Assessment of the Impact on a PADC Neutron Dosimetry System of the new Operational Dose Quantities Proposed in ICRU Report 95

[(a)]**Brahim Moreno**, [(a)]Marc Million, [(b)]David Thomas, [(b)]Graeme Taylor

Presenting author: bmoreno@landauer-fr.com
a. Landauer, 9, rue Paul Dautier – CS 60731 78457 Vélizy-Villacoublay Cedex, France
b . National Physical Laboratory, Hampton Road, Teddington, Middlesex, TW11 0LW, UK

INTRODUCTION

The International Commission on Radiation Units & Measurements, in ICRU Report 95 [1], recommend new operational quantities for use in radiation protection monitoring. Their implementation will pose problems for instrument manufacturers supplying area dosemeters, and for individual monitoring services providing personal dosemeters for radiation workers. The problems arise for photon, neutron, and beta dosimetry, but this report deals solely with personal neutron dosemeters based on PADC plastic. (PADC stands for poly-allyl-diglycol-carbonate. These dosemeters are sometimes referred to by a trade name of the plastic, CR39.)

The required performance characteristics for neutron personal dosemeters are covered by ISO Standard 21909 [2], which has requirements for a range of features. Those considered here are the energy and angle dependence of the dosemeter response. The implications of the change for a personal dosimetry system based on PADC, already tested [3] against the requirements of ISO 21909 using the current dose quantities as published in ICRU 57 [4], are presented here.

THE NEW QUANTITIES, DIFFERENCES AS A FUNCTION OF ENERGY

The conversion coefficients from neutron fluence to the relevant personal dose quantity for 0° incident neutrons, $h_p(10,0°)$ in the case of ICRU 57, and $h_p(0°)$, in the case of ICRU 95, are presented in Figure 1 as a function of neutron energy. The new coefficients extend to higher energies than the old, so comparison is not possible above 20 MeV, but below this energy the new coefficients are smaller, except in a small region between 2.5 MeV and 11 MeV. This means that over much of the energy range a neutron personal dosemeter that read correctly for the current quantity will read high for the new quantity. This poster quantifies this effect.

