Objectives of the project
Brachytherapy (BT) is a particular radiotherapy technique in which small encapsulated radioactive sources are placed inside or in close proximity to the treatment volume delivering a high dose to the tumour at small distances while sparing the surrounding tissue. About 100,000 patients per year are treated in the European area with BT (about 10% of radiotherapy treatments). In recent years the use of BT has increased in Europe and in the rest of the world but in order to optimize these treatments there is still a need for more accurate dosimetry with high spatial resolution.
On 1 July 2008 the project “T2.J06, Increasing cancer treatment efficacy using 3D brachytherapy” (short name “Brachytherapy”) was launched, aiming to establishing a more accurate metrological basis for the dosimetry of radioactive sources used in the clinic for BT across Europe. It responds to the need for traceability of absorbed dose measurements of BT radiation sources to absorbed dose to water primary standards. The absorbed dose to water, D_W, is the quantity of interest for dosimetry in radiotherapy, but no absorbed-dose-to-water primary standards are so far available for dosimetry of BT. Currently, the procedures to determine the absorbed dose imparted to the patient based on measurements traceable to the existing air kerma standards are affected by an uncertainty higher than the limit recommended by the IAEA dosimetry protocol (IAEA-TRS 398, 2000) to assure the effectiveness of radiotherapy treatments. A significant fraction of this uncertainty is due to a lack of metrology. The ultimate goal of the “Brachytherapy” project is to develop methods and standards for the direct measurement of the quantity D_W in BT dosimetry with a reduced uncertainty in the dose delivered to the patient (target value less than 5% (k=1) at clinical level).
In order to achieve the objectives of the project, the research and measurement capabilities of ten European National Metrology Institutes (NMIs) in the field of ionizing radiation measurements have been brought together. Most of the partner NMIs have a long experience in the development of standard instruments for measurements of air kerma and absorbed dose in a wide range of photons energy. Many partner NMIs have contributed to international guides and codes of practice for quality assurance in dosimetry. All of these NMIs have a broad experience in dosimetric procedures and related Monte Carlo calculations. This will ensure a closer cooperation in research, a reduced delay for the dissemination of results and greater accuracy and precision with the results validated through cross-checking and comparisons.
Collaborations for research activities were also formalized with the company PTW Freiburg (Germany), the Linkoping University (Sweden) and the company IBA Dosimetry GmbH (Germany). A scientific collaboration has started with the BRAPHYQS group of ESTRO.

Description of work
The project is structured around four technical work packages (WP2, WP3, WP4 and WP5) and two additional work packages dedicated to the project management (WP1) and impact (WP6). The first objective of the project is to construct primary standards to measure the absorbed dose to water due to radioactive sources for Low Dose Rate (LDR) and High dose rate (HDR) BT. Once these new standards are developed, the project aims at optimising BT treatments by accounting for the strong spatial variation of absorbed dose around BT sources. To this end, the project aims to develop high resolution methods to allow an accurate determination of 3D dose distributions. Finally, a new international protocol will be promoted for dosimetry in BT based on absorbed-dose-to-water standards in place of the current air kerma standards.

A system of independent absorbed dose to water standards will be delivered in WP2 for LDR BT sources and in WP3 for HDR BT sources. The standards developed within each work package, are different in method and/or design in order to highlight possible systematic errors and give together a more robust determination of absorbed dose to water. In particular, three LDR standards based on ionometric methods, two HDR standards based on water calorimetry and two other HDR standards based on graphite calorimetry are under development. With these new absorbed dose standards, reference values of the absorbed dose to water at the reference distance of 1 cm from LDR and HDR BT sources will be determined with a target value for the best relative measurement uncertainty $u(D_W, 1\, \text{cm}) < 2\%$ (with a coverage factor $k=1$, which is equivalent to 1 standard deviation). The two groups of standards (LDR and HDR) will be validated by comparison by the end of 2011.

