Periodic QA Program for Scattering Proton Beam

Z. Li
University of Florida Proton Therapy Institute

Physics Team @ UFPTI

- Jatinder R. Palta, PhD
- Stella Flampouri, PhD
- Wen Hsi, PhD
- Soon Huh, PhD
- Darren Kahler, PhD
- Zuofeng Li, DSc
- Roelf Slopsema, MS
- Daniel Yeung, PhD
- Liyong Li, PhD
- Sri Duvvuri, PhD
- George Zhao, PhD

Outline

- Periodic QA Program in Radiotherapy
- Designing A Periodic QA Program for Proton Therapy
- Periodic QA Program at UFPTI
- Results and Summary

Periodic QA in Radiotherapy

- Professional standards available for most of conventional radiotherapy modalities
  - With specific tests to be performed, frequencies, and tolerances
- Periodic QA tests and tools available from equipment or third party vendors
  - For example, front pointers, EPID test phantom, CBCT test phantom, etc
- Physicist or designee to perform QA tests, with engineering support as necessary
- Beam availability not a concern

Periodic QA in Radiotherapy

Comprehensive QA for radiation oncology: Report of AAPM Radiation Therapy Committee Task Group 40

Gerald J. Kutcher
Department of Medical Physics, Memorial Sloan-Kettering Cancer Center, New York, New York 10021

Lawrence Coia
Department of Radiation Oncology, Fox Chase Cancer Center/University of Pennsylvania, Philadelphia, Pennsylvania 19111

Michael Gillin
Radiation Therapy Department, Medical College of Wisconsin, Milwaukee, Wisconsin 53226

William F. Hanson
Radiological Physics Center, Department of Radiation Physics, University of Texas M.D. Anderson Cancer Center; Houston, Texas 77030

Steven Leibel
Department of Radiation Oncology, Memorial Sloan-Kettering Cancer Center; New York, New York 10021

Robert J. Morton
Siemens Medical Laboratories, Inc., Concord, California 94520

Jatinder R. Palta
Department of Radiation Oncology, University of Florida, Gainesville, Florida 32610-0385

James A. Purdy
Radiation Oncology Division, Mallinckrodt Institute of Radiology, Washington University School of Medicine, St. Louis, Missouri 63110

Lawrence E. Reinstein
Department of Radiation Oncology Health & Science Center University Hospital at Stony Brook, Stony Brook, New York 11794-7028

Goran K. Svensson
Radiation Therapy Department, Harvard Medical School, Boston, Massachusetts 02115

Mona Weller
Radiation Oncology, Hahnemann University, Philadelphia, Pennsylvania 19102-1192

Linda Wingfield
Central Arkansas Radiation Therapy Institute, Little Rock Arkansas 72215

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Periodic QA in Radiotherapy: AAPM TG-40 Report

- TG-40 has been functioning as the standard of comprehensive QA in radiotherapy, with adoptions by agreement states in the US for regulatory enforcement

TABLE II. QA of medical accelerators.

