IAEA
International Atomic Energy Agency

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PROPOSAL FOR RESEARCH CONTRACT

1. NAME AND ADDRESS OF CONTRACTING INSTITUTE:	CONTACT DETAILS:
University Hospital Centre "Sestre milosrdnice", 29 Vinogradska Street, 10000 Zagreb CROATIA	Telephone: 385 1 3787 541, 385 1 3787 419 Fax: 385 1 3768 303 E-mail: tomislav.bokulic@kbcsm.hr
2. DEPARTMENT WHERE RESEARCH IS TO BE PERFORMED: Department of Oncology and Nuclear Medicine, UHSM Clinic for Radiotherapy and Oncology, Physics Division, University Hospital Rijeka, Rijeka, UH Rijeka Department for Radiotherapy and Oncology, University Hospital Osijek, Osijek UH Osijek; Department of Physics, School of Medicine, University of Osijek, Osijek	Further information on the IAEA's Coordinated Research Activities can be found on the following website: **http://cra.iaea.org**

3. TITLE OF RESEARCH CONTRACT PROPOSAL:

Impact of QA programme on dosimetric accuracy in radiotherapy-anthropomorphic phantom measurement verifications of treatment planning systems

A. Part of the IAEA's Coordinated Research Project (CRP)/ if applicable:

The Relationship Between Delivery Accuracy and Quality Assurance in Radiotherapy (E24017)

4. SUMMARY OF PROPOSED RESEARCH:

The goal of this investigation will be to estimate how the level and depth of quality assurance (QA) programme, commissioning of a treatment planning system, dosimetry procedures and treatment techniques relate to the level of clinical accuracy achievable in external beam 3D conformal radiotherapy (EBRT-3DCRT) radiotherapy in three Croatian radiotherapy (RT) centres *). As a part of activities in line with Government's policy to strengthen capacity in cancer control, all radiotherapy centres obtained new equipment and now routinely perform 3DCRT. During the last two IAEA TC cycles (2009-11 and 2012-13) radiotherapy departments of University Hospitals Osijek and Rijeka have been working on establishment of comprehensive QA/QC programme in radiotherapy. To promote QA in EBRT, two centres carried out the survey of QC protocols and conducted two national audits dedicated to the dissemination of good QC practice
Systematically measured data of output of the linear accelerator, the reproducibility, time behaviour of output and long-term stability will be analyzed in attempting to fine-tune that important part of the QA programme. These measurements will also help in assessing the effectiveness of different internationally recommended quality control programs for output measurement. Scarcely employed statistical process control (SPC) will be considered for application to QA in EBRT for the purpose of establishing action level that would differentiate between the different types of uncertainties. The same methodology will be applied also to other important beam parameters such as flatness, symmetry and quality of the beam.
In extensive phantom measurements, the range of dose discrepancies for selected test cases that mimic the 3DCRT in the departments using same TPS will be investigated. The previously carried out measurements will be supplemented with a new set of measurements using comparison of treatment planning systems (TPS) and verification of individual patient plans and delivery. The part of our investigations will be the development of test cases that would, as clinically realistic as possible, resemble the complicated treatment localizations such as the head and neck. Other representative treatment sites of interest are the most frequent localisations like breast and prostate, which together with the head and neck site, cover the majority of all localisations treated in our RT departments.
Some practical methods, suggestions and criteria will be proposed to improve the accuracy of the absorbed dose determination.
These results will be critically important for other foreseen research and professional activities in the institutions aiming at "in-phantom" anthropomorphic phantom dose measurements with TLD dosimeters and radiophotoluminescence (RPL) dosimeters, in-vivo dosimetry with the same type of dosimeters, and finally in clinically quantifying the differences in set-up errors as measured with the electronic portal imaging (EPID) and cone beam CT (CBCT), and comparing their performances with prospective suggestion for a setup margin definition depending on the imaging modality.

*) *1.) Department of oncology and nuclear medicine, University hospital "Sestre milosrdnice", Zagreb, UHSM; 2.) Clinic for Radiotherapy and Oncology, Physics Division, University Hospital Rijeka, Rijeka, UH Rijeka 3) Department for Radiotherapy and Oncology, University Hospital Osijek, Osijek UH Osijek; Department of Physics, School of Medicine, University of Osijek, Osijek, UH Osijek*

5. RESEARCH PERSONNEL (if space provided below is insufficient, please attach additional sheets):

A. Chief Scientific Investigator:

First Name	Family Name	Date of birth	Nationality	Position held	Sex M/F
Tomislav	Bokulić	18.04.1964	Croatian	Medical Physicist	M

Academic degrees held: PhD in medical physics, assistant professor

Previous related scientific experience:
- participated in four research projects with the IAEA, in one of them as a chief investigator ("In-vivo dosimetry with silicon diodes for Co-60 photon beam" (IAEA Research Contract No. 13115 RO, 2004-07)
- major interests in in-vivo dosimetry in radiotherapy and Monte Carlo simulations in nuclear medicine imaging and radiotherapy
- publication list attached

