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Photon Beam and Electron Beam Dosimetry Using Calorimetry at ARPANSA

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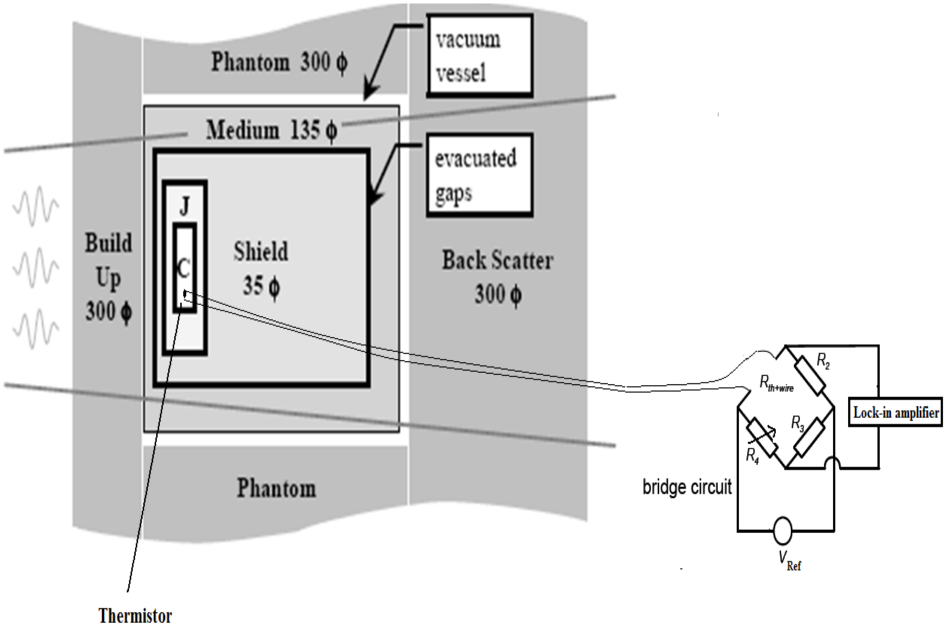
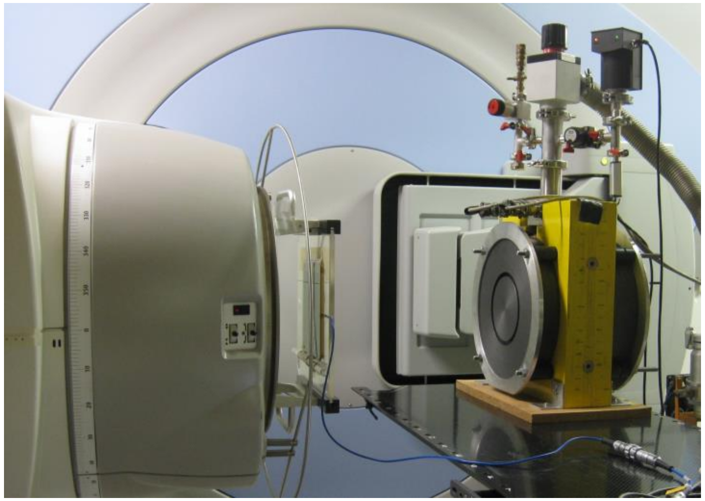
Outline:

- Description of the ARPANSA Photon calorimeter
- Establishment of the calorimeter as Australia's Primary Standard
- Direct calibration of therapy level dosimeters
- Electron calorimetry with graphite calorimeters
- Results of the absorbed dose to water calibration with Roos chamber
- Absolute x-ray dosimetry on a synchrotron medical beam line with a graphite calorimeter
- Conclusions

ARPANSA Photon Calorimeter





ARPANSA Graphite calorimeters:

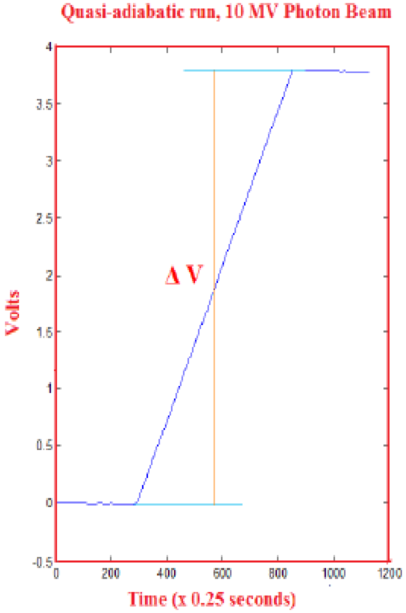
- A graphite calorimeter procured from BEV, Austria has been established as primary standard at the newly (2010) installed ^{60}Co and Linac (2009) photon energies

- A similar calorimeter loaned by IAEA has been compared giving good agreement in measurements with a ^{60}Co source at ARPANSA[2].

Calorimetry Measurements

Calorimetry Measurements:

Quasi-adiabatic measurements:



$$D_g = (\Delta V * C_{VM} * C_E / m_c) * \Pi k_i$$

D_g = Dose to graphite

ΔV = Voltage rise due to heat

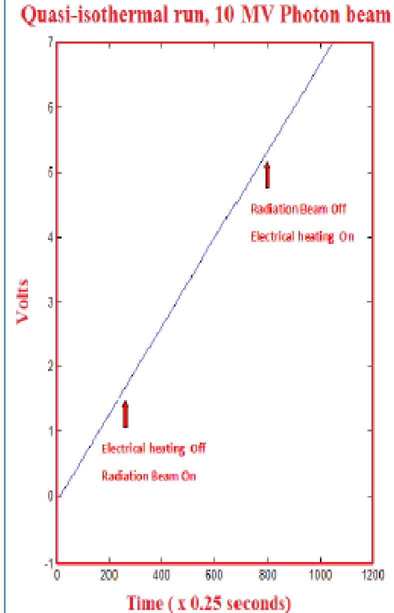
C_{VM} = Voltmeter calibration factor

C_E = Electrical calibration factor

m_c = Buoyancy corrected core mass

Πk_i = Product of correction factors

Quasi-isothermal measurements



$$D_g = (E_e * t_R / m_c) * \Pi k_i$$

D_g = Dose to graphite

E_e = Electrical Energy

t_R = Radiation runtime

m_c = buoyancy corrected core mass

Πk_i = product of correction factors

- **Elekta Synergy Linear Accelerator providing 7 photon energies from 4 MV to 25 MV and 10 electron energies from 4 MeV to 22 MeV .**
- **Calorimetry measurements of the photon beams of 6 MV, 10 MV and 18 MV to establish the Australian Primary standard of absorbed dose.**
- **Measurements validated in intercomparisons with BIPM, NPL and NMIJ**

Direct Megavoltage calibrations

Steps in the procedure

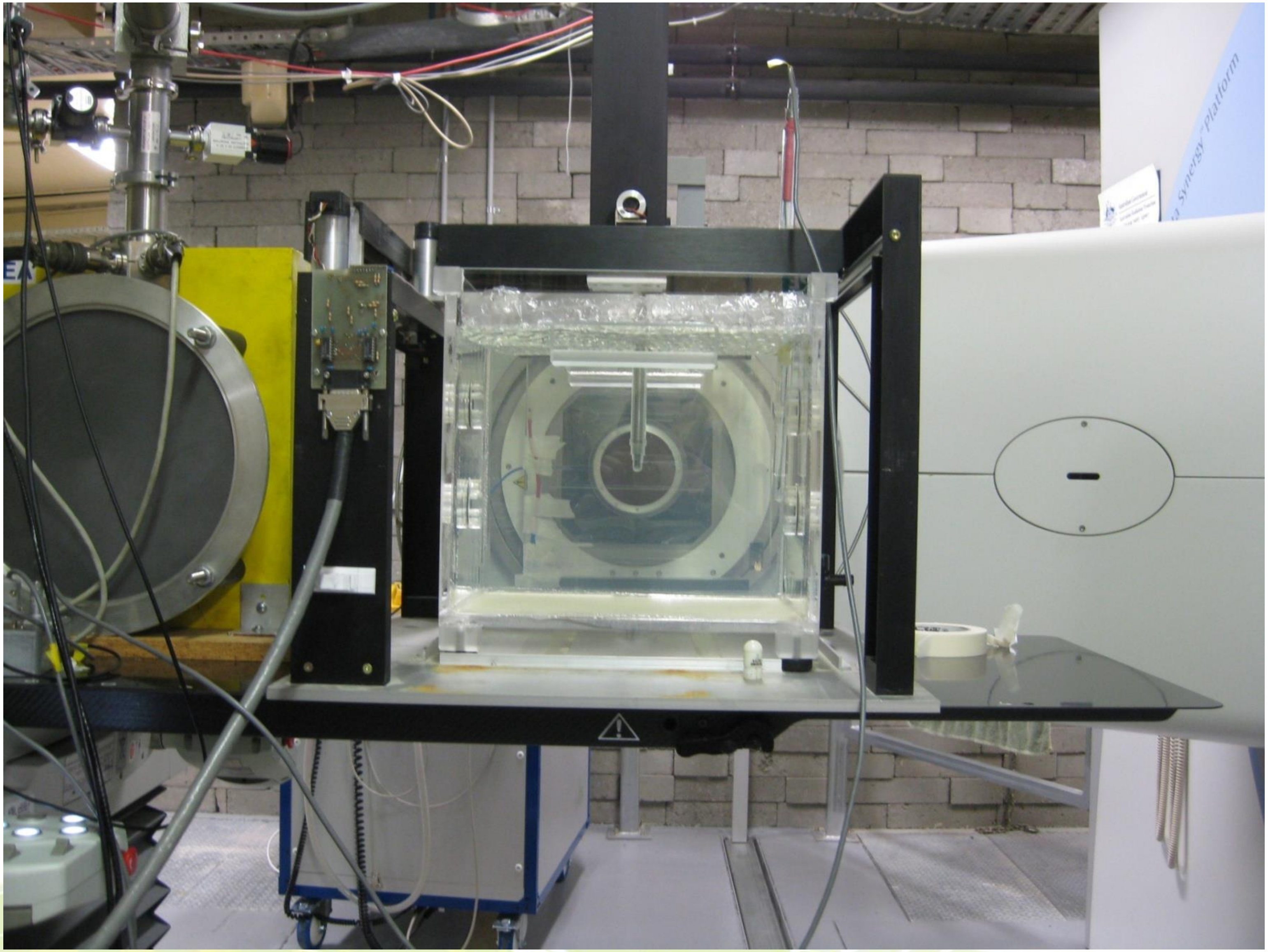
Calorimetry measurements and conversion of dose to water from dose to graphite

