

DESIGN OF AN ANTHROPOMORPHIC INTENSITY MODULATED RADIATION THERAPY QUALITY ASSURANCE PHANTOM

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Introduction

The dynamic nature of IMRT delivery poses unique problems relating to the accurate and reproducible quality assurance of dose delivery. The usefulness of point detectors is limited to static fields and regions within low dose-gradients for treatment verification. However, dose distributions generated in intensity modulated radiation therapy (IMRT) often have complex shapes with high dose gradient regions surrounding critical patient structures. Currently, there is no standardized tool for evaluating IMRT treatment delivery. As part of its commitment to the Advanced Technology Consortium, the Radiation Physics Center (RPC) is developing an anthropomorphic quality assurance phantom for the purpose of reviewing IMRT treatment modalities at institutions participating in future NCI cooperative clinical trials. The phantom will verify the ability of institutions to meet the criteria for field localization and three-dimensional dose delivery for IMRT treatments. Specifically, the design of the phantom will allow the measurement of target dose homogeneity to within 5%, field localization for high dose-gradient regions to within 2mm, and absolute dose to isocenter to within 5%. In this poster we present the development of a quality assurance tool for use in the verification of IMRT delivery modalities used in dose-escalated conformal therapy of the prostate. These treatment modalities include the MIMiC arc delivery system, dynamic MLC, and compensators.

Hypothesis for IMRT Phantom Design Project

An anthropomorphic treatment verification phantom can be developed that is capable of assessing field localization, dose homogeneity and absolute dose as delivered by an IMRT technique within specified criteria:

- Absolute dose delivery to isocenter shall be within 5%.
- Planar dose homogeneity shall be within 5% assessed by a dose area histogram
- Field localization shall be within 2 mm in high dose-gradient regions assessed by profiles

Materials and Methods

Phantom Design Requirements

- Mailable
- Imageable target & critical structures
- Heterogeneous
- Contain dosimeters for absolute dose, dose homogeneity and field localization
- Easy to use
- Accommodate current IMRT treatment techniques

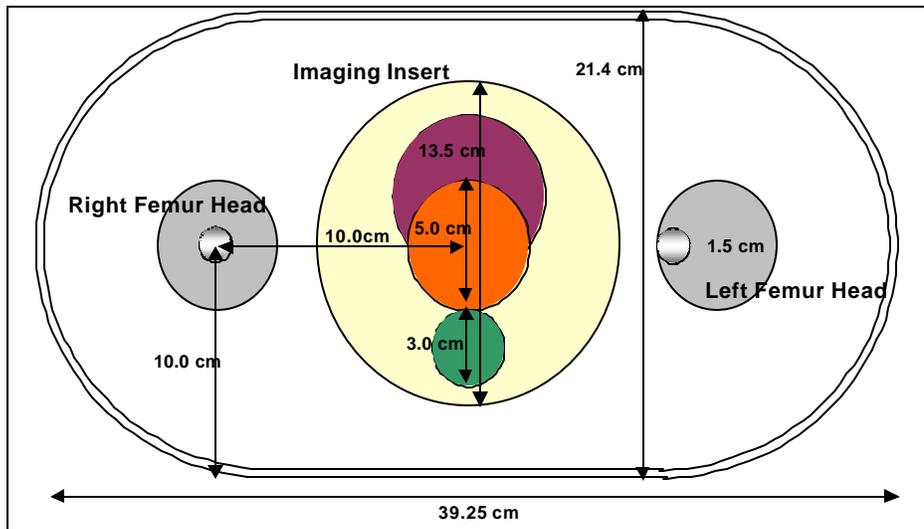
Phantom Design Geometry

Phantom materials and densities

Phantom Region	Phantom Material	Density (g/cm ³)	CT Number	Patient CT Number
Insert	acrylic	1.17	1123	-----
Rectum	polyethylene/wax	0.95/1.00	950	922
Prostate	Nylon	1.15	1088	1026
Bladder	polyethylene	0.95	923	1001
Femoral Heads	PBT-Polyester	1.31*	1203	1297
Marrow	acrylic	1.17	1123	-----
Phantom	PVC	1.37	1297	-----

