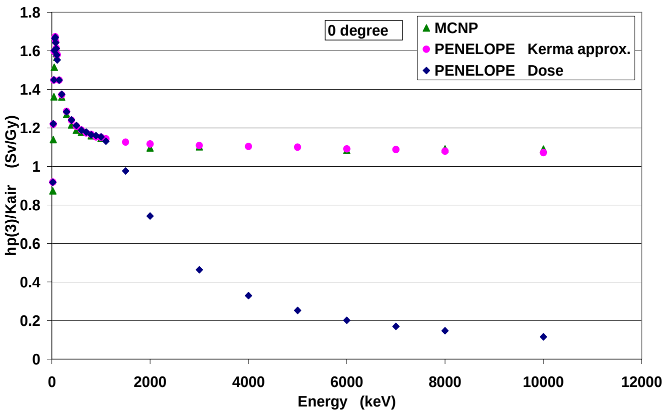
LNE-LNHB Highlights 2009-2010

1. Dosimetric references for X-rays used in interventional radiology/cardiology (ORAMED)

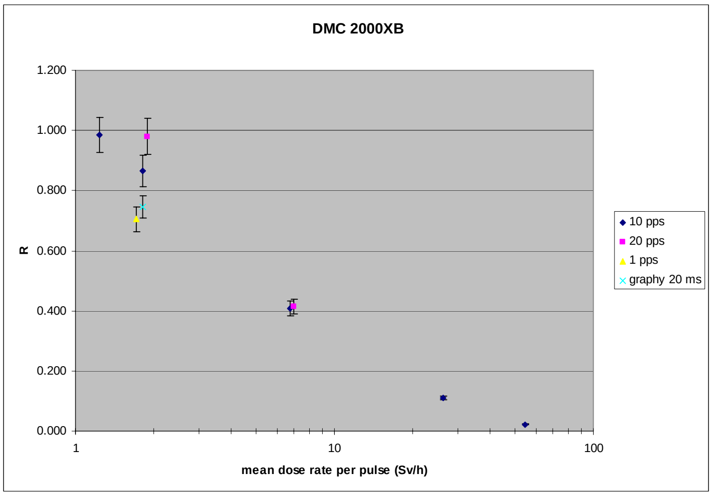
This study is part of the European project ORAMED. LNE-LNHB had to develop new radioprotection references for interventional radiology/cardiology.

For eye-lens dosimetry, a specific ICRU tissue phantom has been proposed and designed in collaboration with ENEA (Italy). It's a cylindrical phantom with a diameter and a height of 20 cm. Monte-Carlo calculations of $H_p(3)/K_{air}$ have been done with PENELOPE And MCNP (LNE-LNHB) and MCNP (ENEA). Two sets of conversion coefficient from air kerma do dose equivalent at 3 mm depth has been calculated with and without taking into account the electron transport. The results show that for energies higher than 1 MeV, discrepancies up to 80% can be found. Calculations have been done for 30 energies and 15 incident angles (CEA-R-6235 (2009) "Conversion coefficients from air kerma to personal dose equivalent $H_p(3)$ for eye-lens dosimetry"). An extract of the CEA report is shown in the following graph.