Frequency	Procedure	Tolerance[a]
Daily	Dosimetry	
	X-ray output constancy	3%
	Electron output constancy[b]	3%
	Mechanical	
	Localizing lasers	2 mm
	Distance indicator (ODI)	2 mm
	Safety	
	Door interlock	Functional
	Audiovisual monitor	Functional
Monthly	Dosimetry	
	x-ray output constancy[c]	2%
	Electron output constancy[c]	2%
	Backup monitor constancy	2%
	x-ray central axis dosimetry parameter (PDD, TAR) constancy	2%
	Electron central axis dosimetry parameter constancy (PDD)	2 mm @ therapeutic depth
	x-ray beam flatness constancy	2%
	Electron beam flatness constancy	3%
	x-ray and electron symmetry	3%
	Safety Interlocks	
	Emergency off switches	Functional
	Wedge, electron cone interlocks	Functional
	Mechanical Checks	
	Light/radiation field coincidence	2 mm or 1% on a side[d]
	Gantry/collimator angle indicators	1 deg
	Wedge position	2 mm (or 2% change in transmission factor)
	Tray position	2 mm
	Applicator position	2 mm
	Field size indicators	2 mm
	Cross-hair centering	2 mm diameter
	Treatment couch position indicators	2 mm/1 deg
	Latching of wedges, blocking tray	Functional
	Jaw symmetry[e]	2 mm
	Field light intensity	Functional
Annual	Dosimetry	
	x-ray/electron output calibration constancy	2%
	Field size dependence of x-ray output constancy	2%
	Output factor constancy for electron applicators	2%
	Central axis parameter constancy (PDD, TAR)	2%
	Off-axis factor constancy	2%
	Transmission factor constancy for all treatment accessories	2%
	Wedge transmission factor constancy[f]	2%
	Monitor chamber linearity	1%
	x-ray output constancy vs gantry angle	2%
	Electron output constancy vs gantry angle	2%
	Off-axis factor constancy vs gantry angle	2%
	Arc mode	Mfrs. specs.
	Safety Interlocks	
	Follow manufacturers test procedures	Functional
	Mechanical Checks	
	Collimator rotation isocenter	2 mm diameter
	Gantry rotation isocenter	2 mm diameter
	Couch rotation isocenter	2 mm diameter
	Coincidence of collimetry, gantry, couch axes with isocenter	2 mm diameter
	Coincidence of radiation and mechanical isocenter	2 mm diameter
	Table top sag	2 mm
	Vertical travel of table	2 mm

[a]The tolerances listed in the tables should be interpreted to mean that if a parameter either: (1) exceeds the tabulated value (e.g., the measured isocenter under gantry rotation exceeds 2 mm diameter); or (2) that the change in the parameter exceeds the nominal value (e.g., the output changes by more than 2%), then an action is required. The distinction is emphasized by the use of the term constancy for the latter case. Moreover, for constancy, percent values are ± the deviation of the parameter with respect its nominal value; distances are referenced to the isocenter or nominal SSD.
[b]All electron energies need not be checked daily, but all electron energies are to be checked at least twice weekly.
[c]A constancy check with a field instrument using temperature/pressure corrections.
[d]Whichever is greater. Should also be checked after change in light field source.
[e]Jaw symmetry is defined as difference in distance of each jaw from the isocenter.
[f]Most wedges' transmission factors are field size and depth dependent.

Criticisms of TG-40

- Prescriptive
  - Partly due to misapplication of TG-40 recommendations as regulatory requirements
- Not easily adaptable to new technologies
  - AAPM and other organizations have since then developed QA guidelines and other documents for IMRT, Tomotherapy, Cyberknife, CT simulation, prostate seed implant, HDR, etc… and *proton therapy*
- Does provide clear pathways for development of new QA standards
- AAPM Task Group 100 formed to address these criticisms

Periodic QA in Radiotherapy:

- AAPM Task Group 100: "Methods for Evaluating QA Needs in Radiotherapy"
  - *Identify a structured systematic QA program approach that balances patient safety and quality versus resources commonly available*

  http://aapm.org/org/structure/default.asp?committee_code=TG100

- QA needs evaluated based on *Likelihood of Occurrence (O); Severity of Consequences (S); and Likelihood of Detection (D)*
- Tests developed for fulfill QA needs henceforth identified
  - Tolerances defined
  - Actions defined for out-of-tolerance test results

