Facility Start Up, Training, and Operational Issues AT PTC H or Protons – A Positive Marathon Inelastic Collision Experience

Presented from a Physics Bias

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And
Many Others A Great Team Is Needed
UT MDACC

Learning Objectives

- 1. To describe the phased approach to clinical commissioning and patient treatments at PTC H
- 2. To present pre-commissioning training for both the treatment delivery and the treatment planning systems
- 3. To review the current operational schedule, which includes patient treatments, patient QA, machine QA, and continued commissioning.

Summary: Advice

Diet

- Eat food.
- Mostly vegetables.
- Not too much.

Protons

- Plan ahead.
- Work very hard.
- Hire great therapists.

The Reasonably Prudent Criteria

- What would a reasonably prudent medical physicist do when clinically commissioning a treatment delivery system, which has a older version in Japan but a new control system, with a new treatment planning system and a new electronic medical record system in a short time frame and no previous proton experience?
- One solution is to assembly a small highly experienced clinical physics team and stay focused and rely on past experience.

Time Modulated by Protons
The Factor of 3 Rule

- Make your best estimate of the time required to make a measurement and then multiply it by 3.
- Be happy that the number of hours per day (24) and days per week (7) remains a constant.
- Beam time is the major constraint. The beam only goes into one treatment room at a time. Patient treatments have a high priority for beam than commissioning or QA.

Proton Therapy Center - Houston

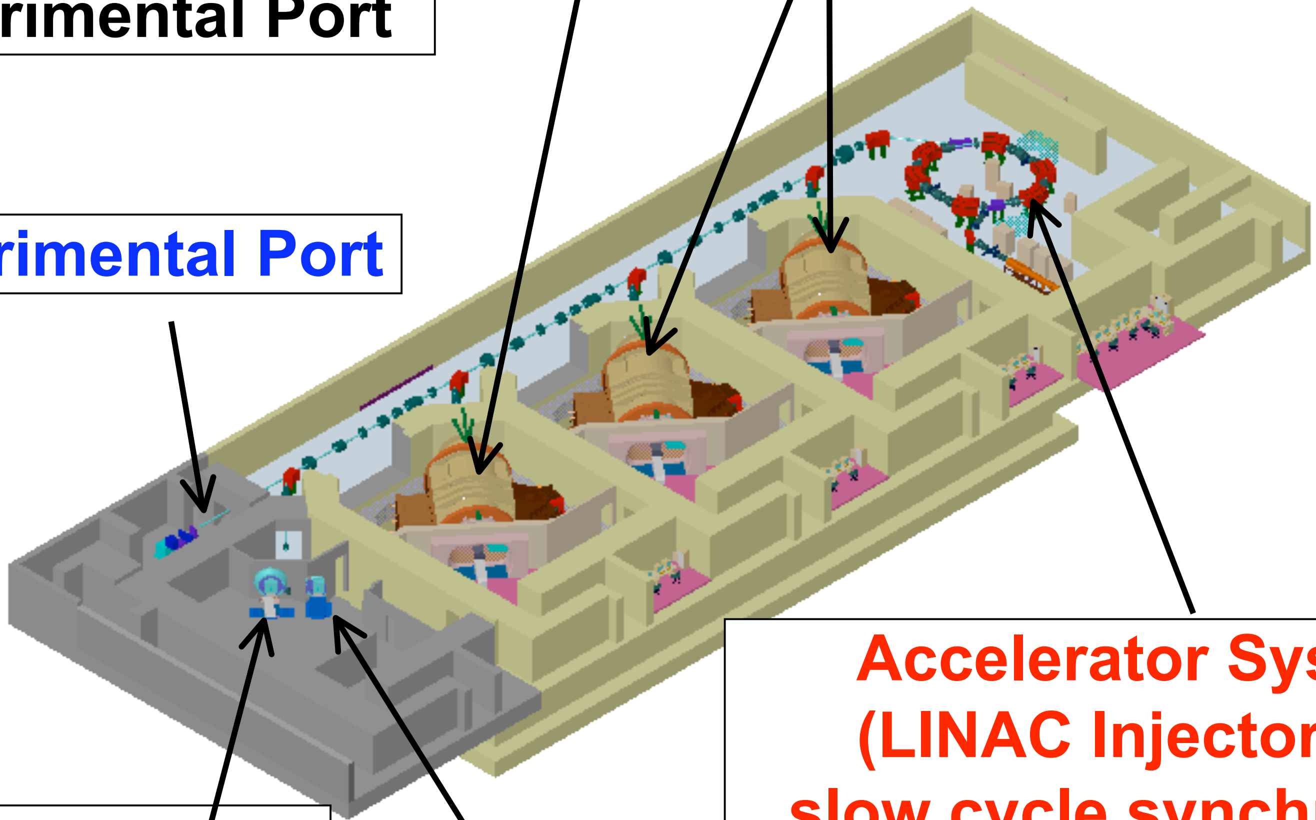
<u>PTC-H</u>
3 Rotating Gantries
1 Large Fixed Port
1 Eye Port
1 Experimental Port

Pencil Beam Scanning Port

Passive Scattering Port

This is a phased project with beamlines being released by Hitachi one at a time.

Experimental Port



Large Fixed Port

Accelerator System (LINAC Injector and slow cycle synchrotron)

PTC H - A Phased Project

- March 6, 2006 Clinical Commissioning begins on G1
- Prior to March, 2006: Design, build building and accelerator and treatment rooms 18 months to design and build plus 18 months to install and acceptance test
- May 4, 2006 First patient treatment on G1 within 3 years of ground breaking
- July 7, 2006 First patient treatment on F2
- September 8, 2006 First patient on G2
- > 500 patients in first 24 months of operation.

PTC H - A Phased Project
Scheduled Completion Date July 17, 2008

- February, 2008 Clinical Commissioning begins on G3 – The Discrete Spot Scanning Beam – First patient May, 2008.
- Summer, 2008 F1 the Eye Line should be available
- Learning to Share – One accelerator with multiple beamlines means that all users learn to share the beam. On Saturdays, it is quite common to wait 5 plus minutes to make a 15 second measurement, while the beam is directed into another room which is making a long measurement.

Pre-commissioning Phase

- A team led by Alfred Smith, PhD, wrote the specifications and observed the installation of the Hitachi synchrotron and treatment rooms and performed the acceptance testing.
- Major systems included the treatment delivery system, the imaging systems, and the shop.
- This was a dynamic process which established the very effective working relationship with Hitachi and resulted in a stable, reliable treatment device with multiple ranges, field sizes, etc.

