1. Background and motivation

Cancers are one of the largest causes of death in Denmark and treatment of cancers is highly prioritized by the Danish healthcare system. External radiotherapy with megavoltage x-rays is one of the main treatment methods for cancer patients, but has the downside that the ionizing radiation also damages healthy tissue. Because of this, the main focus in radiation treatment is to reduce radiation dose to organs at risk while keeping sufficient coverage of the target tumor. Precise location of the tumor is therefore of the outmost importance. To control tumor movement different techniques are used, this can be that the patient being fixed in a certain position, tracking of the tumor with external markers. Linacs with integrated CT-scanners have the possibility perform CT-scans enabling better positioning of the patient before treatment, but this increases the amount of ionizing radiation the patient receives thus increasing the risk for secondary cancers. None of these techniques enables direct tracking of the tumor during treatment.

The new combination of external radiotherapy with megavoltage x-rays and online magnetic resonance (MR) image guidance makes it possible to continuously image the patient during treatment, thus enabling direct tracking of the target tumor. This technique has recently become commercially available and the clinical implementation is in progress worldwide. Denmark is in the forefront of the uptake of this new technology with MR-linacs already in clinical use at three university hospitals (Odense, Rigshospitalet and Herlev).

2. Hypotheses

The main driver for the use of MR-linacs is the ability to continuously image the irradiated volume while treating the patient. MR-linac based treatment requires new data about the capabilities of the device. This data needs to be detailed and realistic information about the quality of the images, time between images and irradiation and dose depositing. For example, any delay between images and the control of the irradiation beam will translate into larger treatment volumes to secure target coverage. In order to deliver this data the system must both be MRI compatible and provide high level of time resolution, able of measuring dose per pulse. These requirements leads to the following hypotheses.

- Hypothesis 1 is that a dosimetry system can be developed that can provide the unique required data about the capabilities of the MR-linac

- Hypothesis 2 is that the dosimetry system ideally can be based on point detectors constructed from organic plastic scintillators coupled to thin PMMA optical fiber cables [2].

- Hypothesis 3 is that the optical nature of the all-plastic dosimetry system will enable online dosimetry with high time resolution that can be used during simulated treatments of phantoms.

- Hypothesis 4 is that the dosimetry system will not disturb the MR imaging, and with a suitable marker the online position of the detector points can therefore be traced on the

MR linac images.

- Hypothesis 5 is that the high degree of water equivalence of the dosimetry system will provide traceable doses essentially without any need for corrections.

- Hypothesis 6 is that the system will be able both (i) to verify that that correct doses are given to the target, (ii) to verify that zero (or very low doses) are given to risk organs, and (iii) to measure the latency between images and beam pulse delivery.

2. Objectives

The objective of this PhD project is to develop a new detector system that is capable of providing new and useful data for improving MR-linac based radiotherapy.
As stated in the hypotheses the detector system is based on organic plastic scintillators integrated in a dynamic phantom able to simulate a moving target. Furthermore along with a method for calibrating the system to absolute dose.
The main objective has been divided into the following aims.

- *Aim 1: Test the feasibility of a all plastic system in an MR-linac, is tracking possible.*

- *Aim 2: Implement the electromagnet with the radiation sources. Characterize beams, magnetic field and temperature conditions during operation.*

- *Aim 3: Characterize scintillator response in strong magnetic fields with a focus on (i) how the the scintillator signal changes with field strength and (ii) how the scintillator light can be separated from the Cerenkov light produced in the fiber cables during irradiation in beam. Alanine may be used as reference detector.*

- *Aim 4: Develop a Monte-Carlo model (for example, using the EGSnrc code system or TOPAS) of the detector to better understand it characteristics and to improve its design.*

- *Aim 5: Construct final system and integrate it with a simple dynamic phantom that can be used for latency and other measurements in clinical beams.*

- *Aim 6: Perform phantom measurements in clinical beams.*

3. Work

The development work will primarily be carried out in the medical dosimetry research laboratory at Risø Campus. This laboratory has one medical linac accelerator (Varian Truebeam), one cobalt source, one large electromagnet (2T), extensive dosimetry equipment, and dedicated laboratories for optics and electronics. Measurements in clinical beams will be performed at Copenhagen University Hospitals at Herlev and Copenhagen. These hospitals recently acquired state-of-the-art ViewRay MR accelerators (0.35 T).

The first part of the PhD will focus on the feasibility of the organic plastic scintillators as suitable for dosimetry in a MRlinac specifically regarding their MRI compatible, along with a calibration technique for the scintillators. A challenge will be correcting for Cerenkov radiation with moving phantom and with a magnetic field.

Throughout the PhD Monte Carlo simulations will be used to understand the experimental data acquired. Especially the TOPAS code will be useful in gaining a deeper understanding of the final system as it enables simulation of moving objects.

4. Relation to other PhD projects

This PhD project will produce data that will ultimately be used by a parallel clinical PhD project supervised by the same team of researchers from DTU, Rigshospitalet and Herlev.

The work will be integrated into the Danish Comprehensive Cancer Care center (RT).

5. References

[1] Raaymakers, B.W. et al: *First patients treated with a 1.5 T MRI-Linac: Clinical proof of concept of a high-precision, high-field MRI guided radiotherapy treatment.* Physics in Medicine and Biology 62(23) L41-L50, 2018.

[2] Beierholm, A.R. et.al: *Characterizing a pulse-resolved dosimetry system for complex radiotherapy beams using organic scintillators.* Physics in Medicine & Biology, 56(10) 3033–3045, 2011.