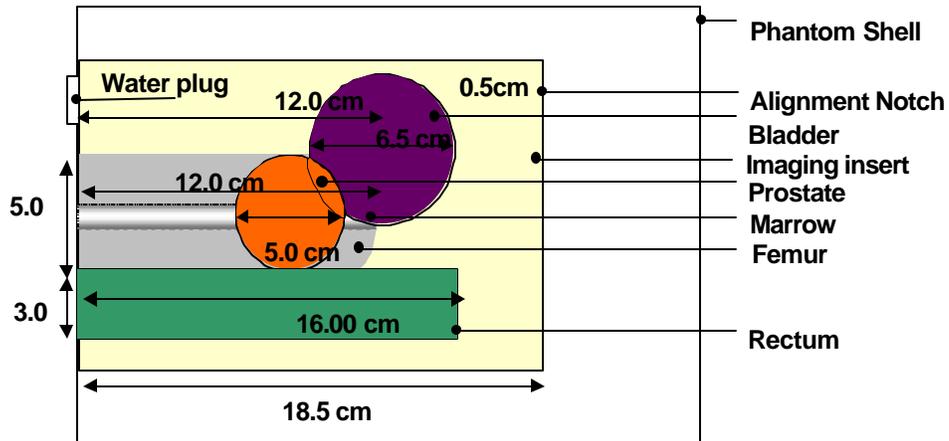
Phantom Design Geometry

Transverse view of the design of the IMRT pelvic phantom



Phantom Design Geometry

Sagittal view of the design of the IMRT pelvic phantom



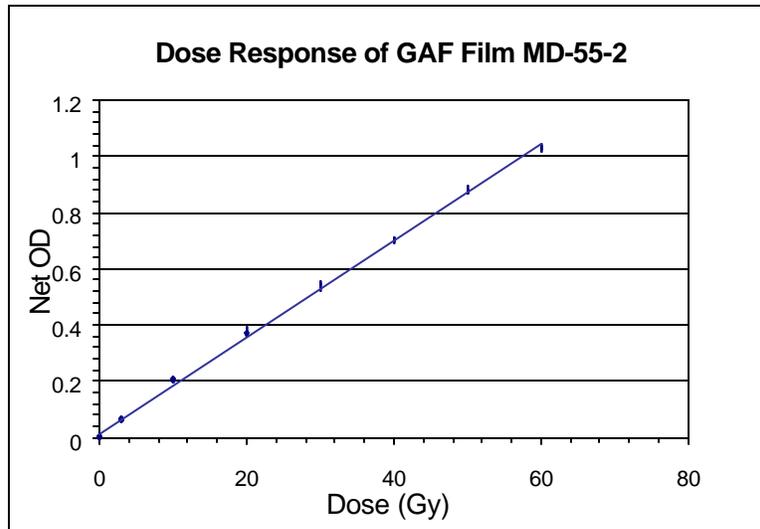
Materials and Methods

Dosimeter Requirements

- A well characterized dose response
- Little to no energy nor angular dependence
- Quantifiable fading without signal to noise reduction
- Ability to resolve to within 2 mm for high dose-gradient regions

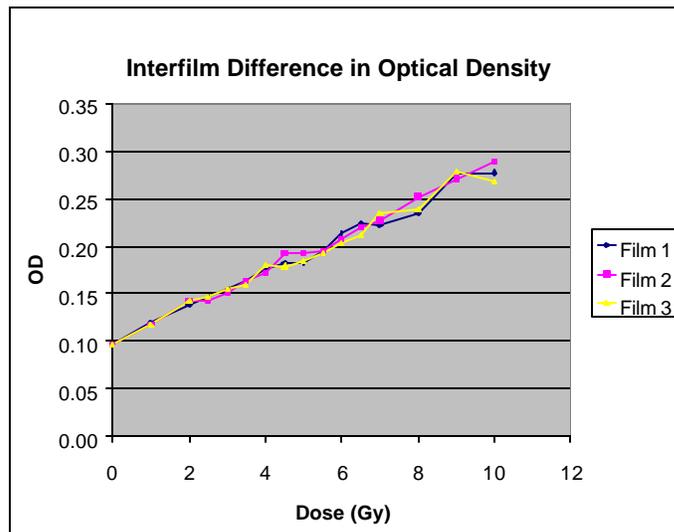
Both TLD and radiochromic film exhibit these qualities, and have been chosen for use within the IMRT pelvic phantom.

Materials and Methods



The dose response of GAF chromic film is plotted above. 3cm x 3cm pieces of GAF film were centered in a 10cm x 10cm field and irradiated from 0 to 60 Gy with a 6MV photon beam under calibration conditions. To obtain optical density, films were scanned with a Molecular Dynamics Personal Densitometer. The dose response of the film over this range is linear.

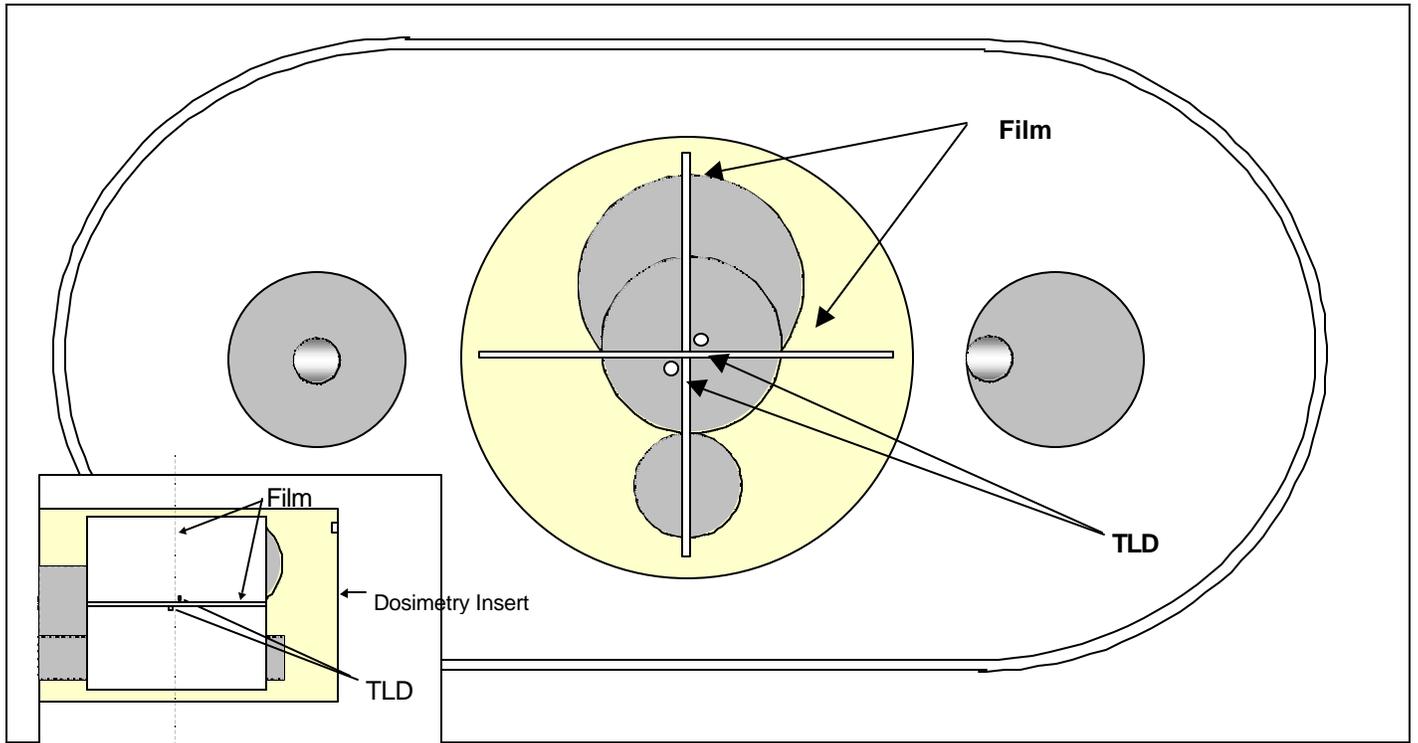
Materials and Methods



To determine if there is an inter-film difference in dose response for films of the same lot, three films were isolated and dose response for each film to a 6 MV photon beam was determined. This plot shows that there is no inter-film dose difference.