Pre-commissioning Phase

- Anderson appointed a lead therapist, Chuck Merrifield, RTT, a lead dosimetrist, Beverly Riley, CMD, and a medical director, Shiao Woo, MD, before the Proton Center was opened.
- As a warm up for protons, clinical physics installed > 12 electron linacs in approximately < 24 months. At Anderson, commissioning equipment is a way of life.

Pre-commissioning Phase

- Eclipse was chosen as the proton treatment planning system relatively early.
- Substantial effort was spent generating Monte Carlo data to input into Eclipse (Wayne Newhauser) long before there was measured data. This permitted the oncologists, the dosimetrists, and physicists to engage in proton treatment planning exercises.
- There was no effort made to use this MC data in the clinical commissioning efforts. For scattering beam, treatment is based upon measured data.

Pre-commissioning Phase

- An Ad Hoc Immobilization Task Group (Therapists, Dosimetrists, Physicists, and Oncologists) reviewed various prospective patient immobilization approaches and eventually decided on initial approaches for prostate, lung, and other sites. This has had a positive effect on our photon practice.
- Dr. Lee decided on a rectal balloon approach during this phase for prostate patients.

Pre-commissioning Phase

- The Electronic Medical Record, Mosaiq.
- Substantial effort by another Ad Hoc Task Group was spent in defining specifications for the proton portion of the EMR (parameters and workflow).
- IMPAC delivered a version of this before the first patient was treated and has provided several new versions.
- The same EMR is used in the entire practice, main campus, satellites, and protons.
- The version of Mosaiq, which will support the scanning beam, V 1.5, was installed over the weekend of April 19th. New versions of Mosaiq are a major task.

Pre-commissioning Phase

- Imaging Equipment – The CT simulation scanner was installed months before clinical commissioning started. This permitted a leisurely consideration of the conversion of HU's to stopping power ratios. It also provided amble time to image the patient support devices.
- Substantial time was spent designing and building alignment jigs for the 3 in-room x-ray systems. (James Yang) These helped in both the acceptance testing and later in the clinical commissioning.

Pre-commissioning Phase

- Dosimetry protocol – Dosimetry protocols were reviewed and a decision was made to use the IAEA TRS 398 protocol.
- Dosimetry equipment – Most dosimetry equipment was ordered in the pre-commissioning phase.
- Dosimetry scanning system – Given the pulsed nature of the synchrotron, scanning equipment was reviewed to insure that this equipment would function during the 1.5 seconds between spills. A PTW MP3 system was ordered. It was delivered within one week of the start of clinical commissioning. Time was spent without much gain on a de-commissioned photon linac attempting to make existing scanning equipment work.

Pre-commissioning Phase

- Many members of the radiation oncology practice traveled to other Proton Centers. (Thank you. This was very important.)
- A Scientific Steering Committee provided guidance to the project.
- There were countless meetings within Radiation Oncology on multiple topics. (Anderson = Meetings.)
- A ‘Protons for Dummies’ lecture series was held. A test was developed for the oncologists in order to be credentialed to use protons. Almost all oncologists (> 40) have been credentialed for protons. A major challenge is to keep the oncologists well informed about the limitations of the planning and delivery systems.

Clinical Commissioning Major Systems

- Treatment Delivery System
- In Room Imaging System
- Treatment Planning System
- Electronic Medical Record
- The Machine Shop Systems
- Special Issues – F2 Challenge – A situation for which DICOM does not offer a solution. A fixed beam line is a challenge to think about.

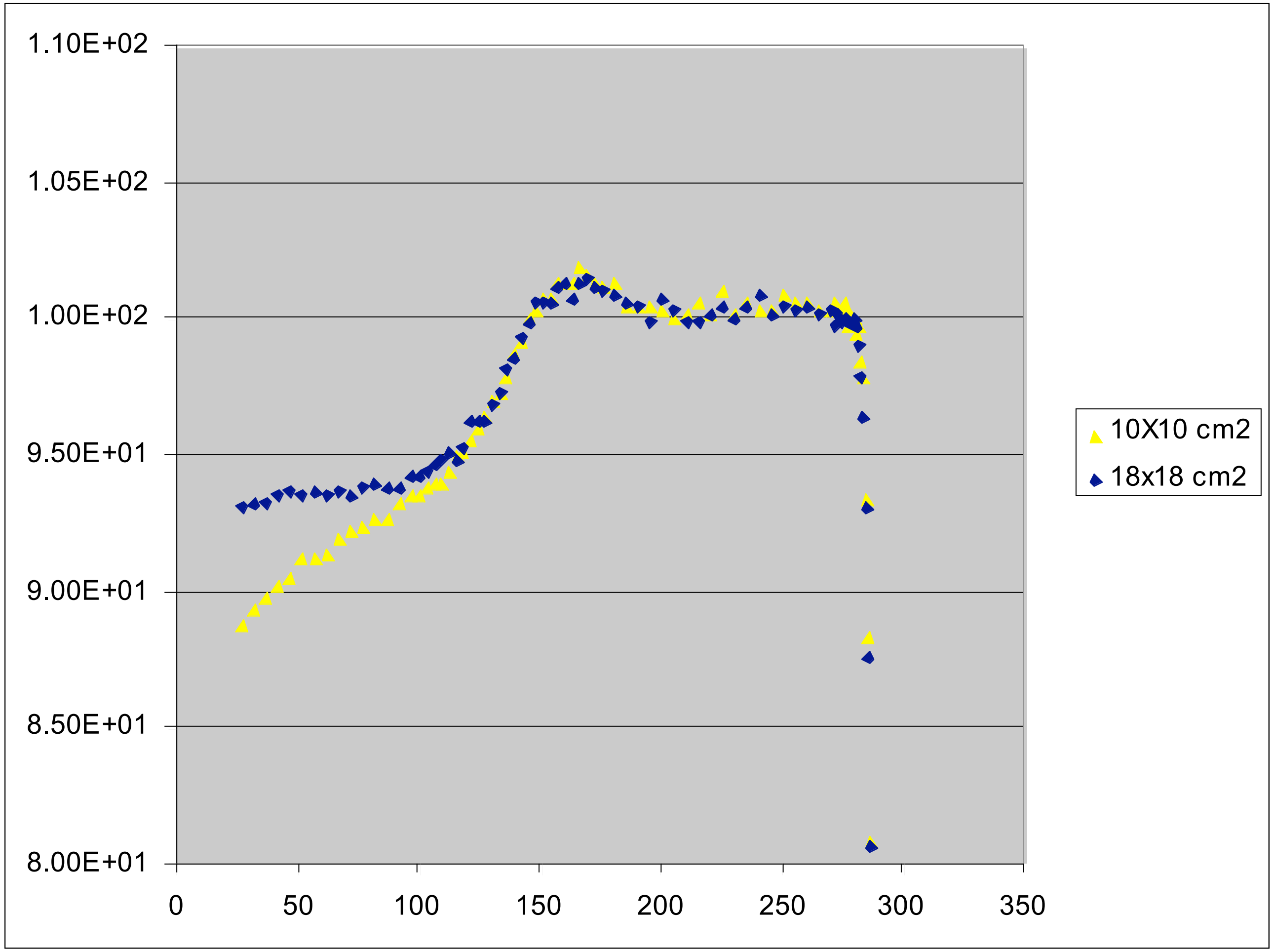
Clinical Commissioning Major Systems Information Flow

