Monte Carlo-based study of primary beta-ray standards of absorbed dose to tissue in $^{90}Sr/^{90}Y$ fields

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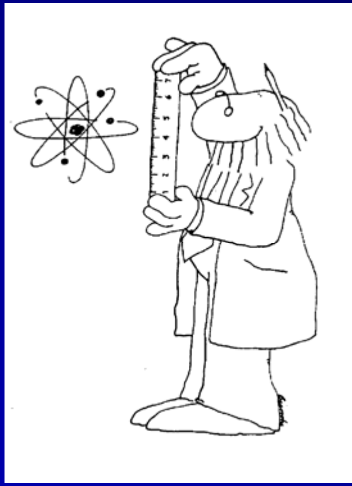

Absorbed dose and air kerma primary standards workshop
Paris May 9-11, 2007

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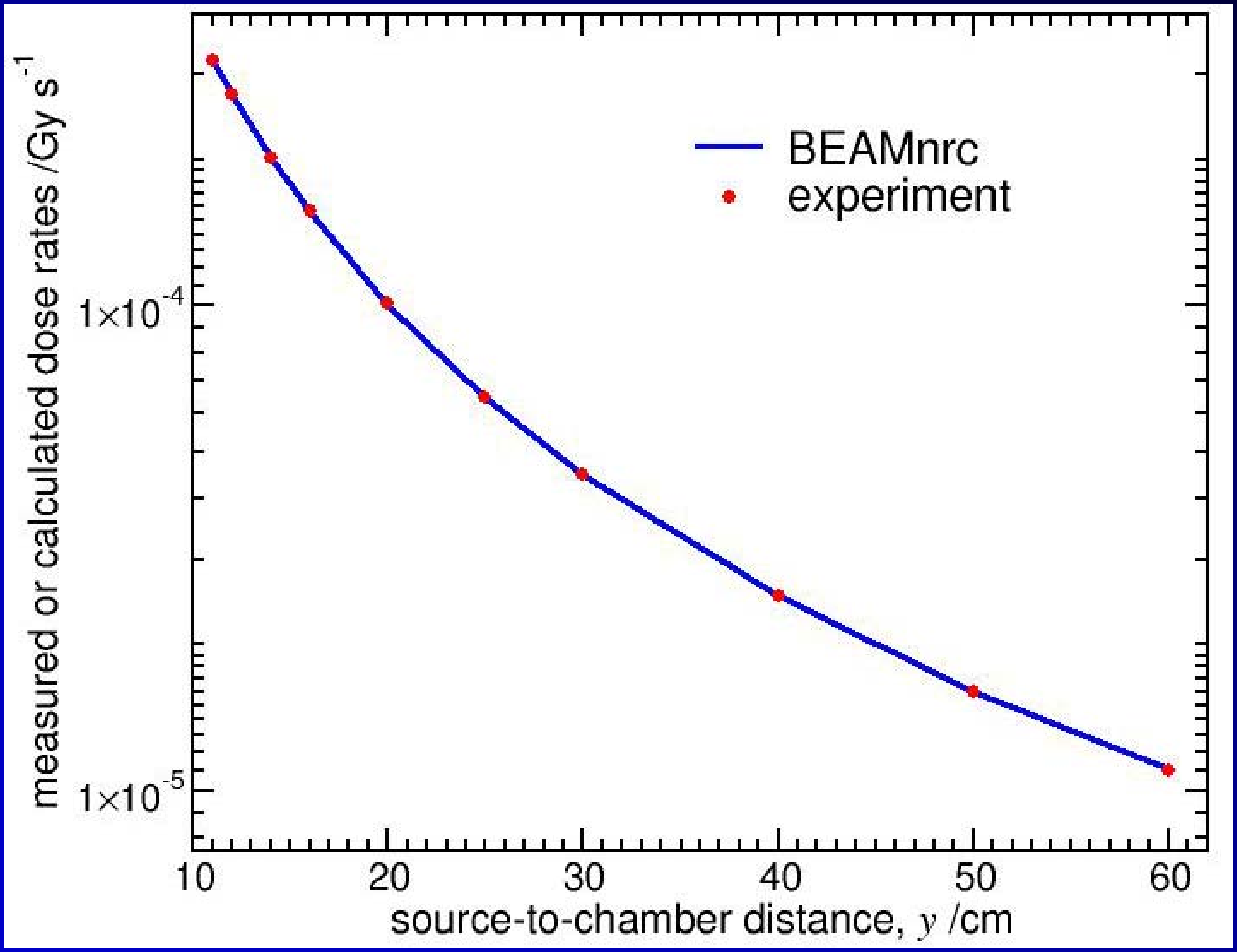
NRC-CNRC