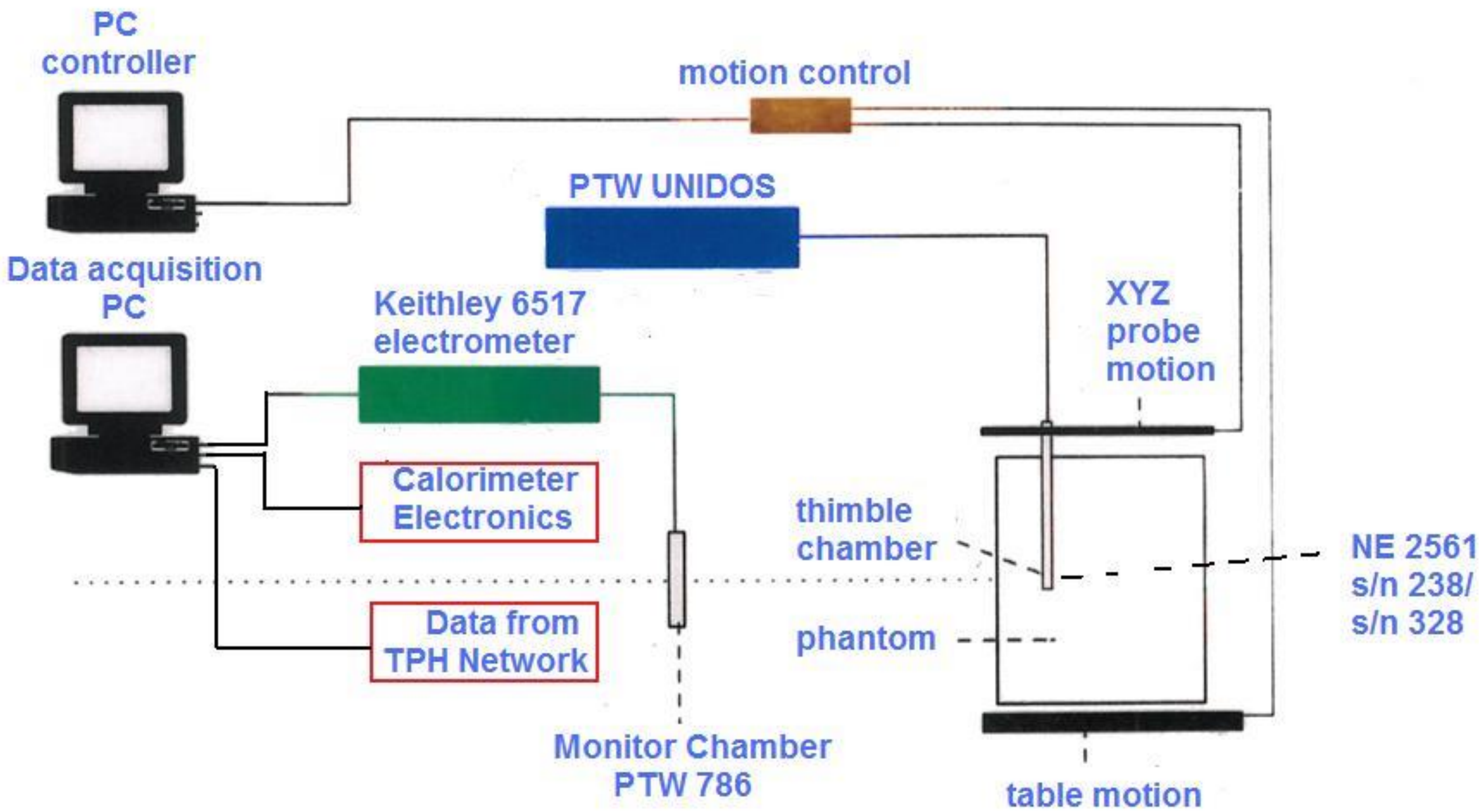
↓

Calibration of reference chamber in water phantom in terms of absorbed dose to water

↓

Calibration of user chamber against the reference chamber





Data Acquisition & control

Electron calorimetry with ARPANSA calorimeter

Methodology

1. Define reference depth in water for electron beams from Elekta Synergy Linac

$$Z_{ref,\,w} = 0.6 * R_{50,w} - 0.1\ \text{cm}$$

2. Use range scaling to get depth in graphite

$$Z_{ref,\,g} = Z_{ref,\,w} * R_{50,\,g} / R_{50,\,w}$$

3. Calibrate reference chamber in graphite against the calorimeter

$$N_{D,ref,\,g} = D_g / M_{ref,\,g}$$

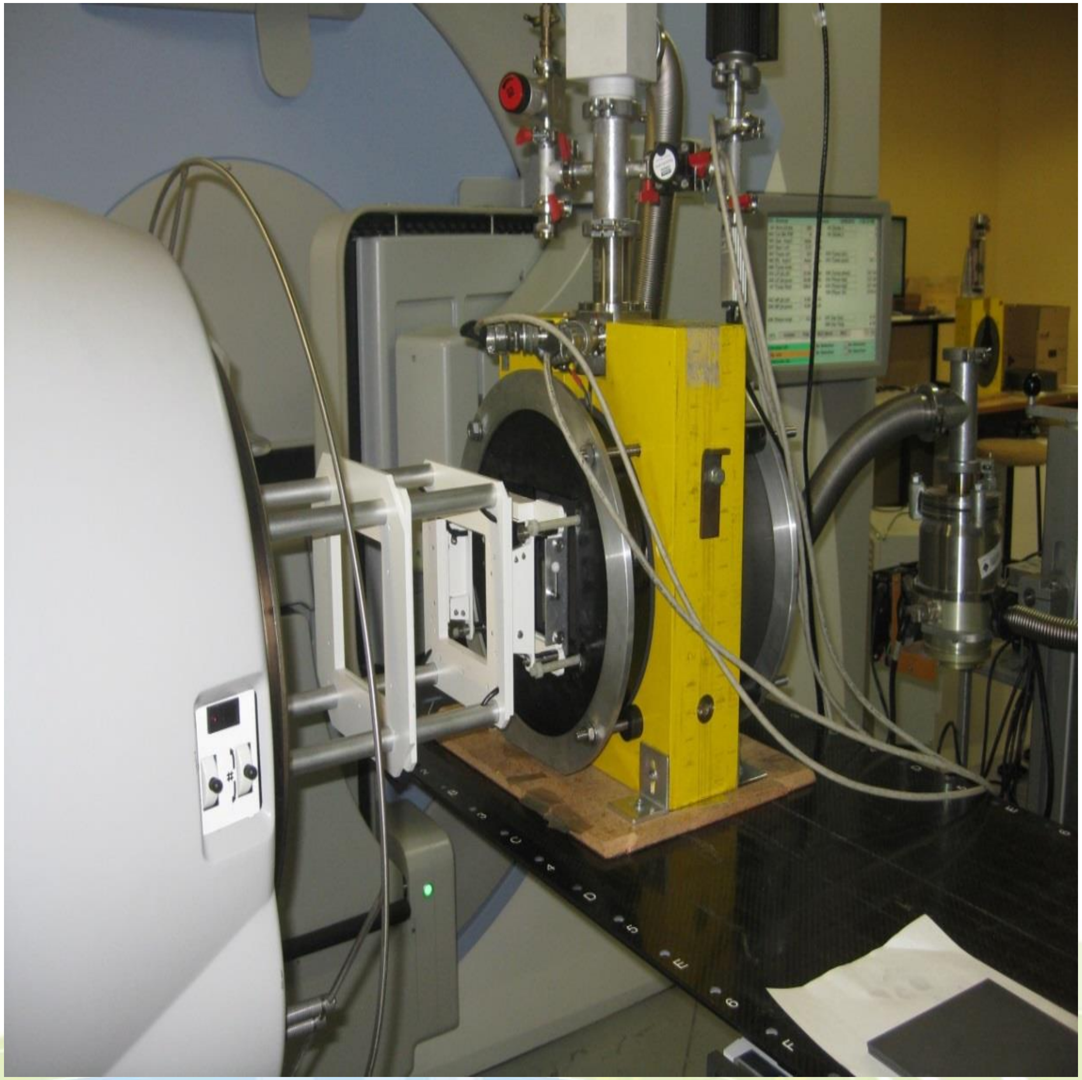
4. Theoretical conversion from graphite dose to water absorbed dose