Materials and Methods

Location of Dosimeters



The target coverage by the dosimeters is shown in this transverse cross-section of the phantom. TLD capsules are located 3mm from the target center. Film is localized using pinholes that fix film within the dosimetry insert. These pinholes are at known distances from the center of the target and are used to localize scanned films into the phantom coordinate system. The femoral heads, providing heterogeneity during irradiation, are mounted inside the phantom shell and are non-removable. To obtain dose information within the heterogeneity, TLD capsules are screwed into the end of acrylic inserts that fit into the femoral heads aligning the capsules parallel to the center of the treatment target. The inset shows a sagittal view of the location of the dosimeters.

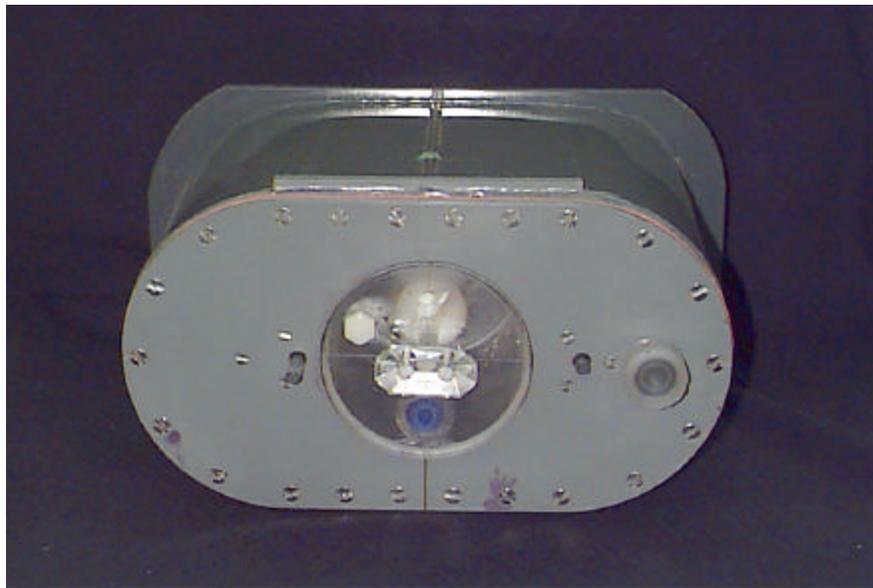
Lateral view of phantom

Results

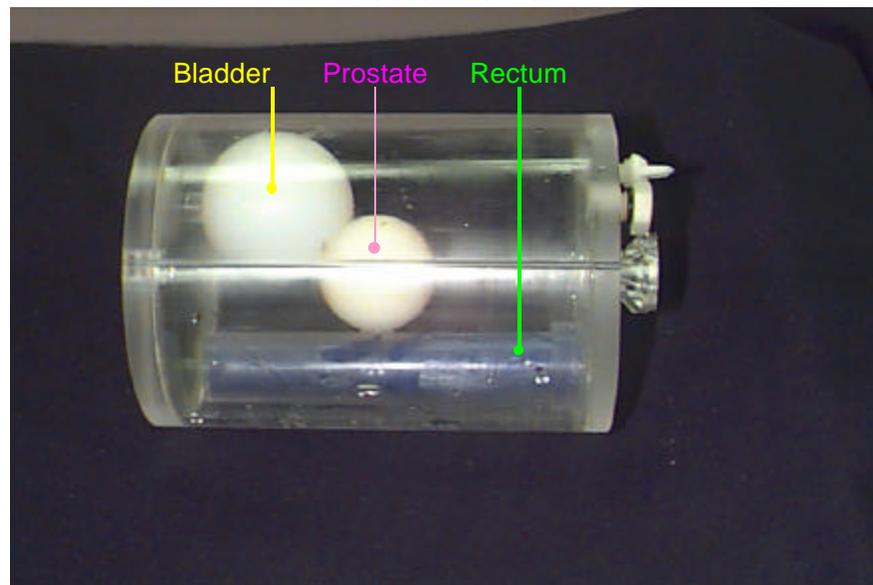


Phantom Description

The phantom sits slightly above the table on level edge rails. This allows for easy removal of the couch from the treatment plan, and easy leveling of the phantom. Because the phantom must be mailable it has been designed to be light weight. It is a PVC shell that can be filled with water. For ease in filling the phantom and to minimize air trapped in the phantom there are two filling spouts and a bleeding screw. A small air bubble within the filled phantom is unavoidable because of the location of the filling spout at the inferior end of the phantom. However, a reliable procedure for removal of the air pocket from the treatment field has been developed. In order to eliminate variation in selection of isocenter, fiducials have been placed on left, right and anterior sides of the phantom shell marking the corresponding center of the target for use in laser alignment. The water fillable hollow PVC shell with both the inserts has a combined mail out mass of 10 kg (22 lbs.). The combined lift mass of the phantom is 21.7 kg (47 lbs.) when filled with water and the dosimetry insert (heaviest insert). The shell was designed to approximate average patient size and its size and shape were modeled from the IAEA pelvic phantom.