Recent publications related to the project (within the past 2 - 3 years):
1. Budanec, M., Knežević Z., Bokulić T., Mrčela I., Vrtar M., Vekić B., Kusić Z. Comparison of doses calculated by the Monte Carlo method and measured by LiF TLD in the buildup region for a 60Co photon beam. Appl. Radiat. Isotopes, 66: 1925-1929 (2008).
2. Fröbe, A., Jones, G., Jakšić, B., Bokulić, T., Budanec, M., I, Mrčela., Stančić-Rokotov, D., Hrabar, D., Bolanca, A., Rosenblatt, E., Kusić, Z. Intraluminal brachytherapy in the management of squamous carcinoma of the esophagus. Dis Esophagus, 22: 513-8 (2009)
3. Mrčela, I., Bokulić, T., Izewska, J., Budanec, M., Fröbe, A., Kusić, Z. Optically stimulated luminescence in vivo dosimetry for radiotherapy: physical characterization and clinical measurements in 60Co beams. Phys Med Biol, 56(18):6065-82, (2011).
Contribution in: IAEA Human Health Report No.8 Development of procedures for in vivo dosimetry in radiotherapy, International Atomic Energy Agency (IAEA), Vienna, in press (2012).

B. Main Additional Scientific Staff:

First Name	Family Name	Date of birth	Nationality	Sex M/F
Mirjana	Budanec	13.02.1969	Croatian	F

Academic degrees held: BSc in Physics, PhD in medical physics

Previous related scientific experience:
- performed verification of the treatment planning system (Theraplan Plus 1000) and the investigation of the response of the thermoluminescent detectors (TLD) and planparallel ionization chamber ("Markus" type) in the inhomogeneous dose regions of the Co-60 fields
- performed and investigated Monte Carlo simulations (EGSnrc code)
- participated in the introduction of the diode in vivo measurements at our department

Relevant publications:
1. M. Budanec, Ž. Knežević, T. Bokulić, I. Mrčela, M. Vrtar, B. Vekić, Z. Kusić "Comparison of doses calculated by the Monte Carlo method and measured by LiF TLD in the buildup region for a Co-60 photon beam", Appl. Radiat. Isot. 66, 1925-1929, 2008.
2. M. Majer, M. Budanec, G. Jerbić-Zorc, S. Pašić, M. Uroić, B. Vuković, K. Ilakovac "Effects of near- source photon scattering at the energy of 60 keV", Nucl. Instr. and Meth. 524, 227-235, 2004.
3. M. Budanec, Ž. Knežević, T. Bokulić, I. Mrčela, B. Vekić, Z. Kusić "Radiation treatment planning system verification", Proceedings of the International Conference on Quality Assurance and New Techniques in Radiation Medicine, Vienna, 218, 2006.

First Name	Family Name	Date of birth	Nationality	Sex M/F
Iva	Mrčela	24.12.1972	Croatian	F

Academic degrees held: BSc Physics, PhD medical physics

Previous related scientific experience:
- Involved in research and implementation of new procedures in external beam radiotherapy and high dose rate brachytherapy, in the department.
- Investigation of in vivo dosimetry methods in external beam radiotherapy: study of dosimetric properties and comparison of different detectors, namely semiconductor diodes and optically stimulated luminescence dosimeters followed by their introduction in clinical practice (PhD thesis).

Relevant publications:
- Mrčela, T. Bokulić, J. Izewska, M. Budanec, A. Fröbe, Z. Kusić *Optically stimulated luminescence in vivo dosimetry for radiotherapy: physical characterization and clinical measurements in ^{60}Co beams* Phys. Med. Biol. **56** 6056-6082, 2011
- Contribution in: IAEA Human Health Report No.8 *Development of procedures for in vivo dosimetry in radiotherapy,* International Atomic Energy Agency (IAEA), Vienna, in press (2012).

First Name	Family Name	Date of birth	Nationality	Sex M/F
Mihaela	Mlinarić	20.1.1986	Croatian	F

Academic degrees held: Mag. Phys. (M.Sc. equivalent in physics)

Previous related scientific experience:
- Graduated physics on Zagreb's University in 2010, research for diploma thesis on computer calculation of NMR parameters of organic matters.
- In 2011 started working at University hospital for tumours
- In 2012 transferred to University hospital centre "Sestre milosrdnice", Department of oncology and nuclear medicine
- Duties in both hospitals included participating in radiotherapy treatment planning and QC.
- Attended IAEA/ICTP workshop "Transitioning from 2D to 3D radiotherapy and IMRT", Trieste, 10 -14 December 2012

Publications:
- In print (Proceedings of the Ninth Symposium of the Croatian Radiation Protection Association, April 2012): Verification of absorbed dose calculation with XiO radiotherapy treatment planning system, based on IAEA 1540 publication.
- NMR and NQR parameters of ethanol crystal, Chemical Physics Letters, Volume 531, 2 April 2012 (based on the work for diploma thesis)