- **The Anderson filter**. Information flows from Eclipse through an Anderson filter to Mosaiq and from Mosaiq to Hitachi.
- The purpose of the Anderson filter is to address different interpretations of DICOM by the various vendors.
- DICOM RT ION was not a mature standard at the time that some of the various software packages were being developed.
- The Anderson filter was recently modified to address specific issues with the scanning beam.

Clinical Commissioning Treatment Delivery - Scattering

- G1, G2, and F2 are the three large field scattering beamlines, which use a double scattering approach.
- Each beamline has three snouts (25 cm x 25 cm, 18 cm x 18 cm, and 10 cm x 10 cm) and 8 energies (250, 225, 200, 180, 160, 140, 120, and 100 MeV.)
- There are 24 options per beamline. In addition, the depth in water can be adjusted to within 1 mm, by using range shifters.
- Approximately two years was required to take all of the initial commissioning data with most work accomplished on Saturdays. The last small snout data was measured on G2 in March, 2008.

Effect of Field Size: Increased scatter in the proximal portion of the dose distribution.



It was reassuring to learn that field size is not that important a variable for field sizes above a certain value. Field sizes < 4 cm x 4 cm are a concern.

250 MeV, medium snout

Clinical Commissioning Treatment Delivery - Scattering

- Clinical commissioning began on G1 with a simple goal, namely limit commissioning to the treatment of prostates and 9 weeks to accomplish this task.
- The clinical commissioning physics start up team (Ron Zhu, Narayan Sahoo, and Michael Gillin) together had approximately 75 year's clinical physics experience with zero years in measuring protons. The first several weeks were an introduction to everything all of the time, i.e. understanding the basics of the treatment unit.
- Xiaodong Zhang was able to convert the initial measurement data into the correct format, input the data and Jim Lii (who had substantial experience with treatment planning systems) tested the output in a very efficient manner
- Richard Amos served as a human physics interface between the treatment planners and physics.
- Chuck Merrifield as the lead therapist helped to form a cohesive therapists/physicists group.

Clinical Commissioning Treatment Delivery - Scattering

- Major commissioning tasks:
  - SOBPs required by Hitachi to perform calculations for the Gating Off Table – This required up to 6 SOBPs and then time for Hitachi to provide the answer. For selected energies, this process was repeated. Time: **Several hours**
  - Eclipse input data which consists of Pristine Bragg Peak and profile data: Time: **3 + hours**
  - Validation of Eclipse output in water phantoms and then in other phantoms: Time: Basic measurements: **4 to 8 hours**
  - Establishment of a basic dosimetry system to understand the individual elements which determine the number of monitor units: Time: **4 to 8 hours for point measurements.**

  - **Rough estimate: 20 hours per option**

Clinical Commissioning Treatment Delivery - Scattering

- Major commissioning tasks:
  - Characterize the in-room imaging systems, the Hitachi Medical x-ray system and the Hitachi Works Patient Imaging and Analysis System (PIAS)
  - Test information flow to and from the EMR
  - Develop a patient specific QA system
  - Develop a daily, monthly, periodic machine QA system

Clinical Commissioning Treatment Delivery - Scattering

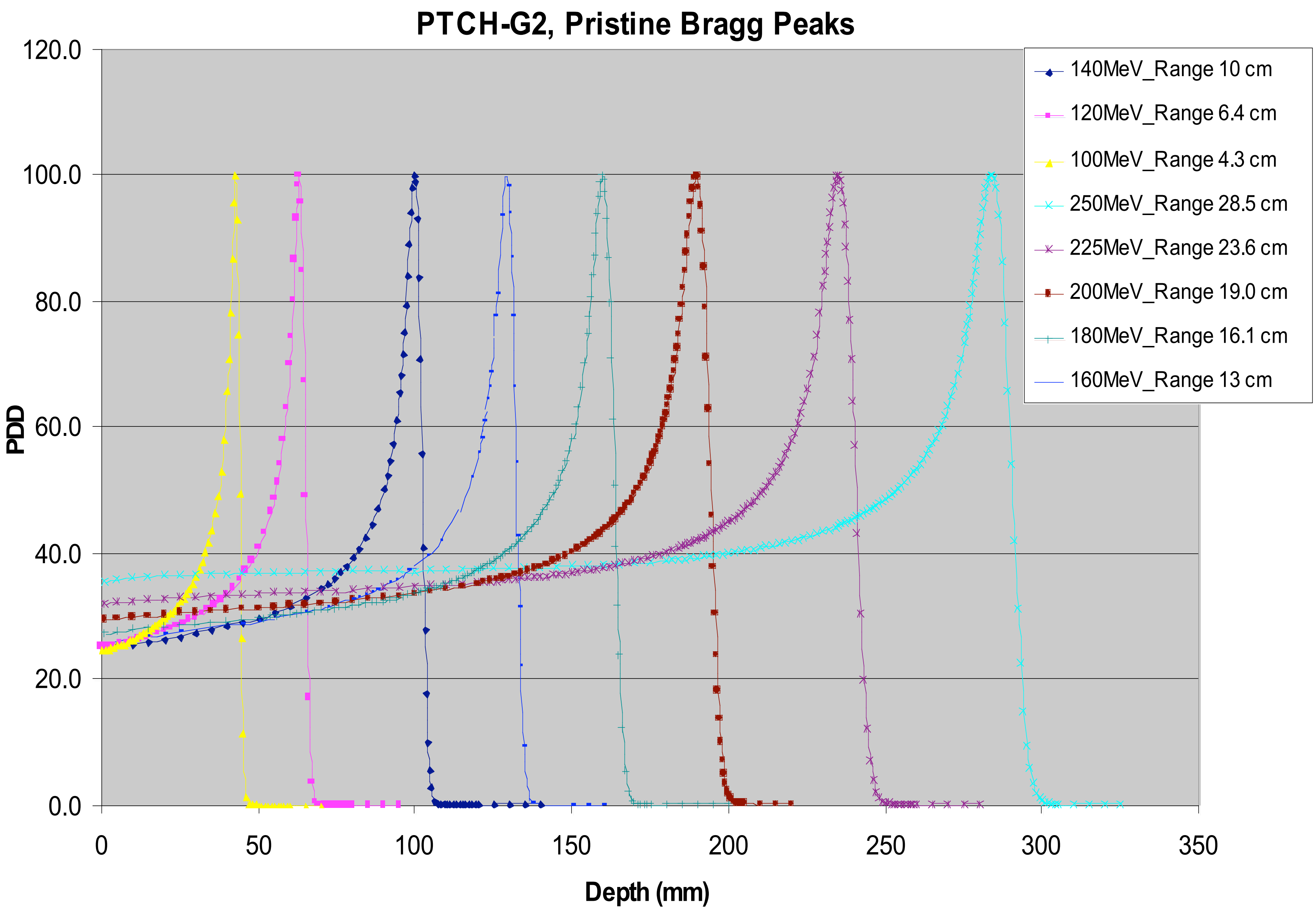
- Major commissioning tasks:
  - Develop a reasonable co-dependent working relationship with Hitachi, which included a clear distinction between business people and business issues and clinical people and clinical issues.
  - Change management is a very important issue to insure that any vendor performed change in the system is reviewed before the change and tested after the change both by the vendor and by the clinical group. In theory, no change is made to the system without my signature.