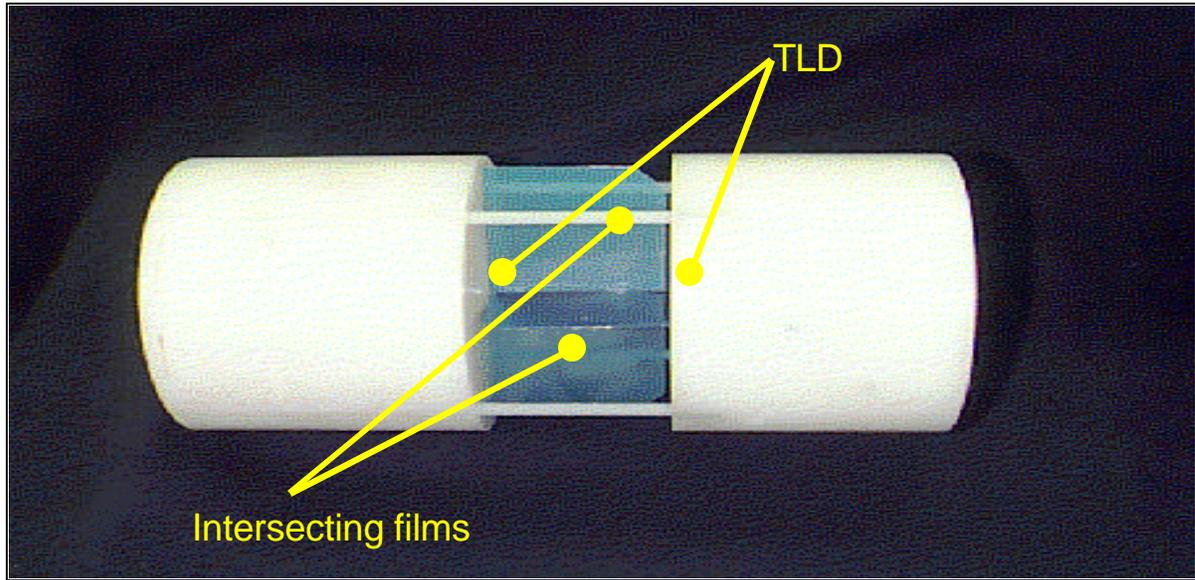


IMRT Pelvic Phantom

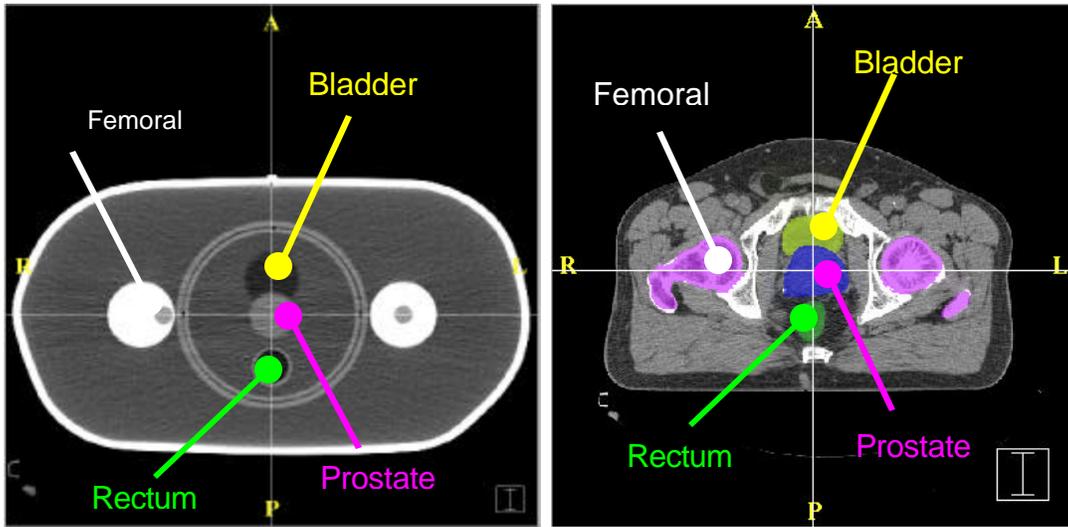


Imaging Insert

There are two interchangeable inserts. The imaging, or anatomy insert, has prostate, bladder and rectum structures mounted in an acrylic water fillable shell. This insert allows the phantom to be imaged with CT and then treatment planned on a 3D treatment planning system. The imaging insert is a hollow acrylic shell that is water-fillable. Trapped air is removed through the air bleed hole at the inferior end of the insert. The insert is aligned within the phantom using an alignment notch. A handle is mounted on the inferior end of the insert for easy removal from the phantom. Because of the extremely tight fit in the insert holder of the phantom, four air release notches have been machined along the length of the insert. A spherical nylon ball simulating the prostate is mounted within the shell. The simulated bladder, which cups slightly around the prostate, is made of polyethylene. A cylinder of wax is enclosed in a thin polyethylene tube to represent the rectum and rectal wall. The polyethylene cylinder encasing the wax rectum also serves to water proof the wax. To accurately represent patient anatomy a small air cavity has been machined through the center of the wax rectum.