First Name	Family Name	Date of birth	Nationality	Sex M/F
Marin	Gregov	28.04.1987	Croatian	M

Academic degrees held: Mag. Phys. (M.Sc. equivalent in physics)

Previous related scientific experience:
- Graduated physics at Zagreb's University in 2010
- in the past year, have been working in the Department of Oncology and Nuclear Medicine, University hospital "Sestre milosrdnice" in Zagreb, in the field of medical physics in nuclear medicine and radiotherapy.
- revised and prepared new procedures for quality control (QC) of nuclear medicine equipment such as gamma cameras and dose calibrators for nuclear medicine practices I
- intensively involved in computerised treatment planning for linear accelerator external beam radiotherapy as well as in carrying out some part of the QA program for accelerator, CT Simulator and CBCT.
- Routinely performing HDR brachytherapy treatments with Gammamed iX afterloading unit and Brachyvision planning software system for gyneacological, bronchial and oesophagus cancer.

First Name	Family Name	Date of birth	Nationality	Sex M/F
Zvonko	Kusić	14.06.1946.	Croatian	M

Academic degrees held: academician, M.D., Ph.D., Full Professor of Oncology
Previous related scientific experience: Guy's hospital, London, 1980-1981; The University of London M.Sc. Course in Nuclear Medicine; The New York Hospital- Cornell Medical Center; University of Cincinnati Medical Centre; University of Michigan Medical Centre, Ann Arbor, U.S.A. 1981; postgraduate program of the American Thyroid Association.
Visiting investigator.: University of Cincinnati Medical Centre; New York Hospital- Cornell Medical Centre; U.S.A. 1984, 1985, 1987, 1988.
Visiting professor. Food and Drug Administration, Washington, 1990; National Institute of Health, Bethesda, U.S.A. 1991. Principal investigator of the joint USA-Croatia project " Body Dose Reduction in I-131 Therapy of Hyperthyroidism", FDA, National Centre for Radiological Health.

UH Rijeka

First Name	Family Name	Date of birth	Nationality	Sex M/F
Slaven	Jurković	13.3.1967	Croatian	M

Academic degrees held: PhD

Previous related scientific experience:
Major research interest in radiotherapy physics with an emphasis on the compensator design in EBRT [1, 2], dosimetry of high energy photon beams and MC calculations of some radiation therapy problems [3, 4] as well as quality control of different parts of radiation therapy system (machines, treatment planning system, procedures) [5-8].
Publications:
1. Jurković, Slaven; Žauhar, Gordana; Faj, Dario; Smilović Radojčić, Đeni; Švabić, Manda. Radiation therapy photon beams dose conformation according to dose distribution around intracavitary applied brachytherapy sources. // Medical dosimetry. 35 (2010) , 1; 49-52
2. Jurković, Slaven; Žauhar, Gordana; Bistrović, Matija; Faj, Dario; Kaliman, Zoran; Smilović-Radojčić, Đeni. An alternative approach to compensators design for photon beams used in radiotherapy. // Nuclear instruments & methods in physics research. Section A. 580 (2007) , 1; 530-533

3. Jurković, Slaven; Žauhar, Gordana; Faj, Dario; Radojčić Smilović, Đeni; Švabić, Manda; Kasabašic, Mladen; Diklić, Ana. Dosimetric verification of compensated beams using radiographic film. // Radiology and oncology 45 (2011), 4; 310-314
4. Faj, Dario; Vrtar, Mladen; Krajina, Zdenko; Jurković, Slaven; Margaretić, Damir. Model of total skin electron treatment using the "six-dual-field" technique. // Collegium antropologicum. 27 (2003) , 2; 713-721
5. Jurković, Slaven; Švabić, Manda; Diklić, Ana; Smilović Radojčić, Đeni; Dundara, Dea; Kasabašić, Mladen; Ivković, Ana; Faj, Dario. Reinforcing of QA/QC programmes in radiotherapy departments in Croatia: Results of treatment planning system verification. // Medical dosimetry. 38 (2013) ; 100-104
6. Jurković, Slaven; Diklić Ana; Kasabašić, Mladen; Radojčić Smilović, Đeni; Švabić, Manda; Ivković, Ana, Faj, Dario. Survey of Equipment Quality Control in Radiotherapy Centres in Croatia: First Results. // Archives of Industrial Hygiene and Toxicology. 62 (2011), 3; 255-260 (2011).
7. Kasabašić, Mladen; Faj, Dario; Ivković, Ana; Jurković, Slaven; Belaj, Nenad. Rotation of the patients' sacrum during the bellyboard pelvic radiotherapy. // Medical dosimetry. 35 (2010) , 1; 28-30
8. Švabić, Manda; Jurković, Slaven; Faj, Dario; Kasabašić, Mladen; Radojčić; Smilović, Đeni; Ivković, Ana. Practices of Radiotherapy Equipment Quality Control in Radiotherapy Centres in Croatia. // Collegium antropologicum. Supplement. 32 (2008), S2; 217-219

First Name	Family Name	Date of birth	Nationality	Sex M/F
Đeni	Smilović Radojčić	26.7.1969.	Croatian	F

Academic degrees held: PhD student
Previous related scientific experience:

Major research interest in radiotherapy physics with an emphasis on the compensator design in EBRT [1, 2], dosimetry of high energy photon beams and MC calculations of some radiation therapy problems [3] as well as quality control of different parts of radiation therapy system (machines, treatment planning system…) [5, 6, 8].