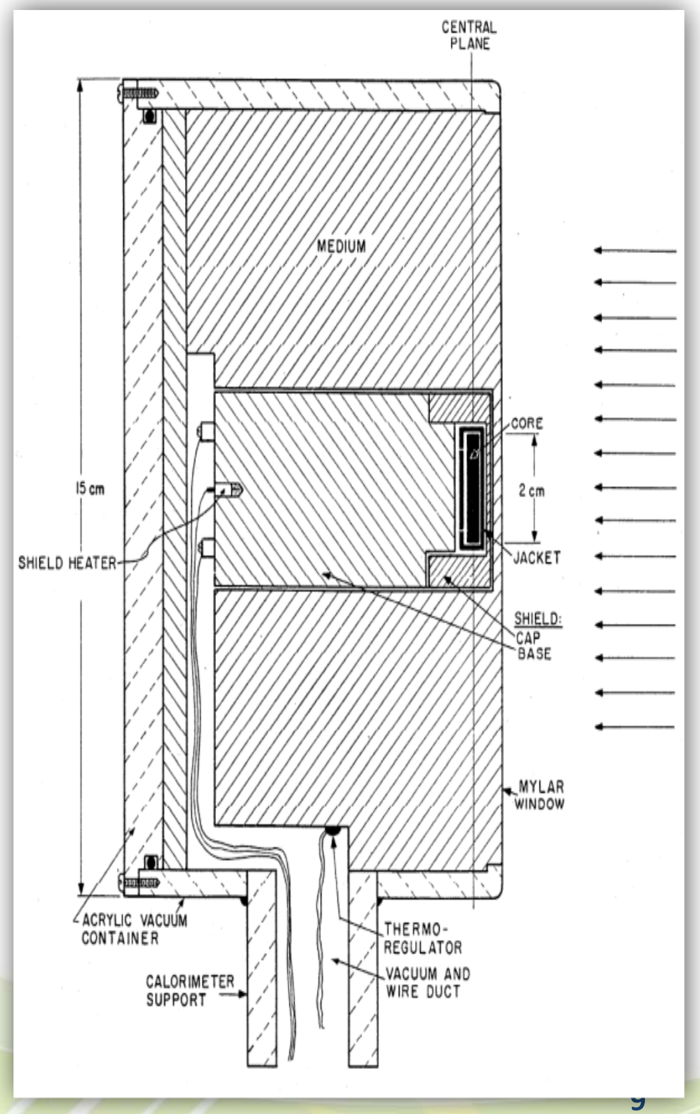
$$N_{D,ref,\,w} = N_{D,ref,\,g} * p_{ref,\,w} / p_{ref,\,g} * S_{w/air} / S_{g/air}$$

5. The absorbed dose to water calibration factor for a user chamber is

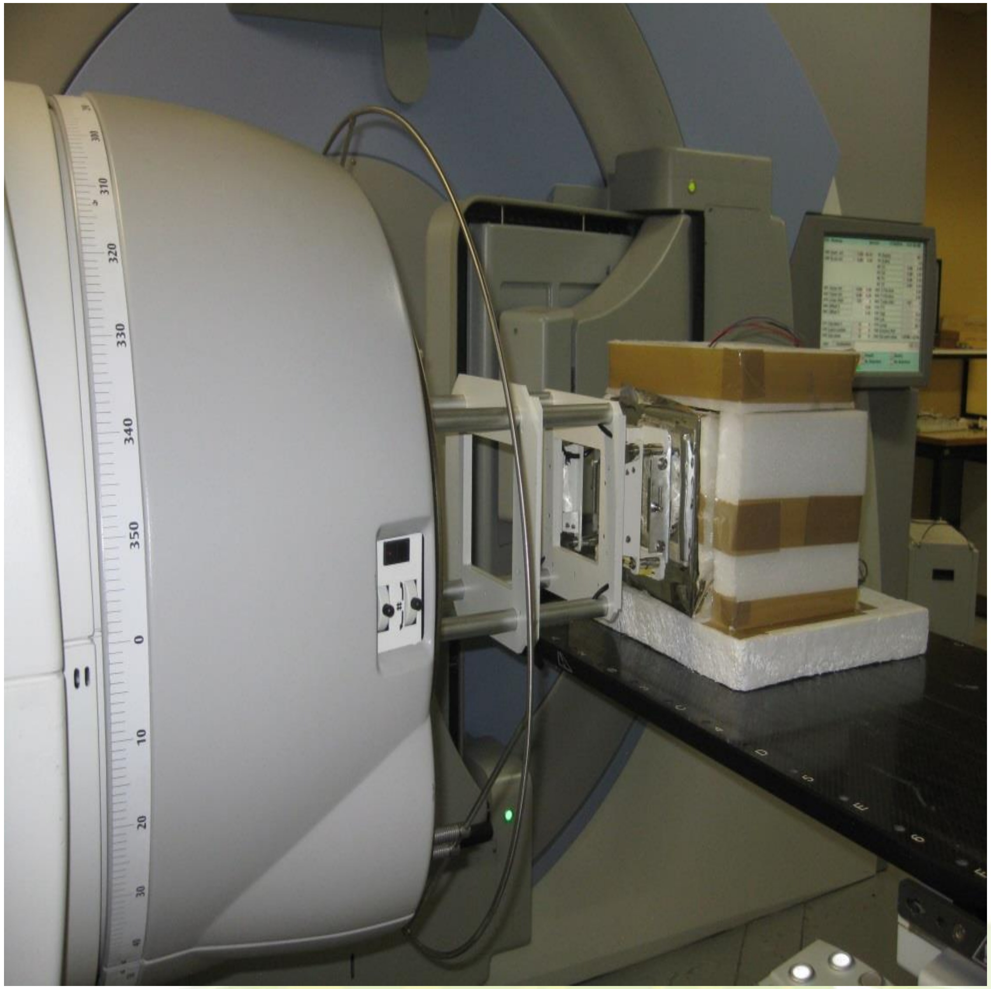
$$N_{D,ref,\,w} = N_{D,ref,\,w} * M_{ref,\,w} / M_{user,\,w}$$

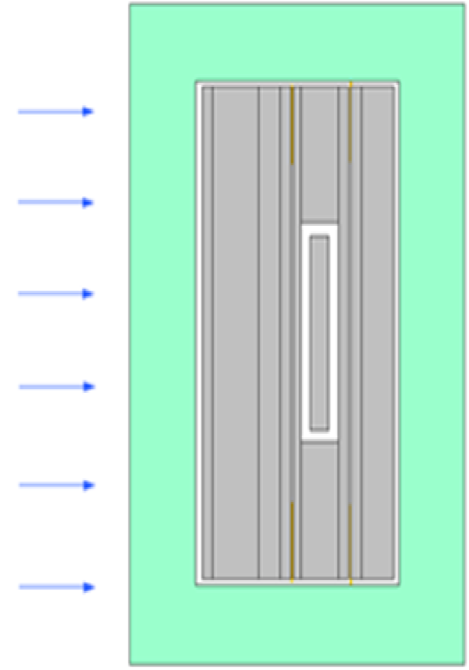
Electron calorimetry with ARPANSA calorimeter