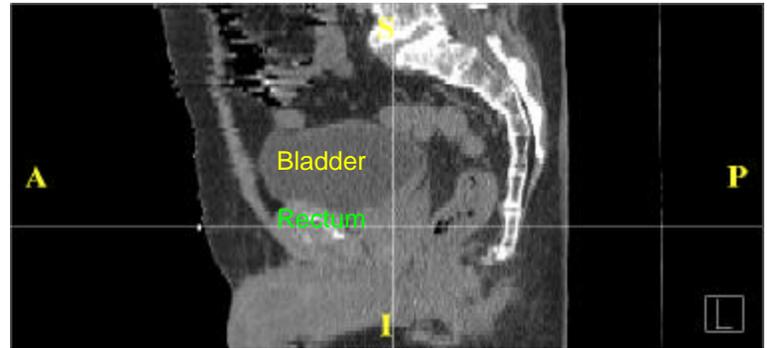
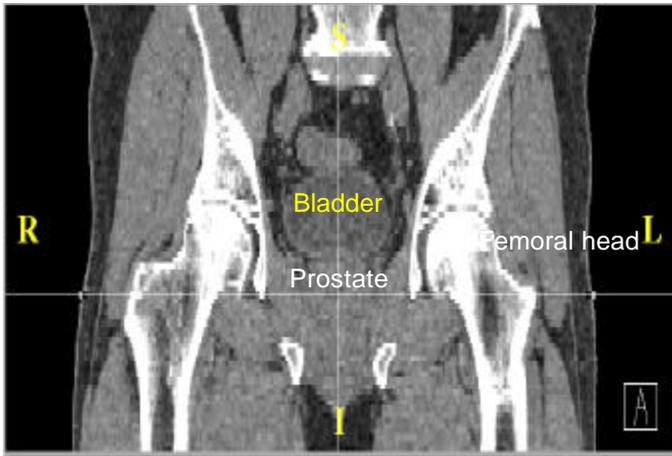
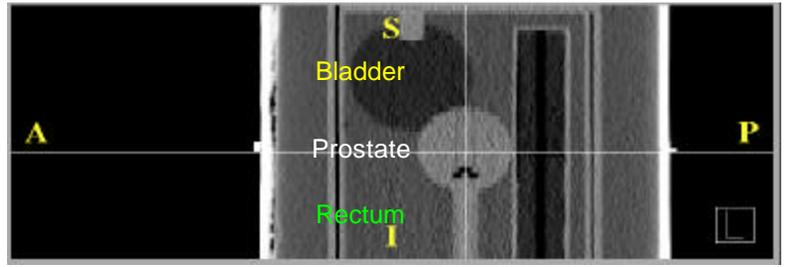
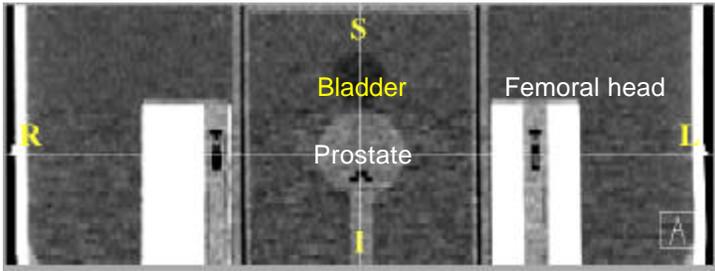
The dosimetry insert is a solid cylinder of high impact polystyrene. Like the imaging insert, an alignment notch is used to correctly place the insert in the phantom shell. An air release notch has been machined along the insert's length and a handle is mounted on the inferior end. The dosimeters within the dosimetry insert are located at known locations relative to the center of the prostate in the imaging insert. Two intersecting pieces of radiochromic film to measure relative dose distributions. The dosimetry insert accommodates two TLD capsules whose centers are located 3mm superior -anterior-left and inferior -posterior-right of the corresponding know location of the center of the target (prostate) of the anatomical imaging insert. To improve spatial localization of the absolute point dose measurement, the powder within the capsules is compressed (4mm x 3mm) minimizing the dimensions of the powder contained in the capsule. This approximately spherical geometry eliminates angular dependence. The same type of capsule is used in the femoral head inserts. The films are placed in coronal and sagittal planes, which is optimal positioning for determining the dose profiles in the directions of the dose limited structures (femoral heads, bladder and rectum).



The phantom was designed to mimic actual patient anatomy as seen above. The femoral heads, bladder and rectum are critical structures used to drive treatment plan optimization. The acrylic inserts of the femoral heads create a lower density region in the central portion of the femoral head simulating bone marrow. The asymmetrical positioning of the acrylic TLD holders within the femoral heads allows the treatment planner to identify phantom left from right and unmask errors in the inverse planning optimization that can be hidden by symmetry.

Coronal

Sagittal



Coronal and sagittal views in the film planes comparing phantom and actual patient geometry

Phantom Commissioning

Compare absolute dose, dose homogeneity and field localization reproducibility of phantom with industry standard

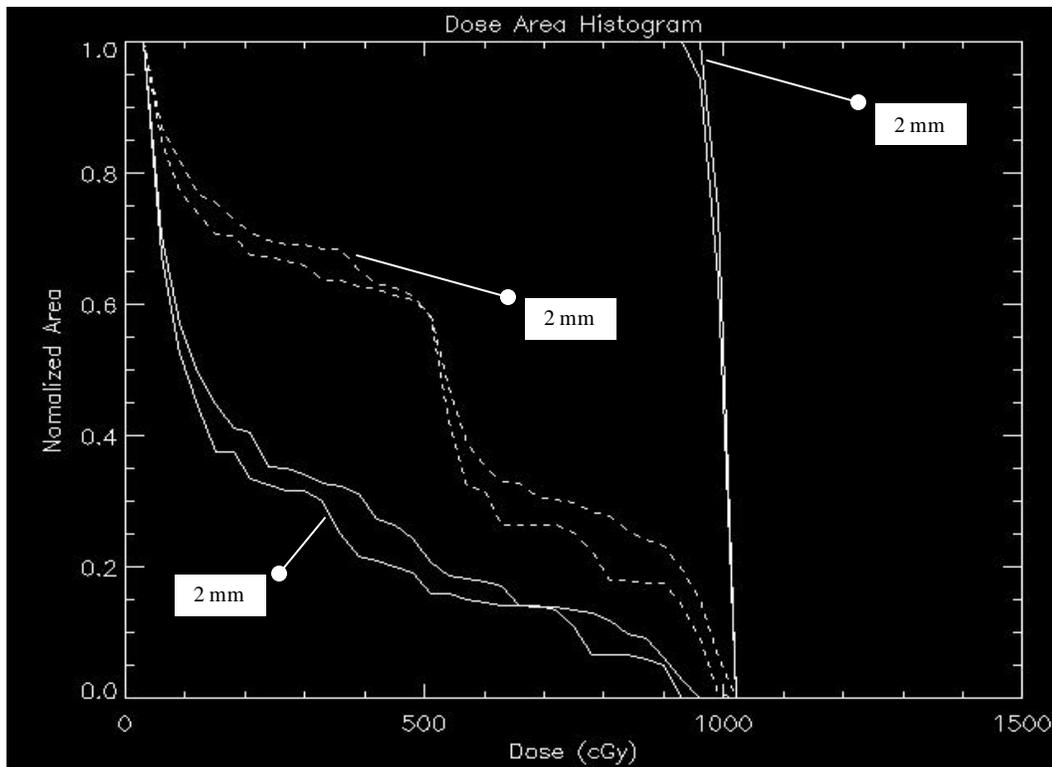
- Deliver Industry Standard (4 field box) to phantom
- Open field, 4 equally weighted beams
- Deliver 5.4, 10 and 20 Gy to isocenter