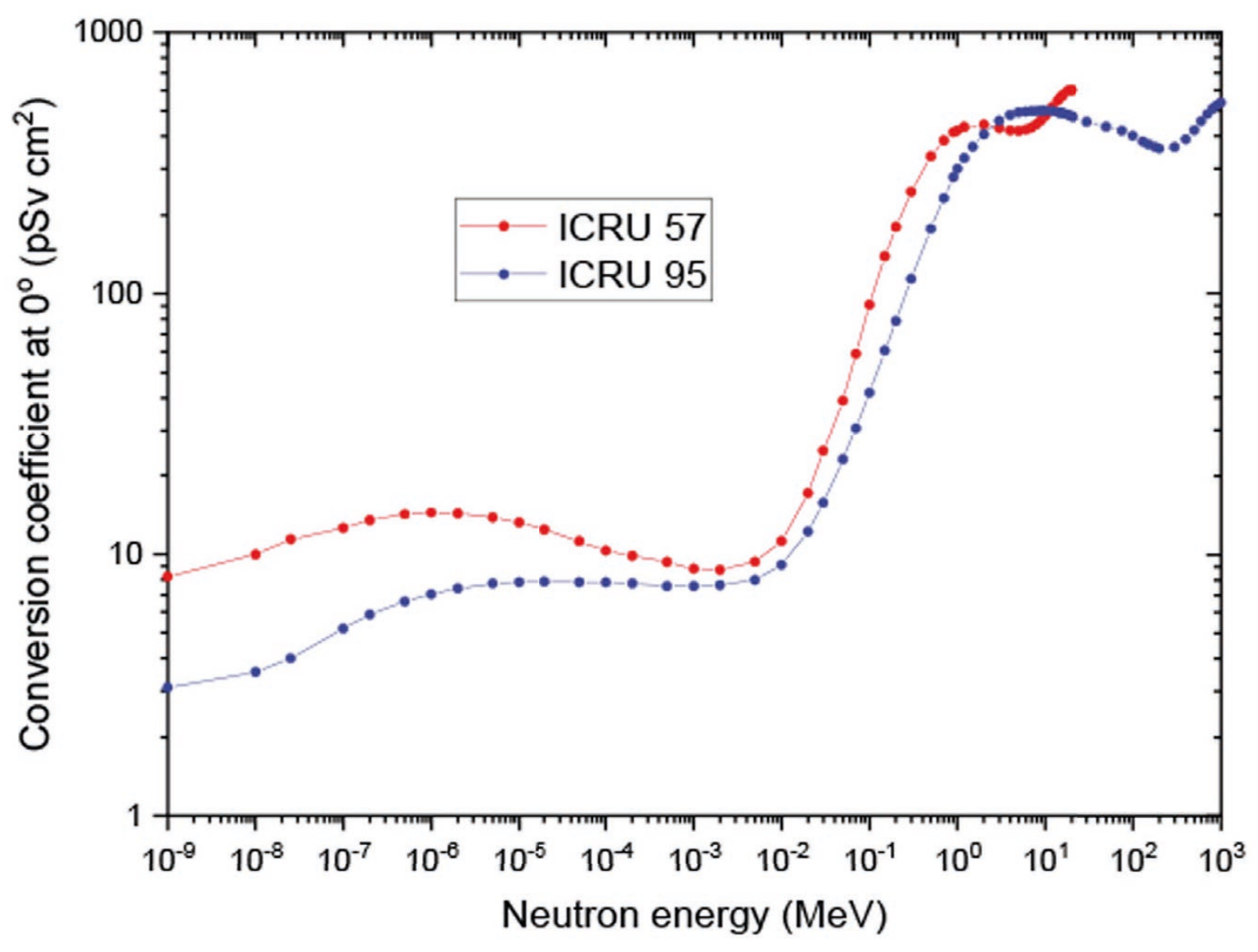

Figure 1. Comparison of old and new coefficients at 0°.

ENERGY VARIATION OF THE RATIO ICRU 95 / ICRU 57

Figure 2 is a plot of the ratio of ICRU 95 fluence to personal dose conversion coefficients, hp(0°), for 0° irradiation to the corresponding values, $h_p(10,0°)$, for the current quantity from ICRU 57, as a function of neutron energy. The points on the curve correspond to ISO 8529 recommended monoenergetic neutron testing energies. Values for radionuclide source spectra, shown in red, are plotted at the personal dose equivalent mean energy. The fact that the plotted ratio is considerably below unity at lower energies is bound to cause problems for dosimetry services if their dosemeters have a good response to the current quantity.