Clinical Commissioning Treatment Delivery - Scattering

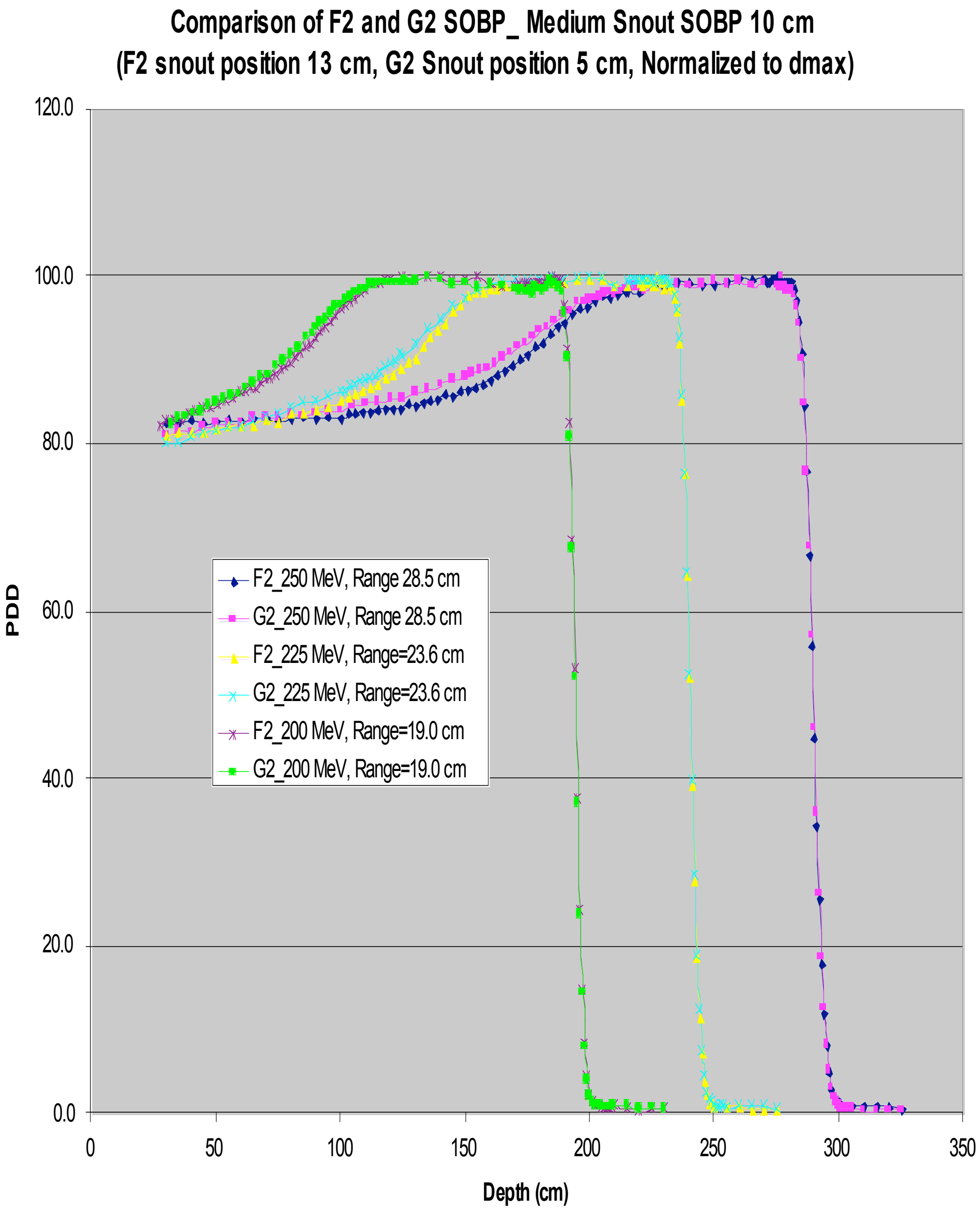
- Major commissioning tasks:
  - The standard for information between Eclipse, Mosaiq, and Hitachi is DICOM. However, while the various vendors did their best to be compatible, it was not always the case. Understanding this required time. There is very limited on-line support when there is an issue with the information exchange between Hitachi and Mosaiq. Time was spent learning how to trouble shoot information exchange problems.
  - Time was also required to understand the required information for make information flow, e.g. male had to be added to the Phantom test file before there could be successful information flow from Mosaiq to Hitachi.

