

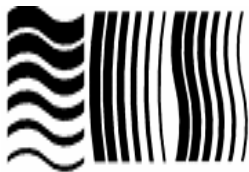


Experimental beam quality correction factors k_Q determined in clinical high energy photon beams

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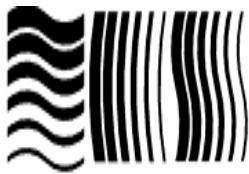
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Outline



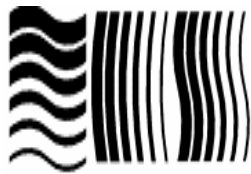
- Background
- Experimental method & measurement campaign
- k_Q for photons → experimental data, parameterisation, analysis



Background



- Revision air kerma based NCS CoPs
- BeNe: primary absorbed dose standards for ^{60}Co reference radiation
- Based on clinical practice in Belgium and The Netherlands
- In agreement with international recommendations (IAEA/TRS 398 and AAPM/TG 51)



Background: experimental versus theoretical k_Q

$$k_{Q,Q_0} = \frac{N_{D,w,Q}}{N_{D,w,Q_0}}$$

$$k_{Q,Q_0} = \frac{N_{D,w,Q}}{N_{D,w,Q_0}} = \frac{\frac{D_{w,Q}}{M_{Q,corr}}}{\frac{D_{w,Q_0}}{M_{Q_0,corr}}} = \frac{\frac{D_{air,Q}}{M_{Q,corr}} (s_{w,air})_Q p_Q}{\frac{D_{air,Q_0}}{M_{Q_0,corr}} (s_{w,air})_{Q_0} p_{Q_0}} = \frac{\frac{(W/e)_Q}{m_{air}} (s_{w,air})_Q p_Q}{\frac{(W/e)_{Q_0}}{m_{air}} (s_{w,air})_{Q_0} p_{Q_0}}$$