Electron calorimeter procured from NPL, U.K





Absorber: 2mm thick, 4 cm diameter graphite disc

10 kilo ohms thermistors embedded within disc to measure temperature

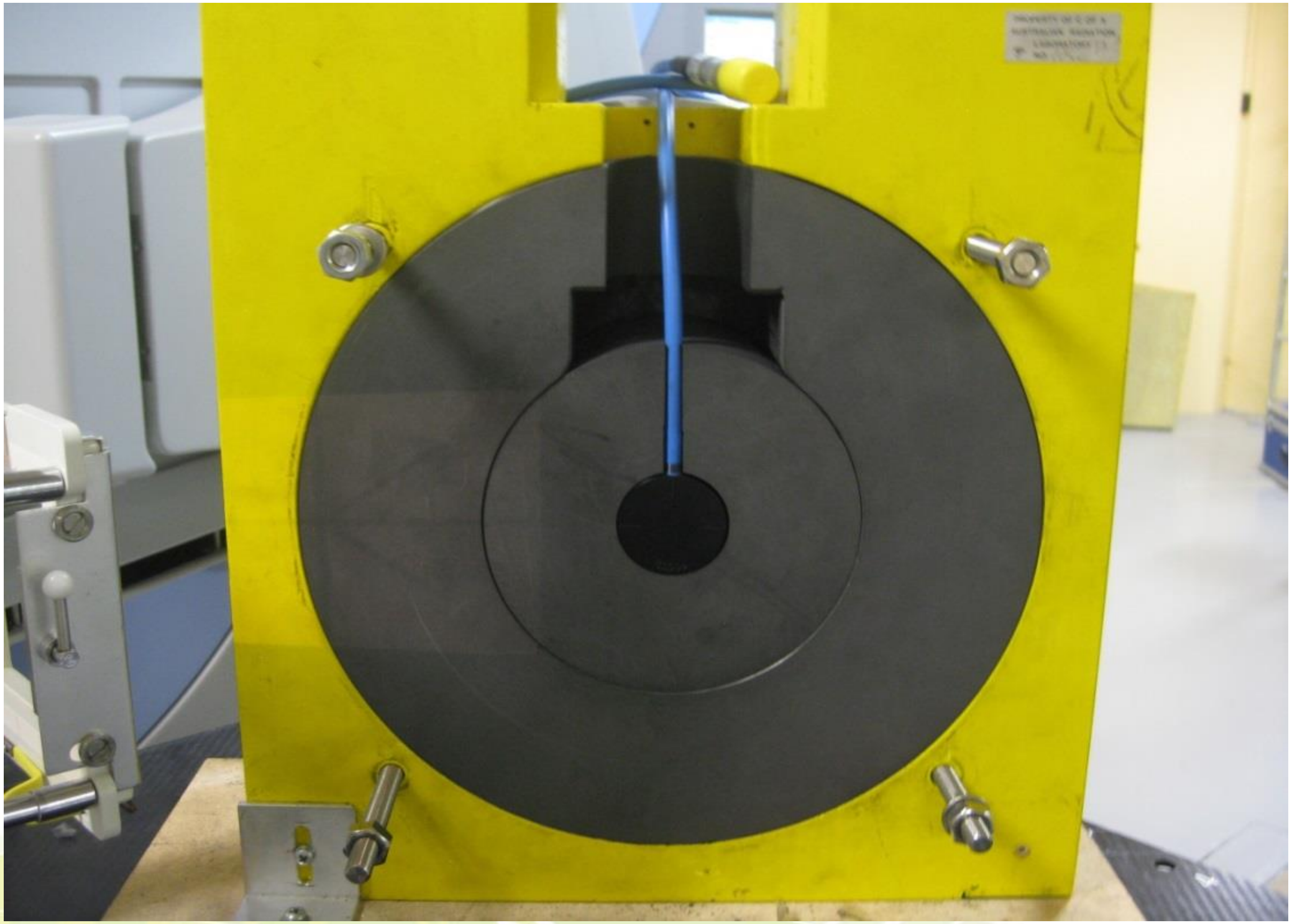
Thermistors calibrated in Hart water bath against PRT

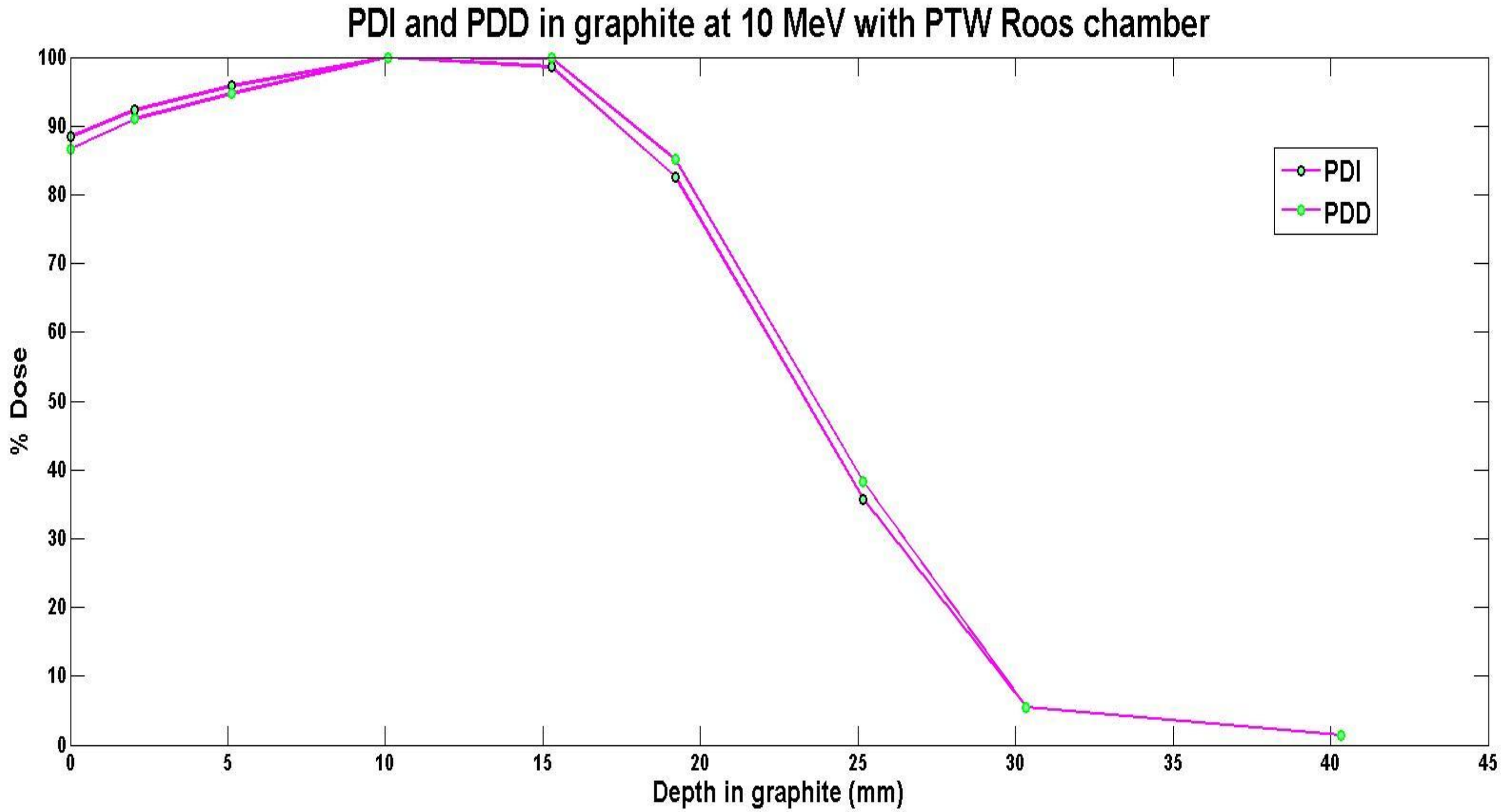
Graphite absorbed dose measured with the two calorimeters

Calorimeter	10 MeV		15 MeV	
Mode	Adiabatic	Isothermal	Adiabatic	Isothermal
ARPANSA calorimeter	27.80 mGy/sec	27.42 mGy/sec	28.09 mGy/sec	27.95 mGy/sec
NPL calorimeter	28.41 mGy/sec		28.42 mGy/sec	

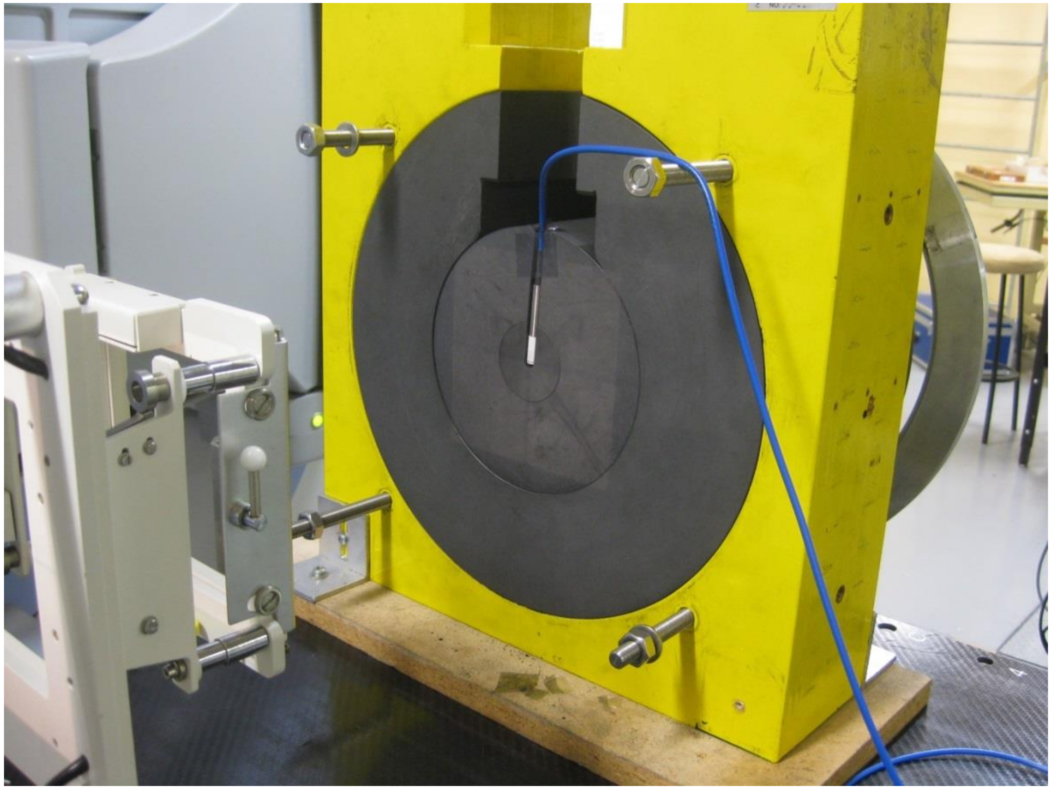
Note:
1. These are raw outputs and no correction factors applied
2. All the measurements have been done at 200 MU/min for a total of 400 MU
3. Same build-up plates were used with both calorimeters
4. ARPANSA calorimeter runs have ~0.1% ESDM
5. NPL calorimeter runs have ~0.2-0.4% ESDM