First Name	Family Name	Date of birth	Nationality	Sex M/F
Manda	Švabić Kolacio	15.3.1976.	Croatian	F

Academic degrees held: PhD
Previous related scientific experience:

Major research interest in radiotherapy physics with an emphasis on the compensator design in EBRT [1], dosimetry of high energy photon beams and MC calculations of some radiation therapy problems [3] as well as quality control of different parts of radiation therapy system (machines, treatment planning system…) [5, 6, 8].

UH Osijek

First Name	Family Name	Date of birth	Nationality	Sex M/F
Dario	Faj	08.01.1971	Croatian	M

Academic degrees held: PhD
Previous related scientific experience:

Major reasearch interest in radiotherapy physics with an emphasis on the dosimetry aand MC simulations of high energy photon beams as well as quality control of different parts of radiation therapy system (machines, treatment planning system, procedures). Also involved in research in improving radiation safety of patients in diagnostic radiology. *List of publications attached*.

First Name	Family Name	Date of birth	Nationality	Sex M/F
Mladen	Kasabašić	27.05.1976	Croatian	M

Academic degrees held: MSc
Previous related scientific experience:

Major reasearch interest in radiotherapy physics with an emphasis on the dosimetry aand MC simulations of high energy photon beams as well as quality control of different parts of radiation therapy system (machines, treatment planning system, procedures). Also involved in research in improving radiation safety of patients in diagnostic radiology. *List of publications attached.*

6. PROPOSED RESEARCH PROJECT (if space provided below is insufficient, please attach additional sheets):

6.1 Scientific Background:

It is known that the need for accuracy in RT is related to the nature of the tumour and normal tissues radiation dose-response curves [1, 2]. These curves have a sigmoidal functional form with a steep slope near the 50% response level. Therefore, a small variation in dose may result in a noteworthy deviation from the intended response with either a decrease in the probability of tumour control or a considerably higher probability of morbidity.
A number of important factors like different mechanical and radiation parameters of machines involved (CT simulators and linear accelerators), beam calibration and dose calculation accuracy, setup uncertainty and uncertainties in contouring of the tumour volumes,

have large impact on the radiotherapy patient outcome. A quality assurance (QA) programme in external beam radiotherapy (EBRT) is mandatory to ensure that the radiation treatment is delivered as intended. Optimisation in designing of QA programme is needed to spare a great deal of time and available resources, while at the same time to provide an efficient and feasible set of QC tests, adjusted to local conditions that would lead to the avoidance of errors with potentially serious consequences and minimise the subtle ones .
Several guidelines and recommendations for linear accelerators QC schedules exist [3, 4, 5] but the uncritical, direct application of them may lead to an unacceptable quantity of work. The choice of QC tests, frequency, and tolerance/action levels, slightly differs between the three departments applying for this project. This is mainly a result of the differences in the time of major equipment acquisition and available personnel. In all centres, the QC protocols relies on a combination of the above mentioned guidelines and documentation, recent regulatory requirements, manufacturers' recommendations and mutual consultations during the extensive preparation of the tests for their institutions.
The daily tests of treatment machines comprise essential safety and mechanical parameters such as the door interlock and audiovisual monitoring, light field size, laser alignment and their alignment with the crosshairs and optical distance indicator (ODI). Additionally, output constancy tests for the low and high energy photon beams and different electron beams for each treatment machine are done on a weekly basis together with basic beam parameters (beam quality, flatness, symmetry). A part of the QC programme intended to follow monthly and quarterly includes different procedures and devices to check more complex mechanical, radiation and dosimetric parameters of the machines. They also involve different dosimetry methods.
The first part of QA for CBCT includes daily tests that are related to system performance and safety (visual checks and tube warm-up) and file database checks. Other part includes accuracy and image tests: geometric accuracy expressed as an agreement of the CBCT isocenter and MV imaging beam isocenter, registration and positional correction accuracy, and image quality tests including visibility/detectability, uniformity and resolution of acquired images. All tests are organized in daily, monthly and annual QA procedures. The document, based on the recommendations from the manuals and AAPM TG-179, with instructions for undertaking QC tests, is written and available.
The conventional simulator and CT simulator QC procedures comprise daily, monthly and annual tests. In essence, the localising lasers and optical distance indicator are checked. In addition to this, a simple phantom manufacturer's test is followed to check the CT numbers. In monthly tests, the field size, gantry/collimator indicators, light/radiation field coincidence and image quality are tested. Annual tests are reserved for thorough mechanical and radiographic checks.