Selvam, Saull & Rogers

Med Phys 32(2005)3084-3094

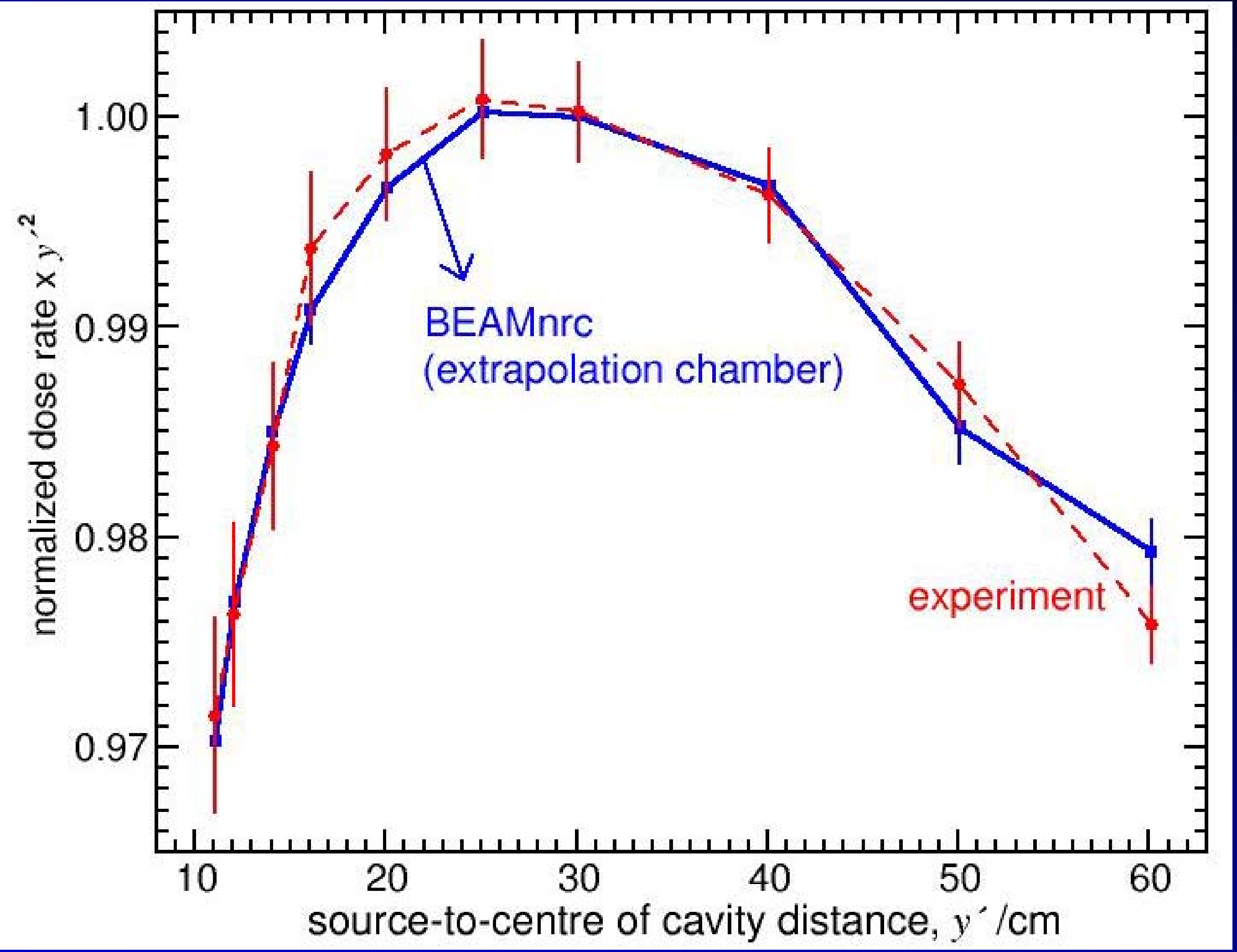
- created a detailed model of the NRC extrapolation chamber using the EGSnrc/BEAMnrc system.
- for $^{90}Sr/^{90}Y$ beta source
- benchmarked it against measured data

response vs distance to source



Selvam et al Med Phys 32 (2005) 3084-3094

normalized dose rate(response) x r^2



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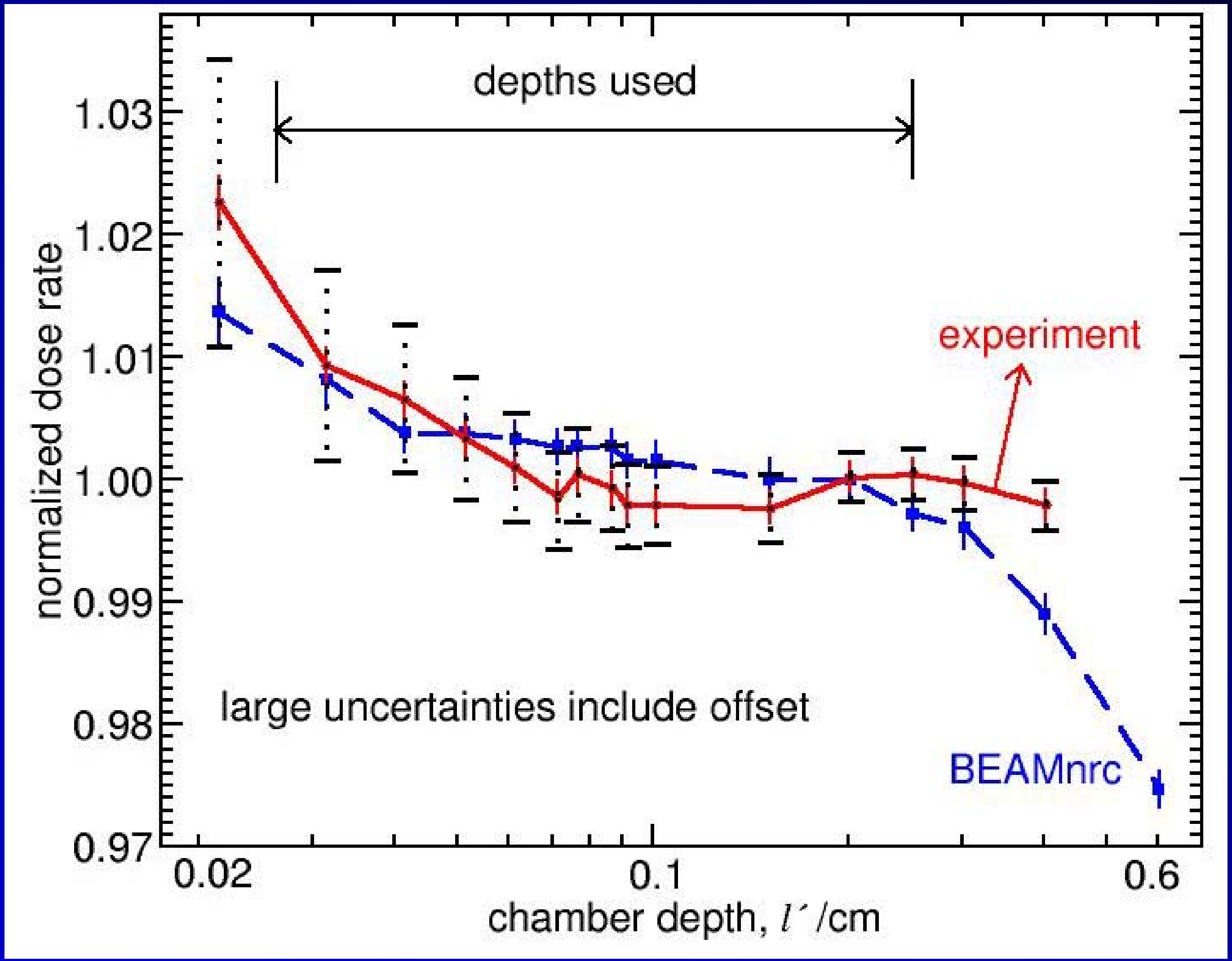
normalized dose rate vs chamber depth