$$k_{Q,Q_0} = \frac{(s_{w,air})_Q p_Q}{(s_{w,air})_{Q_0} p_{Q_0}}$$

with

$$p_Q = (p_{dis} p_{cav} p_{wall} p_{cel})_Q$$

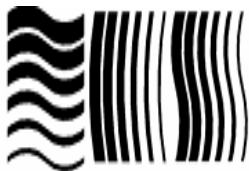


Background: k_Q and NCS-2/5

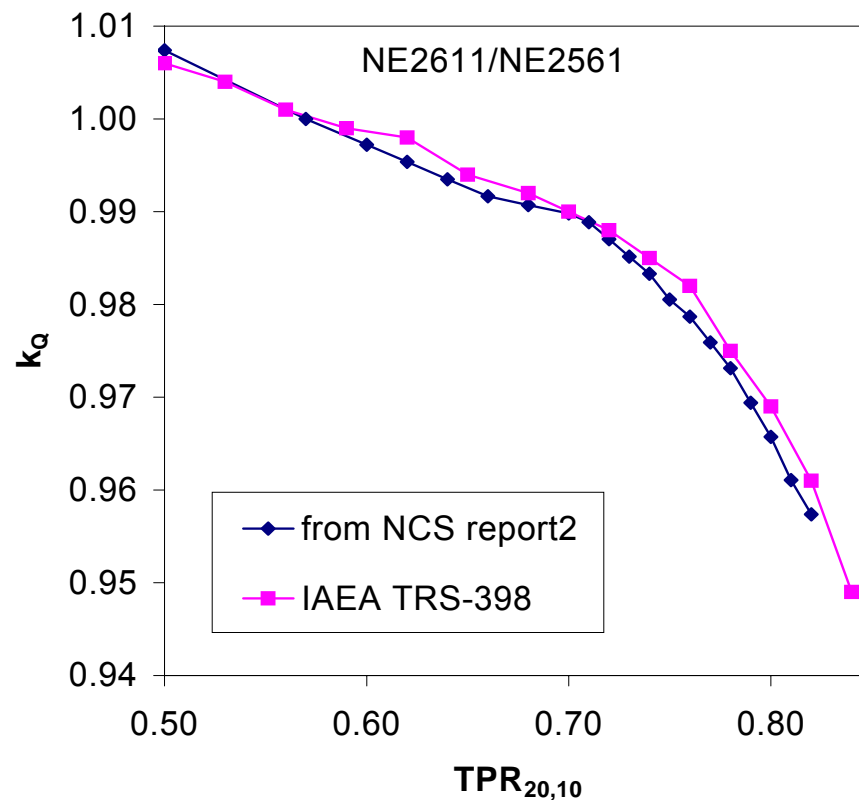
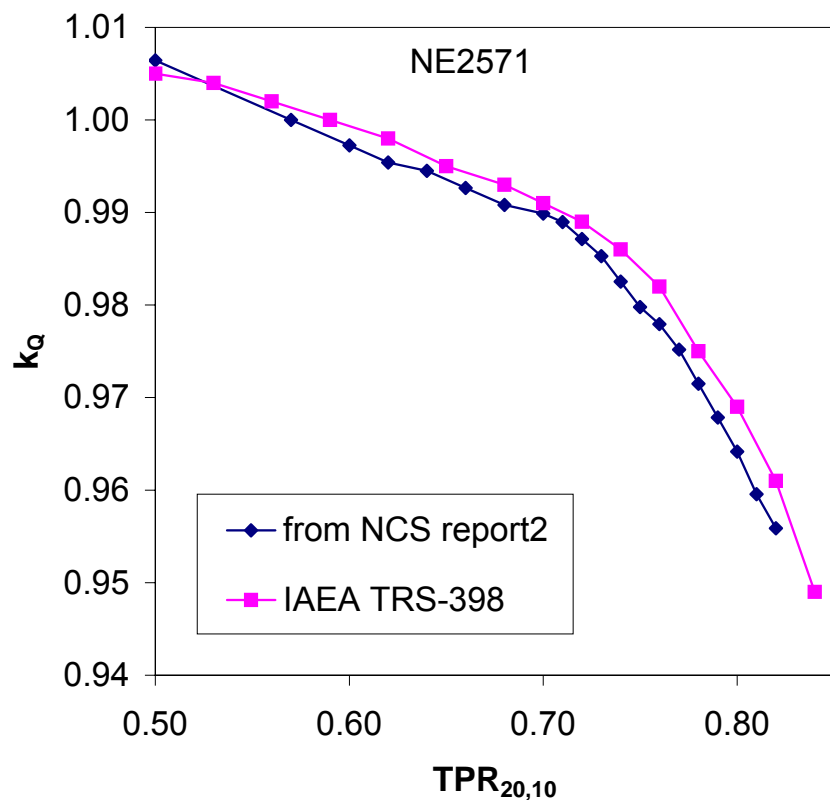
$$k_{Q,Q_0} = \frac{(s_{w,air})_Q P_Q}{(s_{w,air})_{Q_0} P_{Q_0}} \times \frac{k_{att} k_m k_{ce} (1-g)}{k_{att} k_m k_{ce} (1-g)}$$

$$k_{Q,Q_0} = \frac{C_{w,u}(Q)}{C_{w,u}(Q_0)}$$

$$k_{Q,Q_0} = \frac{C_{w,e}(Q)}{C_{w,e}(Q_0)}$$



k_Q for photons: Theoretical IAEA TRS-398 and NCS-2

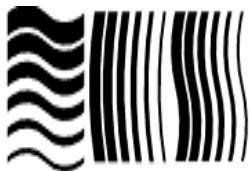




k_Q for photons: IAEA recommendation



- Although IAEA TRS-398 presents only theoretical data, it recommends to use experimental k_Q values, ideally measured for individual chambers
- We decided to measure k_Q values for a representative set of linear accelerators in Belgium and The Netherlands



Selected clinical photon beams



Accelerator	Photon Energy (MV)	Institute	TPR _{20,10}	%dd(10) _x
Elekta SL 15	6	AvL/NKI, Amsterdam, NL	0.6732	66.24
Elekta SL 18	10	AMC, Amsterdam, NL	0.7287	73.06
Elekta SL 18	15	AZ St. Lucas, Gent, BE	0.7583	76.84
Elekta SL 25	25	UCL, Brussels, BE	0.7993	84.38
Siemens Primus	18	Virga Jesse ziekenhuis, Hasselt, BE	0.7674	79.52
Siemens Primus	23	CHU, Liège, BE	0.7829	81.39
Varian 2300C/D	6	VU, Amsterdam, NL	0.6594	65.82
Varian 2300C/D	15	Jôlimont, Haine Saint-Paul, BE (2x) (rep)	0.7576 0.7563	77.97 78.05