The activities of work packages WP4 and WP5 will be addressed to the end users (e.g. radiotherapy centres and secondary standards laboratories). The objective of the work package WP4 is the development of a calibration chain and a measurement procedure optimized to transfer the new reference quantity $D_W$ to the end user minimizing the uncertainty. In particular, a measurement procedure will be developed for the models of well type chamber most widely used in the European secondary standard laboratories and brachytherapy medical centres. Moreover, to allow the linkage between the current reference quantity (air kerma strength or reference air kerma rate) and the new reference quantity (absorbed dose to water), the dose rate constants, $\Lambda$, will be experimentally re-evaluated with an uncertainty of about 3% ($k=1$) for the LDR and HDR BT sources used in WP2 and WP3.

Finally, the task of work package WP5 is to improve the verification of the 3D dose distributions in irregularly shaped fields by brachytherapy sources in water or water equivalent phantom. The expected output are suitable portable methods with assessed reliability and accuracy -leading to the target of a delivered dose with an uncertainty less than 5% ($k=1$)- for the verification of dose distributions around BT sources. At first, this includes the determination of energy and dose response curves of various detection methods (gel dosimeters, radiochromic films, scintillation detectors, TLD dosimeters, alanine dosimeters, liquid ionization chambers, semiconductor detectors, and 2D multidetector systems). Then the spatial dose distributions will be determined around BT sources in water or water-equivalent phantoms, and supported by Monte Carlo simulations using EGS, PENELOPE, and MCNP codes. Although some of the detection methods that will be used could be in principle more suitable to attain the JRP task of a lower uncertainty in BT dosimetry, all these methods are worth testing. A final comparison among the methods will show possible advantages and disadvantages of each of them.

**Project progress and main results achieved**
The project is started on 1 July 2008 for a period of 36 months.
The project partners meet five times in this project period (1 July 2008 - 30 April 2010). A kick-off meeting was held in Berlin (Germany, PTB, July 2008) to address all managerial issues relevant to the project, to agree on the final project plan and the rules for its conduct. Four project meetings were held in Rome (Italy, ENEA-INMRI, October 2008), in Braunschweig (Germany, PTB, March 2009), in Paris (France, LNE-LNHB, October 2009) and in Teddington (United Kingdom, NPL, March 2010) to discuss all the technical subjects relevant to the project and to inform all the partners on the project progress. In particular all project partners reported their activities and showed the work progress according to the project plan. Moreover a joint workshop with the project T2.J07 EBCT - also working in the field of ionizing radiation - was organised in Rome (Italy, ENEA-INMRI, October 2008) to share ideas and knowledge.

A project web site has been set up for making known to the public the project activities and results. A restricted area of the site is interactive. In this area the JRP partners can share data and information useful to achieve the project objectives. In the following the JRP progress and results so far achieved are summarized.

The mechanical construction of the two groups of primary standards for LDR and HDR brachytherapy sources is a significant project achievement planned for 2009. The basic designs of the three LDR standards and the four HDR standards were finalized and approved at the first project meeting, after analysis with partners. The construction of five standards is completed, as the involved partners (ENEA-INMRI, LNE-LNHB, PTB, VSL) showed in their presentations and reports at the project progress meetings. The construction of the two standards based on graphite calorimetry is well underway, as the involved partners (ENEA-INMRI, NPL) showed in their presentations and reports at the project progress meetings. The commissioning of all standards is planned since October 2010, after the determination of the relevant correction factors. Preliminary comparison exercises are planned by the end of 2010 for both LDR and HDR brachytherapy standards. The LDR and HDR draft comparison protocols were prepared and discussed at the last project progress meeting.

The activities planned for WP4 and WP5 are mainly scheduled from this period onwards. In the framework of WP4, a questionnaire has been distributed among the European secondary standards laboratories and BT medical centres to identify the widespread models of well type ionization chamber and BT irradiation facilities on which to focus the WP activities. Questionnaires from 135 hospitals in Europe were collected and the results evaluated by partners giving useful information to well address project activities. The partners involved in WP5 finalized the development of water equivalent phantoms to be used for the spatial dose distribution measurements. These phantoms are specifically designed for the verification of dose distributions in HDR (high dose rate) and LDR (low dose rate) BT treatment planning systems by the above mentioned various detection methods. Intensive measurements for the characterization of the dosimeters in terms of energy and dose response curves have been carried out.