30 cm from source



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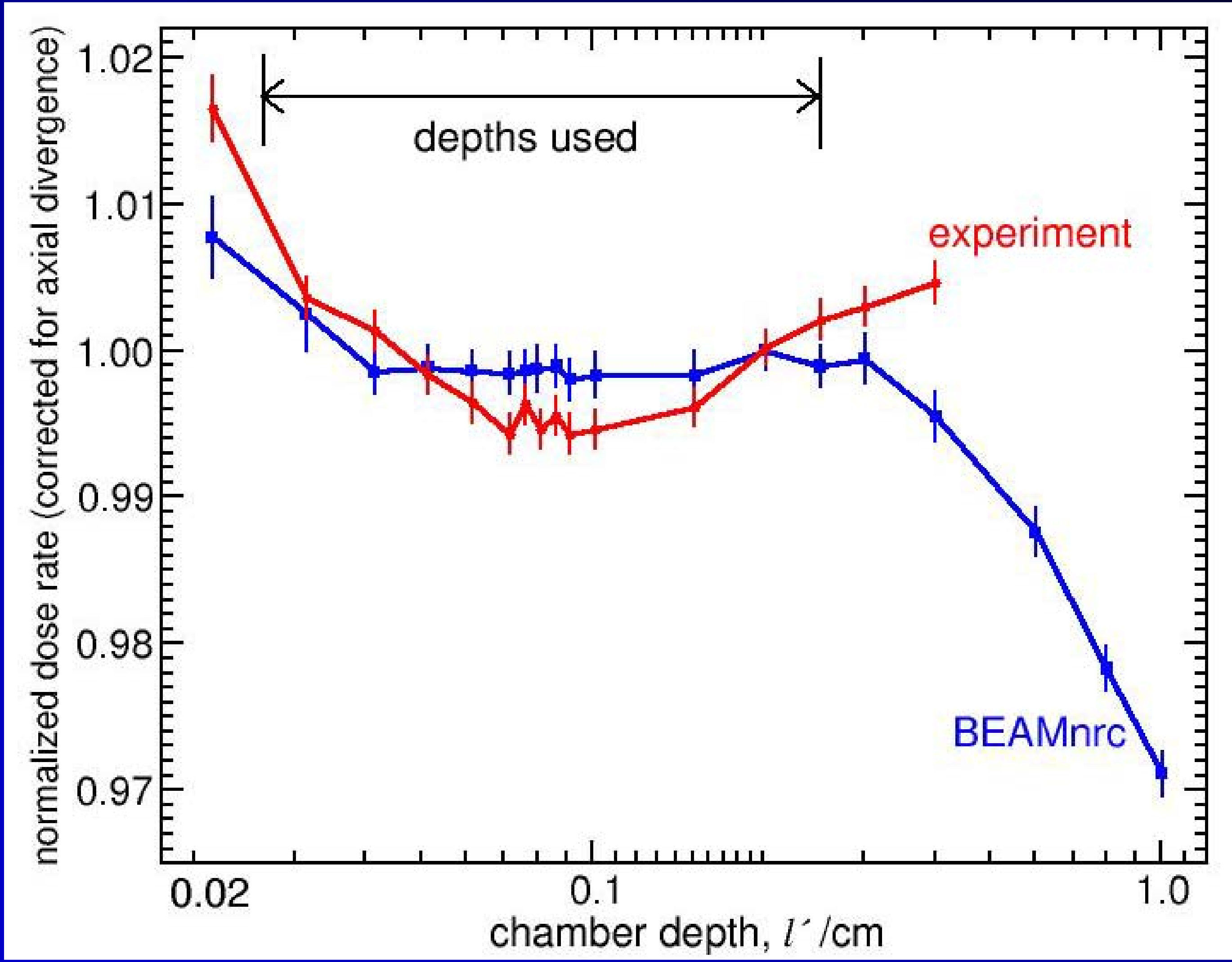
divergence corrected dose rate vs chamber depth