Selected reference ionization chambers

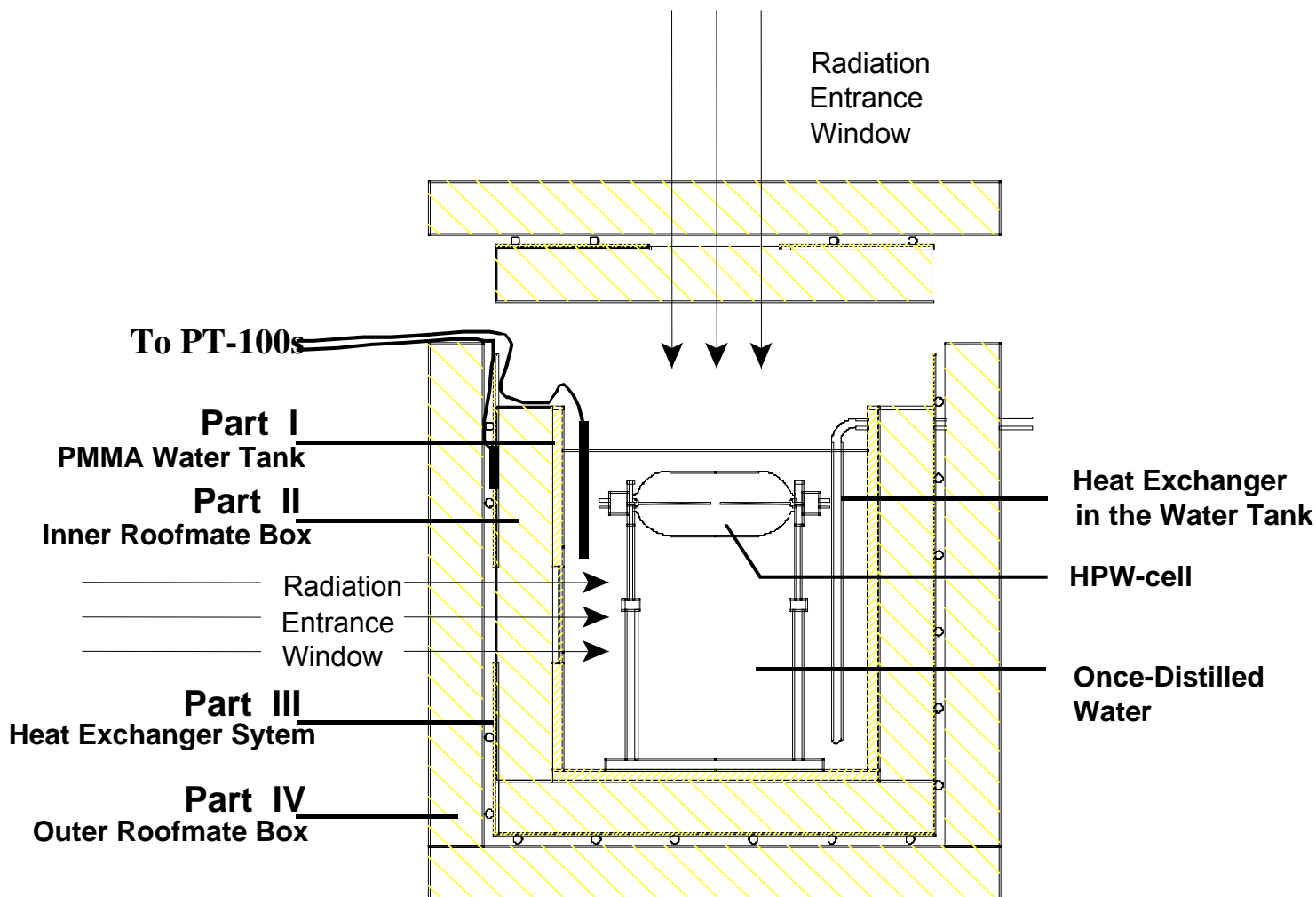


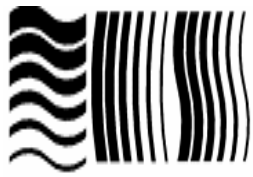
Selected chambers for k_Q measurements in high- energy photon beams (6 chambers of each type):

