Implementation of a Polymer Gel Dosimetry Insert for an Anthropomorphic Head Phantom Used to Evaluate Head and Neck Intensity-Modulated Radiation Therapy

Michael L. Beach, Geoffrey S. Ibbott and Marek Maryanski
Department of Radiation Physics
The University of Texas M.D. Anderson Cancer Center,
Houston, TX 77030

THE UNIVERSITY OF TEXAS
MD ANDERSON
CANCER CENTER

Background and Significance

Recent advances with intensity-modulated radiation therapy (IMRT) allows the ability to plan complex 3-dimensional treatments to cancerous target volumes. The implementation of IMRT has created the need for more careful evaluation of how facilities administer such innovative cancer treatments. As an example the Radiation Therapy Oncology Group (RTOG) is currently evaluating the feasibility of IMRT techniques for oropharyngeal cancer treatment with protocol H-0022. One of the credentialing requirements for institutions wishing to participate in the protocol is a phantom dosimetry test.

The Radiological Physics Center (RPC) at the M.D. Anderson Cancer Center (MDACC) has developed a mail-able anthropomorphic head phantom to perform such a dosimetry test. The phantom currently houses a block style insert that contains the following simulated regions: a planned target volume (PTV), a sub-clinical (or secondary) PTV, and a critical structure that is partially enveloped by the primary PTV. All of these regions are surrounded by material that simulates normal tissue. The quality assurance requirement of the protocol calls for the phantom to be "treated" using one-tenth of the doses described for each of these regions.

The dosimetry of the simulated treatment is currently performed by two sheets of radiochromic film that dissect the PTVs and critical structure as well as thermoluminescent dosimeter (TLD) capsules placed within the PTVs and critical structure region. Unfortunately these dosimeters only have the ability to provide point (TLD) and planar (film) evaluation of the treatment administered to the phantom.

The very nature of the 3-dimensional complexity achievable by IMRT creates a potential problem for completely evaluating such treatments dosimetrically with film/TLD or other point and planar dosimeters. But a thorough evaluation of how institutions conduct IMRT is significant because if errors in treatment administration should occur there is potential for mistreating or even harming patients. To improve the ability of the RPC to evaluate that facilities are performing the RTOG protocol correctly, and thus provide greater assurance of patient safety, a volumetric dosimeter is desirable. A volumetric dosimeter would allow the assembly of 3-dimensional dose maps so that the dose throughout a volume can be evaluated. The need for such a dosimeter was addressed by the development of polymer gel dosimetry.

One such dosimeter is the BANG® polymer gel manufactured by MGS Research Inc. This gel's name is an acronym derived from it's chemical composition of 3% **N**, N'-methylene-**b**is-acrylamide, 3% **a**crylic acid, 1% sodium hydroxide, 5% **g**elatin and 88% water. It is approximately tissue-equivalent in that it has an electron density, attenuation coefficient, absorption coefficient, radiative stopping power and scattering power all within 2% to that of water (Keall and Baldock, Maryanski 1994). It has been shown to have a linear dose response over useful clinical ranges (Maryanski 1996). The gel response has been shown to be independent of beam energy or dose rate (Ibbott *et al*). And the gel has demonstrated uniform sensitivity with a long period of stability (Ibbott *et al*). The gel works by radiation-induced polymerization and cross-linking of acrylic monomers, which are dispersed uniformly in an aqueous gel. This results in a turbid volume that is representative of the dose "cloud" when the gel is irradiated. This cloud has optical attenuation properties that are proportional to the dose the gel received (Shahnazi *et al*). This "stored" dose information can then be read out, by measuring the relative optical densities, at a later time using optical computed tomography (OCT) (Ranade *et al*). One such OCT scanner is a commercially available unit sold by MGS Research, Inc.