Clinical Commissioning Treatment Delivery - Scattering

- Measurements: 4 seconds per point using the PTW 3D scanning system. Consider an SOBP measurement for a beam with a range of 30 cm and a 5 mm separation between points for a total of 60 plus points. The beam time for this measurement is approximately 4 minutes. Also include cross plane and in plane profile measurements which may have more points per scan, e.g. 60 points at 4 seconds x 3 planes equals 12 minutes of beam time per option. It is possible to spend substantial amount of beam time on each option.



PTCH-G2, Pristine Bragg Peaks
PDD
Depth (mm)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
50
100
150
200
250
300
350
140MeV_Range 10 cm
120MeV_Range 6.4 cm
100MeV_Range 4.3 cm
250MeV_Range 28.5 cm
225MeV_Range 23.6 cm
200MeV_Range 19.0 cm
180MeV_Range 16.1 cm
160MeV_Range 13 cm



The commissioning task became easier when measurements indicated that the beam characteristics in beam beamline were essentially the same. This was established after the design of the RMWs was finalized.

Statement of Calibration Scattering

- For a beam of protons with a range of 28.5 g cm^{-2} with the medium snout (which corresponds to the nominal 250 MeV proton beam), for a 10 cm x 10 cm field, at the center of a 10 cm SOBP (which will be at a depth of approximately 23.5 cm) at a TSD of 246.5 cm, 1 MU will equal 1 cGy (water).

- This will put the point of calibration at approximately 270 cm, the nominal isocenter distance.

- Calibration is independently verified with TLD and site visit from the Radiological Physics Center.

Simple Dosimetry System

- MU = Point Dose (cGy)/(1 cGy/MU x Relative OF (energy and snout size), SOBP factor, Range shifter factor (energy and amount of range shifter), Inverse Square factor, Compensator and Patient scatter factor, SOBP off-center factor, Unknown factor)
- 200 MeV, SOBP 15.3 cm, WET 8.7 cm, Point Dose 90.3 CcGyE or 82.1 cGy requires 103.7 MU's
- Only physicists think both in terms of physical dose and biological dose. All other disciplines think in terms of dose equivalent.

SOBP Factors – Large Snout

Every point represents time to measure, analyze, and distribute.

SOBP (cm)	250 MeV 25.0 cm	225 MeV 20.6 cm	200 MeV 16.5 cm	180 MeV 13.7 cm
2	1.494	1.535	1.556	1.638
4	1.267	1.285	1.299	1.336
6	1.154	1.150	1.158	1.176
8	1.086	1.062	1.073	1.072
10	1.000	1.000	1.000	1.000
12	0.962	0.949	0.938	0.937
14	0.925	0.916	0.881	
16	0.892	0.872	0.832	

Clinical Commissioning Treatment Delivery - Scanning

- There are approximately 94 beams with ranges from 4 cm to 30.6 cm, which are being delivered in two phases with ranges 10.5 cm to 30.6 cm being delivered first.
- Commissioning is a Saturday activity as the other three beamlines, which are in treatment mode, have priority over physics mode commissioning.
- Perhaps another 2 years will be required to take the first step of measurements for all of the combinations available with the scanning beam.

Clinical Commissioning Treatment Delivery - Scanning

- Treatment delivery calibration – The calibration in terms of cGy/MU is straight forward and is almost the same as for the passive scattering beams.
- Planning system calibration – Inputting the integrated Pristine Bragg Peaks in terms of Gy mm^2 per MU is more challenging for all 94 beams.

Statement of Calibration Scanning

- For a beam of protons with a range of 30.6 g cm^{-2} for a 10 cm x 10 cm field, at the center of a 10 cm SOBP (which will be at a depth of approximately 25.6 cm) at a TSD of 244.4 cm, for equally weighted spots with a center-to-center spacing of 8 mm, 1 MU equals 1 cGy (water).

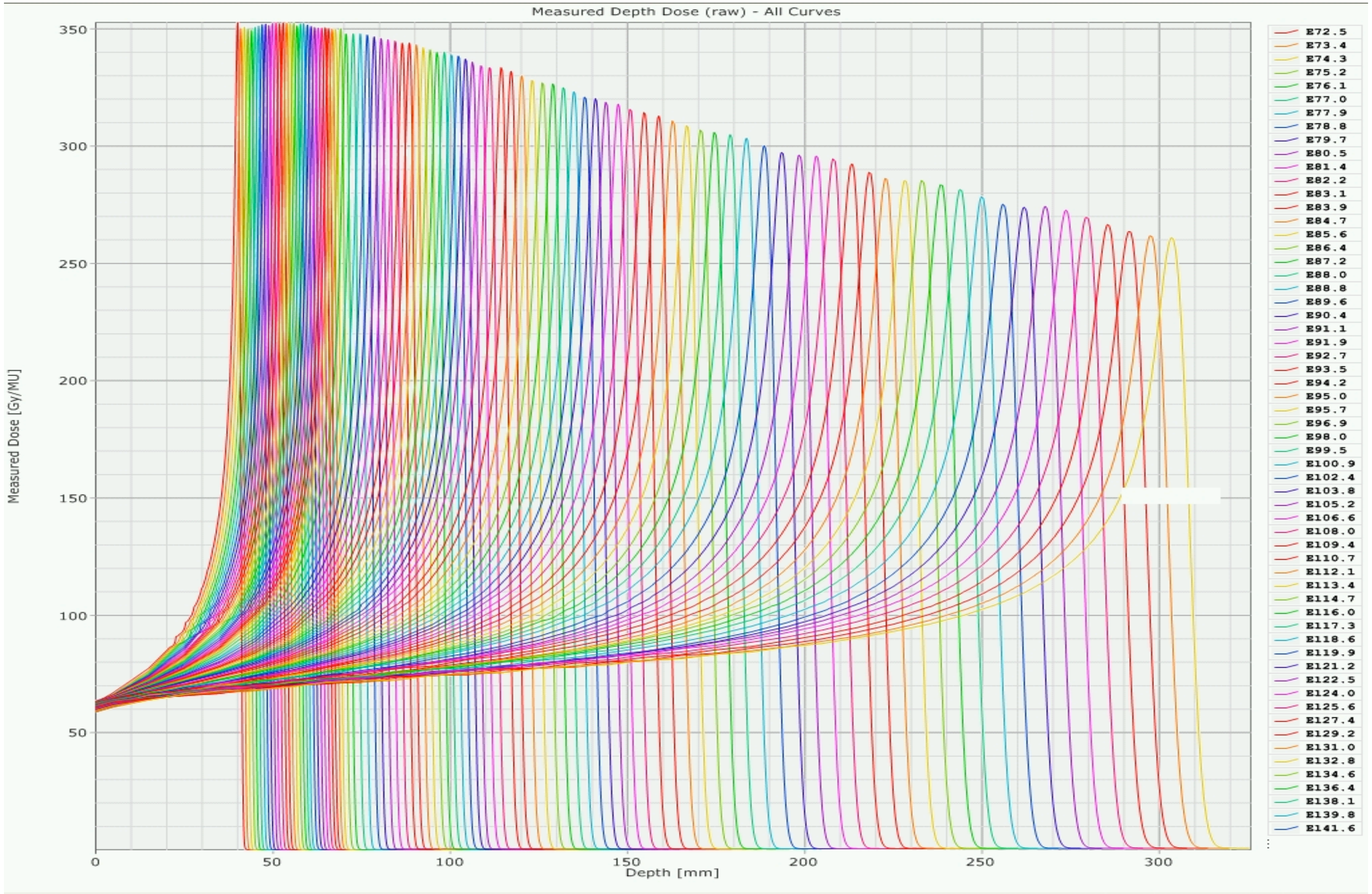
- This will put the point of calibration at approximately 270 cm, the nominal isocenter distance.
- This file was provided by Hitachi and is independent of the TPS, Eclipse.