1. NE 2611A
2. NE 2571
3. PTW 30012
4. Wellhöfer IC70 (FC65G)

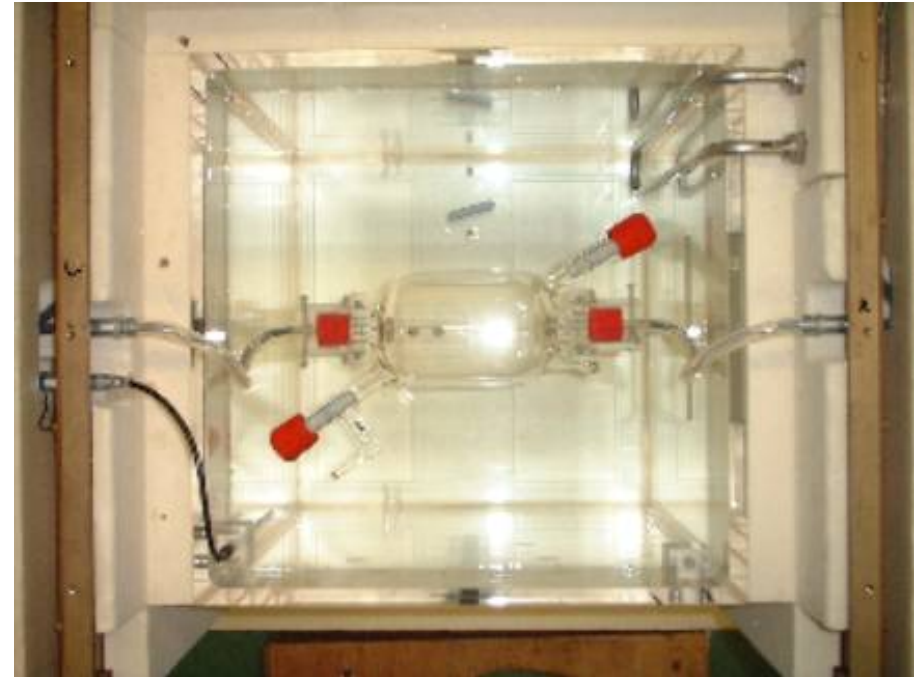


Schematic diagram of the portable NMi water calorimeter





Measurement set up and top view portable NMI water calorimeter





Experimental method (1)



$$N_{Dw,Q} = \frac{D_{w,Q}}{M_Q}$$

$$D_{w,Q} = \frac{1}{M_{mon,Q} \cdot k_{TP,mon,Q}} \cdot \Delta R_{midrun,Q} \cdot \frac{dT}{dR}(T_Q) \cdot C_w(T_Q) \cdot (k_{SDD} \cdot k_{depth} \cdot k_{hd} \cdot k_{xs-heat} \cdot k_{HPC})_Q$$



Experimental method (2)



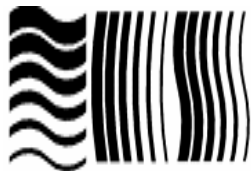
$$k_{Q,Q_0} = \frac{M_{Q_0}}{M_Q} \cdot \frac{M_{mon,Q_0} \cdot k_{PT,mon,Q_0}}{M_{mon,Q} \cdot k_{PT,mon,Q}} \cdot \frac{\Delta R_{midrun,Q_0} \cdot \frac{dT}{dR}(T_{Q_0}) \cdot C_w(T_{Q_0})}{\Delta R_{midrun,Q} \cdot \frac{dT}{dR}(T_Q) \cdot C_w(T_Q)} \cdot \frac{(k_{SDD} \cdot k_{depth} \cdot k_{hd} \cdot k_{xs-heat} \cdot k_{HPC})_{Q_0}}{(k_{SDD} \cdot k_{depth} \cdot k_{hd} \cdot k_{xs-heat} \cdot k_{HPC})_Q}$$