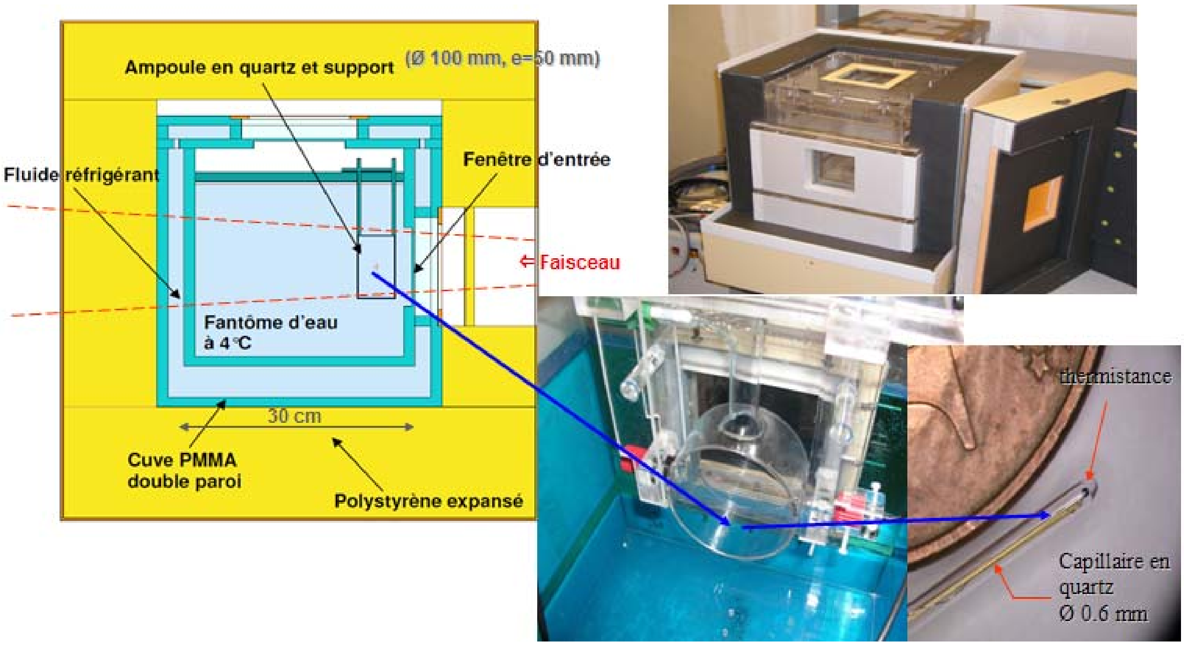
$H_p(3)/K_{air}$ at 0°

Some Active Operational Dosimeters have been checked in a pulsed X-ray beam produced by the multi-pulse PHASIX 80 X-ray generator of LNE-LNHB (CEA-R-6233 (2009)). The selected beam was: 70 kV with 4.5 mm Al + 0.2 mm Cu. The responses of two dosimeters for seven different commercially available types (MGP Instruments DMC 2000; Atomtex AT3509C; Siemens EPD MK 2.3; Polimaster PM1621A; Rados DIS-1; Panasonic EDM III; Unfors EDD30) have been checked in terms of dose-rate and beam frequency. The graph below (for DMC 2000) presents typical results for silicon detectors: strong decrease of the signal in function of the dose-rate per pulse. The POLIMASTER PM 1621A had a null response for pulsed beams (Geiger-Müller). Only the DIS-100 of RADOS (silicon detector and ionization chamber hybrid) had an almost constant response but shows also high measurement standard uncertainties. It is important to add tests in pulse mode in Type-Test of APDs in IEC 61526.



Typical results for silicon detectors: strong decrease of the signal in function of the dose-rate per pulse

2. Measurements in ^{60}Co with the new water calorimeter



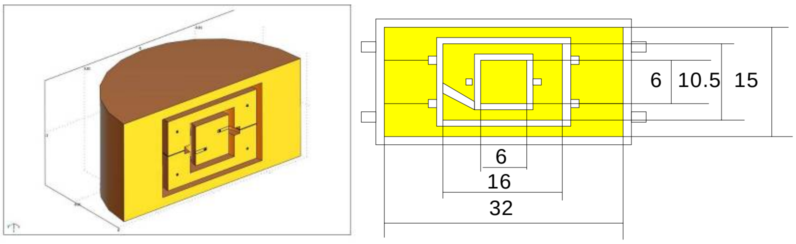
LNE-LNHB water calorimeter

The water in the inner vial is saturated in nitrogen. Measurements in a ^{60}Co source have been done in 2009. With 420 measurements, the standard uncertainty on the absorbed dose to water is 0.49% (0.07% due to the measurements). The two main uncertainty sources are related to the temperature probe position (0.3%) and to the heat defect (impurities on glass wall, in nitrogen, air going inside during the water filling, imperfect sealing caps … 0.3%). The present reference of absorbed dose to water based on graphite calorimetry and the one determined from water calorimetry differ by less than 0.1%. The new water calorimeter is planned to be used for other beams (high-energy X-rays and e^- beams) in the future.

3. Building of a small graphite calorimeter (JRP7)

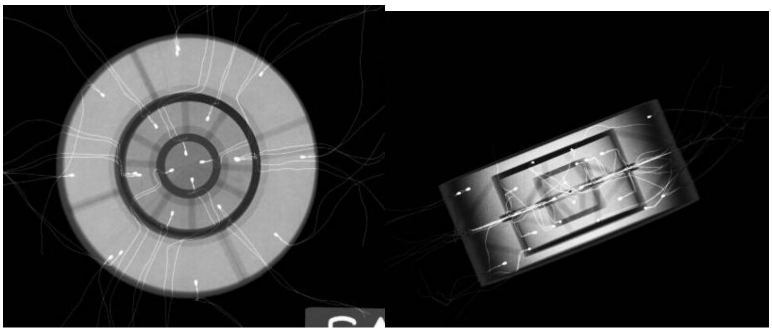
This study is part of the European metrology project JRP7 “External Beam Cancer Therapy”. The purpose of the 2011 experiments is to determine the absorbed dose to water in the 2 x 2 cm^2 fields for the 6 and 12 MV beams as well as the 6 MV beam without flattening filters.