Clinical Commissioning Treatment Delivery - Scanning

- Monte Carlo data was used as the input data for Pristine Bragg Peaks and the in air beam profile data. (Thank you Uwe Titt and Xiaodong Zhang.) This data was normalized using measurements made with the 8 cm diameter PBP chamber at 2 cm depth.

Pristine Bragg Peak TPS Input Data

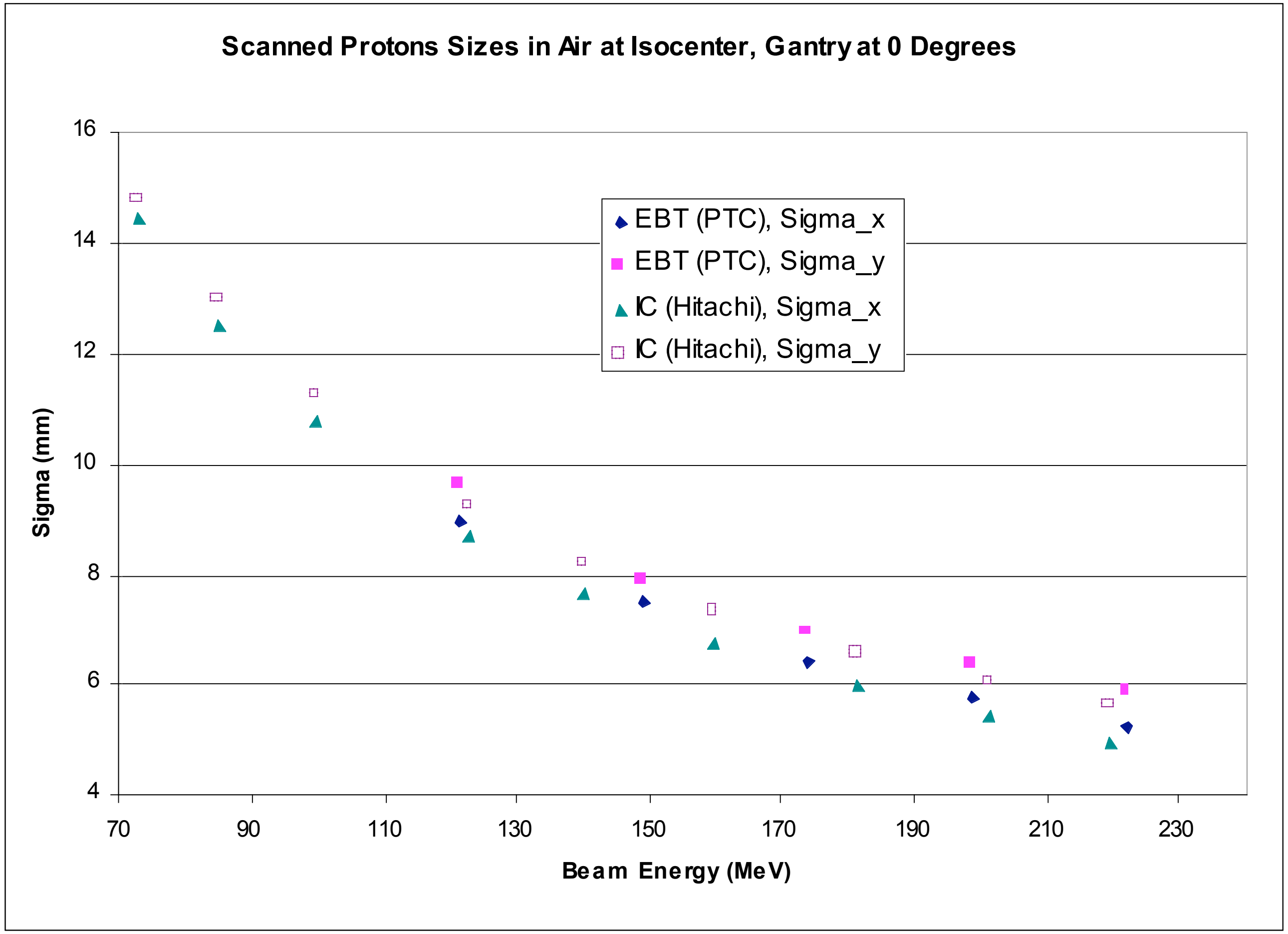
Calculated-Measured Dose in Gy/MU versus range



Clinical Commissioning Treatment Delivery - Scanning

- Major steps include:
  - Characterization of a single spot in air and in water for various gantry angles
  - Dosimetry measurements of a single line and a plane.
  - Dosimetry measurements of a volume (one point or one plane at a time).