Measurement campaign k_Q in photon beams



- Initial phase: determination of correction factors and beam specifier data in selected clinical photon beams
- Absorbed dose measurements on location during weekends: vertical beam set up
- Repeated calibration of all chambers in ^{60}Co during the campaign
- Delay: IR facilities NMI from Utrecht -> Delft
- Additional measurements of all Farmer type chambers in (horizontal) ^{60}Co beam facility at LSDG in Gent



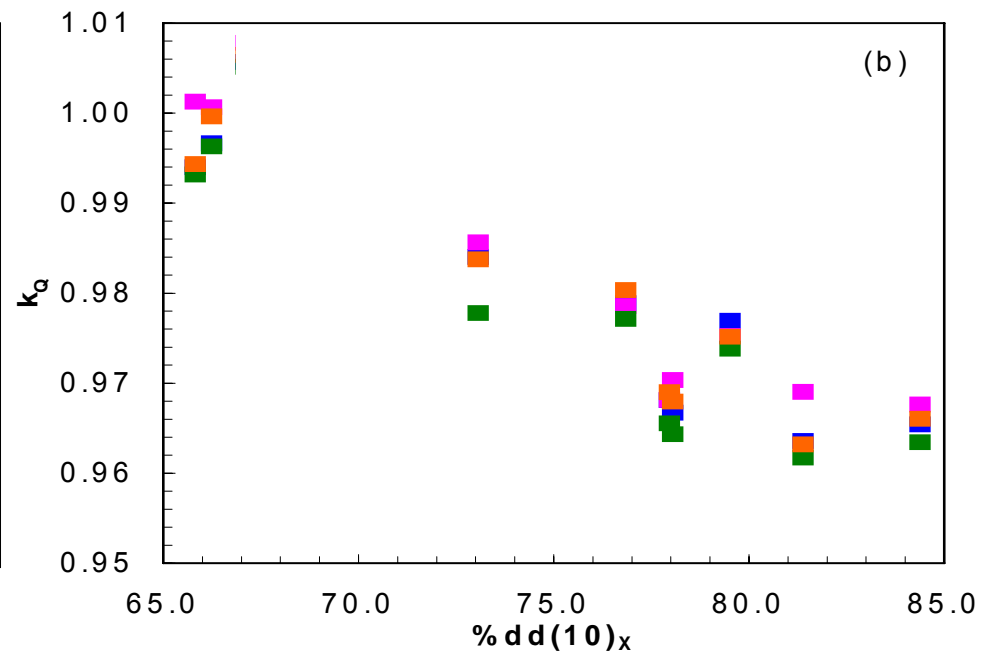
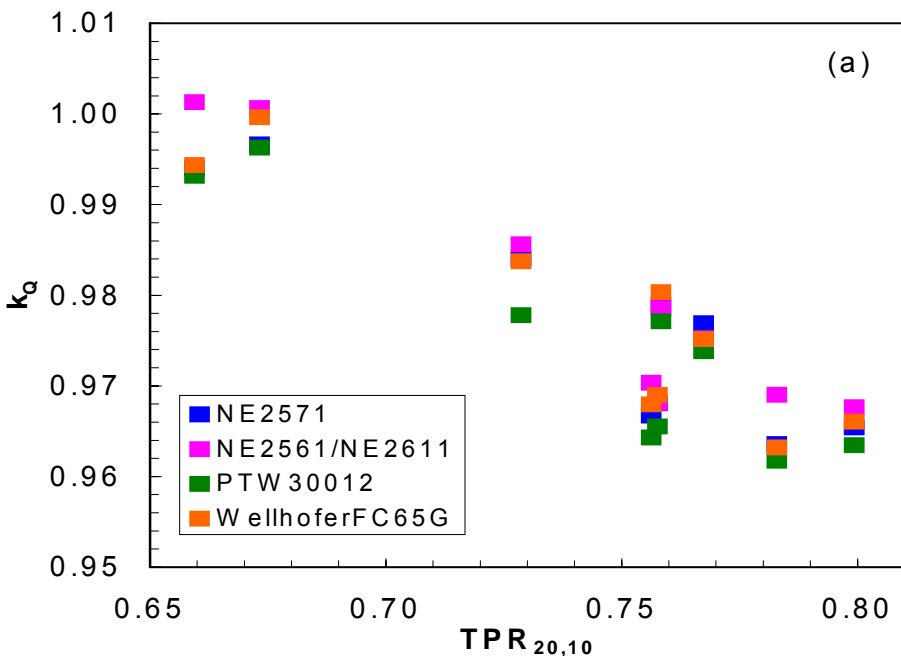
Uncertainty in measured k_Q values