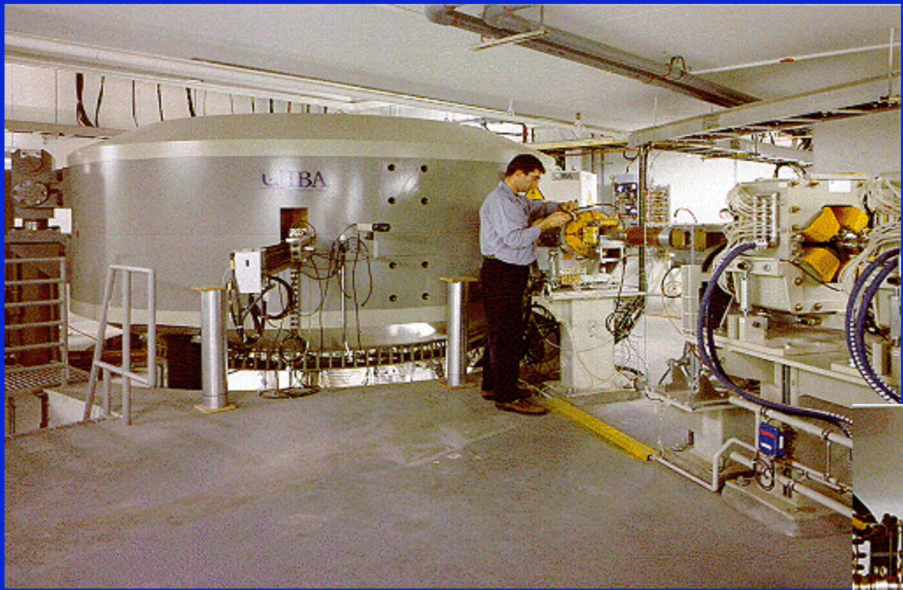
Periodic QA Program for Proton Therapy

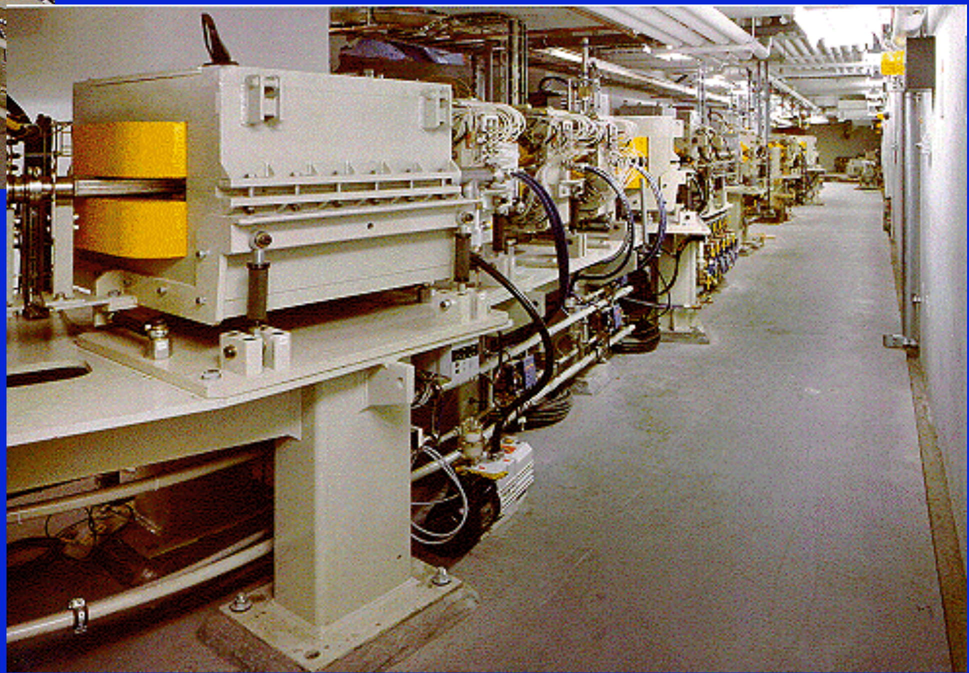
- No standards available
- QA needs may be significantly system-specific
  - Scattering beam vs. scanning beam
  - Fixed vs. gantry treatment rooms
  - SOBP generation method
  - Image localization system
  - PPS design
- QA needs may be specific to institutional clinical workflow
  - Use of lasers
  - Use of light field
- Competition of beam time with patient treatment

