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Proposal of a novel concept on neutron-gamma mixed field dosimetry by using paired ionization chambers

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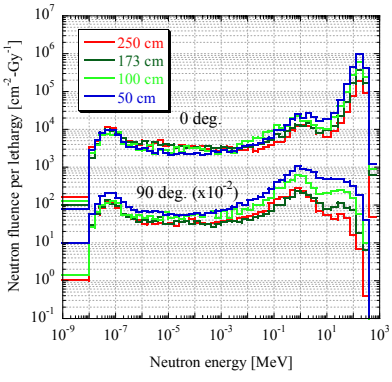
【 Abstract 】

In order to expand the available energy range of neutron dosimetry by the paired ionization chambers, an alternative concept has been newly proposed. The concept employs another TE-TE chamber with a gamma-ray attenuator instead of conventional C-CO_2 chamber. A rough comparison of uncertainty estimates between conventional method and newly-proposed one is carried out. The result indicates that the accuracy of the present method is far less-sensitive to the change of neutron energy and is evidently superior to that of the conventional method [1].

【 Neutron Generation around High Energy Medical Accelerators 】



290MeV/n ^{12}C @HIMAC by "Boner Balls"

N. Matsufuji *Ionizing Radiation*, Vol.39, No.4 (2008)

Distance dependence of neutron fluence for the incidence of C-290MeV/n in water.

【 Principle of Dosimetry by Paired Ionization Chambers 】

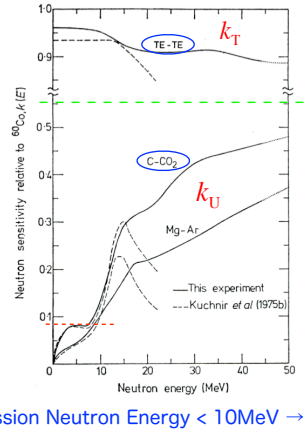
Paired Ionization Chamber Method

Type-T : TE-TE chamber
Type-U : C-CO_2 chamber

$$\begin{cases} R_T = k_T D_N + h_T D_G & k_T, k_U : \text{neutron relative sensitivities} \\ R_U = k_U D_N + h_U D_G & h_T, h_U : \text{gamma relative sensitivities} \end{cases}$$

$$h_T \equiv h_U \equiv k_T \equiv 1$$

neutron dose [Gy): $D_N = \dfrac{R_T' - R_U'}{1 - k_U}$, gamma dose [Gy]: $D_G = \dfrac{R_U' - k_U R_T'}{1 - k_U}$



Waterman et al. *Phys. Med. Biol.* Vol.24 (1979) [3]

Fission Neutron Energy < 10MeV → $k_U \cong 0.08$ Ref.[4]

for Neutron Energy > 10MeV
→ Single value approximation is no longer valid !!

【 Newly Proposed Method 】

In order to overcome the energy limitation ・・・

Conventional ---	neutron	gamma
Type-T : TE-TE	$k_T \sim 1$	$h_T \sim 1$
Type-U : C-CO_2	$k_U \leq 1$	$h_U \sim 1$
Newly-proposed ---	**neutron**	**gamma**
Type-T : TE-TE	$k_T \sim 1$	$h_T \sim 1$
Type-T': [TE-TE]	$k_T' \sim 1$	$h_T' = \gamma h_T$
+ γ ray attenuator + γ ray spectrometer	$k_T' = k_T$	$\gamma = h_T'/h_T$

Conventional ---
Type-T : k_T h_T
Type-U : k_U h_U

$$D_N = \frac{h_U R_T - h_T R_U}{h_U k_T - h_T k_U}$$

Newly Proposed ---
Type-T : k_T h_T
Type-T': $k_T' = k_T$ $h_T' = \gamma h_T$

$$D_N = \frac{R_T' - \gamma R_T}{k_T(1-\gamma)}$$

【 Consideration on Accuracy of D_N 】

ICRU Report 26 [2]

It can be shown that an overall uncertainty of Δk_U in the relative neutron sensitivity contributes overall uncertainties to the absorbed doses of neutrons and of photons of ΔD_N and ΔD_G, respectively, given by

$$\frac{\Delta D_N}{D_N} = \frac{\Delta k_U / k_U}{(1/k_U) - (1 + \Delta k_U / k_U)} \quad (2.7\text{-}7)$$