Step 1: Absorbed dose determination in ^{60}Co	<i>Relative Standard Uncertainty (%)</i>
<i>Type of physical quantity or procedure</i>	
D_w determination with water calorimeter	0.34
Long term stability in ^{60}Co	0.18
Charge measurement and experimental procedure	0.14
<i>Combined uncertainty in $D_{w,0}$</i>	<i>0.41</i>
Step 2: Absorbed dose determination in high energy photon beam	
<i>Type of physical quantity or procedure</i>	
D_w determination with water calorimeter	0.25
Charge measurement and experimental procedure	0.17
<i>Combined uncertainty in Step 2</i>	<i>0.30</i>
Combined standard uncertainty in $D_{w,Q}$ (Step 1+2)	0.51



k_Q for photon beams: experimental results ($1\sigma \approx 0.5\%$)



No significant differences between NE2571, PTW-30012 and Wellhofer FC65G
Not sufficient as self-standing data-set -> pool data with literature data



NCS data + data from Literature



- Literature data mainly available for NE 2571 and NE 2561/2611A
- Not only data measured by NMIs, but also data with comparable metrological quality
- All data assigned equal weight, chamber to chamber variations are small (0.1% - 0.2%), spread in data more likely due to differences in measurement method and variety of beams
- Data included measured with Fricke chemical dosimeters, corrected for energy dependence according to Seuntjens et.al. (*Med. Phys.* **27**, 2763-2779, 2000)