For this, a new graphite calorimeter with a smaller core diameter had to be designed and built. GR10 looks like the previous graphite calorimeters except for the size of the different elements.



Drawings of GR10 (lengths in mm)

The core mass is only a third of the previous calorimeter core. Kapton pipes were used instead of silk wires to suspend the core and the number of heating thermistors has been reduced (2 instead of 4) in order to keep the mass of impurities low. The fresh memory of the GR9 building allowed to design and to build this calorimeter in less than one year.



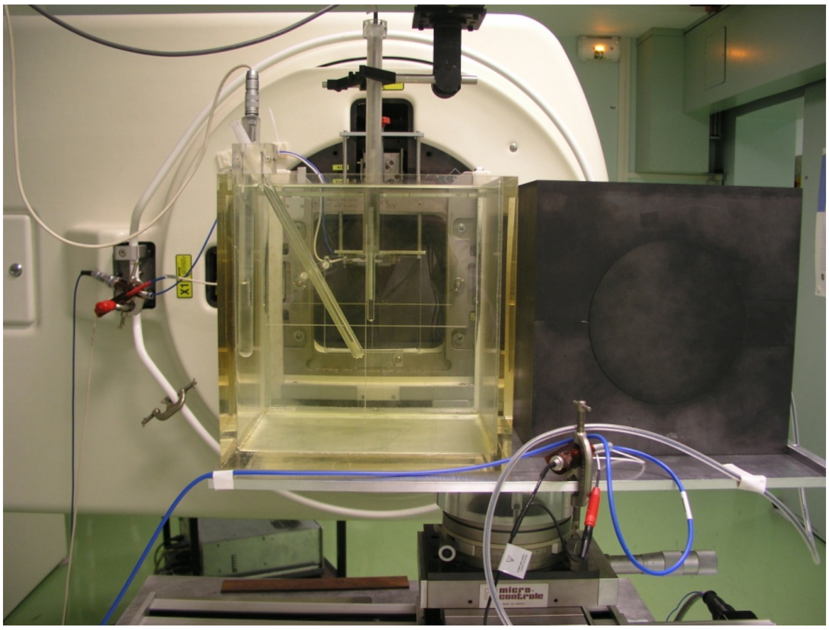
Radiography of the GR10 graphite calorimeter

4. Absorbed dose to water references for high-energy X-ray beams in 4 x 4 cm^2 fields (JRP7)

This study is part of the European metrology project JRP7 “External Beam Cancer Therapy”. The purpose of the experiments done in 2010 was to determine the absorbed dose to water in 4 x 4 and 10 x 10 cm^2 fields for the 6 and 12 MV beams as well as the 6 MV beam without flattening filters.

The method is based on graphite calorimetry measurements in a graphite phantom. First the absorbed dose in the calorimeter core is determined. Second, the ratio between the absorbed dose to water in the reference conditions to the absorbed dose in the calorimeter core is calculated with two different Monte-Carlo codes: EGSnrc and PENELOPE. And finally, a reference ionization chamber set up at the reference point in the water phantom is calibrated in absorbed dose to water.

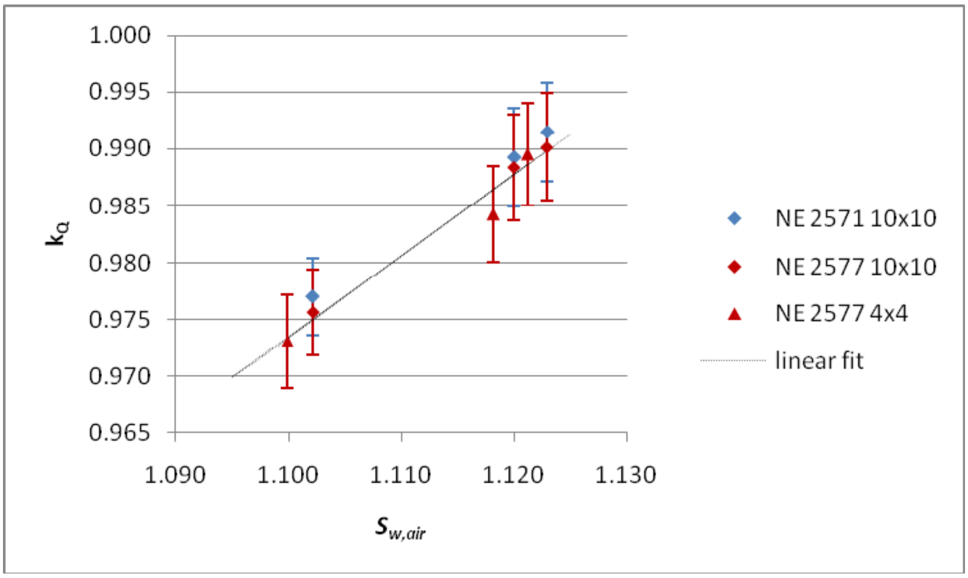
The absorbed dose to water is based solely on measurements in graphite. Only the final calibration of the reference ionization chamber is done in water. This method is valid if the beams characteristics between the water and graphite phantom irradiations are stable enough. To insure the beam stability, the graphite calorimeter and the water phantom are positioned on a perpendicularly-to-the-beam mobile plate in order to automatically and quickly alternate both phantoms in the beam (see photo). This method implies that the beam monitor measurements relationship, when the graphite phantom and the water phantom are irradiated, can be determined precisely (influence of the backscattering difference). For the influence of the backscattering difference on the monitor, the ratios of different monitors responses positioned at different distances of the phantoms were compared in function of the irradiated phantom. Measurements were not able to show a difference for our usual monitoring system when the water or the graphite phantoms were irradiated.