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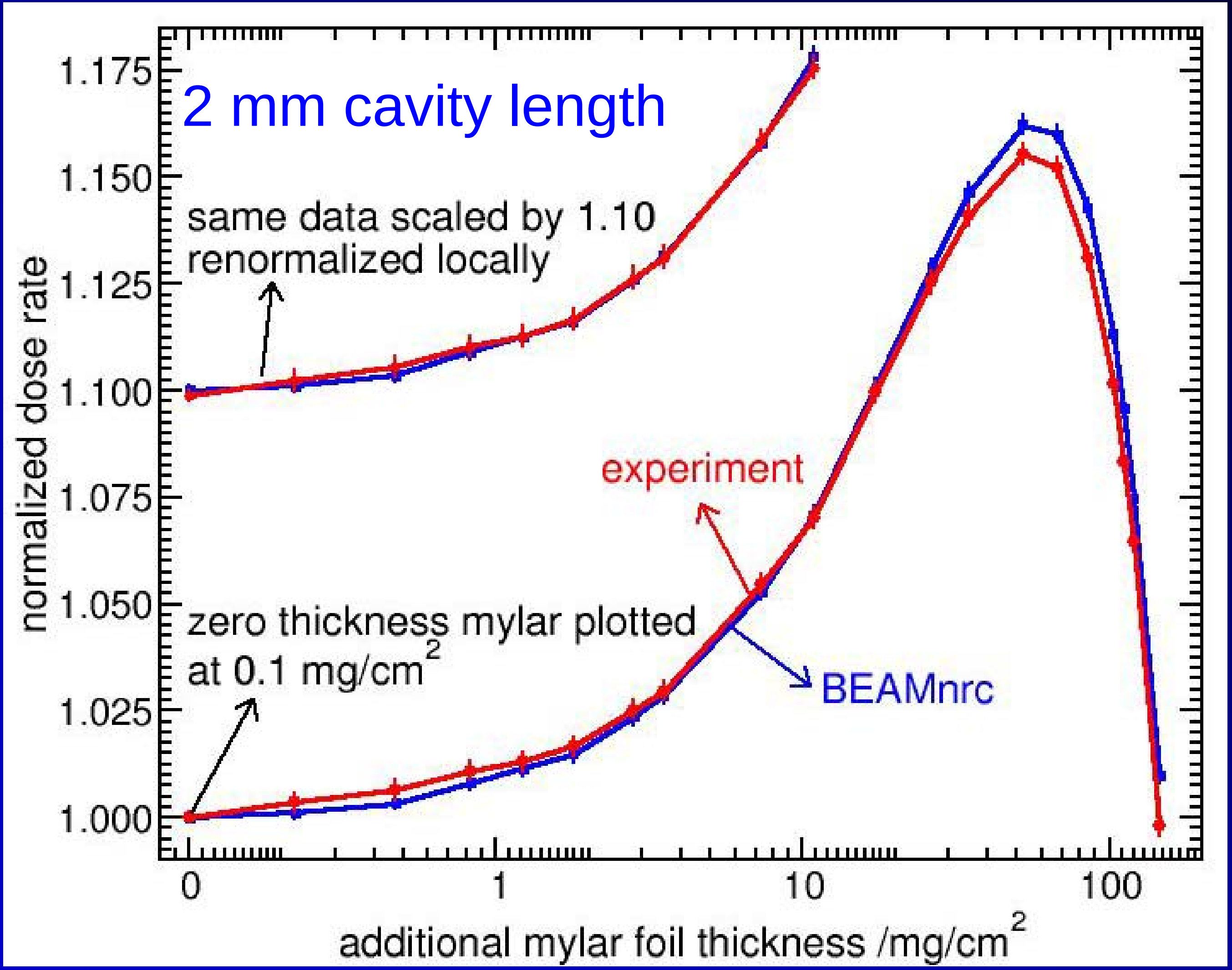
response vs added mylar

used to convert to proper tissue thickness



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$1 mg/cm^2$ tissue = 10 μm

ISO approach to beta-ray standards

- measure I(l), i.e., current vs of cavity length
- correct for cavity dependent effects
  - divergence of beam
  - effects of side walls - i.e., effectively there are no walls
- determine slope and relate to dose to air in "cavity" on surface
- Bragg-Gray cavity theory => dose to tissue
- correct for backscatter not being from tissue
- correct for front wall not being 70μm of tissue
- determine D_R(70μm): dose to tissue at 70μm

ISO approach to beta-ray standards

$$\dot{D}_R(70\mu m) = \frac{\left(\frac{W}{e}\right)_{\rm hum} S_{t,a} k_{ba} k_{\rm abs}}{A\rho_{\rm hum}} \left(\frac{d}{dl}(k'_{\rm iso}(l) I(l))\right)$$

$$k'_{\rm iso}(l) = k_{pe}(l) k_{di}(l)$$

$$k_{ba} = 1.01 \pm 0.3\%$$

$$k_{\rm abs} = 1/T'$$

$$k_{pe}(l)$$

$$S_{t,a} = 1.110 \pm 0.6\%$$

$$k_{di}(l) = 1 + \frac{l}{y}$$

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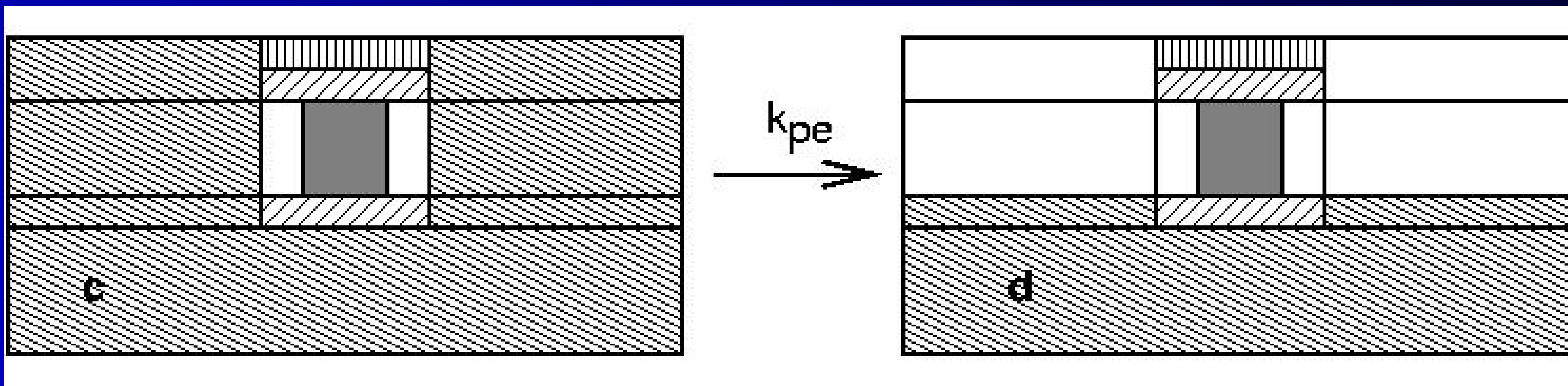
Correction for humidity in cavity

