Australas Phys Eng Sci Med (2013) 36:1–3
DOI 10.1007/s13246-013-0190-4

GUEST EDITORIAL

Reporting uncertainties in measurement: what approach should be followed?

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Published online: 16 March 2013

Introduction

Much of the work of a scientist or engineer involves taking measurements. For example, a radiation oncology medical physicist measures the absorbed dose in a water phantom. However any measurement has some limit in the accuracy of the final value you obtain. This is due to limits in the accuracy of the measuring equipment, any bias in the measurements, calibration issues or simple mistakes you make. All of these contribute to an uncertainty in the value of the parameter you are measuring. For example, the absorbed dose of radiation from a linear accelerator can be measured in a water phantom using a well characterised ionisation chamber. In this particular case of radiation dose measurement, there will be uncertainties due to the equipment consisting of an ionisation chamber, electrometer and the water phantom. There will also be uncertainties in the setup of the equipment, the linear accelerator. Traditionally these uncertainties are characterised as random errors or systematic errors. Random errors can be minimised by taking multiple measurements while the reduction of systematic uncertainties requires a good understanding of the equipment. Systematic errors are often "fixed" by application of some calibration factor or may be even missed.

The method used to determine the uncertainty of a measurement is widely varied. For example, you can repeat the measurements a number of times usually between 3 and 5, and from this calculate the standard deviation. A more systematic approach is to determine random and systematic errors and summate these together to give the final uncertainty in your parameter. This takes a bit more time and requires that you have a good understanding of your equipment. Finally, you can ignore your errors, assume your equipment is working correctly and just quote your results. A review of published papers in any medical physics or biomedical engineering journal will show a similar variation in reporting of uncertainties. This can give the impression of a much lower uncertainty in your measurements. For example, the IAEA TRS 398 dosimetry protocol reports that the estimated relative uncertainty in the dose calibration of megavoltage X-ray beams is ± 1.5 % [1]. Therefore any absolute dose measurements using these X-ray beams must have an uncertainty larger than this.

There is a more uniform approach for uncertainty analysis as prescribed by the International Organization for Standardization (ISO). The ISO has published a document called the "Guide to the expression of uncertainties in

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Table 1 Uncertainties associated with B_w measurements using EBT2 film [4]

Component of uncertainty	Type A (%)	Type B (%)
OD measurement over pixels	2.8	
Pantak X-ray unit reproducibility	0.5	
Gafchromic film calibration curve		1.0
Effect of position of film at the end of the applicator		1.1
SSD variation between cones (from standard 300 mm)		1.1
Total	4.0 %	

measurement", more simply known as ISO GUM [2, 3]. An excellent summary of the ISO GUM is found in Appendix D in the IAEA TRS 398 dosimetry protocol which is free to download [1]. The ISO GUM is routinely used in standards laboratories such as ARPANSA or NPL but in fact can also be used in the clinical or research environment.

The ISO GUM indicates that the quantity of interest is uncertainty and not error [1]. All uncertainties are divided into type A and type B uncertainties. Type A uncertainties are those that are evaluated by statistical analysis and can be reduced by increasing the number of measurements. Type B uncertainties are those determined by other methods and can include correction factors and influence quantities such as those used in radiation dosimetry. Type B uncertainties are often estimated from information from measuring equipment, published factors or by other means. The summary in the IAEA TRS 398 protocol states that the physicist should use the best of their knowledge and experience to estimate these type B uncertainties [1]. The final uncertainty in any measurement should then be expressed as the estimated relative standard deviation based on a summation of the type A and type B uncertainties.

The practical application of the ISO GUM can be achieved by the development of an uncertainty budget or an uncertainty analysis table. An example of an uncertainty budget is given in Table 1 where Gafchromic EBT2 film was used to determine backscatter factors in water (B_w) for kilovoltage X-ray beams [4]. The total uncertainty in the values of B_w was estimated to be 4.0 % based on the different components of uncertainty as listed in the table.

There are a number of good references on the ISO GUM which the reader is referred to in developing an uncertainty budget. Firstly, a review paper published in this journal in 2005 by Gregory et al. [5]. There is an excellent book summarising the ISO GUM published by the National Measurement Institute of Australia [6]. Finally, there are a number of medical physics papers that have used the ISO GUM methodology to determine an uncertainty budget [7–11].

I would like to make a number of recommendations most of which are easily achievable and would lead to a more rigorous understanding of the scientific process involved in measurements we are take:

1. The APESM journal should adopt the ISO GUM methodology as the standard process for reporting uncertainties. All papers published in the APESM journal should include an uncertainty budget.
2. Presentations at the annual ACPSEM conferences should include details of the uncertainty budget using the ISO GUM.
3. The ISO GUM should be included in the syllabus for science and engineering courses. This includes post-graduate courses in medical physics and biomedical engineering in Australia and NZ.
4. The ISO GUM should be a part of the TEAP training for medical physics registrars.

Acknowledgments Elizabeth Claridge-Mackonis and Johnny Morales from Royal Prince Alfred Hospital, Sydney are acknowledged for providing useful comments.

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