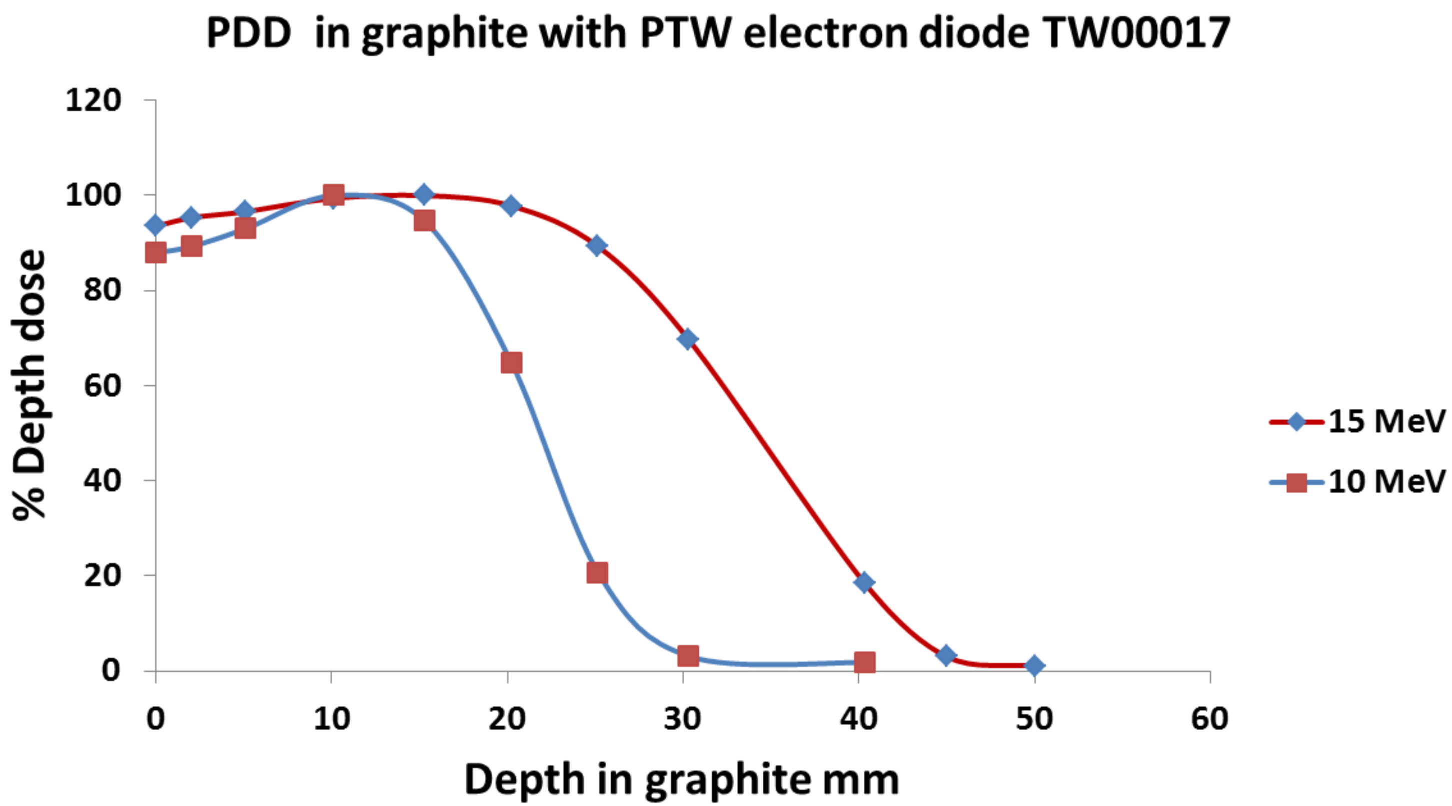
Roos chamber in graphite phantom




PDI and PDD in graphite at 10 MeV with PTW Roos chamber
% Dose
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
35
40
45
Depth in graphite (mm)
PDI
PDD

PTW electron diode in graphite phantom

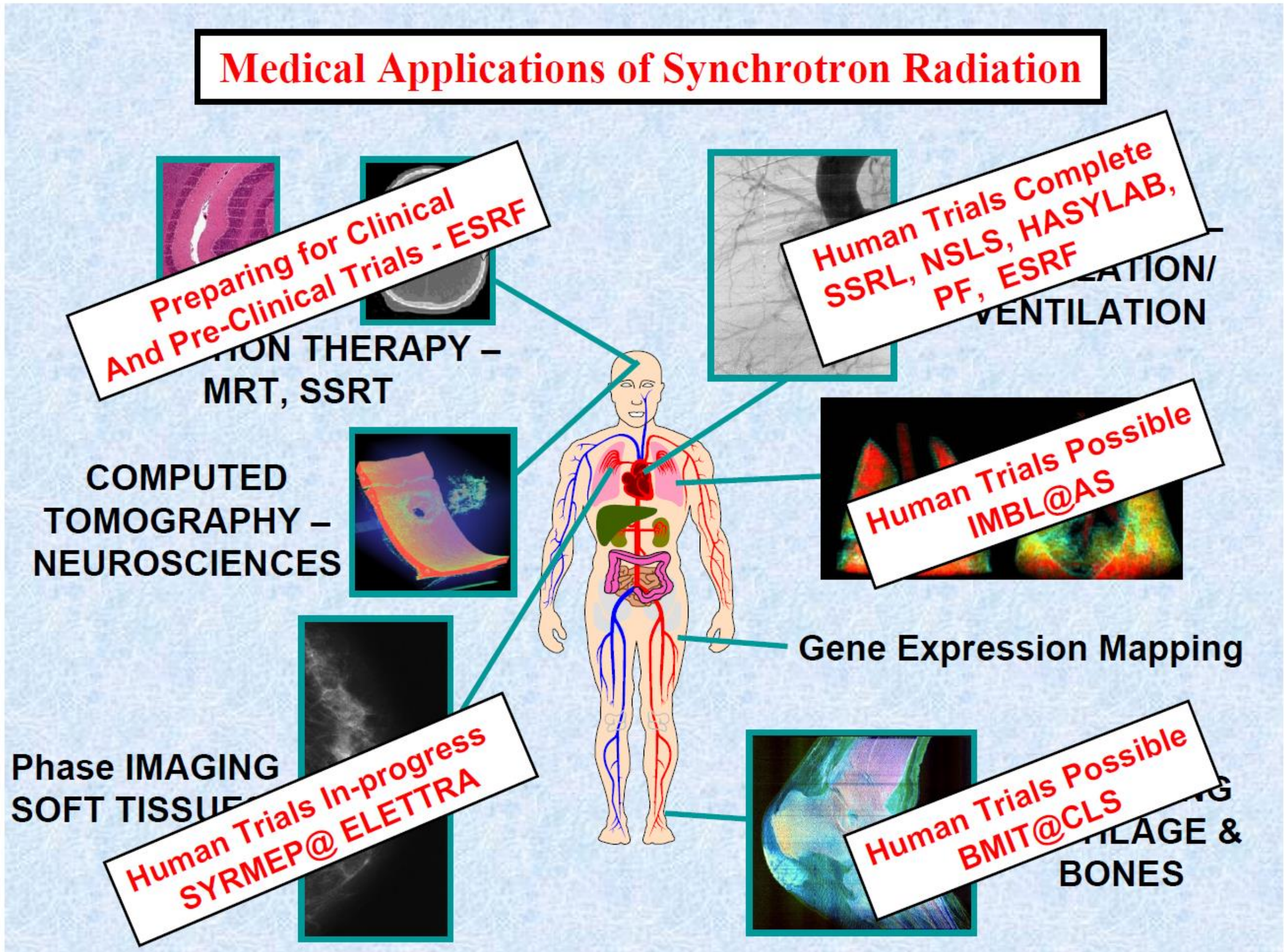


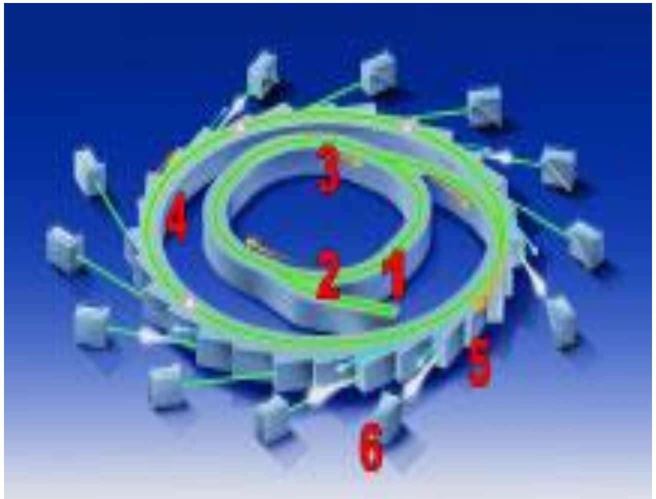

PDD in graphite with PTW electron diode TW00017
% Depth dose
120
100
80
60
40
20
0
0
10
20
30
40
50
60
Depth in graphite mm
15 MeV
10 MeV