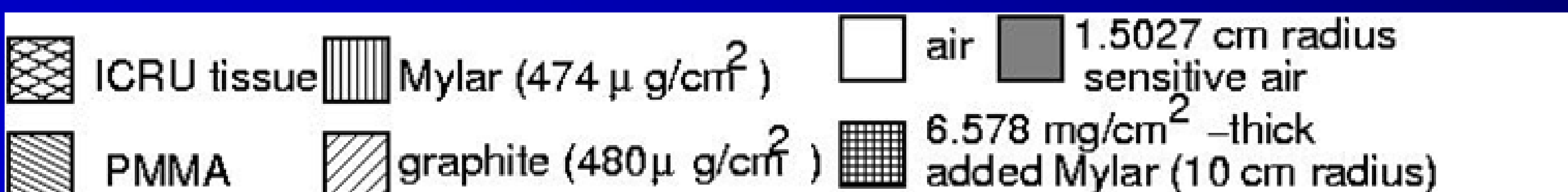
- ISO
  - uses W/e for humid air and measures in humid air
  - uses stopping-power ratio for dry air
  - uses air density for humid air
- to be consistent one needs spr for humid air
  - it differs by 0.15%

- ISO uses W/e for a humidity of 15%, not 65%
  - value is 33.83 J/C = 0.996x33.97 J/C $\left(\frac{W}{e}\right)_{65\%} = 33.97 \times 0.9926 = 33.7$
  - proper value is 33.72 (diff = 0.33%)

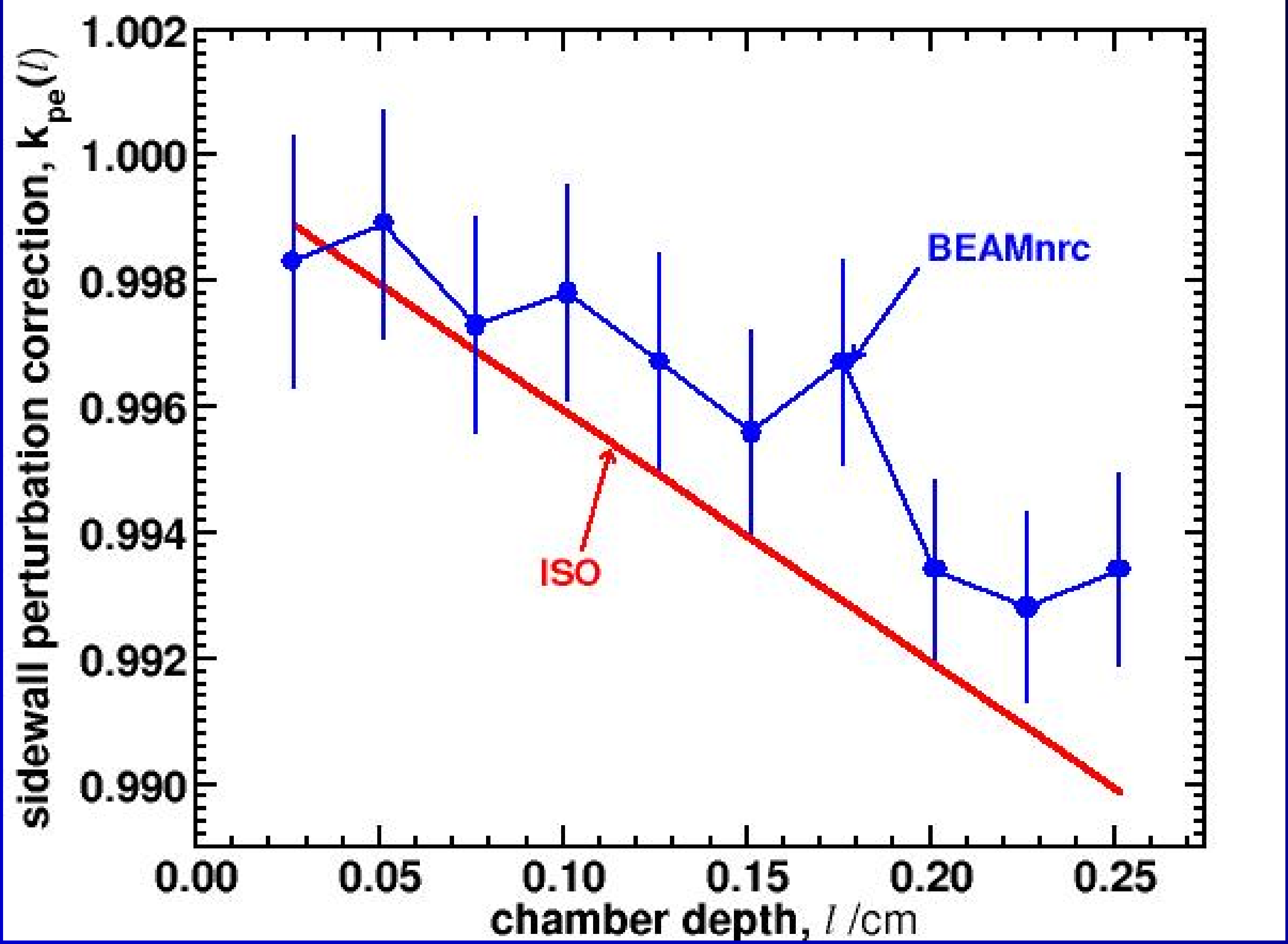
- better approach, use k_h =0.997 with all calculated quantities for dry air (overall 0.5%)