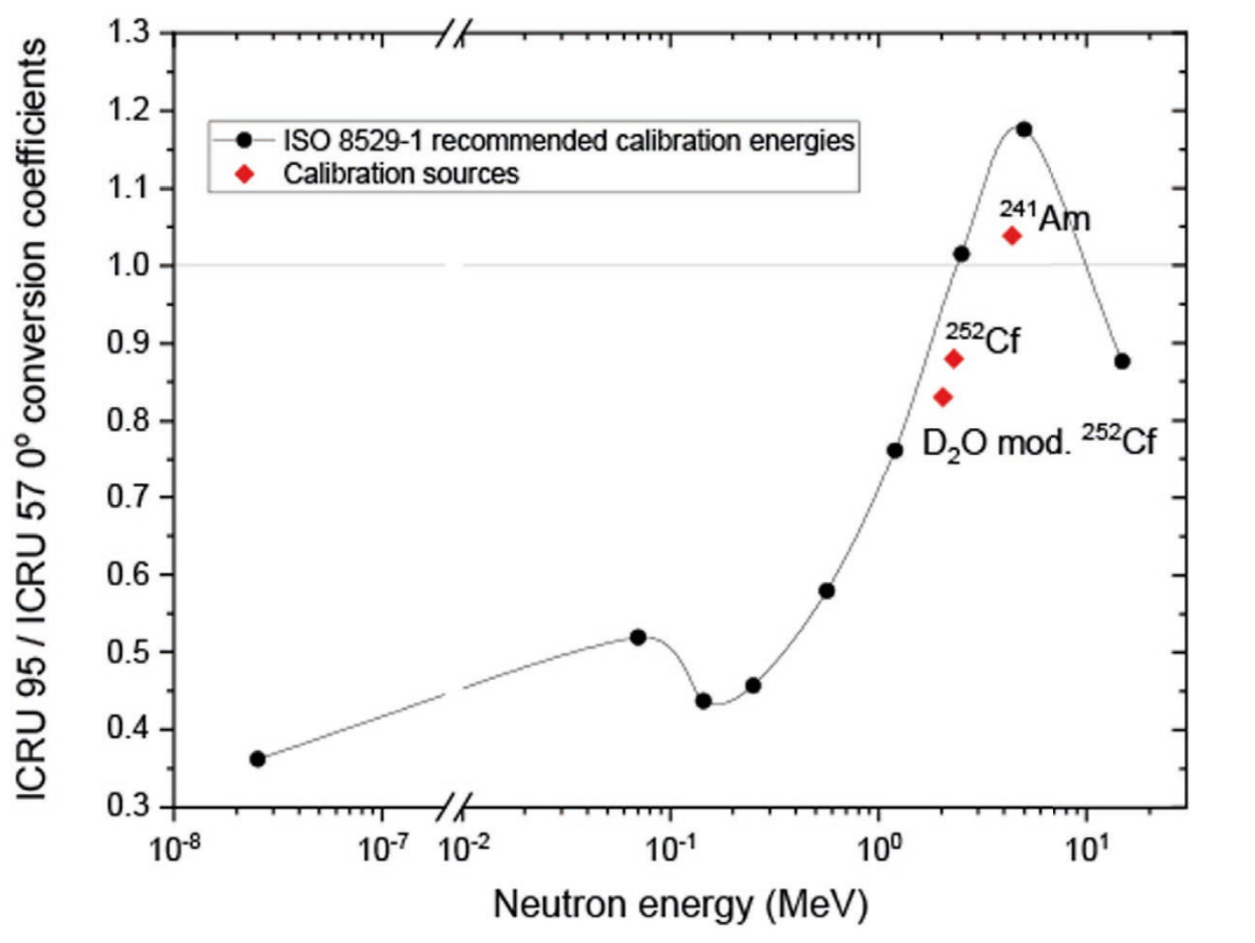

Figure 2. Ratio of ICRU 95 personal dose quantity at 0° to that from ICRU 57 for the monoenergetic energies and the source spectra recommended by ISO 8529.

ANGLE EFFECTS

For the energies recommended in ISO 8259 for calibrations with monoenergetic neutrons the ratio of the conversion coefficients for ICRU 95 and ICRU 57 are not very dependent on angle for angles below 60°, the largest angle tested in ISO 21909, - see Figure 4. Thus, at energies where the change in the 0° conversion coefficient is small the angle requirements will still be met on going over to the new quantities. However, at energies where the 0° conversion coefficient has changed dramatically, so that the dosemeter fails the 0° test, the dosemeter will also fail the test at larger angles. This is illustrated below in Figures 5 and 6 for ^{241}Am-Be neutrons and 144 keV neutrons respectively.