Design of A Periodic QA Program for Proton Therapy Systems

- Identifying critical system operating parameters
  - Frequency of QA testing as a function of severity of component failure, as well as its likelihood of failure
  - Tests designed to evaluate functioning of multiple components at the same time where applicable
  - Purpose-built QA devices to improve reproducibility and efficiency of QA measurements (for example, daily QA compensator phantom)
  - *Optimize efficiency of QA tests*

IBA Cyclotron and Energy Selecion System (ESS)

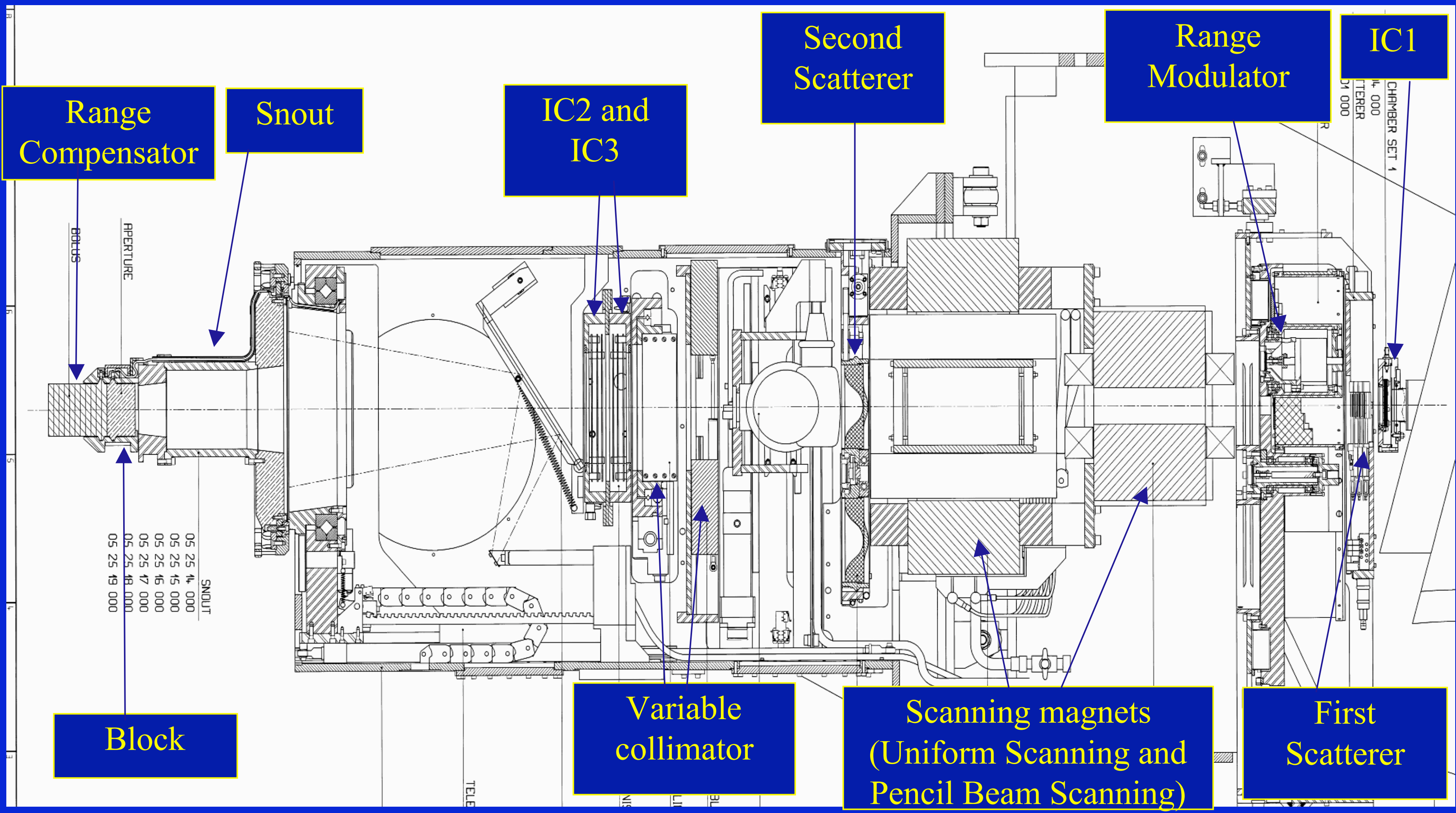




Identification of System Failure Modes – Beam Line

- Potential beam line failure modes
  - Ion chamber at cyclotron exit (IC_{cyclo})
    - SOBP changes due to beam regulation problems
  - Energy Selection System (ESS) drifts
    - Range changes
  - Beam focus and steering
    - Lateral dose profiles
    - Average proton energy
      - Pristine peak width
- Potential Treatment Control System (TCS) failure modes
  - SOBP changes due to errors of Beam Current Modulation (BCM)