The OCT scanner itself is fashioned similar to first generation X-ray CT scanners. It passes a He-Ne laser beam through a beam splitter with one beam going to a reference detector that is to calibrate any beam drift that may occur. The second beam is then directed through the gel container via mirrors run in tandem using a translate-rotate manner. A second detector then receives the attenuated signal. A computer, using a filtered back projection technique, then processes the reference and attenuated beam signals in order to assemble the measured 3-dimensional dose distribution. MGS Research advertises that the scanner is capable of measuring doses on the order of 1 Gy with a spatial resolution of <1 mm (www.connix.com).

References

•de Deene Y, Achten E, de Neve W and de Wagter C 1999 MRI polymer gel dosimetry in conformal radiotherapy: Quantitative comparison with film dosimetry and planning applied to a mediastinal tumor *Radiother. Oncol.* **51** (Suppl. 1) S23

•Gluckman G, Foraci J, Meek A, Reinstein L, Radford D and Followill D 2001 Adaptation of the RPC IMRT prostate phantom for full 3D dose verification using polymer gel and multiple-plane radiochromic film *Med. Phys.* **28**, 1269

•Ibbott G S, Maryanski M J, Eastman P, Holdcomb S D, Zhang Y, Avison R G, Sanders M and Gore J C 1997 Three-dimensional visualization and measurement of conformal dose distributions using magnetic resonance imaging of BANG polymer gel dosimeter *Int. J. Rad. Oncol. Biol. Phys.* **38** 1097-103

•Keall P and Baldock C 1998 Radiological properties and water equivalence of dosimetry gels *Med. Phys.* **25** A194

•Maryanski M J 1994 Magnetic resonance imaging of radiation dose distributions using a polymer-gel dosimeter *Phys. Med. Biol.* **39** 1437-1455

•Maryanski M J 1996 Radiation therapy dosimetry using MRI of polymer gels *Med. Phys.* **23**, 699-705

•Oldham M, Baustert I, Lord C, Smith TAD, McJury M, Warrington J, Leach M O and Webb S 1998 An investigation into the dosimetry of a nine-field tomotherapy irradiation using BANG-gel dosimetry *Phys. Med. Biol.* **43** 1113-1132

•Ramm U, Damrau M, Thilmann C and Bottcher H D 1999 3D Heavy ion dosimetry using BANG polymer-gel and magnetic resonance imaging Abstract 192 5th Biennial Meeting of Physics for Clinical Radiotherapy, Bottingen, Germany, April 8-11

•Ranade M, d'Errico F, Barry M and Maryanski M 1998 Clinical 3D dosimetry by optical laser CT scanning of BANG polymer gels *Med. Phys.* **25** A192

•Shahnazi K, Yue J, Bongiorni P, Nath R and Maryanski M 1999 Absence of dose rate effect on optical response of BANG polymer gels at low and intermediate dose rates *Med. Phys.* **26** 1126

Purpose

The purpose of this project is to design, build and characterize a BANG® gel insert for the RPC head and neck phantom that is used for the evaluation and certification of radiation treatment facilities using RTOG protocol H-0022. Using such a volumetric dosimeter would provide the 3-dimensional information so desired for the evaluation of head and neck IMRT treatment facilities. As a result, such evaluation would provide greater assurance that patients at these facilities are being treated effectively and safely.

This work is supported by PHS grants CA10953 and CA81647 awarded by the NCI, DHHS.

Phantom Design and Construction

A polymer gel insert was designed and constructed for use in the RPC's anthropomorphic head and neck IMRT phantom. In addition an imaging insert with TLD and film provisions was constructed (based upon the current insert being used) so that a direct comparison of these conventional dosimeters can be made with the gel. The imaging insert has a primary target volume, a secondary target volume and a critical structure volume that are of similar material and geometry to that of the current block style insert.

The gel insert is a cylindrical container made of Barex® plastic. Barex® is used because it can be manufactured according to design parameters and is impermeable to oxygen (BANG® gel must be kept oxygen free). The cylindrical design is necessary to minimize artifacts that can occur when the gel is measured by the OCT scanner. Because of the change in insert dimensions, the phantom itself was redesigned to accommodate the inserts (figure 1). The cylinder has a radius of 5 cm and a depth of 8.5 cm.

