be clarified by the time proton units are operating in Australia or New Zealand.

If clinics decide to consider the WET in reference dosimetry, the best approach is to match the reference point used in the calibration of the plane-parallel chamber. This calibration will have been performed either by the manufacturer, ARPANSA (or another standards laboratory), or by the clinic itself.

For relative dosimetry, the correction for WET may shift the depth dose curve and affect the beam quality measurement. In our experience these changes may be neglected for electron beams, but the clinic should check that this is the case.

Reference depths are specified in TRS-398 Revision 1 in g/cm^2, implying that a correction for the density of water may be required. For example, the density of water is 0.998 g/cm^3 at 20 °C so that the chamber should be placed

1.002 times deeper in the water than if the density was 1 g/cm^3. This correction is negligible for clinical practice and may be ignored. ACPSEM recommend that clinics state the measurement depth in cm.

Although rarely used in clinical practice, side-entry water tanks may require a correction for the water equivalent thickness of the entrance window. In TRS-398 Revision 1, care should be taken not to confuse the water-equivalent thickness of a water tank window with that for the entrance window of a plane-parallel ionization chamber. In cases where a correction is made, good practice includes recording the physical distances and depths as well as the water-equivalent values.

Kilovoltage photons

The ACPSEM recommends that AAPM TG-61 [8] continues to be used for external beam kilovoltage radiotherapy [9]. It also recommends that AAPM TG-61 be used for reference dosimetry of kilovoltage x-ray beams in radiobiology (e.g. cell and small animal kV irradiators). We note that TRS-398 Revision 1 can be applied to kV sources associated with image guidance in radiotherapy, but we make no recommendation as TRS-398 Revision 1 is explicitly intended for radiotherapy sources. Electronic brachytherapy systems utilising external kilovoltage x-ray sources may be covered by TRS-398 Revision 1, but we recommend consulting published methods developed for each technique as these can be highly specialised. Diagnostic and interventional radiology sources are covered by IAEA TRS-457 [10].

The recommendation for AAPM TG-61 for kilovoltage photon radiotherapy beams remains because absorbed dose to water calibrations for kilovoltage photons are not available locally, and a significant majority of clinics currently use the in-air method for all their beams. TRS-398 Revision 1, like the previous version, does not recommend the in-air method for x-ray beams above 100 kV, requiring reference dosimetry for these beams to be performed in water. However, it now includes a formalism that permits the use of air-kerma based calibrations with in-water measurements. Without a dose-to-water calibration, we feel that the advantages of an in-water approach are not significant, and as the change would require significant effort in the clinic, we do not recommend it.

It should be noted, TRS-398 Revision 1 provides a website (https://kvx-rays.iaea.org/About) with new backscatter and μ/ρ data, which includes data for in-air calibrations for x-ray beams above 100 kV. As such, this newer data could be used in the clinic and might be worth considering. Additionally, it should be noted that AAPM TG-61 is currently under review. These recommendations should be reassessed when new information arises.

Review and endorsement

The guideline should be reviewed in 5 years or earlier if new international recommendations become available or if relevant scientific information emerges. The review should be performed by RDAG and ROSG and/or other suitable groups depending on the structure of the ACPSEM at that time.

This guideline was endorsed by the ACPSEM Board of Directors on 31 July 2026.

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Declarations

Conflict of interest The authors declare no conflicts of interest relevant to this publication.

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