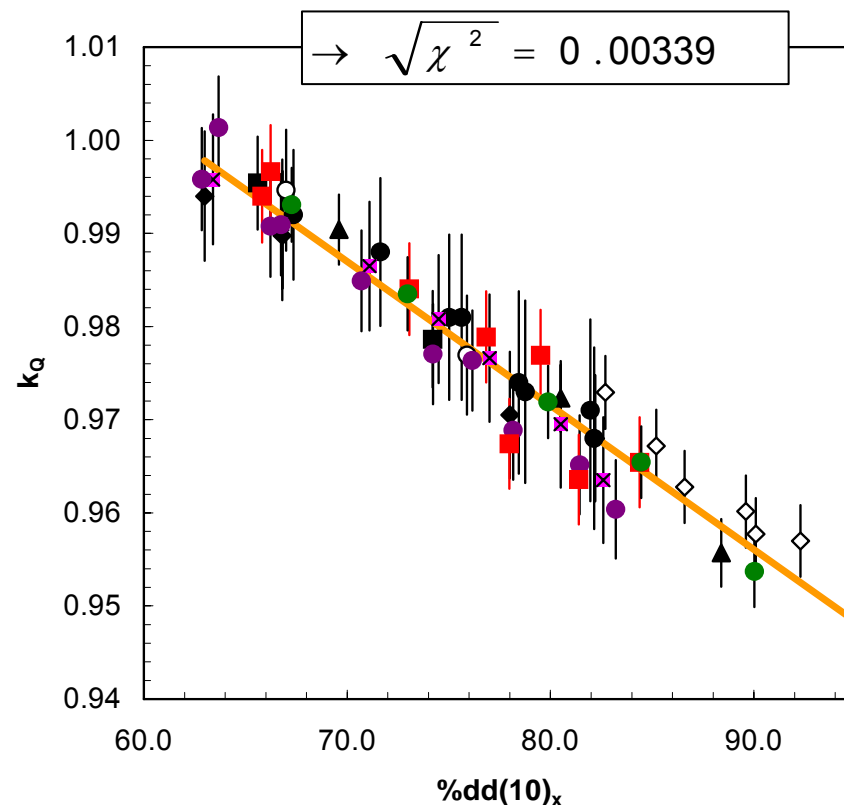
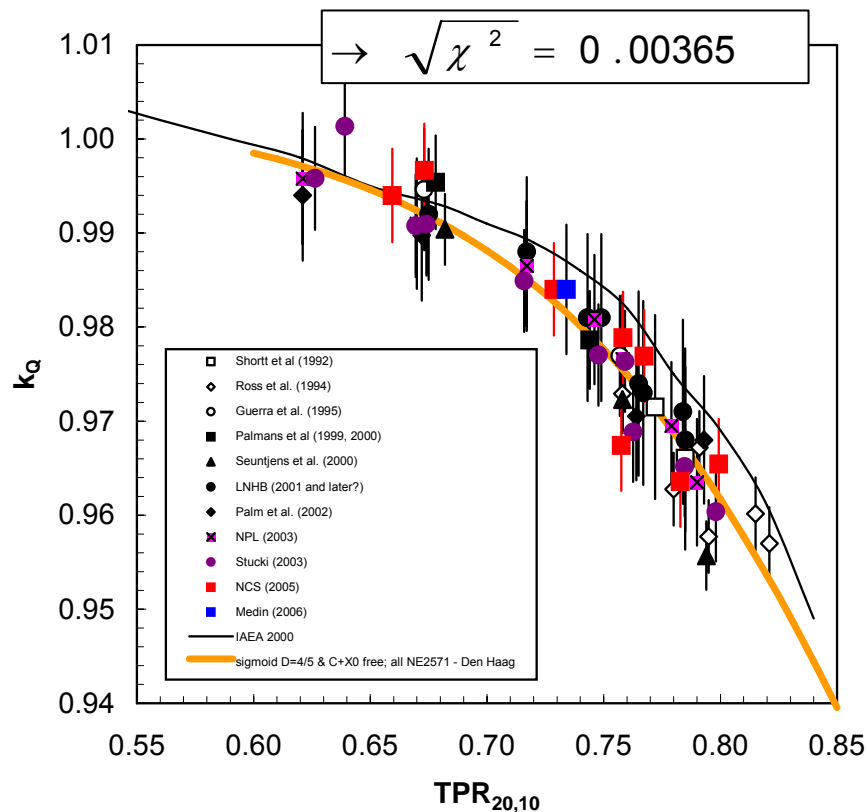


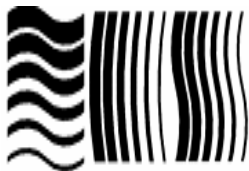
Function to fit ?

- Based on underlying stopping power data (linear function of $\%dd(10)_x$, sigmoid function of $TPR_{20,10}$)
- Also p_{wall} for cylindrical, graphite walled chambers can be modelled by such a function