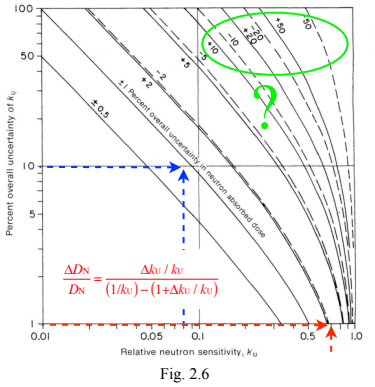


Fig. 2.6

[E-mail from Dr. S. M. Seltzer, NIST (2009/8/26)]

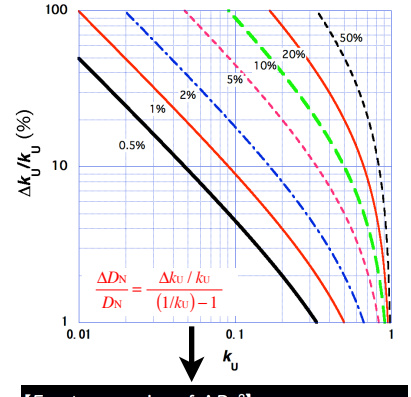
Dear Dr. Nohtomi,

I've been asked if I could respond to your query, and I apologize for taking a bit long to respond.

Indeed, I also find the equations you indicate, Eqs. 2.7-7 and 2.7-8, to be incorrect. If I derive corresponding expressions from the material above them in ICRU Report 26. Thus, Fig. 2.6 is presumably defective also.

・・・・・Reviewing my copies, I find no such erratum. I asked a colleague in neutron dosimetry about this, but he has not indicated he found any erratum published elsewhere.

Steve Seltzer



【Exact expression of ΔD_N^2】

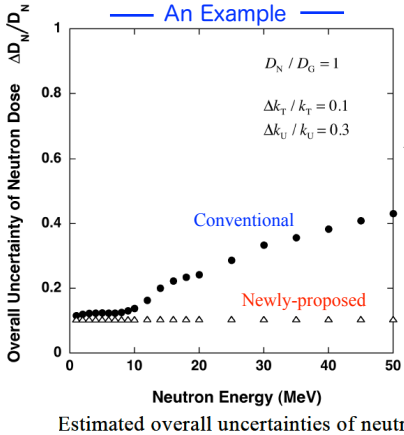
Conventional ---

$$\Delta D_N^2 = \left[\frac{h_U D_N}{h_U k_T - h_T k_U}\right]^2 \Delta k_T^2 + \left[\frac{h_T D_N}{h_U k_T - h_T k_U}\right]^2 \Delta k_U^2 + \left[\frac{R_U - k_U D_N}{h_U k_T - h_T k_U}\right]^2 \Delta h_T^2 + \left[\frac{R_T - k_T D_N}{h_U k_T - h_T k_U}\right]^2 \Delta h_U^2$$

Newly Proposed ---

$$\Delta D_N^2 = \left[\frac{D_N}{k_T}\right]^2 \Delta k_T^2 + \frac{1}{k_T^2 (1-\gamma)^2}\left[R_T - \frac{R_T' - \gamma R_T}{1-\gamma}\right]^2 \Delta\gamma^2$$

【 Comparison of Actual Accuracies 】



Estimated overall uncertainties of neutron dose.

Assumed Conditions

- Numerical values of k_T and k_U are from Watermann et al. [3]
- For gamma-rays $\begin{cases} h_T = 1, & \Delta h_T / h_T = 0.05 \\ h_U = 1, & \Delta h_U / h_U = 0.05 \\ \gamma = 0.95, & \Delta\gamma / \gamma = 0.05 \end{cases}$
- ^{60}Co calibration constants of chambers are from Ref.[5]

【 References 】

[1] A. Nohtomi, et al., Nucl. Instr. and Meth. A 614 (2010) pp.159 [2] ICRU REPORT 26 (1977)
[3] F. M. Waterman et al., Phys. Med. Biol., Vol.24, No.4 (1979) pp.721
[4] S. Endo et al., J. Radiat. Res., Vol.43 (2002) pp.381 [5] M. Hoshi et al., Phys. Med. Biol., Vol.33, No.4 (1988) pp.473