k_{pe}: sidewall correction





k_{pe}: sidewall correction



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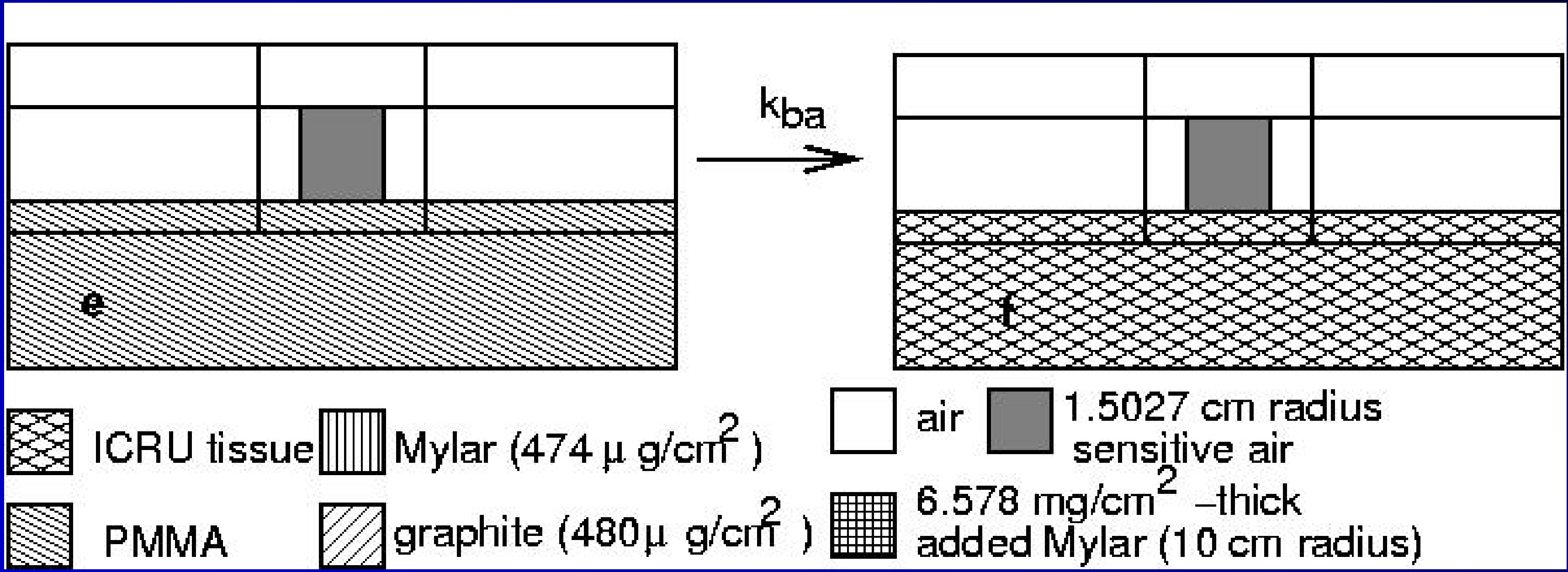
k_{ba}: backscatter correction



$$k_{ba} = 1.01 \pm 0.3\%$$

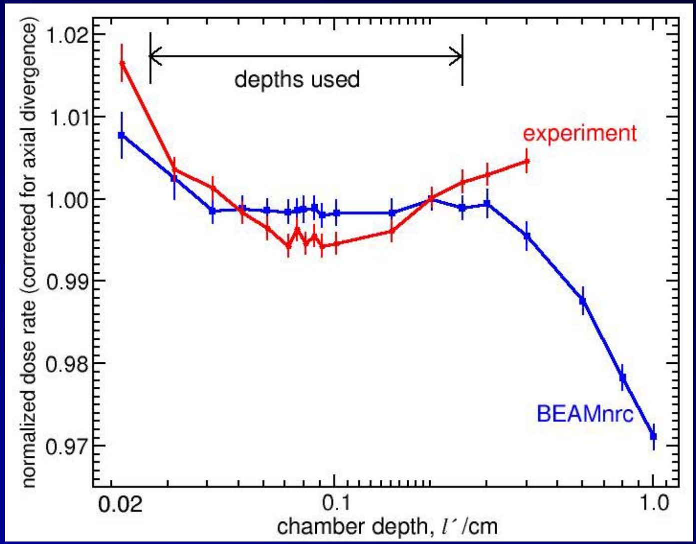
EGSnrc value 1.0157+-0.16%, independent of cavity length

No change if include front window or if include 2.82 μm of graphite on collector

k_{di}: divergence correction

- ISO uses

$$k_{di}(l) = 1 + \frac{l}{y}$$



- we saw earlier that this “flattens” calculated response vs cavity length
- did a MC calculation of dose in cavity behind the front window, without any other part of the chamber. Got perfect agreement with above formula.

stopping-power ratio

$$S_{t,a} = 1.110 \pm 0.6\%$$

- ISO uses a Bragg-Gray spr calculated by Bohm using measured spectra (in air) and ICRU Report 37 stopping powers
- issues - this spr should be:
  - for humid air to be consistent
  - for spectrum at depth of measurement in phantom
  - Spencer-Attix not Bragg-Gray since this is not an equilibrium situation