Graphite and water phantom alternating plate in front of LNE-LNHB linac

A NE 2577 is used as reference ionization chamber for the 4 x 4 cm^2 fields and a NE 2571 for the 10 x 10 cm^2 fields. The NE 2577 has also been calibrated in the 10 x 10 cm^2 field. Monte-Carlo was used to calculate water-to-air stopping power ratios $S_{w,air}$ for both field sizes. The following table and figure show experimental k_Q values for the NE 2571 and NE 2577.

k_Q						
	X6 wtht FF	*u* (%)	X6	*u* (%)	X12	*u* (%)
10 x 10 cm^2						
NE 2571	0.9915	0.65	0.9892	0.64	0.9770	0.59
NE 2577	0.9902	0.67	0.9884	0.67	0.9756	0.61
4 x 4 cm^2						
NE 2577	0.9895	0.66	0.9842	0.64	0.9731	0.63

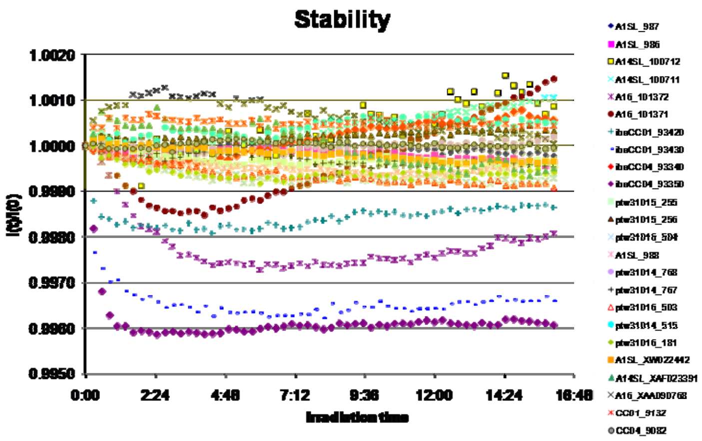


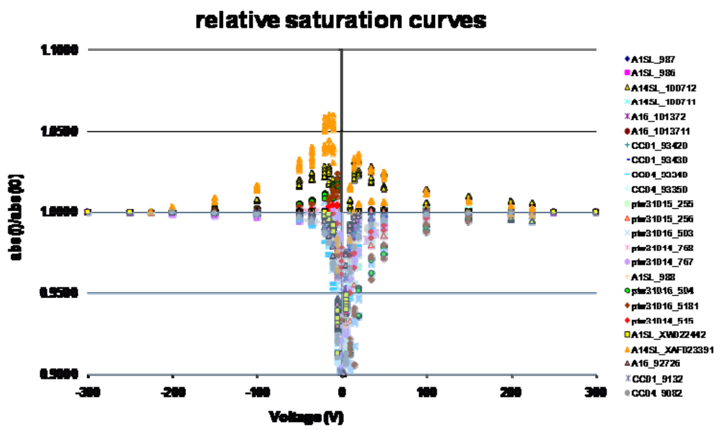
k_Q in function of $S_{w,air}$ for one NE 2571 and one NE 2577 ionization chambers. Remark: the uncertainties on the graph (one standard deviation) do not take into account the common uncertainty on ^{60}Co.

5. Study on pin-point ionization chambers to choose a reference ionization chamber for the high-energy X-ray beams in 2 x 2 cm^2 fields (JRP7)

This study is part of the European metrology project JRP7 “External Beam Cancer Therapy”. Its purpose was to check in a ^{60}Co beam some commercially available ionization chambers which could be used as reference ionization chambers in high-energy X-ray beams for fields as small as 2 x 2 cm^2. The evolution of the signal of the chamber during irradiation (of more than 10 h) and the shape of the saturation curves in function of polarity were particularly looked at. For an ionization chamber to successfully pass the first test, any measured current during 10 h or more of irradiation time should not be different by more than 0.1% from the first measurement. For the second test, for both polarities, the absolute value of the current for a smaller voltage than the nominal one should be smaller than the absolute value of the current at the nominal voltage. The nominal voltages were lower than the ones advised by the manufacturer to reduce the avalanche effects (100 to 200 V/mm).