Comparison of the absorbed dose to water calibration factors

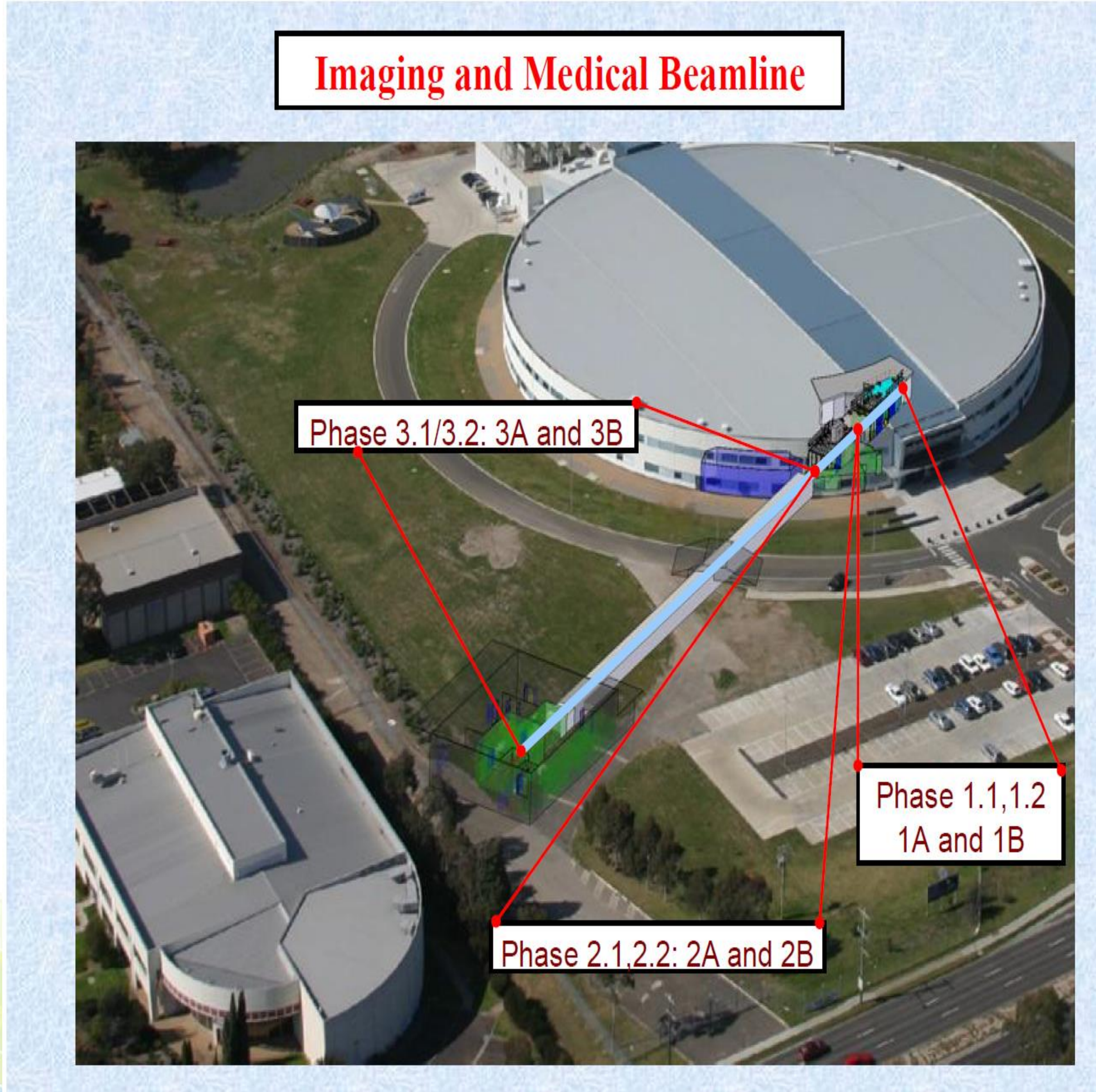
Electron energy	NPL Calibration (Gy/C x 10^7)	ARPANSA Cross-calibration (Gy/C x 10^7)	% Diff	Calorimetry Based calibration (Gy/C x 10^7)	% Diff
10 MeV	7.91	7.81	-1.4	8.0	1.0
15 MeV	7.76	7.65	-1.4	7.69	-0.9

Absolute dosimetry using a Graphite Calorimeter on a Synchrotron Medical Beam Line





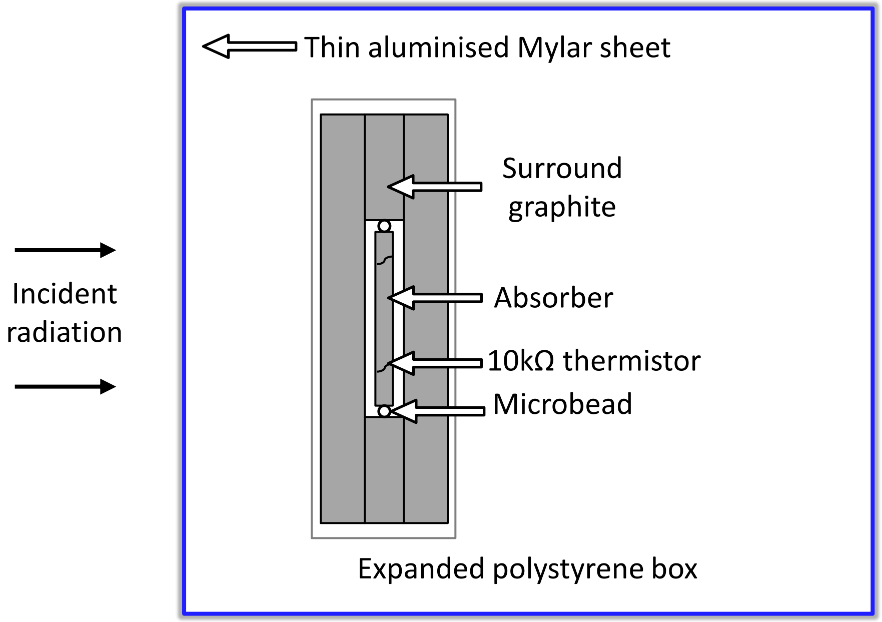
Hutch	Distance from source (m)
1B	22
2B	34
3B	138



Dose Rate and Field Size from IMBL compared to a clinical linear accelerator

X-ray source	Dose Rate (Gy/sec)	Typical Field Size	Typical Energy
Clinical linear accelerator	0.07	10 cm x 10 cm	6 MV
Australian synchrotron IMBL Hutch 3B	50	4 mm x 4mm	80 keV
Australian synchrotron IMBL Hutch 1B	3000	1 mm x 1 mm	80 keV

Graphite Calorimeter

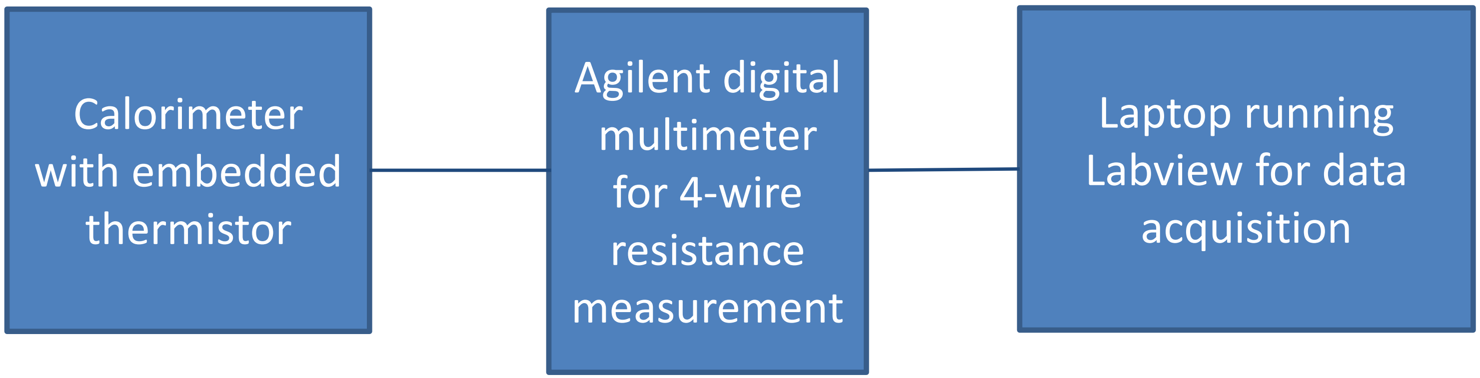


- The temperature is measured by a 10kΩ thermistor embedded in the core.
- The calorimeter is insulated from ambient air temperature changes by an expanded polystyrene box.