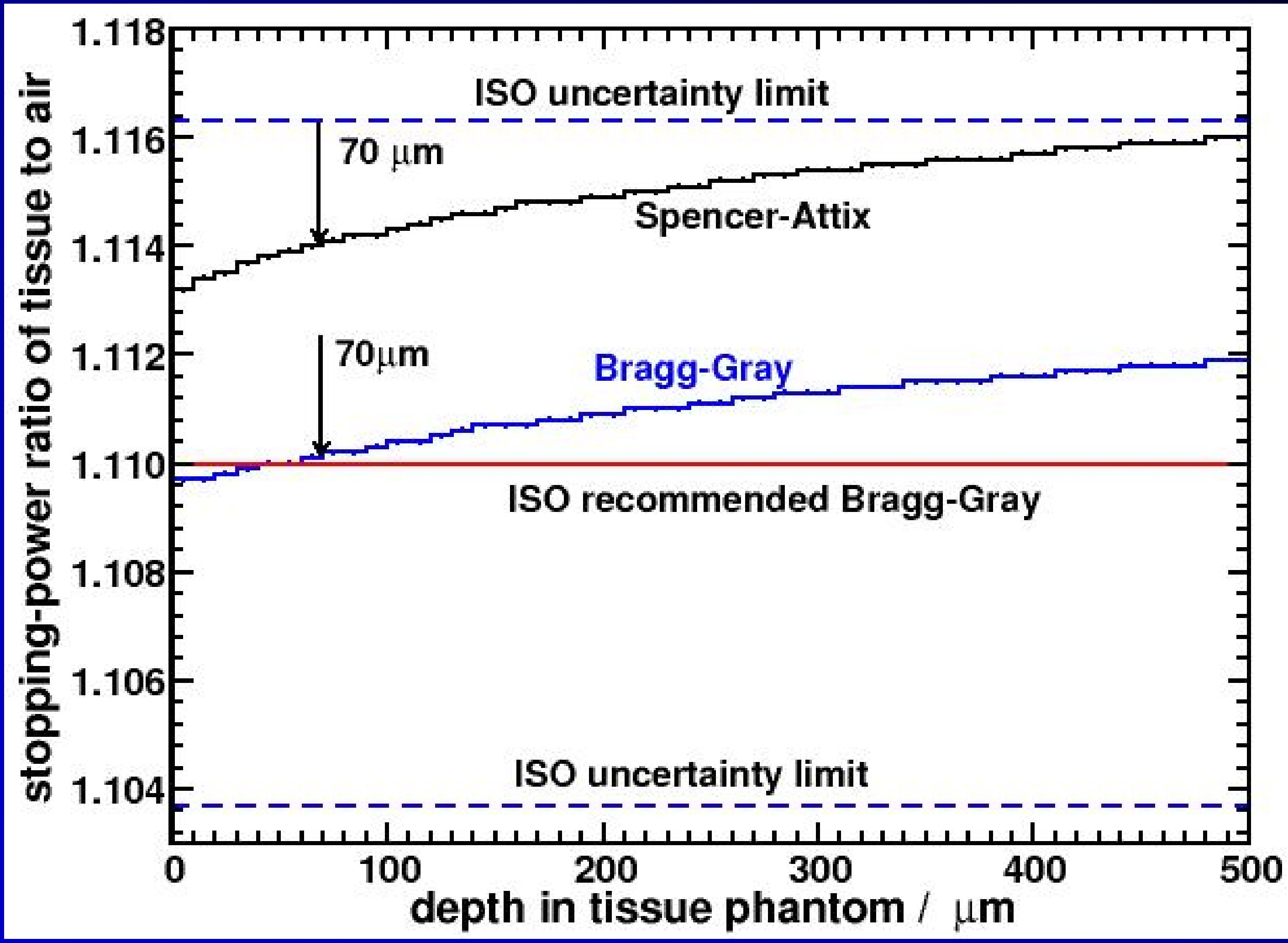
stopping-power ratio (Δ = 10 keV)

calculated with SPRRZnrc

-was used for TG-51 & TRS-398 electron beam sprs

-0.4% variation with cavity length via Δ dependence

(3 keV 1.1164
13 keV 1.1125)



Conceptual problem in the ISO approach

- cavity theory applies to cavities in a material
- as applied by ISO to beta standards, we are talking of a "cavity" on the surface
- why not apply standard Spencer-Attix cavity theory as done for all external beam radiotherapy protocols and ionometric standards for absorbed dose?

$$D_m(d) = D_a \left(\frac{\overline{L}}{\rho}(\Delta) \right)_a^m P_{\mathrm{repl}} P_{\mathrm{wall}}$$

$$D_a = \frac{k_h Q_{\mathrm{hum}} \left(\frac{W}{e} \right)_{\mathrm{air}}}{\rho_{\mathrm{air,o}} V}$$

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Spencer-Attix cavity theory

$$D_t(z) = D_a(z,l)\left(\frac{\overline{L}}{\rho}(z,\Delta)\right)_a^t P_{\mathrm{repl}}(z,l)P_{\mathrm{wall}}(z,l)$$

- P_{wall} corrects for walls not being tissue
- P_{repl} corrects for effects of the cavity on the electron spectrum
  - includes $k_{di}(l)$

    which is not used in external beam radiotherapy dosimetry

$$P_{\mathrm{repl}}(z,l) = P'_{\mathrm{repl}}(z,l)k_{di}(l)$$

Spencer-Attix cavity theory for beta standards

$$k'(z,l) = \left(\frac{\overline{L}}{\rho}(z,\Delta)\right)_a^t \times k_{di}(l) \times P'_{\mathrm{repl}}(z,l) \times P_{\mathrm{wall}}(z,l)$$

$$D_R(70\ \mu m) = T(z)D_t(z)$$

$$D_R(70\ \mu m) = \frac{k_h \times \left(\frac{W}{e}\right)_{\mathrm{air}} \times T(z)}{A \times \rho_0}\left(\frac{d}{dl}k'(z,l)I(z,l)\right)$$