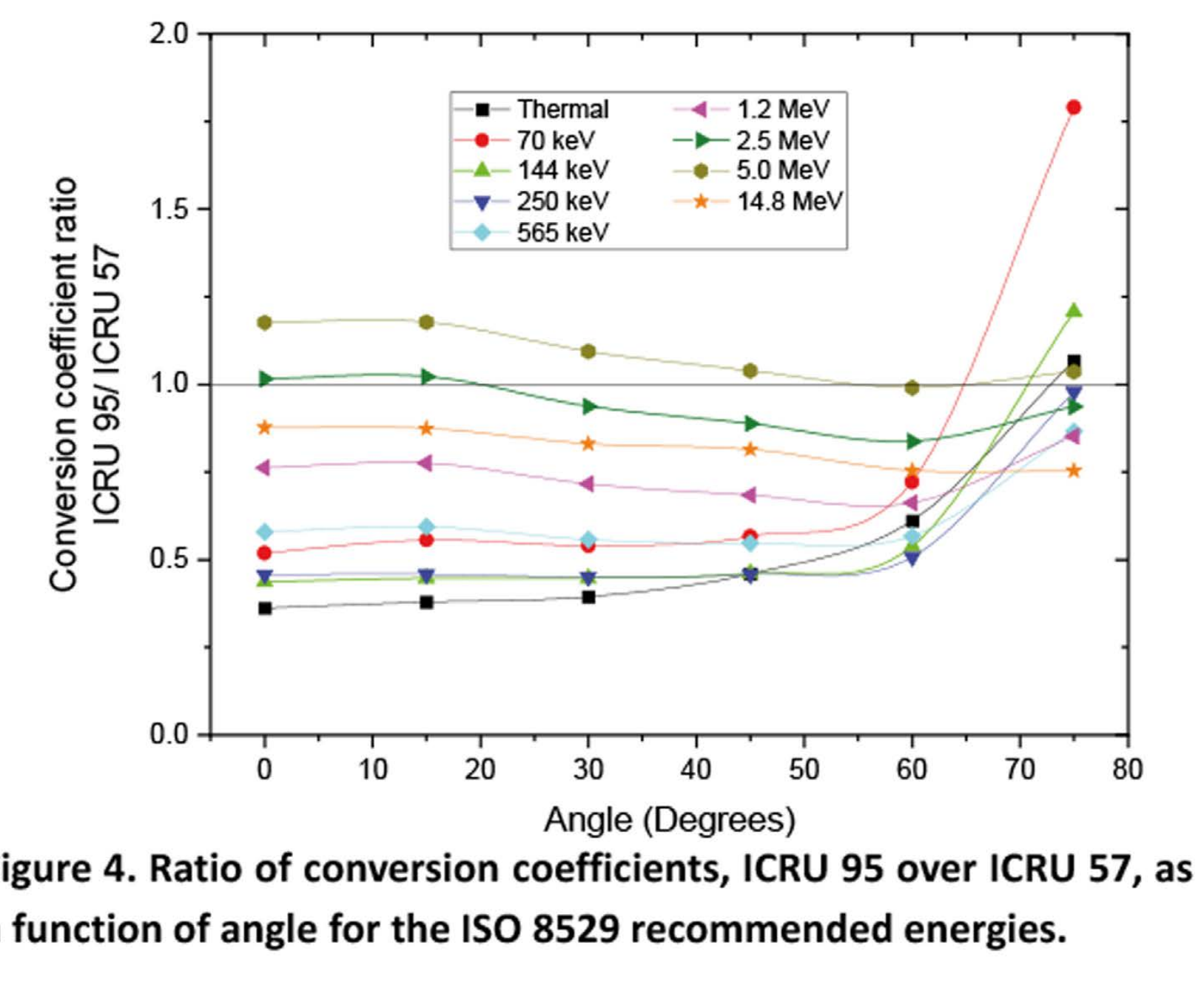

Figure 4. Ratio of conversion coefficients, ICRU 95 over ICRU 57, as a function of angle for the ISO 8529 recommended energies.