Eight different types of ionization chambers have been tested: PTW 31014, PTW 31015, PTW 31016, Exradin A1SL, Exradin A14SL, Exradin A16, IBA CC01 and IBA CC04 (24 ionization chambers).

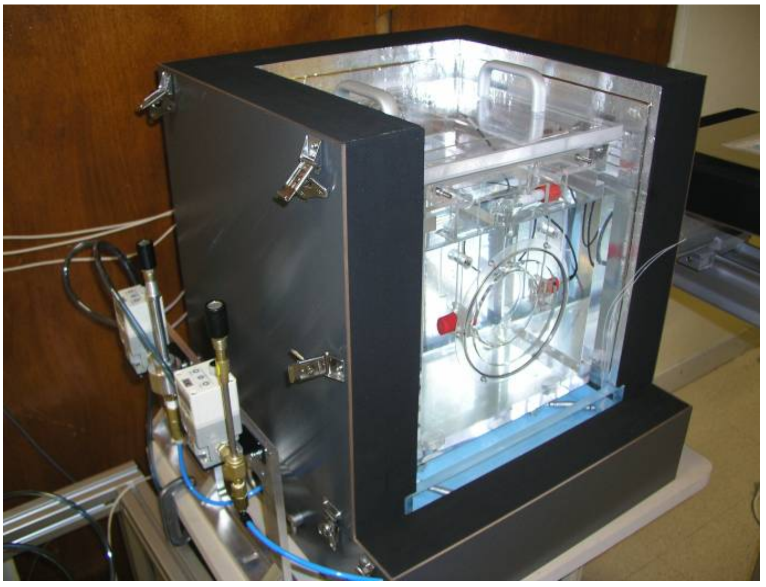




3/4 of the checked Exradin A1SL (all the new ones), 2/3 of the IBA CC04 and 1/3 of the IBA CC01 successfully passed both tests. One of the new Exradin A1SL was chosen as reference ionization chamber for the 2 x 2 cm^2 beam.

6. Building of an air-cooled water calorimeter to measure absorbed dose to water in medium energy X-ray beams

Today, for the medium energy X-ray beams (80 to 300 kV), the interesting quantity is the absorbed dose to water but the calibrations are done in air kerma. A new water calorimeter has been built to directly measure the absorbed dose to water.



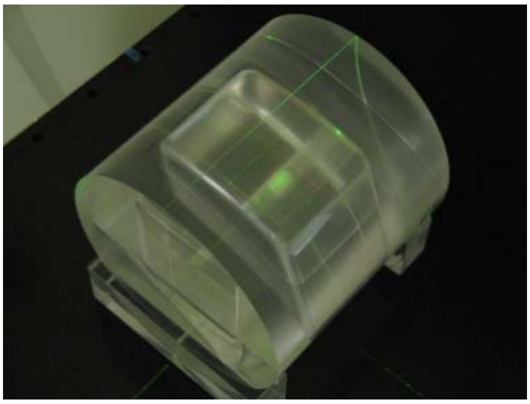
Water calorimeter for small depth measurements

Measurements should be done at 2 cm depth and 50 cm from the source in the reference conditions defined in protocols. The water heating is measured with temperatures probes in a quartz vial. The quartz vial is directly inserted in the front window of the PMMA water phantom to do measurements at 2 cm depth. The thermal regulation at 4°C is done with a cold air flux generated by vortex tubes (on the left of the photo). Pressure regulators and temperature probes are included in a PID loop to regulate air temperature around the water phantom with an accuracy better than 0.1 °C.

The calorimeter temperature stability is of the same quality than with the previous water calorimeter regulated with water cooling. The maximum measured temperature shift was 20 µK/min. The new water calorimeter is presently considered operational.

7. Calibration of a clinical Tomotherapy beams by EPR/alanine dosimetry

Alanine dosimeters read by electron paramagnetic resonance (EPR) are used as transfer dosimeter between a ^{60}Co-γ-ray beam and the clinical Helical Tomotherapy beam. This study had two purposes: to measure the absorbed dose rate to water in those beams in reference conditions (maximum field size: 40 x 5 cm^2 at 85 cm SAD) and to compare the absorbed dose delivered in patient treatment conditions (including the TPS calculations). The irradiations have been done in a PMMA cylindrical phantom.