The imaging insert is made to fit the same dimensions, which allows for approximately 1 cm of space between PTVs and critical structure from the inside diameter of the cylinder (figure 2). Both the gel and imaging inserts are fitted with a registration pin that is in the same positions within both inserts. This serves several purposes: 1) It ensures that both inserts are registered within the phantom at a precise position, 2) it serves as an alignment marker for the X-ray CT image taken from the imaging insert (which is used for the treatment planning process) and 3) they serve as alignment markers for the gel insert when it undergoes the OCT measurement/image construction process. Lastly, the registration pin provides a reference to that planned isodose distributions (based upon X-ray CT images of the imaging insert) can be accurately overlaid with the measured isodose distributions from the gel insert OCT measurements.

Figure 1: The RPCs redesigned IMRT head and neck phantom with imaging insert installed. The Barex BANG gel insert is shown in the foreground.

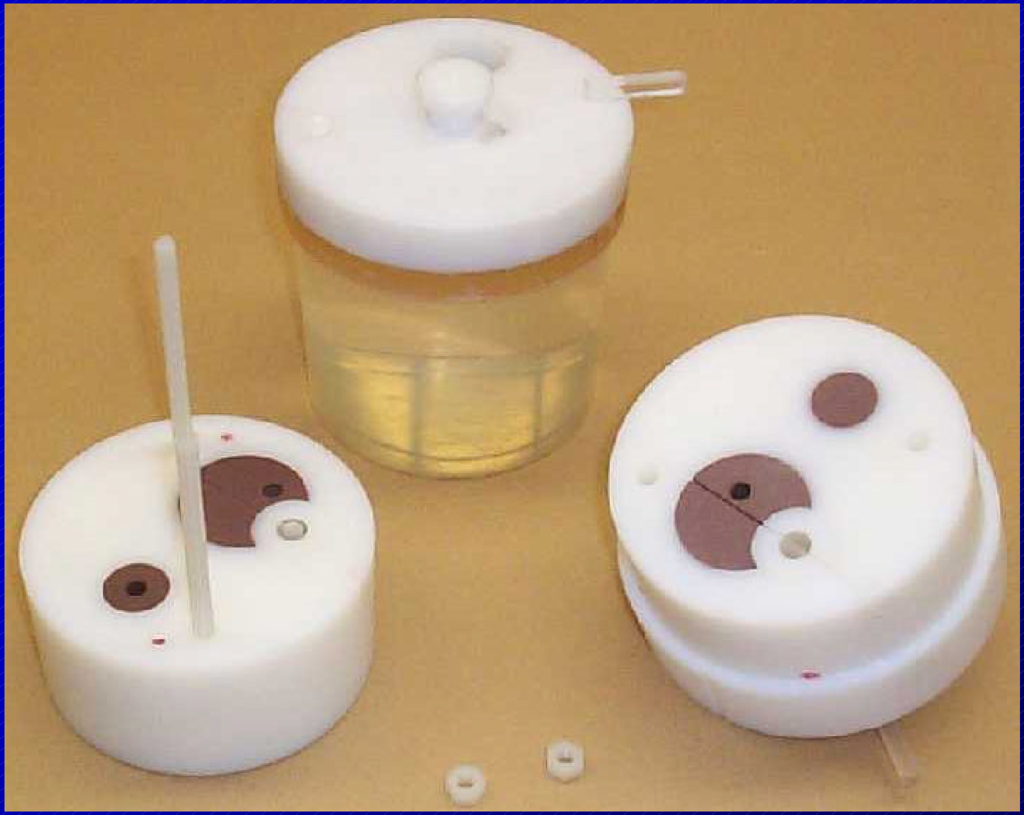

Figure 2: The BANG gel and imaging/dosimetry inserts. Note the PTVs, critical structure and film/TLD provisions in the disassembled imaging insert.

“Simple” Treatment Evaluation

As an initial test of the gel dosimetry insert, a uniform dose was delivered to the gel insert while the canister was in a water tank. This allowed measured gel dose points to be compared to both treatment plan calculated dose points as well as ion chamber measurements.