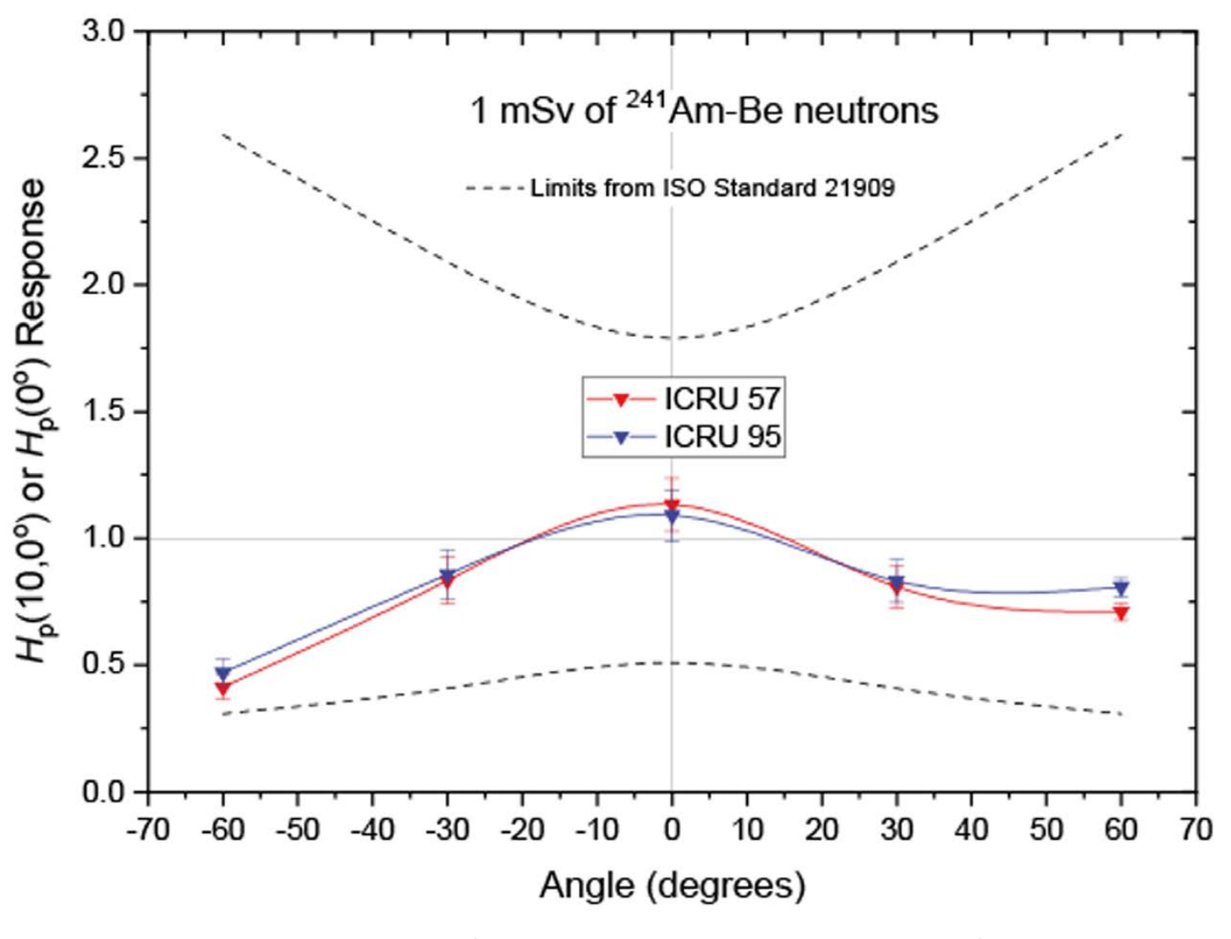

Figure 5. Comparison of the angle dependence of the response of a personal dosemeter to ^{241}Am-Be neutrons when using the ICRU 57 and ICRU 95 quantities.