Absolute Dose Delivery

TLD Location	TPS Dose (cGy)	TLD Dose (cGy)	TLD/TPS
Prostate (isocenter)	539.6	543.9	1.01 ± 0.006
Right Femoral Head	306.2	302.1	0.99 ± 0.008
Left Femoral Head	305.7	313.4	1.03 ± 0.006

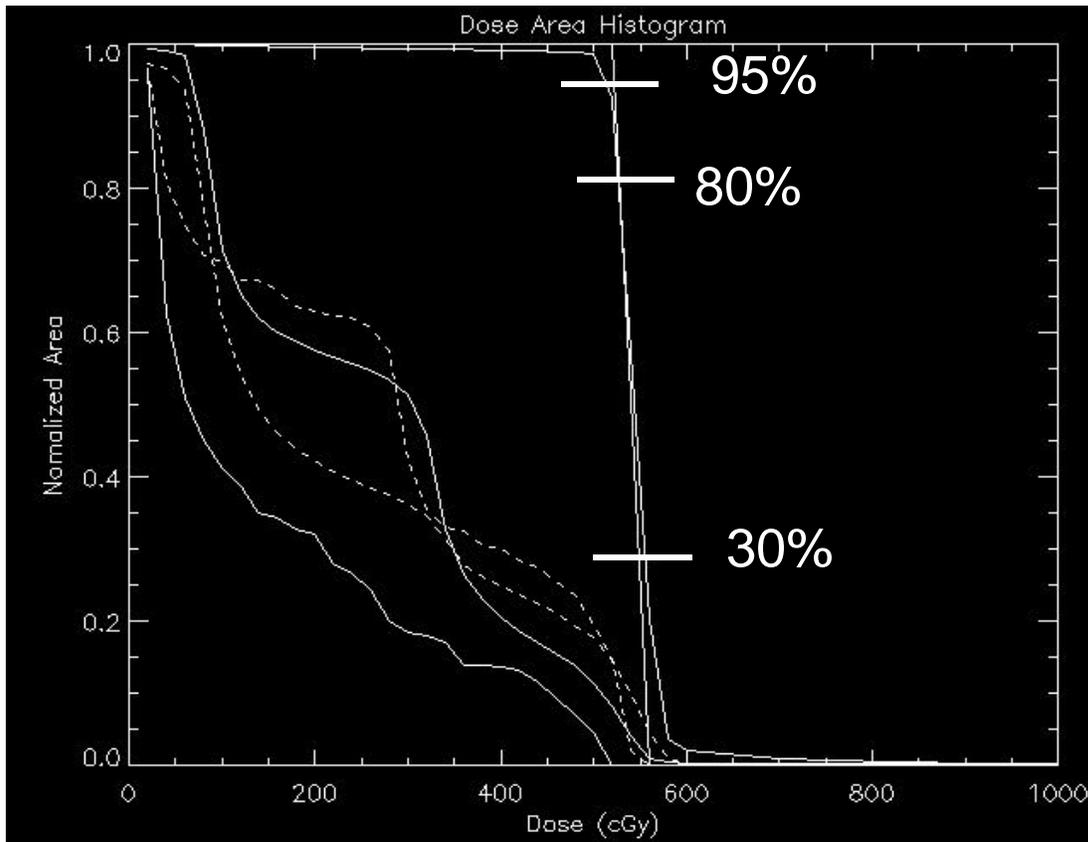
The above table shows the absolute dose as measured by TLD in the target center and the femoral heads for a prescribed dose of 5.4 Gy to isocenter. TLD doses agree within 3% of the treatment planned dose at all locations and the phantom gives reproducible absolute dose measurement results. TLD doses are the average of four phantom irradiations.

Dose Homogeneity



Dose area histograms are used to determine the target coverage in sagittal and coronal planes. The figure above compares ADAC pinnacle dose histograms generated with 2mm and 4mm dose grid resolution in the sagittal plane. The qualitative comparison shows that there is a difference in DAH due to dose grid resolution for critical structures. but very little difference in

Target Coverage



Dose area histograms were determined in the sagittal plane for a prescribed dose of 10 Gy to isocenter. The graph above shows a comparison of film and treatment planning system histograms. Areas of quantitative analysis are shown. Dots indicate bladder.

TARGET COVERAGE

Area	Film Dose (cGy)	TPS Dose (cGy)	Film Dose/ TPS Dose
95%	955.1	970.2	0.98
80%	983.6	972.6	1.01
30%	1014.6	1003.6	1.01

Overall DAHs for each region of interest (prostate, bladder, and rectum) were qualitatively inspected for agreement. Critical structure doses do not agree. However, there is good qualitative agreement in target area coverage. The doses for three target coverage areas were compared (95%, 80% and 30% of the prostate area in sagittal plane). In the table above, the doses measured by the film agree with the treatment planning system within 2%. The phantom can reproduce the same dose homogeneity as the industry standard treatment plan.