The calibration of the treatment machine, a Varian-2100, was first verified and documented by performing dose output measurements using TG-51 formalism. Then test tubes filled with the same batch of BANG gel were irradiated to known doses of 2, 6 and 10 Gy as previously determined during the TG-51 calibration check. These test tubes were used to determine an optical density (OD) versus dose response curve. One of the gel insert canisters was also irradiated to a known value of 6 Gy. This gel would serve to provide a correction factor accounting the volumetric variation between the test tubes and the insert canisters. Equally weighted parallel-opposed 6 MV beams were then used to irradiate the tank to a dose of 7 Gy at isocenter. Ion chamber measurements were taken along the three principal axes of the water tank with the origin acting as the common isocenter for the ion chamber measurements, treatment planned calculations, and gel measurements.

Preliminary Analysis

A smooth monotonic response curve was established using the calibration test tube gels (figure 3). Using a fitted linear calibration equation results in an optical density per cm (OD/cm) value of 0.1308 for a dose of 6 Gy. We were unable to establish a dose calibration correction factor for the Barex® containers due to a background control gel becoming damaged in handling. Since an accurate calibration correction was unavailable only relative dose comparisons have been attained to date. The relative dose comparisons proved to be promising, considering this was the first analysis using our recently commissioned OCT scanner. Representative plots of the relative doses along the central axes of the parallel beams and an axis perpendicular to this show general agreement with ion chamber measurements and the treatment planning calculations (figures 4 & 5). As can be seen, the gel measurement process is perturbed by the laser being reflected and refracted along the sides of the canister walls. As a result, only the central 70% of the canister provides reliable data. With a closer view of the dose plots, noise in the measurements becomes readily apparent (figures 6 & 7). We have determined that this can be attributed to microscopic particles attenuating the laser beam. These may be from particles suspended in the bath in the scanner tank and/or stuck on the glass walls that the laser passes through. Subsequent experiments will be conducted in confirm this assumption and to prevent noise in the IMRT dose distribution imaging and analysis.