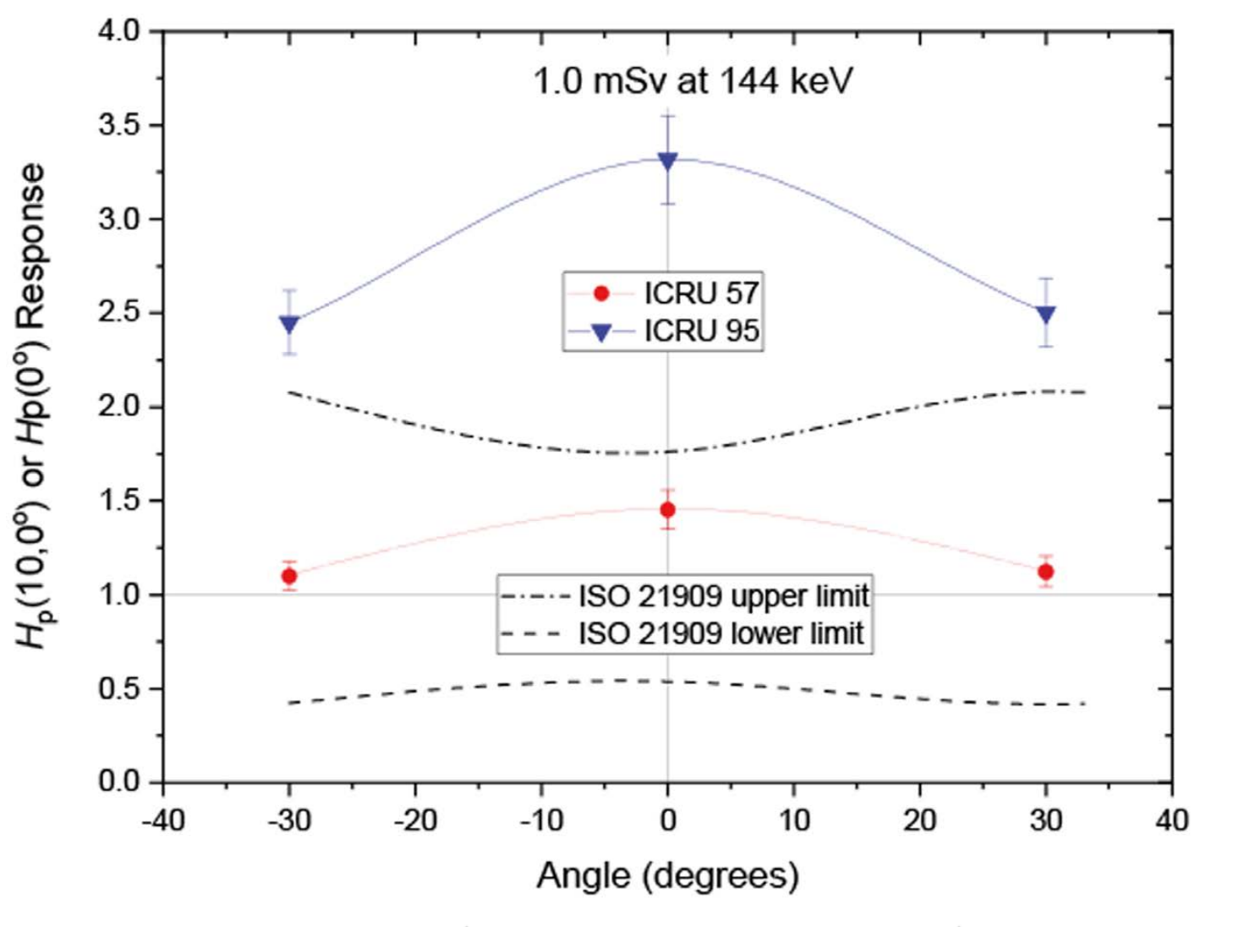

Figure 6. Comparison of the angle dependence of the response of a personal dosemeter to 144 keV neutrons when using the ICRU 57 and ICRU 95 quantities.

SPECTRUM-AVERAGED CONVERSION COEFFICIENTS

For radionuclide neutron calibration sources, the fluence to dose equivalent conversion coefficients need to be averaged over the source neutron spectrum. Values derived using spectral data from ISO Standard 8529-1. are shown in the tables. Values for $h^*(10)$ and $h_p(10,α)$ are from ISO Standard 8529-3 and are compared with values calculated with the new ICRU 95 coefficients. Units are pSv cm².

^{252}Cf	Ambient	Personal					
Angle α		0°	15°	30°	45°	60°	75°
$h^*(10)$ or $h_p(10)$ from ISO 8529-3	385	400	397	409	389	346	230
h^* or h_p using ICRU 95 coeffs	352	352	353	337	309	267	213
ICRU 95 / ISO 8529-3	0.914	0.880	0.890	0.824	0.794	0.772	0.925
Angle		90º	180º	ROT	ISO	SS-ISO	IS-ISO
h_p using ICRU 95 coeffs		150	210	224	180	188	172

^{241}Am-Be	Ambient	Personal					
Angle α		0°	15°	30°	45°	60°	75°
$h^*(10)$ or $h_p(10)$ from ISO 8529-3	391	411	409	424	415	389	293
h^* or h_p using ICRU 95 coeffs	427	427	427	412	385	342	285
ICRU 95 / ISO 8529-3	1.092	1.039	1.045	0.972	0.928	0.880	0.974
Angle		90º	180º	ROT	ISO	SS-ISO	IS-ISO
h_p using ICRU 95 coeffs		211	293	296	243	253	233

D$_2$O moderated ^{252}Cf	Ambient	Personal					
Angle α		0°	15°	30°	45°	60°	75°
$h^*(10)$ or $h_p(10)$ from ISO 8529-3	105	110	109	109	102	87.4	56.1
h^* or h_p using ICRU 95 coeffs	91.4	91.4	91.7	87.3	79.6	68.6	54.5
ICRU 95 / ISO 8529-3	0.870	0.831	0.841	0.801	0.780	0.785	0.971
Angle		90º	180º	ROT	ISO	SS-ISO	IS-ISO
h_p using ICRU 95 coeffs		38.4	56.3	58.2	46.7	48.8	44.6

IMPLICATIONS OF ENERGY CHANGES FOR DOSEMETERS

Figure 3 is a plot of the measured responses [3] of a Landauer Neutrak-T dosemeter analysed with a track morphology algorithm, NTMA, for the current quantity. Also shown is the response as it would be for the new quantity. Thus, a dosemeter that has response characteristics well within the limits prescribed by ISO 21909 for the current quantity will over-respond significantly in the region below about 1 MeV for the new quantity. **This will not show up in measurements with routine calibration sources where the mean energies are above 1 MeV.** The differences between the two curves are simply a result of the differences between the curves for the quantities as illustrated in Figure 1. The energy dependence problem cannot be solved by a simple alteration of the calibration factor for one of the commonly used radionuclide calibration sources.