IBA Nozzle Components

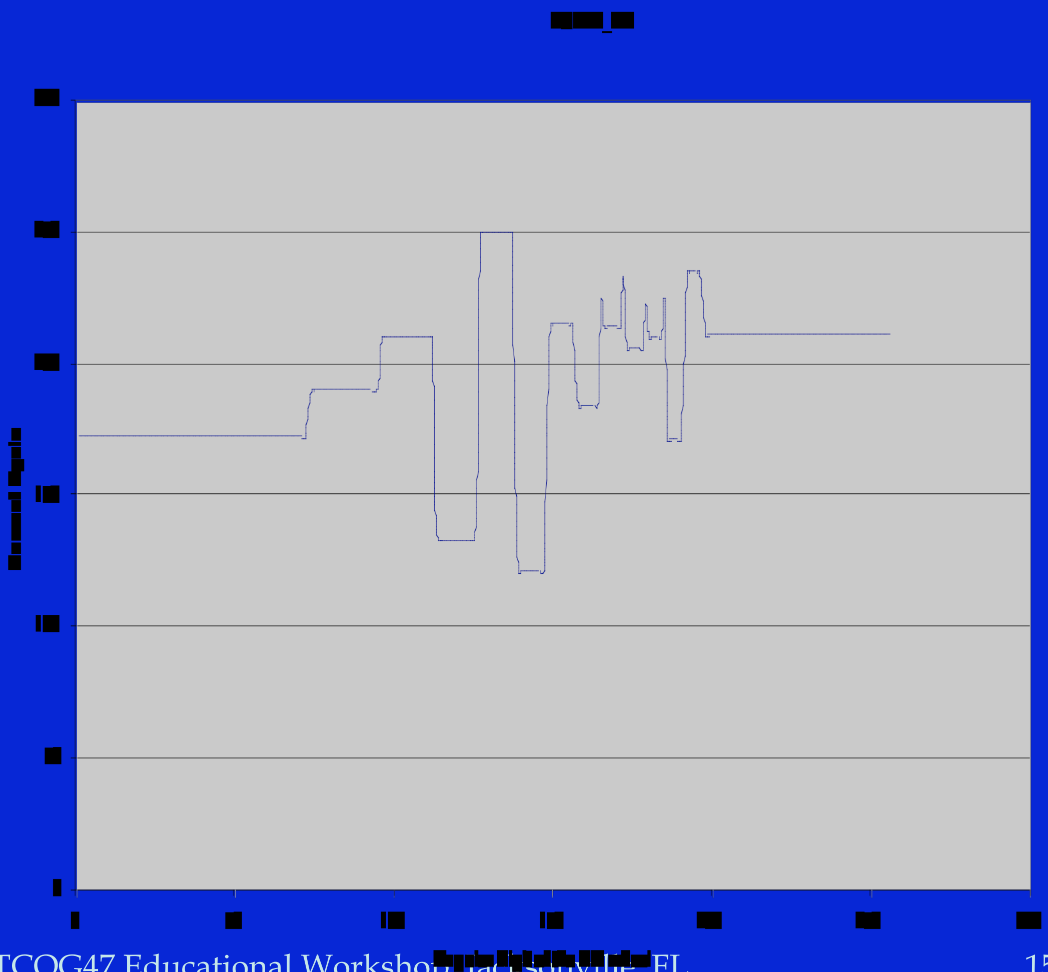


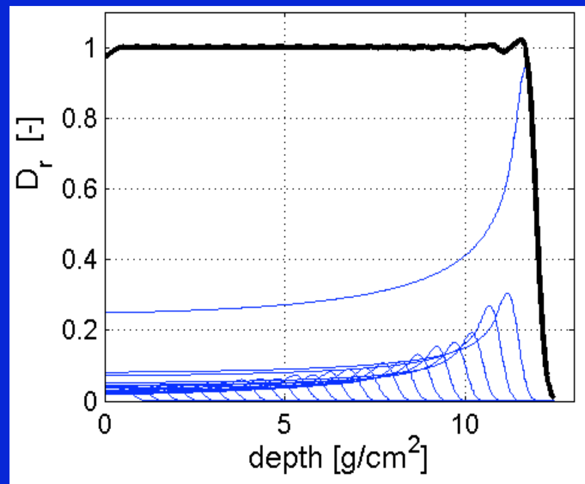
Identification of System Failure Modes – Nozzle

- Potential nozzle failure modes
  - Ion chambers and their electronic units
    - Output changes
    - Lateral profile changes
    - Small range changes