PMMA cylinder

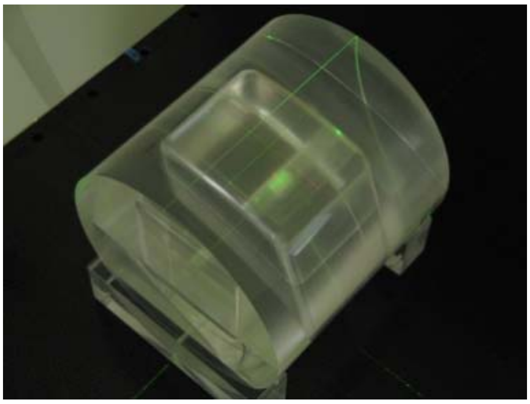
The results on the absorbed dose rate in reference conditions are in good agreement (difference of 2.0%) for an uncertainty of 2 % from the manufacturer and 1 % for alanine dosimeters (one standard deviation).

The comparison of the doses delivered to the alanine dosimeters (calculated with TPS) and the doses measured disagree by 4 % with an uncertainty of 2 % for the delivered dose and 1.5 % for alanine dosimeters. The discrepancy can be explained by an improper value of the PMMA density used in the TPS calculations (CT-scan measured 1.12 instead of 1.19 g/cm^3). Using MCNP simulation to correct this effect, the discrepancy is around 2%.

A comparison for every Tomotherapy unit in France began in 2010 and should be finished in 2011.

8. Calibration of clinical Cyberknife beams by EPR/alanine dosimetry

Alanine dosimeters read by electron paramagnetic resonance (EPR) are used as transfer dosimeter between a ^{60}Co-γ-ray beam and the clinical Helical Tomotherapy beam. This study had two purposes: to measure the absorbed dose rate to water in those beams in reference conditions (with static irradiation at maximum field size ø 6 cm at 80 cm) and to compare the absorbed dose delivered in patient treatment conditions (dynamic irradiation) including the TPS calculations. The irradiations have been done in a water phantom and in a PMMA cylindrical phantom for dose-rate calibrations and in an anthropomorphic head for the dose comparison (and not in the PMMA phantom as it has been done for the Tomotherapy unit).



PMMA cylinder and anthropomorphic head

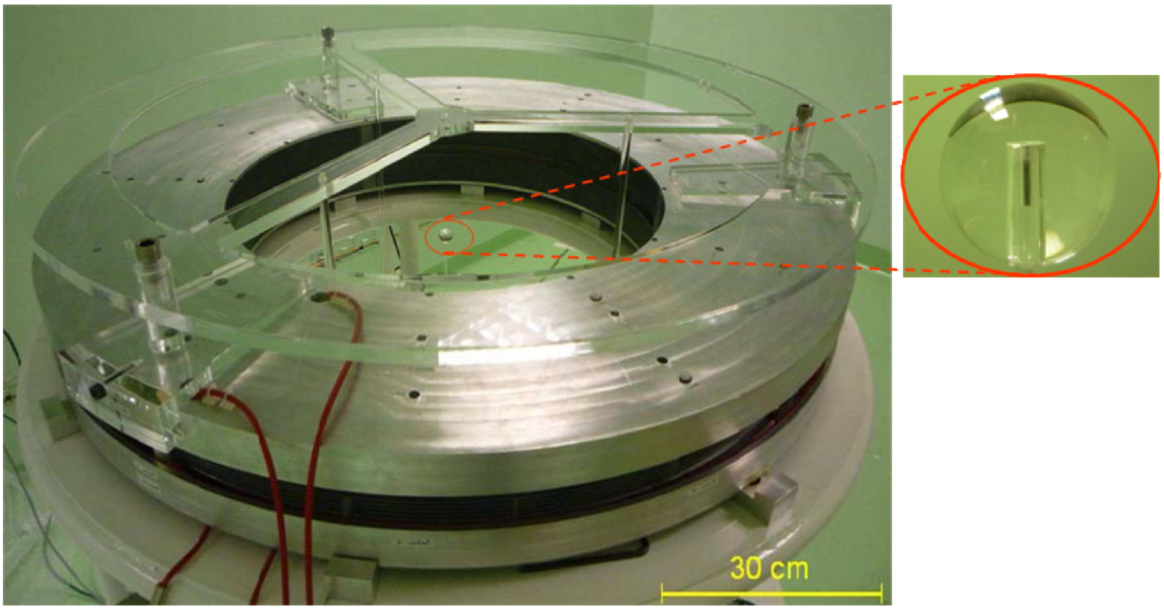
The results on the absorbed dose rate are in good agreement (difference of 0.5% in both phantoms) for an uncertainty of 2 % from the manufacturer and 1 % for alanine dosimeters (one standard deviation).