- a measurement at any one cavity length gives the proper dose to tissue. No artificial cavity on the surface without walls

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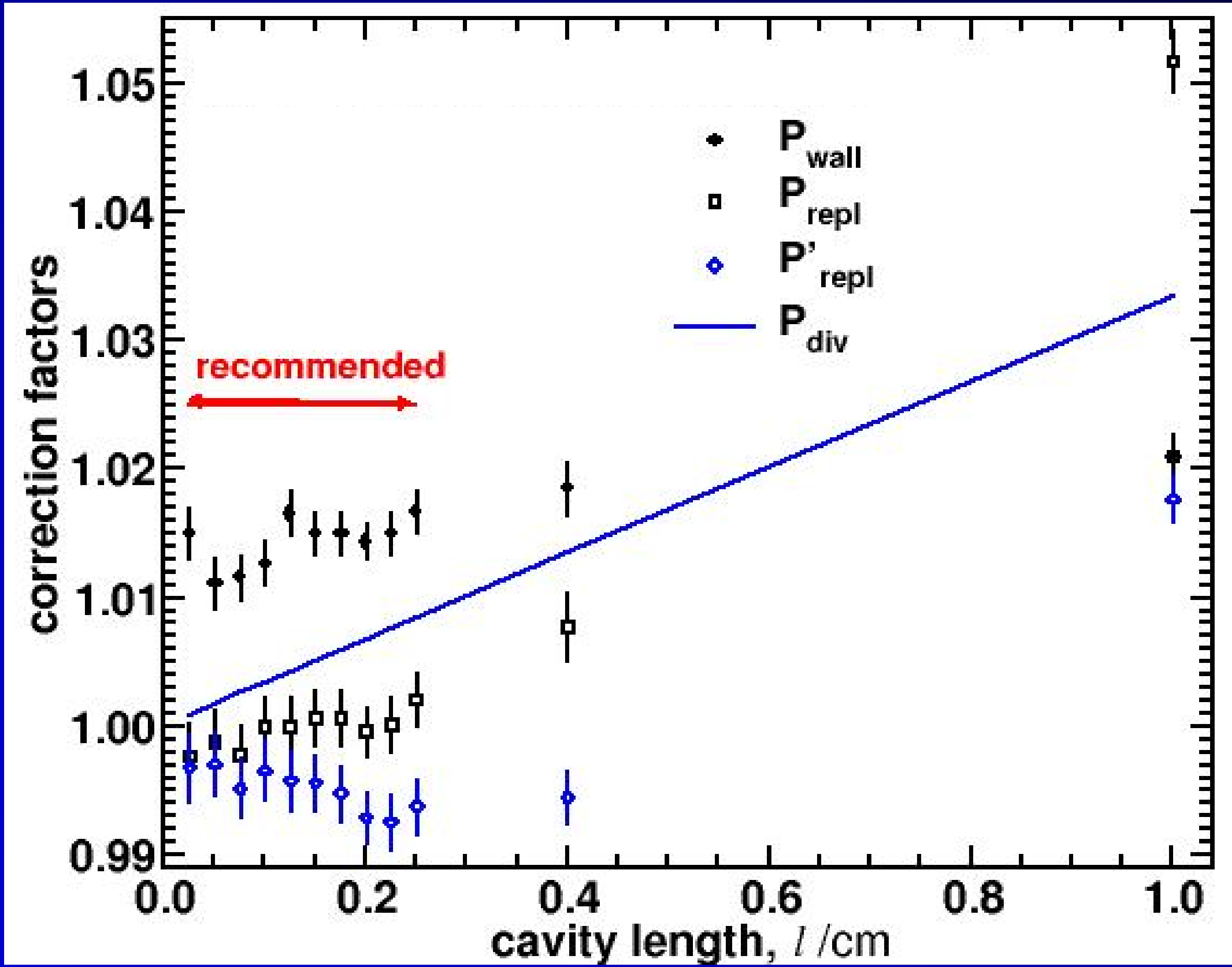
P_{wall} & P_{repl} corrections

- P_{wall} ratio of two Monte Carlo calculations, one with all tissue walls, second with realistic model of chamber
  - have published 4 papers using this technique for external beam chambers
  - basis of some values in protocols (TG51/TRS398)

- P_{repl} force eqn for dose to hold when calculate the dose at the appropriate depth in a phantom

P_{wall} & P_{repl} corrections: 6.25 μm window



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Testing the approaches with Monte Carlo

- calculate the dose to the tissue as well as the chamber response => we can check the overall approaches
- using simulated data as a function of cavity length and standard ISO approach we find a discrepancy of 2.2% (preliminary).
- using ISO approach but our MC -parameters
  - the discrepancy is reduced to 0.3%

Testing the approaches

- using our proposed approach
  - everything cavity length dependent (including spr)
    => agreement by definition of P_{repl}
- ignoring P'_{repl} => 0.8% accuracy
- further ignoring changes in spr => 1.0% accuracy
- taking all corrections as independent of cavity length except $k_{di}(l)$ - still within 1%.

Conclusions

- based on our (preliminary) results, the ISO approach is biased by about 2.2%.
  - MC corrections reduce this error considerably
  - still leaves conceptually awkward approach
- standard Spencer-Attix cavity theory approach is:
  - conceptually more rigorous
  - produces answers which are within 1% using approximations which make application easier

- should we abandon the extrapolation chamber?
  - greatly simplifies the analysis and instrumentation
  - requires accurate volume determination

Thank you