The project objectives and the preliminary results were presented in the BIPM Workshop on Brachytherapy Dosimetry (Sevres, France, May 2009). Oral presentations on the project activities have been done at the International Congress of Metrology (Paris, France, June 2009), the IMEKO World Congress 2009 (Lisbon, Portugal, September 2009), the Medical World Congress 2009 (Munich, Germany, September 2009) and in a number of national congress. The purpose of these presentations was to inform users/experts and receive feedback from them. The text of these papers are available on the Congress Proceedings.
An invited talk on the new brachytherapy standards and some individual presentations will be presented at the IAEA, International Symposium on Standards, Applications & QA in Medical Dosimetry, 2010.

A significant deliverable of the project, is the organization of a workshop with the stakeholders (i.e. national and international medical physicists associations) to promote a new international protocol for dosimetry in BT based on absorbed dose standards. The project T2.J07 EBCT has also planned a final workshop for the dissemination of the project results. Both the T2.J06 and T2.J07 workshops are addressed to the medical physicist community and to improve their impact it was agreed to hold a joint dosimetry workshop in autumn 2011 after the conclusion of the two project. A joint working group between the two projects was formed dedicated to the organization of this workshop and main details were discussed in two meetings with all partners of both projects. It was agreed to held the workshop in on 28-30 November 2011 in Braunsweig (Germany, PTB).

In conclusion, the JRP has fully achieved its objectives and technical goals for the period, no significant changes are planned and no corrective actions are needed.

**Potential use and impact of the project results**

The metrological research of the iMERA-Plus Brachytherapy project will contribute to the "improvement of procedures and better knowledge of multidimensional dose distribution delivered to patients for radiotherapy", and to the "realization of new devices for the traceable characterization of radiation sources", as explicitly requested by the European Metrology Research Programme. By this collaborative project a strengthened impact –compared to the dispersed individual initiatives– will be achieved. In the long term, the most relevant contribution of this project will be the improvement of the EU citizens' lives by increasing the brachytherapy efficacy.

The dissemination of the JRP results is of direct interest to the international community of radiotherapy centres performing brachytherapy clinical treatments. In this respect, all the National Metrology Institutes partners in this project have a recognized scientific position –in their respective countries as well as in the international community– and have many opportunities (conferences, workshops, working groups, commissions, etc.) to disseminate the results at national and international level. In particular, the project partners have direct links with the radiotherapy centres in their respective countries, thus the dissemination of the joint research project results will be effective and will impact directly on the improvement of the EU citizens’ lives.
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JRP Co-ordinator:
Name, Title, Organisation: Maria Pia Toni, Dr ENEA-INMRI, “Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti” of the “Ente per le Nuove tecnologie l’Energia e l’Ambiente”, Italy
Tel.: +39 06 3048 3957
E-mail: mariapia.toni@enea.it
JRP website address: http://brachytherapy.casaccia.enea.it

Other JRP partners:
Organisation, Country: Bundesamt für Eich- und Vermessungswesen (BEV), Austria;
Czech Metrology Institute – Inspectorate for Ionizing Radiation (CMI), Czech Republic;
Instituto Tecnológico e Nuclear (ITN-LMRI), Portugal;
Laboratoire National Henri Becquerel (LNE-LNHB), France;
Van Swinden Laboratorium B.V. (VSL), The Netherlands
National Physical Laboratory (NPL), United Kingdom;
Physikalisch-Technische Bundesanstalt (PTB), Germany;
Swedish Radiation Safety Authority (SSM), Sweden;
Säteilyturvakeskus Radiation and Nuclear Safety Authority (STUK), Finland.

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