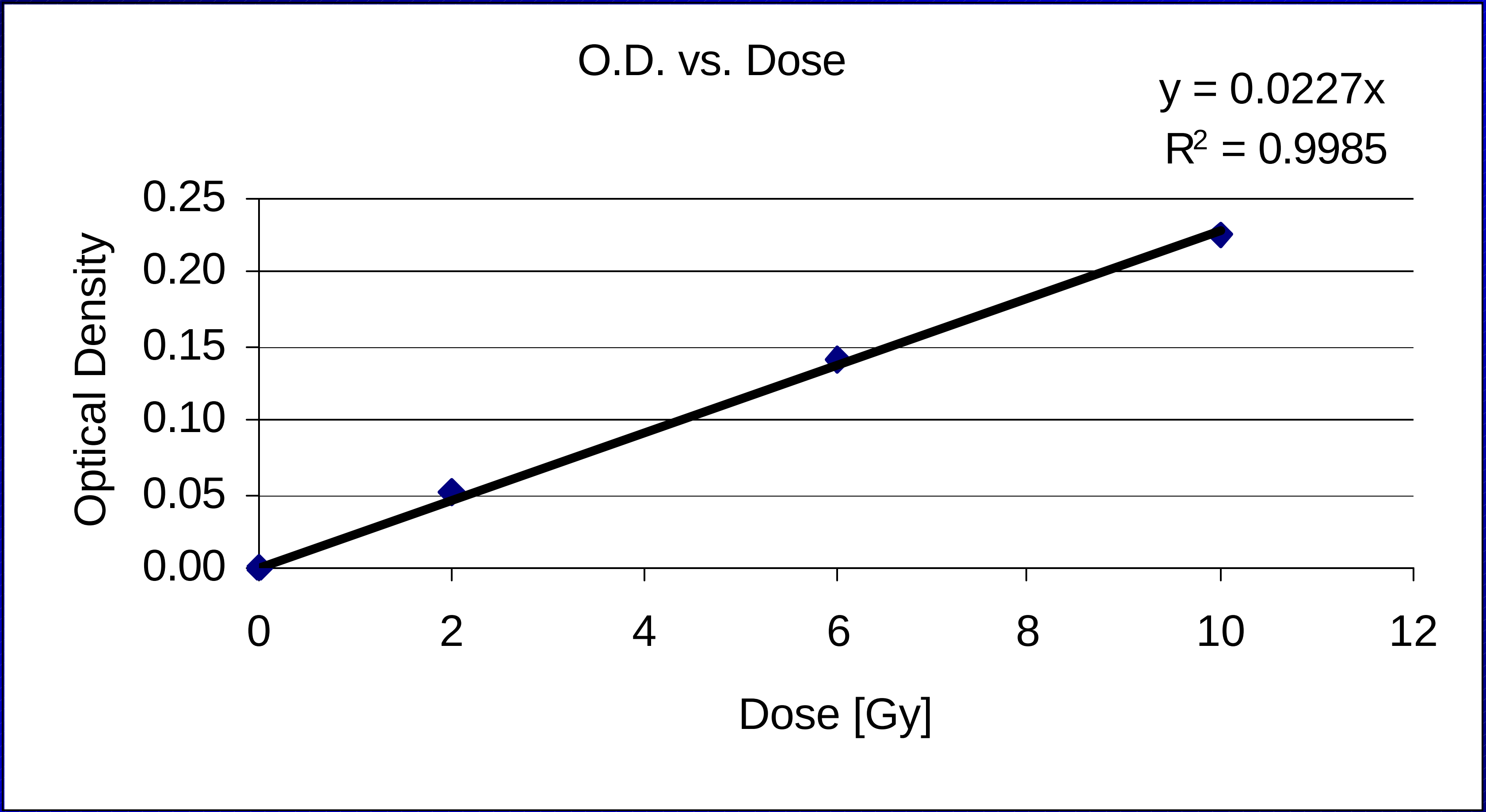

Figure 3: Calibration curve for optical density as a function of dose.