The comparison of the doses delivered to the alanine dosimeters (calculated with TPS) and the doses measured disagree by at most 4 % with an uncertainty of 2 % for the delivered dose and at most 1.5 % for alanine dosimeters. When the diameter field size was of 2.5 cm around the dosimeter, the difference was lower than 1%. It was around 2.3 % for a diameter of 1.25 cm and 3.4 % for a diameter of 0.5 cm. This problem could be due to the evaluation of the output factor correction which is difficult to determine for such small fields or to the Treatment Planning System algorithm itself and in particular the profile modeling.

9. Development of a primary standard in terms of absorbed dose to water for ^{125}I brachytherapy seeds (JRP6)

The LNE-LNHB, under the European project "Increasing cancer treatment efficacy using 3D Brachytherapy", is developing and investigating a method to directly determine the absorbed dose to water of iodine 125 seeds used for treatment of ophthalmic and prostatic cancers. The fundamental purpose of this project is to reduce the uncertainty on the absorbed dose delivered to the tumor to a level comparable to typical external beam radiotherapy procedures performed with accelerators (5 %, k = 1).

The LNE-LNHB proposal for the LDR primary standard is based on a free-in-air ionization chamber. LDR brachytherapy seeds are of small sizes, about 0.8 mm in diameter and 4.5 mm in length, cylindrically shaped and of complex internal design. This causes anisotropy of emission in the longitudinal and transverse planes. To overcome the difficulties linked to a transversal anisotropic emission of the seed and to an expected low signal-to-noise ratio, a circular ring-shaped free-in-air ionization chamber as shown on the left figure below has been designed. The ^{125}I source seed is placed at the center of this ring detector in a 1 cm radius water-equivalent spherical phantom, as shown on the right figure below.



Primary standard device developed to assess the reference absorbed dose rate to water

The LNE-LNHB methodology is based on the determination of the water kerma rate $\dot{K}_{w,S}(1\,cm, 90°)$ at the surface (S) of the water-equivalent spherical phantom placed in air and containing the LDR seed in its centre. This quantity is measured in the plane passing through the seed centre and perpendicular to its longitudinal axis. The reference absorbed dose rate to water is theoretically defined in the transverse plane of the seed source at one centimeter of distance from the source center with the source surrounded only by water. Thus, a correction factor is applied to account for the contribution of scattered photons arising when water replaces air around the spherical phantom.

All the correction factors (either linked to the dosimetric reference conditions or to measurement defaults) were defined and evaluated, by measurement or using the Penelope Monte Carlo code, for the Bebig iodine seed sources referenced I125 S16.

The absorbed dose to water quantity can be determined with an uncertainty budget of 1 % (k = 1) excluding the type B uncertainty component due to the Monte Carlo calculation of the correction factor which remains to be estimated (at that time only the statistical uncertainty part of the numerical calculations is taken into account). A comparison of LDR brachytherapy sources calibration is currently performed with other partners of the joint research project (ENEA and PTB).

Publications

J. M. Bordy et al., « Radiation protection dosimetry in medicine – Report of the working group n°9 of the European Radiation Dosimetry Group (EURADOS) Coordinated Network for Radiation Dosimetry (CONRAD – contract EC n°FP6-12684) ». Rapport CEA-R-6220

L. de Carlan, F. Delaunay, A. Ostrowsky, J. Daures, S. Sorel, J.-M. Bordy, "Traceability of absorbed dose in radiotherapy: from primary standard to patient treatment", Accreditation and Quality Assurance.

I. Clairand, J.-M. Bordy, J. Daures, J. Debroas, M. Denozière, L. Donadille, M. Ginjaume, C. Itié, C. Koukorava, S. Krim, A.-L. Lebacq, P. Martin, L. Struelens, M. Sans-Mercé M. Tosic and F. Vanhavere, "Active personal dosemeters in interventional radiology: tests in laboratory conditions and in hospitals", Radiation Protection Dosimetry (2010) 1-6, doi :10.1093/rpd/ncq556 (journal web site)

J. Daures, J.Gouriou, J.M. Bordy, "Conversion coefficients from air kerma to personnal dose equivalent $H_p(3)$ for eye-lens dosimetry ». Rapport CEA-R-6235

J. Daures, J. Gouriou, J.M. Bordy, "Monte Carlo determination of the conversion coefficients $H_p(3)/K_a$ in a right cylinder phantom with Penelope code. Comparison with MCNP simulations", Radiation Protection Dosimetry (2011)1-6, doi: 10.1093/rpd/ncq359 (journal web site)

F. Delaunay, M. Donois, J. Gouriou, E. Leroy, A. Ostrowsky, "New LNHB primary standard for ^{60}Co air kerma", Metrologia **47** (2010) 652-658

M. Denozière, J.M. Bordy , J. Daures, N. Lecerf , "Pulsed X-Rays for Interventional Radiology: test on Active Personal Dosemeters (APD), European Project FP7 ORAMED WP3" . Rapport CEA-R-6233 (2009)

C. Falgueres, J.-J. Bahain, M. Duval, Q. Shao, F. Han, M. Lebon, N. Mercier, A. Perez-Gonzalez, J.-M. Dolo, T. Garcia (2010) "A 300-600 ka ESR/U-series chronology of Acheulian sites in Western Europe" Quaternary International, 223-224, 293-298.