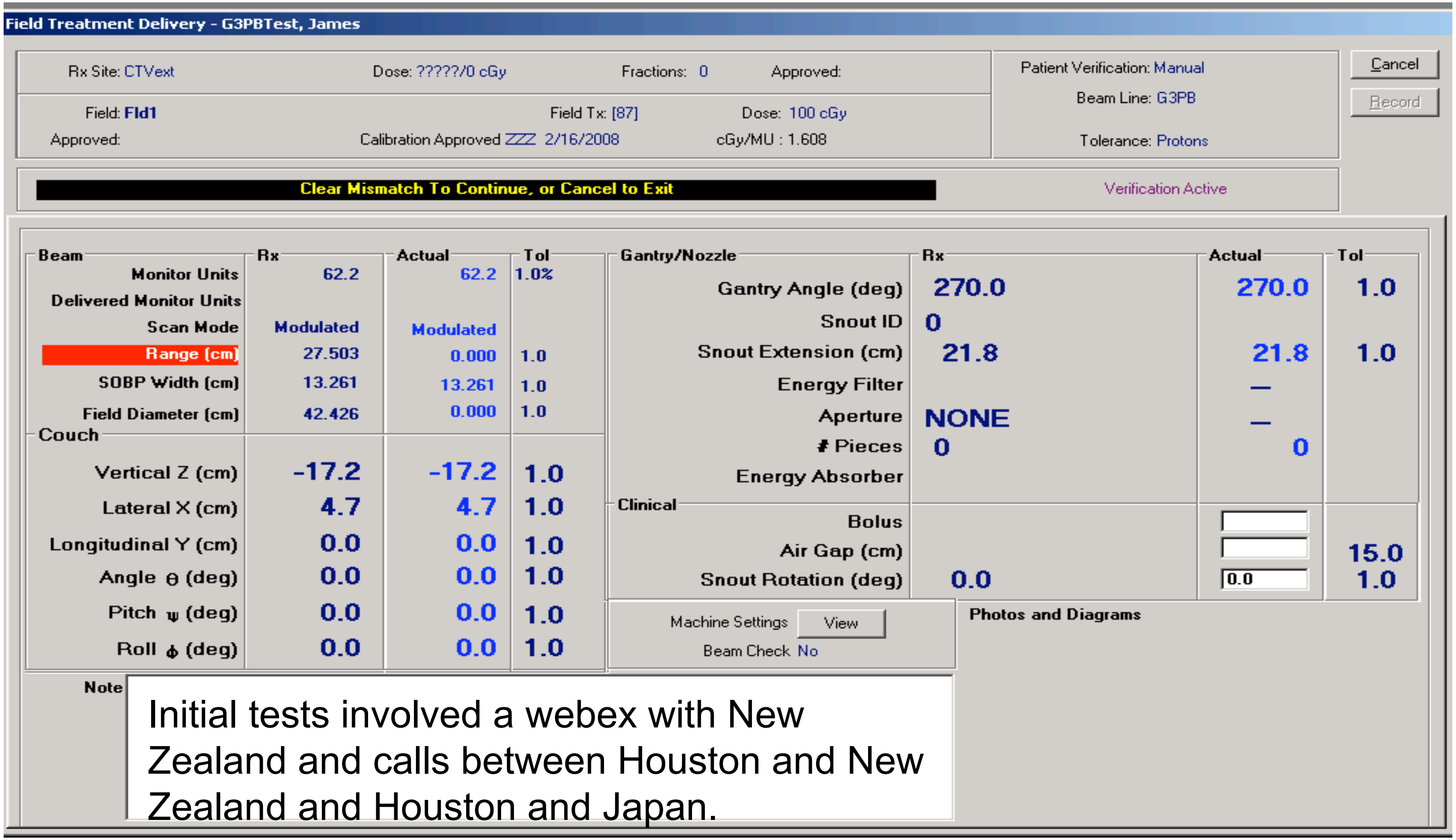
Spot Sizes in Air, Gantry 0 degrees



Clinical Commissioning Treatment Delivery - Scanning

- Major steps include:
  - EMR development time. IMPAC was given substantial time during the week and on Saturdays to test their software, with recovery from an aborted or interrupted treatment being a major focus.
  - Mosaiq V 1.5, G 9, was delivered to Anderson on March 24 and installed in the test environment one week later.
  - Additional tests are scheduled for April 2, 3, and 4th. Migration weekend for the entire practice was completed on the weekend of April 18 – 20th.

MOSAIQ V 1.5
Scanning Mode Modulated
One mismatch



Initial tests involved a webex with New Zealand and calls between Houston and New Zealand and Houston and Japan.

Clinical Commissioning Treatment Delivery - Scanning

- Major steps include:
  - Eclipse TPS, Version 8.17. Anderson was originally scheduled to migrate in September, 2007. This was accomplished on the weekend of January 26th, 2008. The scanning beam portion of this software, which is limited to our current delivery capabilities, was released to the clinic for initial experience on March 24th.

Operational Issues Weekdays

- 5:30 to 6:00 AM Hitachi developmental team turns system over to Hitachi Service and Maintenance for TQA
- 6:30 to 7:00 AM Hitachi Service and Maintenance turns system over to Anderson Physics for morning QA.
- 7:30 to 8:00 AM treatments start
- 6:00 PM to 10:00 PM treatments stop and patient specific QA begins for 1 to 2 hours
- 8:00 PM to 11:00 PM Anderson returns the system to Hitachi for continued program development.

Operational Issues
Weekends

- Saturday – Clinical commissioning, machine QA, special projects from 8:00 AM until 5:00 PM or so.
- Saturday evening – Hitachi development
- Sunday – Preventive Maintenance. Approximately 97% uptime.

Physics Staffing at PTC 60 patients + commissioning

- QMP 6 + (GU clinical physics covers both photons and protons) The entire process is understood by Ron and Narayan. This is a weakness.
- MP 4 +
- Physics Assistants 2.5
- Engineers 2+ Anderson + 7 Hitachi
- Shop 3.5
- Others (Trainees) 2.0

Operational Issues
Monday March 31, 2008

- G 1 22 patients scheduled from 8 AM until 6:30 PM. Last patient is a non-anesthesia cranial spinal with 5 fields who was on the treatment table for over 100 minutes with the last treatment delivered at 9:50 PM. There were no scheduled snout changes.

Operational Issues
Monday March 31, 2008

- G 2 15 patients with schedules from 8 AM until 5:30 PM, including 4 with anesthesia who are scheduled for 45 minutes each. Last field was treated at 7:10 PM.   There was one scheduled snout change, which requires 15 to 20 minutes. The snout changes are performed by Hitachi Service and Maintenance.

Operational Issues
Monday March 31, 2008

- F 2 23 patients with schedules from 8 AM until 6:00 PM. Last field was treated at 6:30 PM.   There were no scheduled snout changes.
- The average time to deliver a simple two field treatment is 27 minutes. Approximately 10% of this time is beam on time and approximately 10% of this time is waiting for the beam time.