References:
1. Mijnheer B.J., Battermann J.J., Wambersie A. What degree of accuracy is required and can be achieved in photon and neutron therapy?, Radiother.Oncol., 8, 237-252, (1987).
2. Brahme A. Dosimetric precision requirements in radiation therapy, Acta Radiol.Oncol., 23, 379-391, (1984).
3. Institute of Physics and Engineering in Medicine, "Physics aspects of Quality control in Radiotherapy", Report 81, edited by: W.P.M. Mayles, R. Lake, A McKenzie, E.M. Macaulay, H.M. Morgan, T.J. Jordan and S.K. Powley (IPEM, York, 2000).
4. Kutcher GJ, Coia L, Gilin M, Hanson WF, Leibel S, Morton RJ, et al. Comprehensive QA for radiation oncology. AAPM Task Group 40 report. Med Phys 1994;21.
5. Klein, E.E., Hanley, J., Bayouth, J., et al. Task group 142, American Association of Physicists in Medicine. Quality assurance of medical accelerators. Med. Phys. 36:4197–212; 2009.

6.2 Scientific Scope of the Project (Scientific problems to be addressed with overall and specific objectives):

Dosimetric uncertainties are introduced during the calibration of the reference ionization chamber used for absolute dosimetry, during the relative dose measurements, in the dose calculation by the TPS, and in the actual dose delivered during the irradiation of the patient. Quality assurance is sometimes, for the purpose of formal distinction, divided roughly into dosimetric and geometric QA. Dosimetric quality assurance (QA) in EBRT should grasp all radiation therapy actions affecting the value of the dose absorbed to a patient. The main issues of dosimetric QA at the hospital level are the maintenance of dose output of an accelerator in the predefined tolerance limits, the accuracy of dosimetric measurements (relative dose measurements) and the accuracy of dose calculation that is done by a commissioned treatment planning system.
Geometric QA includes all radiation therapy procedures affecting the location to which the dose is delivered in a patient. Geometric accuracy is crucial for conformal radiotherapy (3D CRT) and particularly in IMRT due to steep dose gradients.
Recent results of an IMRT credentialing process from the Radiological Physics Centre, for example, showed that almost 30% of the participating centres failed to satisfy accuracy criteria of 7% for dose in a low gradient region and/or 4 mm distance to agreement (DAT) in a high gradient.
In hereby proposed set of studies, representative 3DCRT treatment techniques will be tested in phantom measurements (CIRS thorax and head and neck phantom) with available photon beams in three different RT centres. Already available measurement results with CIRS thorax phantom prepared as a part of the IAEA TC project CRO6010-Reinforcement and Further Development of Quality Assurance/Quality Control Programme in Radiotherapy in Croatia, and conducted nationally will be supplemented with additional measurements. In one centre the established (IAEA document) set of measurements will be conducted for the first time. The phantom studies will be done to verify that treatments can be planned and dose delivered with adequate accuracy. In doing so, particular care will be paid to minimize measurement uncertainties and they will be quantified, where applicable. Differences between calculated and measured doses can only be expressively evaluated if the uncertainties are well understood.

6.3 Detailed Work Plan for first year, including proposed methods or techniques:

1. Since one of the centres (UH Rijeka) started with the implementation of conformal radiation therapy a few years earlier than the other two centres involved, part of the QA/QC programme intended to assure quality of treatment planning system started earlier there. It involved comprehensive tests of different parts of treatment planning system. During commissioning the extensive set of dosimetric tests either in water phantom or anthropomorphic phantoms were performed. Dosimetric data were analyzed and repeated with different type of detectors where needed. Measurements in anthropomorphic phantom according to this protocol were also performed in radiotherapy centres which started with 3DCRT in 2010. (UH Zagreb, UH Osijek and UH Split). Tests conducted in accordance with the IAEA protocol for TPS dose calculation verification using homogeneous phantom, in the Department of Oncology and Nuclear Medicine (UHSM), provided the deviations between the measured and calculated dose. Similarly to the previously published results, results for irregular L shaped field and asymmetric wedged fields were out of tolerance for certain groups of points. Additional measurements with ionization chambers with different volumes will be conducted to elucidate the observed discrepancies for wedged and irregularly shaped fields. Of particular interest will be to investigate the behaviour of the planning algorithm for smaller fields that are frequently used in 3D CRT head and neck applications.