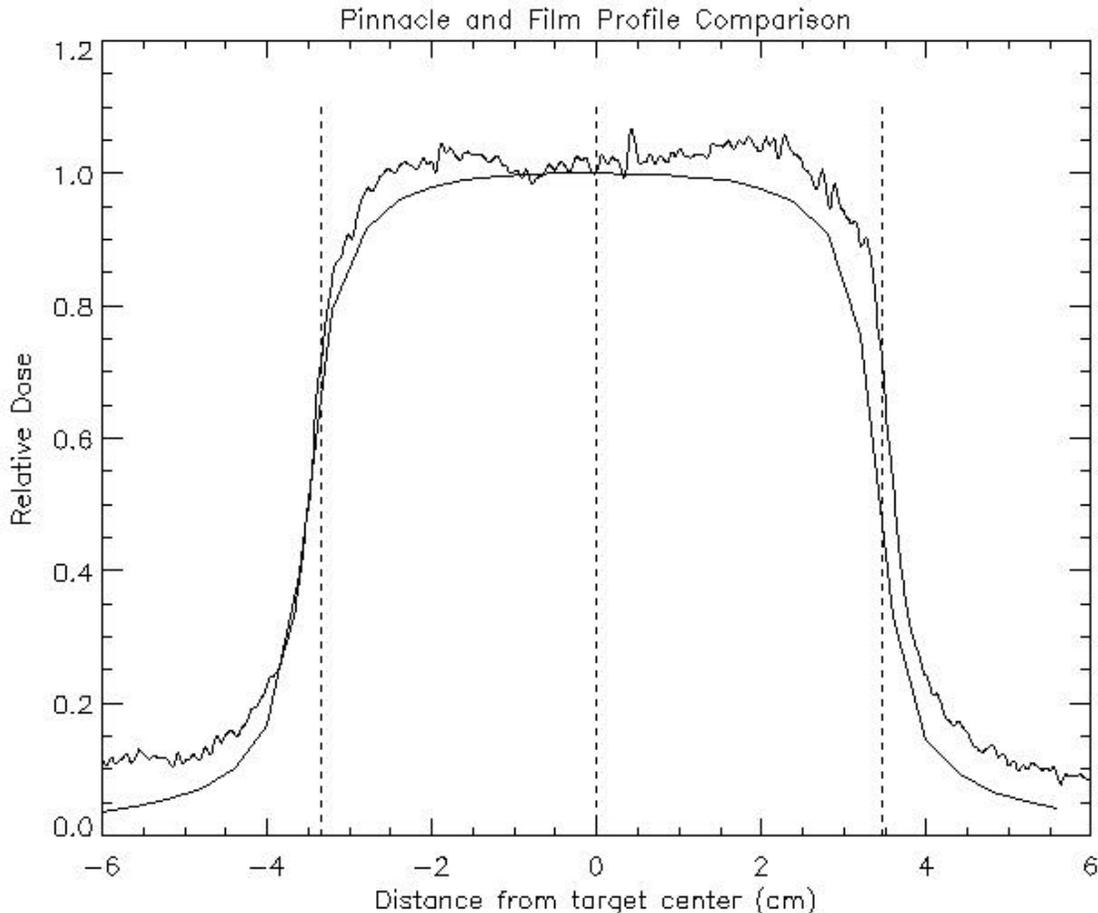
Field Localization

Profiles were acquired through the center of the prostate along each axis: left-right, anterior-posterior, and inferior superior. The location of the 70% isodose line was identified on each of the film profiles and compared to the corresponding line of the treatment planning system profiles acquired at two dose-grid resolutions.

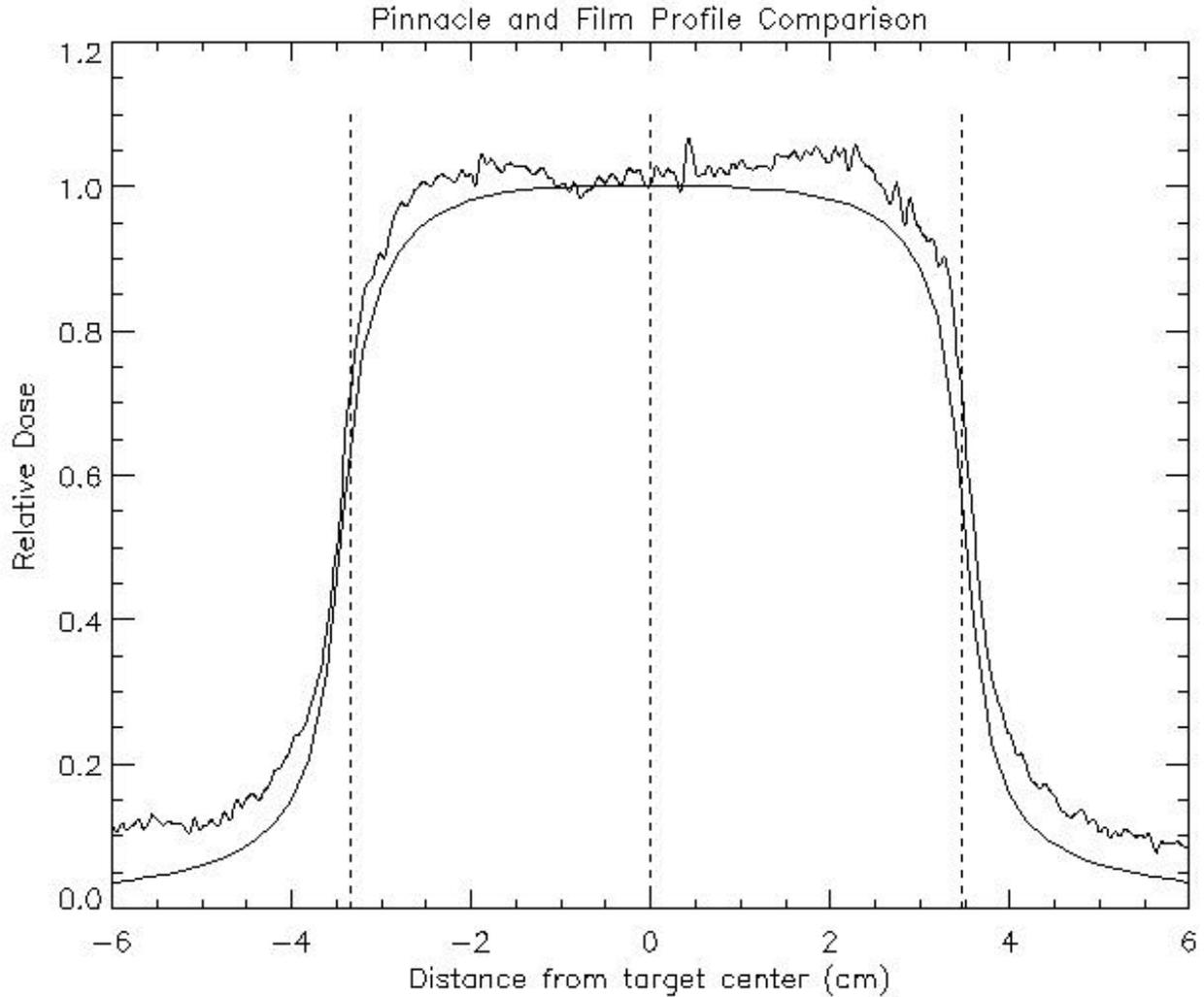
	2mm Dose Grid	4mm Dose Grid
Average difference (cm)	0.133	0.117
Standard Deviation of difference(cm)	0.167	0.078
Maximum Difference (cm)	0.365	0.345
Minimum Difference (cm)	0.015	0.035