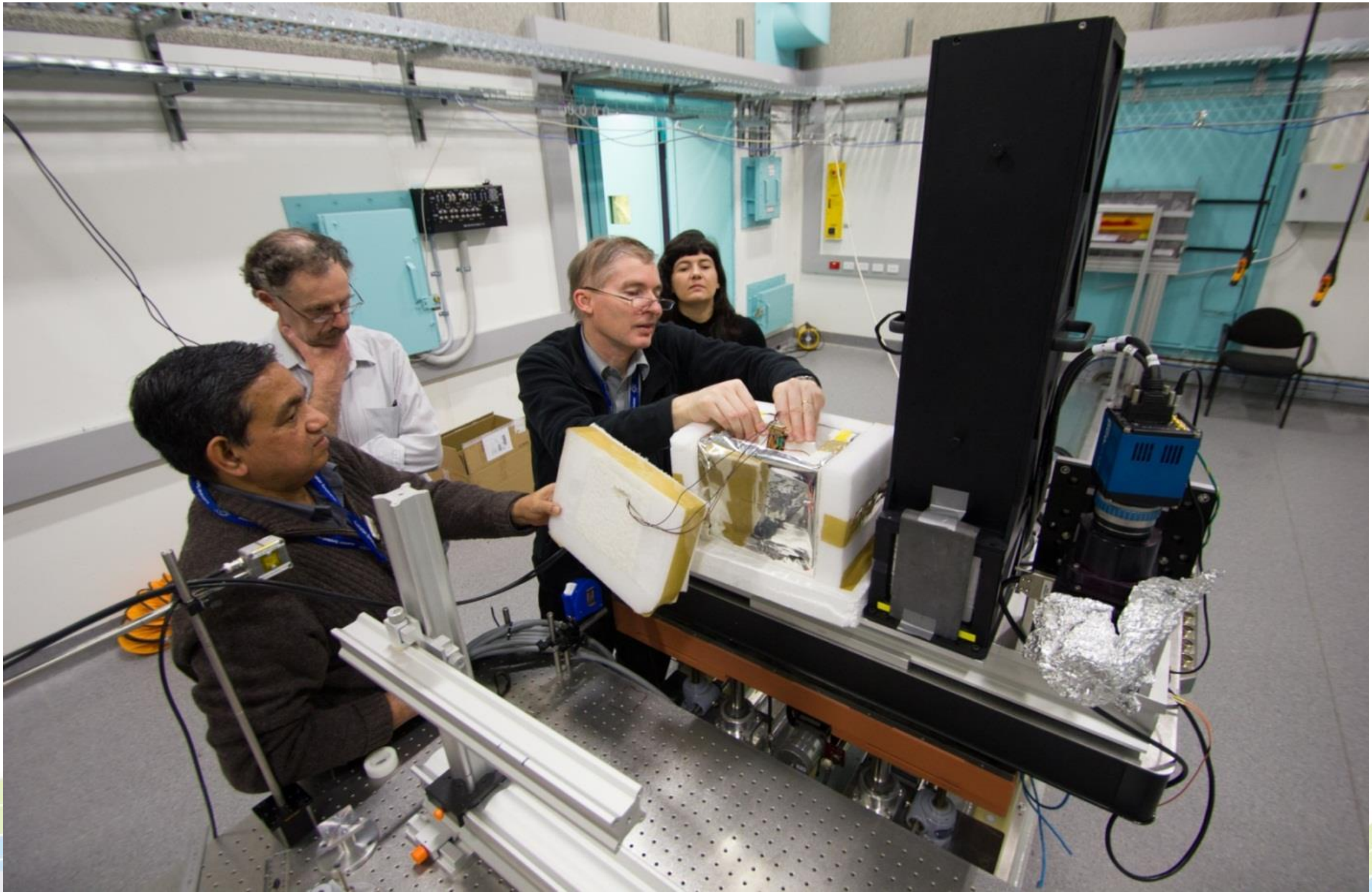
Temperature calibration in Hart Bath

- The thermistor in the calorimeter was calibrated against a platinum resistance thermometer immersed in a Hart Bath.
- Calibration was from 20-30° C.

Circuit for temperature measurement



Putting the graphite calorimeter into place

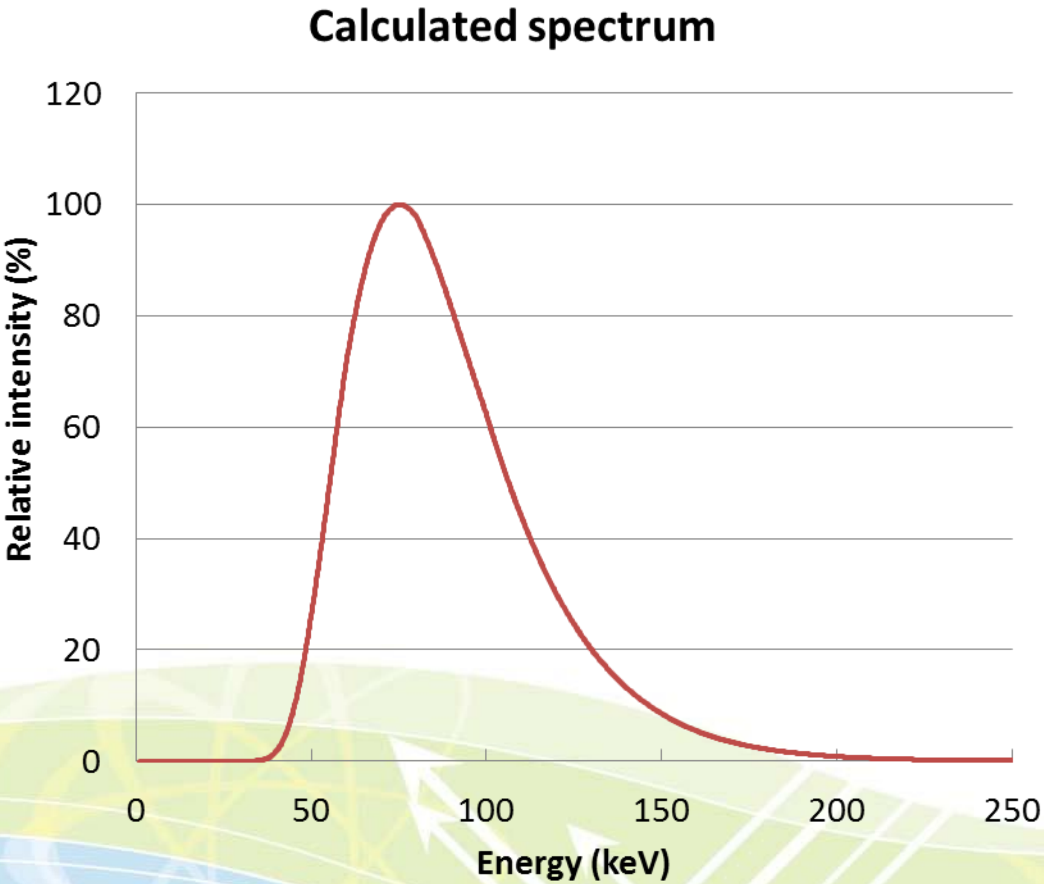


Filtration of Synchrotron Beam

Absorbing material	Filtration Set 1
Graphite	15 mm (at 45°)
Cu	1 mm (at 45°)
Al	1.5 mm (at 45°)
Al foil	0.038 mm
Be	0.35 mm
He	68 mm
air	1 m

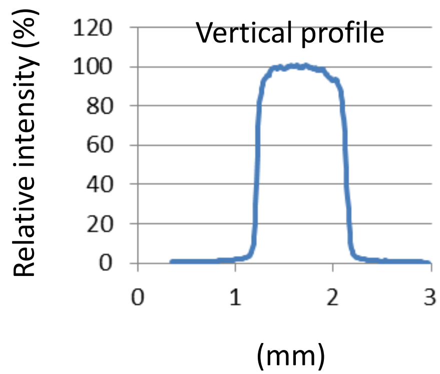
Calculated energy spectrum

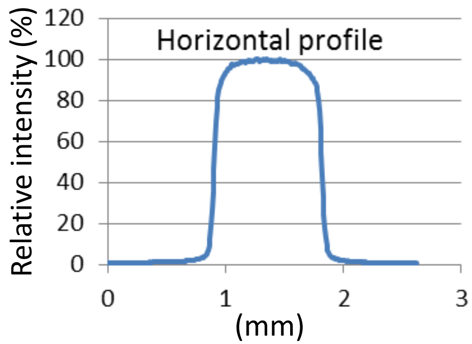
- The energy spectrum as calculated using the SPECTRA program (Version 9.0) (T. Tanaka and H. Kitamura, “SPECTRA: A synchrotron radiation calculation code,” J. Synchrotron Radiation **8**, 1221-1228 (2001).



Beam size

Film





- The beam size from IMBL recorded using HD-810 radiochromic film
- Films scanned using high resolution EPSON V700 desktop scanner to create horizontal and vertical profiles.
- Beam size in this case measured as 0.908 mm x 0.913 mm (H x V) = 0.829 mm^2.