2. An anthropomorphic CIRS (CIRS Inc., Norfolk, VA) thorax phantom measurements will be conducted according to the IAEA Technical Report Series 430 and IAEA Technical Document 1583 tests, for both photon energies of Elekta Synergy S, two (2) Siemens Oncor Expression and (1) Siemens Oncor Impression linear accelerators. The phantom will be scanned using Aquillion (Toshiba) and Siemens Somatom Open, CT-simulators clinically used for the planning of patients. Scans of the phantom will be performed initially to obtain CT numbers to the relative electron density conversion. The department's scanning protocol will be followed to obtain CT image sets for the planning of various clinical test cases in the centre where no such measurements have been carried out before. Only clinically employed TPS calculation algorithm and dose calculation grid will be used in measurements. Verification criteria will be set according to IAEA TRS 430. The measured data will be compared with available data from other departments that had already performed these measurement sets.

3. One of the most frequent treatment sites are head and neck sites. The treatment of these sites requires what is known as the conformal parotid sparing technique (ConPas), in which a large number of mostly asymmetric fields are used to shape the satisfactorily concave dose distribution, with a purpose of reducing the dose to the parotid glands and the spinal cord. For such a combination of fields, in only one centre (UH Rijeka), the verification phantom measurements have been conducted up to now. The measurements were performed with 0.6 cc ionization chamber (due to phantom inserts holes) and regarding that, some of the measurements in large dose gradients of half wedged beams were of limited value. These areas will be additionally measured using small volume chamber when conditions (inserts with small hole) for this will be fulfilled. CIRS head and neck phantom offers a possibility to get this information, and therefore the test mimicking the typical field arrangement and would be crucial in further development of the technique and the appropriate QC procedures. Different type of CBCT units available in departments may also provide additional comparison of their properties important in clinical settings.

4. Conformal radiotherapy (3DCRT) is a standard treatment for localised carcinoma of the prostate. Main challenge in radiotherapy treatment of prostate cancer is accurate treatment delivery to the prostate, due to changing anatomy caused by differences in bladder and rectal conditioning/filling of the patient. Image guided radiotherapy (IGRT) is routinely used worldwide to solve this problem, but has not been fully implemented in radiotherapy centres in Croatia. Since CBCT patient position verification is an option in all above-mentioned centres, what remains is to determine the frequency of the position checks and appropriate protocols for position determination and correction of the prostate. Anthropomorphic phantom measurements would enable determination of positional margins acceptable to achieve adequate dose delivery to the target volume. In the first phase, improvised prostate field arrangements (e.g. “box” technique, 5 and 6-field techniques) could be tested with the available CIRS phantom.

5. Depending on available time and resources, the tests with (0.6 cc) ionisation chambers (and films) and CIRS phantoms, will be complemented, where missing, with measurements using small volume chambers and afterwards with anthropomorphic phantom measurements with TLD and RPL dosimeters particularly for the head and neck treatment localisations. These measurements will be compared to the results obtained from the ionisation chamber measurements with CIRS head and neck and thorax phantoms.

6.4 Expected Outputs:

The expected ultimate outcome of the research project will be to properly recognise the causes and level of the uncertainties associated with particular dosimetric measurements (relative dose measurements) and the accuracy of dose calculation steps in RT process, and to reduce them to provide safer and more effective patient RT treatments.

More specifically:

1. A thorough critical overview of the existing QC practices related to the treatment and imaging machines and related procedures, motivated by specific goals of this study will be carried out. The results will be utilized for fine tuning of a local QC program in the sense of revised measurement time intervals and re-establishment of tolerance/action levels. These results will help us in attempting to harmonize the QA/QC practices throughout the RT departments in Croatia.
2. Anthropomorphic CIRS thorax and head and neck (CIRS Inc., Norfolk, VA) phantom measurements will be conducted according to the IAEA Technical Report Series 430 and IAEA Technical Document 1583 tests, for available photon energies with the linear accelerator where these measurements have not been conducted before. New clinical test cases will be discussed and beam arrangements will be designed and tested to further expand the previous studies. As the TPS algorithm is one of the most important factors that influences the final dose to the patient, these measurements will give us better understanding of what may be expected in treatment techniques where small, asymmetric, wedges and inclined fields are used to irradiate small volumes. The tests may also provide information on potential discrepancies that may exist in the TPS input data or that were generated in doing the beam fitting procedure.
3. The output of these investigations will enable us to design further clinical studies in which the differences in set-up errors as measured with the electronic portal imaging (EPID) and 3D CBCT could be determined and quantified as to propose set-up margin definitions depending on the imaging modality used.