Operational Issues

- 24 hours is the minimum time between finishing the treatment plan and the start of treatments and it is not enough.
- After the plan is finished, physics is spending 1(prostate) to 8 hours (CSI) reviewing the plan, calculating the verification plan, preparing the EMR, reviewing the aperture and compensator, measuring for MU determination, and approving the EMR.
- To date to determine the monitor units, two independent approaches have been used, namely measurement and calculation.

Operational Issues

- Morning QA has shown that the radiation characteristics are very stable. The least stable portion of the system is the Anderson IT Network.
- Periodic machine QA shows that the unit is very stable.
- Monitor unit determination is straight forward and could be simplified.
- There is always something new to measure. One weakness in our system is small fields.

Operational Issues

- New versions of SW to include Eclipse, Mosaiq, Zenkei Control System, PIAS, Gibbscam, etc.
- One observation of planning systems, proton relative to photon, is that proton commercial systems are not as mature as photon systems, which makes the migration from one version to another more adventuresome.

Unsolved Operational Issues

- Definition of Priorities, both in treatment planning and treatment delivery. (Oncologists want it all now.)
- Systematic review of clinical history with the goal of improving the delivery system, e.g. What did we learn from our first 30 cranial spinal patients?
- Development of an appropriate clinical/dosimetric database. Currently the following independent DB's are being used: the hospital record, Mosaiq, Eclipse, Physics QA
- Management of a complex facility to meet clinical, research, business, and other needs.

Management of Major Unexpected Events

- Occasionally information flow takes an unexpected turn, e.g. Mosaiq indicates that the treatment has been delivered during the initial downloading from Mosaiq to Hitachi after the therapists are given to contradictory instructions to the delivery system. Working with Hitachi and IMPAC, these infrequent events identify weak parts of the system which result in changes in either the Hitachi control system or the IMPAC EMR. It is very rare that treatment is delivered outside of Mosaiq (<0.0001 p value).

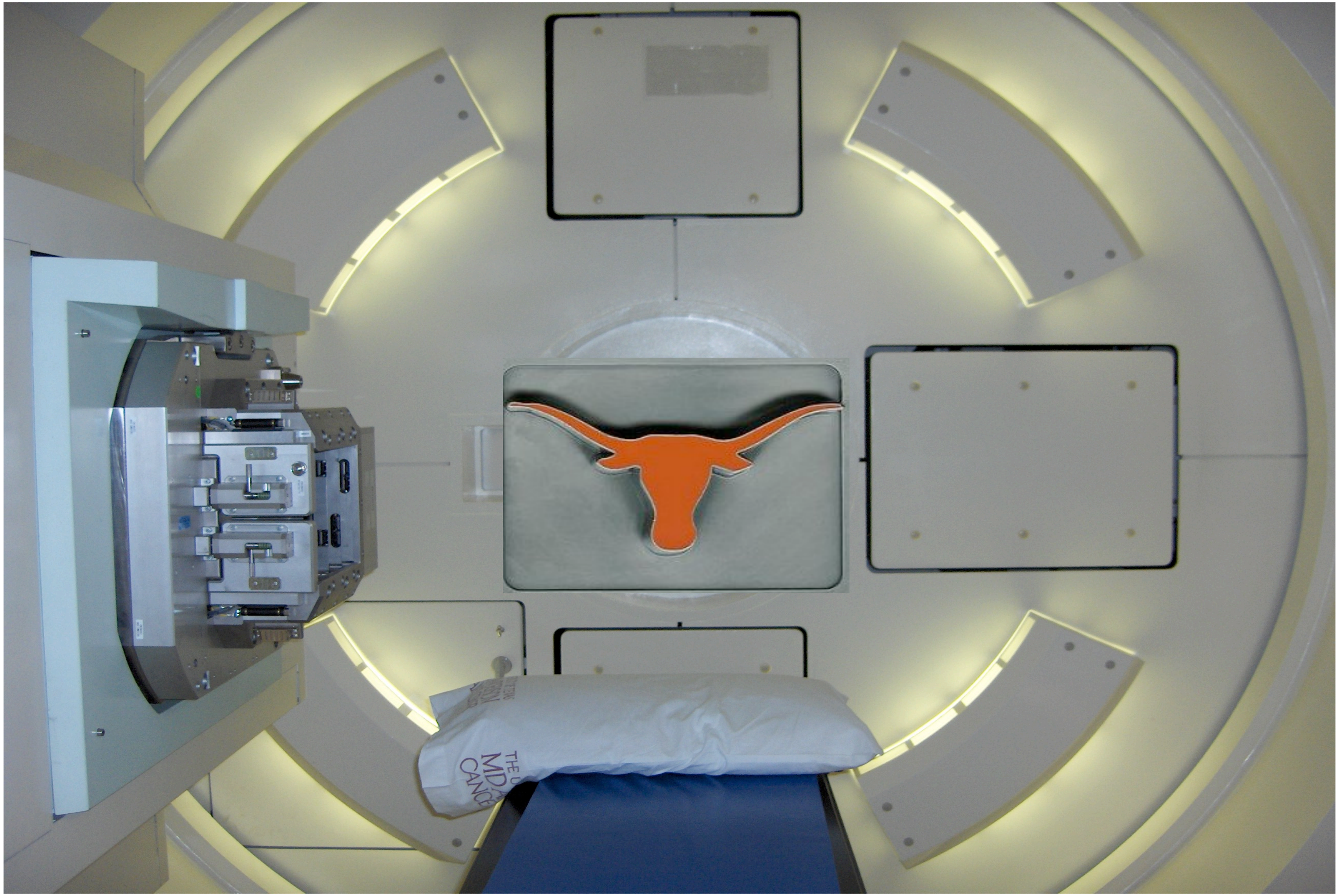
Routine Proton Conferences

- Fridays at 2 PM – Physics Conference to review specific physics issues and data – Oncologists are welcome.
- Fridays at 3 PM – Planning Clinic
  - First 5 minutes are hosted by physicists who present various physics/treatment planning issues to the oncologists
  - Next 55 minutes cases are used for peer review, which at times can be very lively.

Summary

- Be moderate - proton therapy is very detail sensitive. There is a conflict between taking appropriate care and paying the bills.
- Work hard.
- Have good communication - Dr. Woo "Please inform me when you are more uncertain than usual."

The University of Texas M.D. Anderson Cancer Center Proton Therapy Center



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