The table above shows the average deviation between film and treatment planning system profiles at the 70 % dose line to be within less than 2mm for two dose grid sizes.

The criteria for field localization agreement is 2mm in high gradient regions. Six profiles were acquired along the inferior-superior axis which represents the only high dose-gradient region in the four field box treatment as shown in the profile comparisons below. All of these profiles agreed within a maximum deviation 1.15 % of the treatment planning field localization.



A comparison of film and treatment planning system inferior-superior profiles for a treatment planned with 4mm dose grid resolution is shown above.



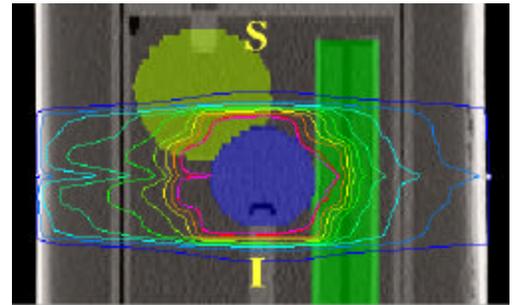
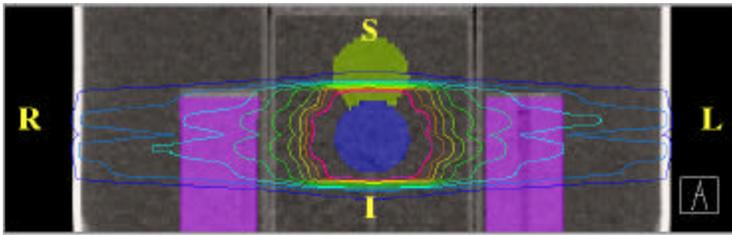
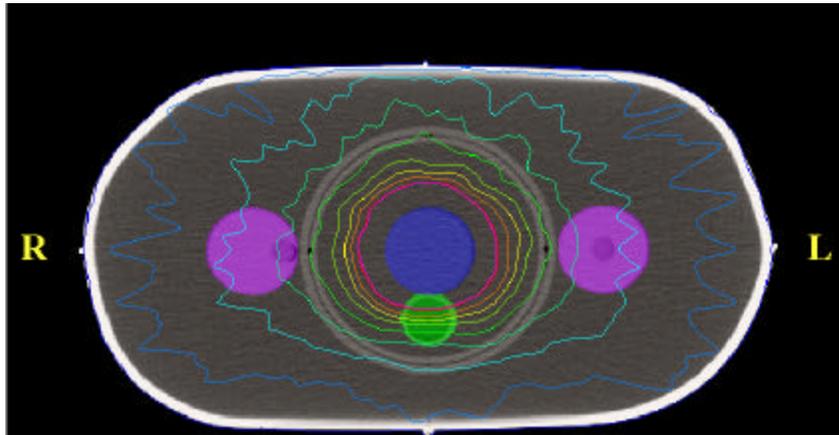
A comparison of film and treatment planning system inferior-superior profiles for a treatment planned with 2mm dose grid resolution is shown above.

Conclusion

- A heterogeneous, anthropomorphic, mailable dose-verification phantom has been designed as a comprehensive quality assurance tool for IMRT.
- The phantom can assess
 - Absolute dose within $\pm 5\%$
 - Dose homogeneity of target within $\pm 5\%$
 - Dose localization within $\pm 2\text{mm}$ for high gradient regions

Phantom commissioning with IMRT

In the next phase of commissioning, IMRT treatment plans will be delivered to the phantom.



Phantom Tests

The phantom will then be tested under conditions that simulate clinical dose delivery problems.

These data will provide a baseline for future analysis of potential discrepancies encountered at remote institutions.

- Patient/Phantom misalignment
- Omitted Arc or treatment field
- Heterogeneity correction investigation
- Incomplete arc or dynamic MLC field delivery
- Fixed leaf on MIMiC or dMLC
- Prone patient treatment