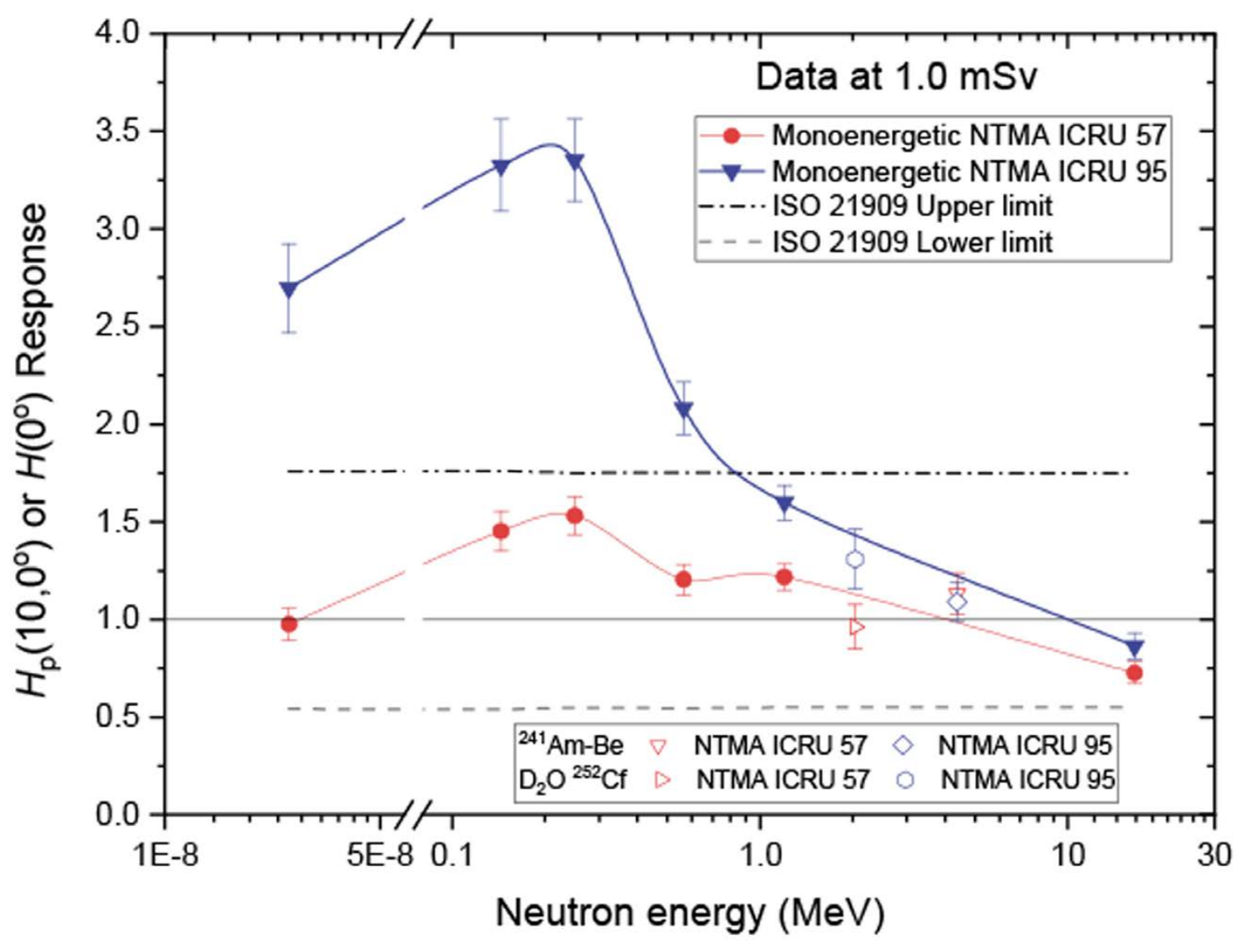

Figure 3. Comparison of the energy dependence of the response of a personal dosemeter when using the ICRU 57 and ICRU 95 quantities.

DISCUSSION AND CONCLUSIONS

The Neutrak-T dosemeter has two different zones as illustrated on Figure 7. The personal dose equivalent $H_p(10)$ is calculated with:

$$H_p\,(10) = F(Q)\times d_f/K_f + d_{th}^{corr}/\,K_{th}$$

where d_f is the track density in tracks/mm² on the fast neutron zone of the PADC surface. The quantity d_{th}^{corr} is the track density on the thermal part of the PADC corrected for the background arising from recoil protons generated by fast neutrons on the thermal part of the detector. It is defined as $d_{th}^{corr} = d_{th} - d_{f/}4$. The variable d_{th} is the total track density on the thermal zone. The quantity $K_f(K_{th})$ is the neutron sensitivity factor of the Neutrak to fast (thermal) neutrons and equals 10 (220) tracks/mm²/mSv. The quantity $F(Q)$ is the correction factor determined by the NTMA algorithm for the radiation quality Q. The algorithm is based on track morphology.