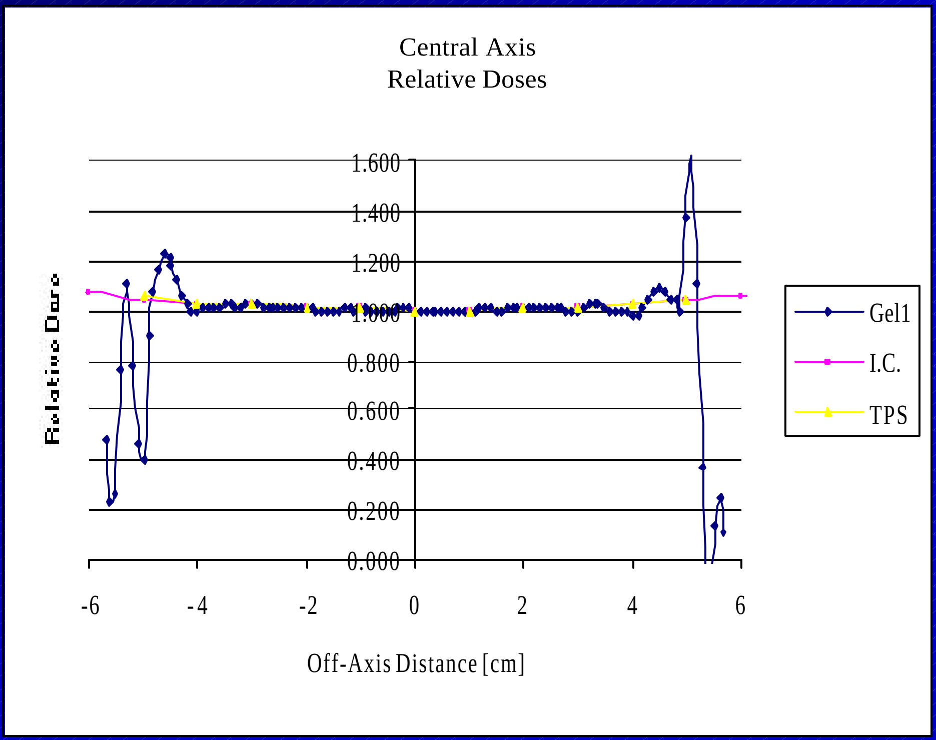

Figure 4

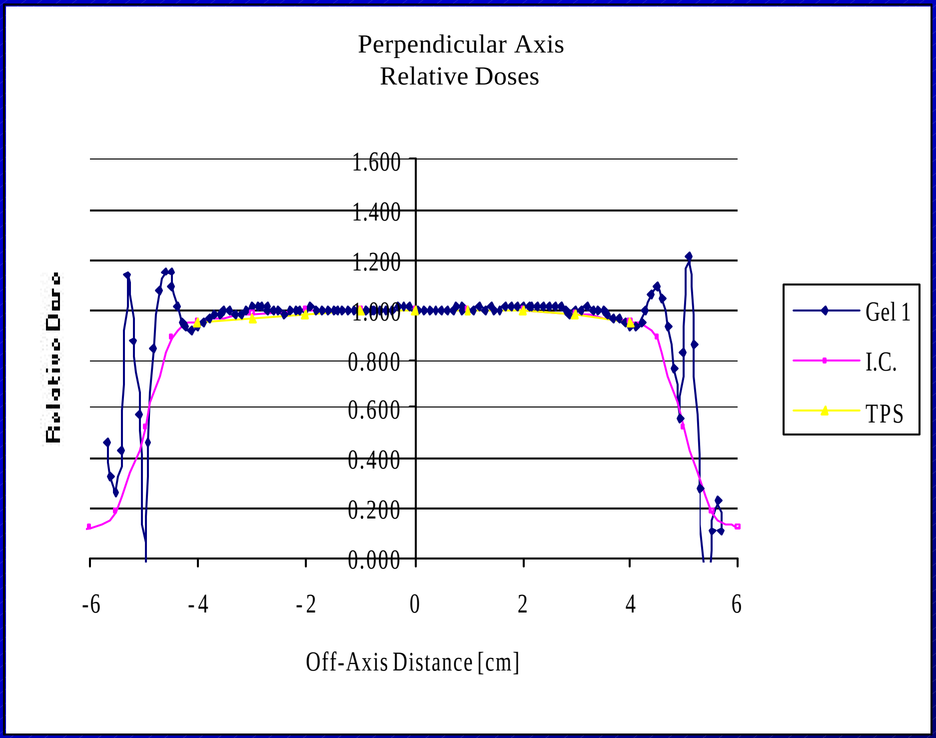

Figure 5

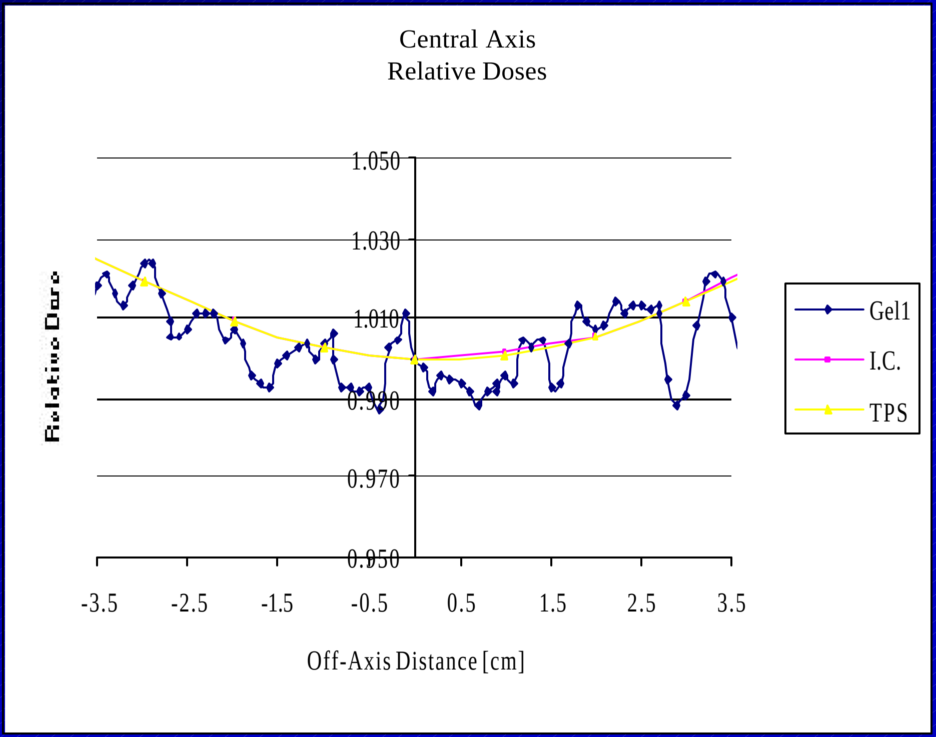

Figure 6

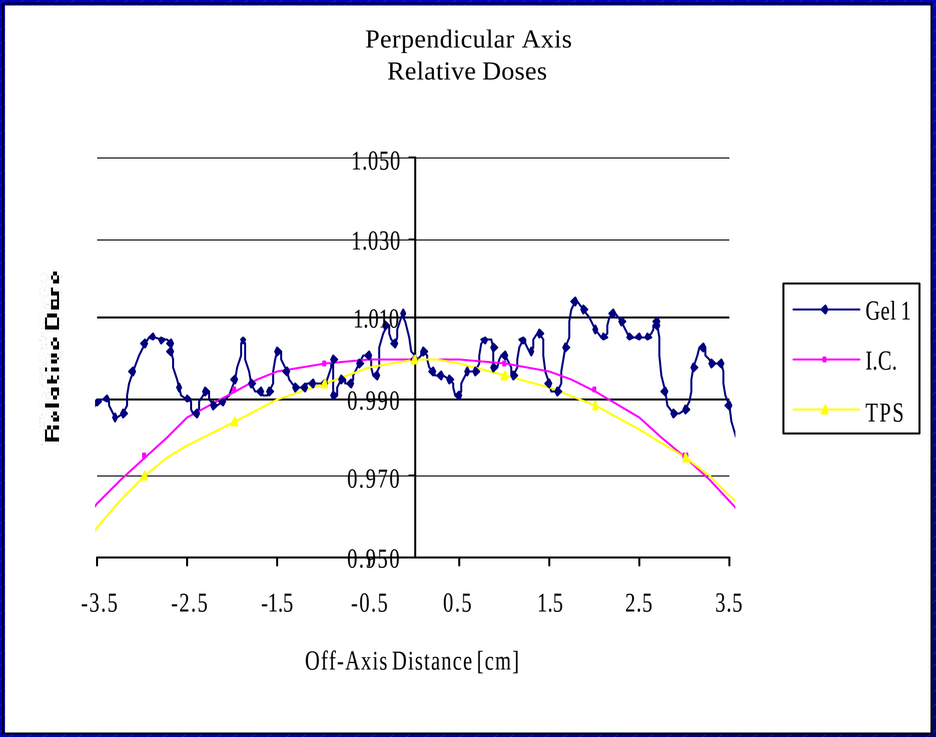

Figure 7

IMRT Treatment Evaluation

We intend to further investigate the gel insert using a non-anthropomorphic environment and conventional treatment methods. However, we have also begun work on the final phase of this project.

The anthropomorphic head phantom was taken through the “normal” IMRT head and neck planning process. The phantom with imaging insert installed was scanned on an AcQsim simulation CT scanner. The imaging study was then used to assemble 9-field IMRT plan using our Corvus treatment planning computer. The RTOG H–0022 protocol dose requirements were adhered to for the target volumes and the critical structure.

For the next phase of this work the phantom will be treated on a Varian 2100 linac using the gel dosimetry insert installed. And the treatment will be repeated using the imaging/dosimetry insert with film and TLD. The film and TLD will be read by the conventional methods used at the RPC and the gel insert will again be read using the OCT scaner. Comparisons between the measured gel and film scans with the calculated plan will then be performed using analysis software for such purposes.