T. Garcia, M. Lin, I. Pasquié, V. Lourenço, "A methodology for choosing parameters for ESR readout of alanine dosimeters for radiotherapy", Radiation Physics and Chemistry, 78 (2009) 782-790

F. Han, C. Falguères, J.-J. Bahain, Q. Shao, M. Duval, M. Lebon, T. Garcia, J.-M. Dolo, C. Perrenoud, G.J. Shen, H. Lumley (2010) « Effect of deposit alterations on the dating of herbivorous teeth from Arago Cave by the ESR-U-series method" Quaternary Geochronology, 5, 376-380.

M. Lin, T. Garcia, V. Lourenço, Y. Cui, Y.Z. Chen, F. Wang., "Bilateral dose comparison of alanine ESR dosimetry system at radiotherapy dose level", Radiation Measurements 45 (2010) 789-796

A. Ostrowsky, J.M. Bordy, J. Daures, L. de Carlan, F. Delaunay, “Dosimetry for small size beams such as IMRT and stereotactic radiotherapy, is the concept of the dose at a point still relevant? Proposal for a new methodoly”, Rapport CEA – R – 6243 (2010)

C.G. Soares, G. Douysset and M.G. Mitch, “Primary standards and dosimetry protocols for brachytherapy sources”, Metrologia 46 (2009) S80-S98

G. Wagner, M. Krbetschek, D. Degering, J.-J. Bahain, Q. Shao, C. Falguères, P. Voinchet, J.-M. Dolo, T. Garcia, G.P. Rightmire, "Radiometric dating of the type-site for Homo heidelbergensis at Mauer, Germany". Proceedings of the National Academy of Sciences of the United States of America, 107 (2010), 19726–19730

Communications

I. Aubineau-Laniѐce, J.-M. Bordy, B. Chauvenet, D. Cutarella, J. Gouriou, J. Plagnard “Development of a primary standard in terms of reference air kerma rate for ^{125}I brachytherapy seeds”, International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS), Book of extended synopses, IAEA-CN-182, p. 23

I. Aubineau-Laniѐce, P. Aviles-Lucas, J.M. Bordy, B. Chauvenet et al., ”Development of a primary standard in terms of absorbed dose to water for ^{125}I brachytherapy seeds”, International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS), Book of extended synopses, IAEA-CN-182, p. 211

T. Garcia, P. François, N. Périchon, V. Lourenço, JM. Bordy « Calibration of helical tomotherapy using ESR/alanine dosimetry”. International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS), Book of extended synopsis, IAEA-CN-182, p.251

T. Garcia, T. Lacornerie, R. Popoff, V. Lourenço, J.-M. Bordy. "Preliminary study to calibrate Cyberknife using EPR/Alanine dosimetry". EPRBioDose 2010, Mandelieu-La-Napoule, France, 10-14 October 2010.

T. Garcia, V. Lourenço, A. Ver, J.-M. Bordy. "Dose mapping of a GammaCell 220 High-dose irradiator - Comparison of Monte-Carlo simulation and experimental approaches". Sixth International Workshop on Dosimetry for Radiation Processing, Karlsruhe, Germany, 4-8 October 2009.

V. Lourenço, D. Vermesse, D. Cutarella, M. P. Avilés-Lucas, I. Aubineau-Lanièce. « 3D distribution measurement of the absorbed dose to water around ^{192}Ir brachytherapy source by thermoluminescent dosimeters”. International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS), Book of extended synopses, IAEA-CN-182, p.337

V. Lourenço, T. Garcia. "The new French Standard for Industrial Radiation Processing". Sixth International Workshop on Dosimetry for Radiation Processing, Karlsruhe, Germany, 4-8 October 2009.

A. Ostrowsky, J.M. Bordy, J. Daures, L. De Carlan, F. Delaunay “ Dosimetry for small size beams such as IMRT and stereotactic radiotherapy, Is the concept of the dose at a point still relevant? Proposal for a new methodology“, International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS), Book of extended synopsis, IAEA-CN-182, p.315

*B. Rapp, A. Ostrowsky et J. Daures “*The LNE-LNHB water calorimeter: measurements in ^{60}Co beam“, International Symposium on Standards, Applications and Quality Assurance in Medical Radiation Dosimetry (IDOS), Book of extended synopses, IAEA-CN-182, p.13