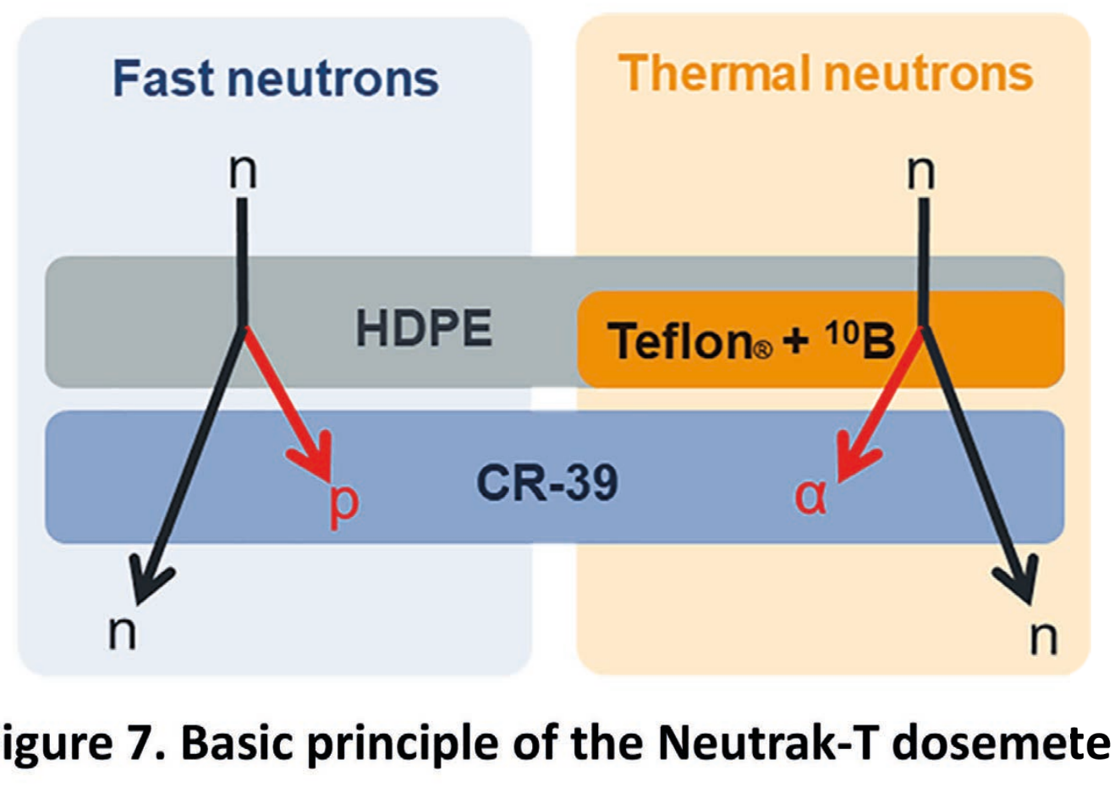

Figure 7. Basic principle of the Neutrak-T dosemeter.

By altering the sensitivity factor to thermal neutrons, it is possible to optimize the response of the dosimetry system at this energy. It simply means that the system will be more sensitive to thermal neutrons in the framework of ICRU 95.

The over-response at 144 keV, 250 keV and 565 keV requires changes in the NTMA algorithm. Work to optimize the response is under way and will focus first on the response at 0° angle of incidence.

References
[1] International Commission on Radiation Units & Measurements, ICRU Report 95 2020.
[2] International Organization for Standardization, ISO Standard 21909-1, Passive neutron dosimetry systems — Part 1: Performance and test requirements for personal dosimetry, 2015.
[3] Brahim Moreno, Alberto Boso, Marc Million, Graeme Taylor, David Thomas, On ISO 21909–1:2015 and the metrological performance of the Landauer Neutrak-T dosemeter, Radiation Measurements 150 (2022) 106699
[4] International Commission on Radiation Units & Measurements, ICRU Report 57 1998.