RELATED WORK ALREADY PERFORMED OR IN PROGRESS AT INSTITUTE (including work performed in connection with the IAEA through Technical Cooperation projects):

Department of oncology and nuclear medicine, UHSM
The main research interests in EBRT are closely related to the previous research topic, in-vivo dosimetry in RT in which the procedures for in vivo dosimetry were developed and evaluated to make them potentially available to radiotherapy centres in various countries and ultimately, improve the radiation dosimetry practices through increased precision of dose delivery to cancer patients. New type of dosimeters for this purpose will be tested (e.g. RPL) and there are plans to evaluate and introduce EPID for dosimetry checks.
Participation in dosimetry audits: The institution participated in the postal dosimetry checks ESTRO EQUAL for the Co-60 beam (Theratron 80) in 1998. The results were within the tolerance level of ± 5%, and all except one, within the optimal level of ± 3%. Later, the institution regularly participated in the postal TLD IAEA-WHO postal dose audit service in which practically all results for the deviation between the measured and calculated dose, in the Co-60 beam) were below ± 1% (period 2000-2009.). Following the linear accelerator (Elekta, Synergy S) installation in 2012, the results of the same service, for two photon energies, 6 and 18 MV, were -0.8 and -1.5%, respectively.

Clinic for Radiotherapy and Oncology, Physics Division, University Hospital Rijeka, Rijeka
Participation in dosimetry audits: The institution participated in the postal dosimetry checks ESTRO EQUAL for the photon beams of linear accelerator and Co-60 beam in 1998. The results of the measurements were within the optimal level of ± 3%. Past ten years we've been periodically (every two years) participated in IAEA-WHO TLD postal audits of high energy photon beams used in radiotherapy. The results of the measurements were well within the optimal level of ± 3%. In 2007. Radiotherapy department participated in IAEA Quality audit in radiation therapy (QUATRO).

Department for Radiotherapy and Oncology, University Hospital Osijek; Department of Physics, School of Medicine, University of Osijek, Osijek
Participation in dosimetry audits: The institution participated in the postal dosimetry checks ESTRO EQUAL for the photon beams of linear accelerator and Co-60 beam in 1999. The results of the measurements were within the optimal level. Past ten years we've been periodically (every two years) participated in IAEA-WHO TLD postal audits of high energy photon beams used in radiotherapy. The results of the measurements were well within the optimal level.

8. PLEASE LIST FACILITIES (building, equipment - including type and name of manufacturer, and materials) PRESENTLY AVAILABLE WHICH WOULD BE USED FOR THE PROJECT:

UHCSM
Facilities and major treatment and imaging units: 1 linear accelerator Elekta Synergy S, with IGRT option (kV CBCT, EPID)**,** CT simulator (Toshiba, Aquillion)**,** simulator (Simview 3000, Siemens)**,** HDR brachytherapy remote afterloading basic unit (Gammamed iX PLus, Varian**,**HDRBT TPS Brachyvision)
Dosimetry equipment: Wather phantoms: 1) Blue phantom, Wellhofer Dosimetrie with CU500E Controller and WP700 Software; 2) MP3-M WP PTW Freiburg with MC2 Mephysto software, both with sets of waterproof ionisation chambers, E and P diodes, 2 water phantoms for absolute dosimetry, QuickCheck Webline, RW3 solid phantom, Alderson-Rando phantom, geometry and quality phantoms for QC of kVCBCT, UNIDOS Universal dosemeter (3 pieces), TW30002-1/0203,0204, Farmer type chamber 0,6 ccm, TW23343/3034, Markus electron chamber 0,055 ccm, advanced Markus chamber,
DPD-3 Scanditronix basic unit with Si diodes EDE-5
TPS for EB and BT: XiO, Brachyvision

Clinic for Radiotherapy and Oncology, Physics Division, University Hospital Rijeka, Rijeka
Facilities and major treatment and imaging equipment: 2 linear accelerators (Siemens) with MLC and portal imaging systems, CT simulator, conventional simulator, superficial/orthovoltage machine
Dosimetry equipment: 2 water phantom system for relative dosimetry with electrometers and sets of ionization chambers (from 0.01 cc to 0,15 cc) and diodes, 2 water phantoms for absolute dosimetry, 4 electrometers for absolute dosimetry with different types of ionization chambers (4 waterproof Farmer type chambers, 3 Roos chambers, 2 Markus chambers, linear diode array IBA LDA**,** 2D array detector IBA Matrixx **,** QuickCheck Webline**,** Vidar scaner and Coherence Physicist software for radiographic film dosimetry**,** Epson10000XL scanner and OmniPro iMRT software for radiochromic film dosimetry**.** Phantoms**:** CIRS Thorax**,** CIRS Head&Neck**,** Raw water phantoms (2 sets)**,** QC3 and FP2 phantoms for QC of portal imaging system**,** geometry and quality phantoms for QC of CBCT**,** geometry and quality phantom for QC of CT**,** CTDI phantom for CT
TPS for EB : XiO, MUCheck-independent monitor unit calculation system