Evaluation of dose by temperature rise

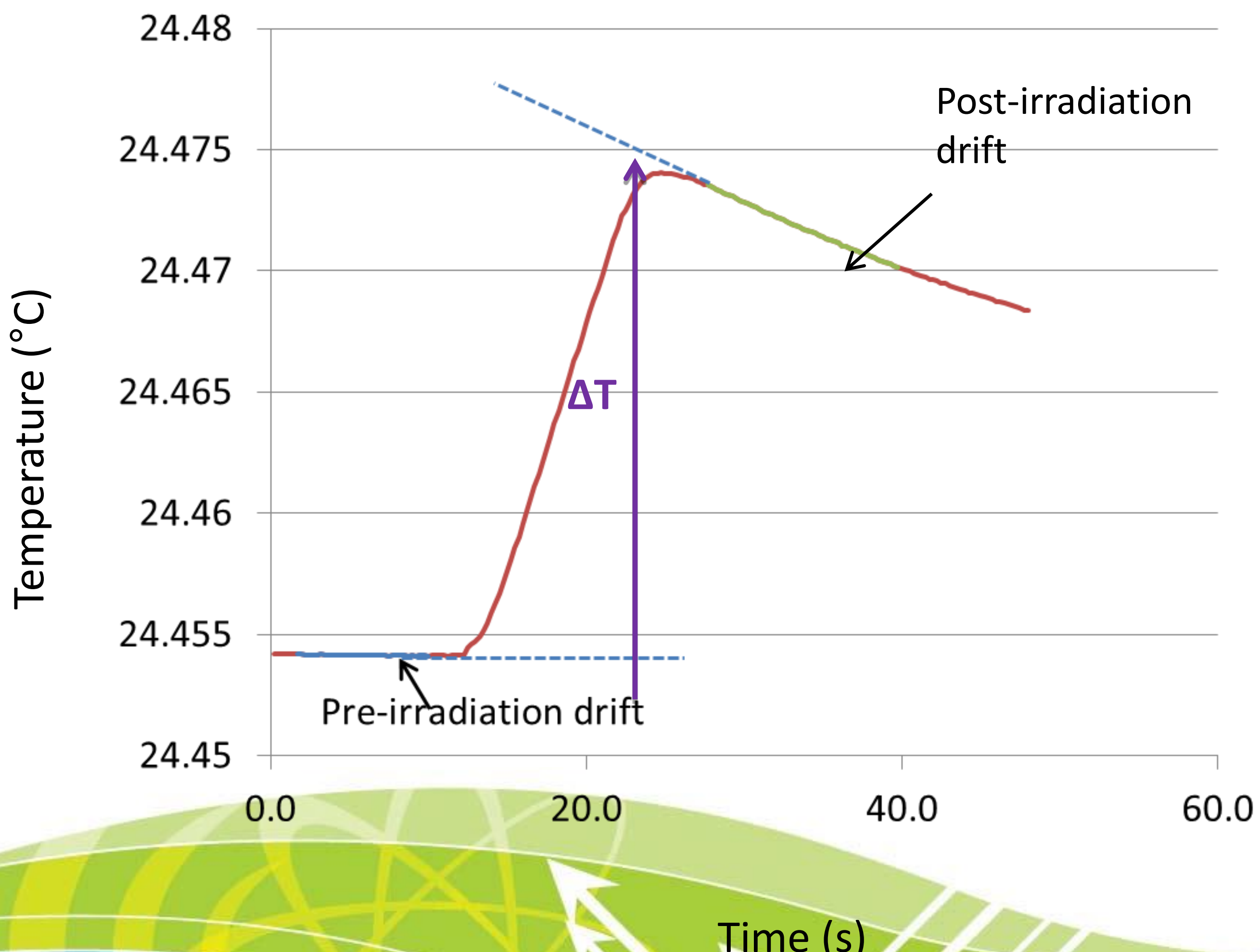


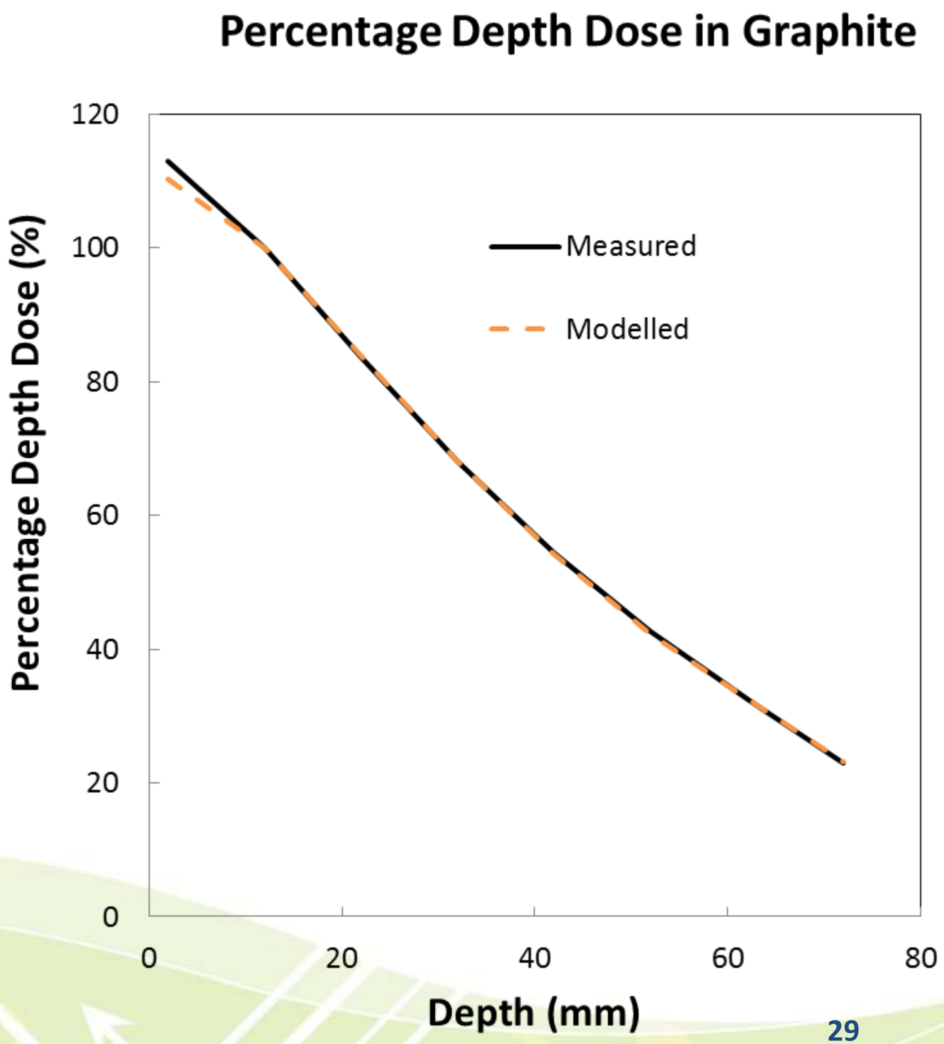
Table 2 Absorbed dose to graphite rate determined for three field sizes in Hutch 1B (November 2013)

	Field size – corrected FWHM (mm × mm)	Calorimeter Dose rate to water at surface (kGy/s)
Film 1	0.383 × 0.907	2.79
Film 2	0.908 × 0.913	2.76
Film 3	1.944 × 0.913	2.82

Standard deviation = 1.2%

Dose at Depth (Hutch 1B) November 2013

Calorimeter measurements were made with thicknesses of graphite in front of the core, to give depths from 2 – 72 mm in 10 mm steps.



A modelled percentage depth dose (PDD) in water is shown for comparison for a 0.9 mm x 0.9 mm synchrotron beam with filtration set 1.

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Measurements in all hutches

Recent dose rate measurements with the calorimeter have also been made in hutch 2B, which sits in between hutch 1B and 3B. The result is shown below for a similar filter combination in all 3 hutches.

Hutch	Distance from source (m)	Beam size used (mm x mm)	Dose to graphite measured (Gy/s)
1B (Nov 2013)	22	1 x 1	2000
2B (Sep 2014)	34	2 x 2	577
3B (July 2013)	138	4 x 4	32

Summary and Conclusions

- The outputs of Elekta Linac at photon energies of 6 MV,10 MV and 18 MV have been standardized with ARPANSA graphite calorimeter and validated through BIPM-RI-K6 intercomparison.
- The output of newly installed Co-60 was also standardized with the ARPANSA graphite calorimeter and validated through intercomparison with BIPM.
- Intercomparisons done with NPL UK, NMIJ Japan and NRC Canada have given good agreements.
- The combined uncertainties in direct calibration of ionization chambers against the calorimeter for photons is estimated as 0.58% at 2σ level which is a significant improvement over the method of using the published *kQ* values
- Preliminary electron calorimetry measurements with ARPANSA calorimeter and a graphite calorimeter procured from NPL UK have given encouraging results.
- Absolute measurements of the IMBL dose rate in Hutch 1B, 2B and 3B of Australian Synchrotron were performed with a graphite calorimeter and measured beam dose rates & theoretical calculations agree within uncertainties.