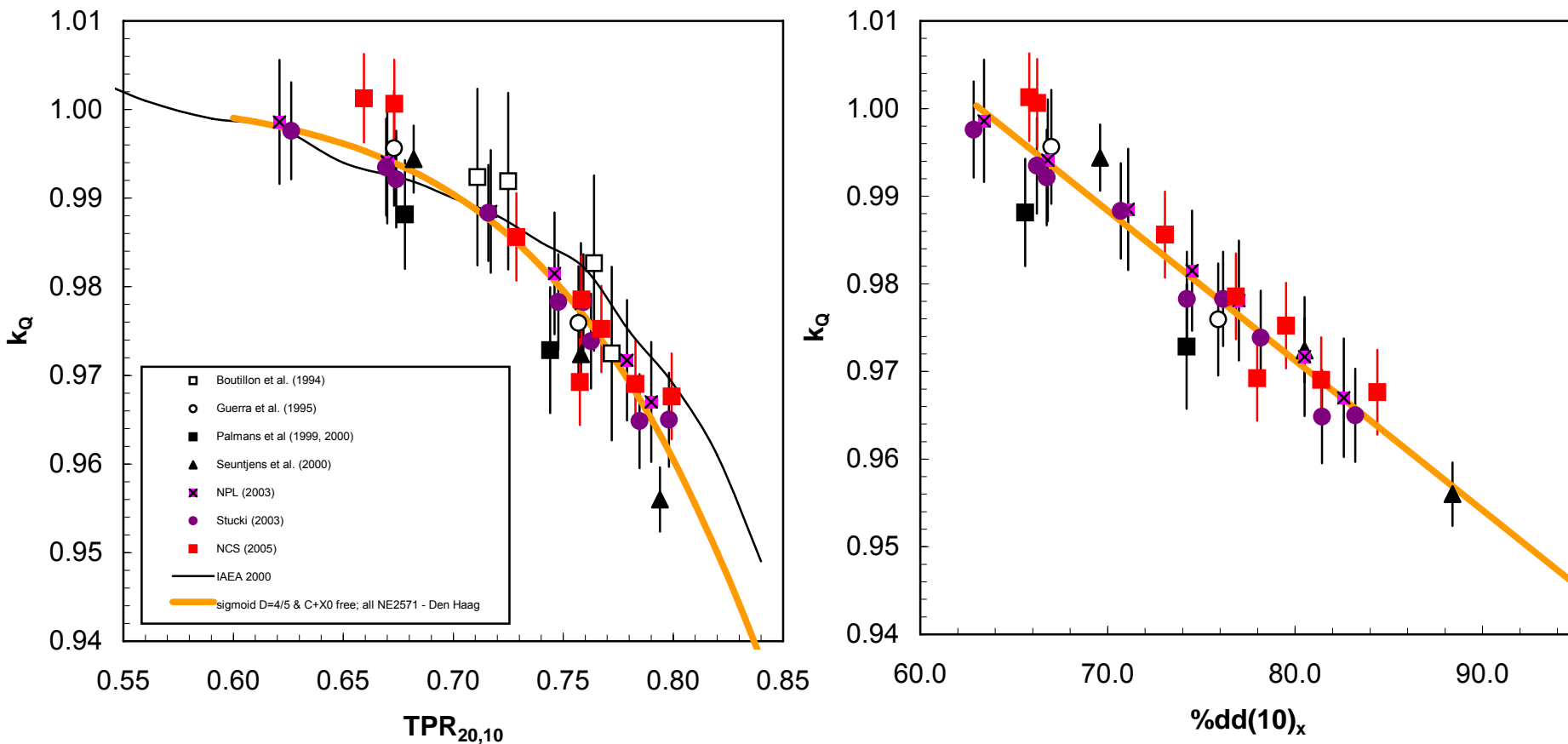


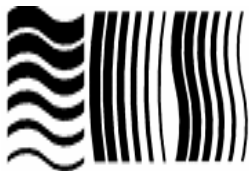
k_Q for photons: NCS data for NE2571 with other data





k_Q for photons: NCS data for NE2611/NE2561 with other data



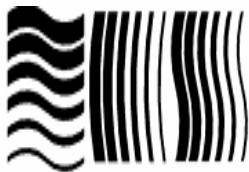


Function to fit ? (continued)

- Based on underlying stopping power data (sigmoid function of $TPR_{20,10}$)
- 1 parameter adjusted (coverage intervals \pm consistent with data spread) + 2 parameters left as fit parameters
- For ^{60}Co , $TPR_{20,10} = 0.57$ assumed ($k_Q = 1$)

$$k_Q = 0.8 + 0.2 \cdot \frac{1 + \exp(C \cdot (0.57 - X_0))}{1 + \exp(C \cdot (TPR_{20,10} - X_0))}$$

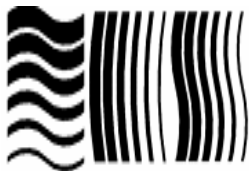
	X_0	C
NE2571, PTW-30012, Wellhofer FC65G	0.920 ± 0.010	11.7 ± 0.9
NE2561/NE2611	0.897 ± 0.012	15.2 ± 1.6



Conclusions



- For photons:
 - NCS data not self-standing
 - NCS data + literature: sufficient data for experimental k_Q
 - No preferred beam quality specifier -> $TPR_{20,10}$
 - No significant differences between Farmer-type chambers
 - We propose parameterisation of data based on underlying stopping power function



Acknowledgments



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