Department for Radiotherapy and Oncology, University Hospital Osijek; Department of Physics, School of Medicine, University of Osijek, Osijek
Facilities and major treatment and imaging equipment: 1 linear accelerator with MLC and MV CBCT imaging system, CT simulator, conventional simulator
Dosimetry equipment: 2 water phantom system for relative dosimetry with electrometers and sets of ionization chambers (from 0.01 cc to 0,15 cc) and diodes; water phantom for absolute dosimetry. 2 electrometers for absolute dosimetry with different types of ionization chambers (3 waterproof Farmer type chambers, 2 Roos chamber…)**;** 2 QuickCheck Webline**;** Gafchromic film dosimetry suite (Epson10000XL scanner and OmniPro iMRT software for radiochromic film dosimetry)
Phantoms: CIRS thorax phantom, Raw water phantoms (2 sets), QC3 and FP2 phantoms for QC of portal imaging system, Geometry and quality phantoms for QC of CBCT, Geometry and quality phantom for QC of CT, CTDI phantom for CT
TPS for EB : XiO

9. BUDGET. Estimate for first year of project (please show all amounts in EUR €):

A. Institute's Staff Contribution

Research personnel and estimated percentage of total working time to be devoted to project:	Estimated project costs in €

Personnel	Time (%)	
Tomislav Bokulić	20	2500
Mirjana Budanec	15	1700
Iva Mrčela	10	1200
Marin Gregov	10	1200
Mihaela Mlinarić	10	1200
Slaven Jurković	20	2500
Đeni Smilović	10	1200
Manda Švabić	10	1200
Darion Faj	20	2500
Mladen Kasabašić	10	1200
	Sub-total:	16400€

B. Equipment

Item	Estimated project costs in €
Sub-total:	0 €

Do you require the Agency to purchase any of the above equipment?

☐ Yes ★ No

C. Miscellaneous (including transport*):

Item	Estimated project costs in €
Transport of the phantom from one centre to another	500€
Organisation of the workshop for scientific staff from the three participating institutions to formulate the measurement work plan, propose timeline and assign tasks	1000€
Sub-total:	1500€

* If funds for travel/transportation have been included in the budget, please indicate specific purpose:

THE IAEA REQUIRES THAT ITS RELEVANT HEALTH AND SAFETY STANDARDS ARE OBSERVED. IF A CONTRACT IS AWARDED, YOU WILL BE NOTIFIED OF THE STANDARDS THAT ARE TO APPLY TO THE ACTIVITIES TO BE CARRIED OUT UNDER THE CONTRACT.

D. Total - All Costs (Budget Items A - C):

Total estimated project cost:	17900€

E. Overall Cost Estimates (in EUR €):

Amount to be contributed by the Institute:	12700€
Amount expected from other (non-IAEA) sources:	0 €
Amount requested from the IAEA:	5200 €
	17900€

10. THE PREFERRED METHOD OF PAYMENT IS BY BANK TRANSFER, PAYABLE TO THE ORDER OF THE INSTITUTE. PAYMENTS ARE MADE IN EURO.

PLEASE PROVIDE THE FOLLOWING INFORMATION:

NAME OF INSTITUTE'S BANK: **ZAGREBAČKA BANKA**

BANK ADDRESS: ILICA 164, 10000 ZAGREB, CROATIA

ACCOUNT NAME (IN THE NAME OF THE INSTITUTE): ZAGREBAČKA BANKA 2360000-3208036

ACCOUNT NO: ID No. 91122718 (IAEA Research Contract No 13115) This ID number was specifically opened for the previous project and it might be changed.

BANK ROUTING NO (SORT CODE, BIC, SWIFT CODE OR IBAN): ZABAHR2X

IF PAYMENTS SHOULD BE MADE TO A DESIGNATED PERSON ON BEHALF OF THE INSTITUTE, PLEASE REQUEST EXCEPTION BELOW, STATING THAT THE DESIGNATED PERSON IS SO AUTHORIZED BY THE RULES AND REGULATIONS OF YOUR INSTITUTE.

11. IF THE PROJECT NEEDS MORE THAN ONE YEAR TO COMPLETE, PLEASE GIVE ESTIMATE OF FUNDS REQUIRED (in EUR €) FOR EACH PROJECT YEAR.

Project Year	Staff Costs	Equipment	Miscellaneous	Project Total	Requested from the IAEA
1st	16400€	0 €	1500€	17900€	5200 €
2nd	17200 €	0	0	17200	4000
3rd	18000 €	0	0	18000	4000
Total	51600€	€	1500€	53100€	**13200**€

12. DOES INSTITUTE HAVE INDEPENDENT LEGAL PERSONALITY? **X** Yes ☐ No

If no, please provide details of the organization that would be the contracting partner:

13. PROPOSED PROJECT COMMENCEMENT DATE: 1.06.2013.

14. SIGNATURES:

CHIEF SCIENTIFIC INVESTIGATOR*:*
Tomislav Bokulić, Ph.D., assistant professor

Signature Date
15.03.2013

HEAD OF INSTITUTE*:*
Academician Zvonko Kusić, full professor of oncology, M.D., Ph.D.

Signature Date
15.03.2013

PLEASE NOTE: RESEARCH CONTRACT PROPOSAL FORMS WILL NOT BE PROCESSED UNTIL SIGNED COPIES ARE RECEIVED BY THE IAEA.