  - Range modulator wheel and its electronic unit
    - Range, modulation, and SOBP changes due to loss of beam synchronization with wheel rotation
  - First and second scatterers and their electronic units
    - Lateral profile changes
    - Output changes
    - Range changes

Range Modulation

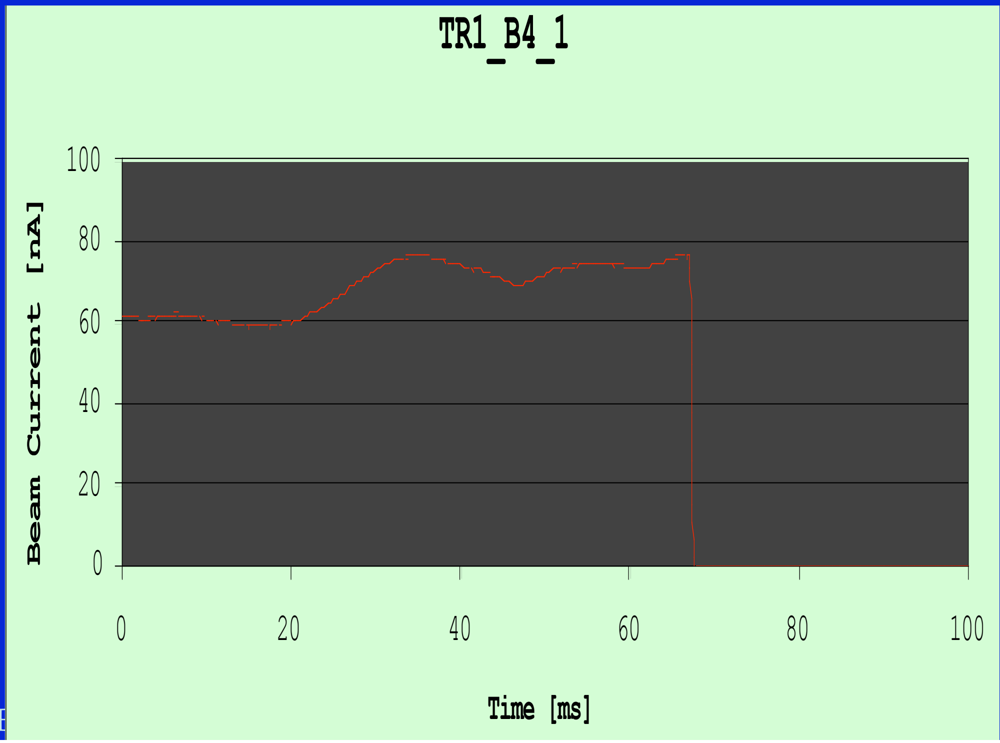
- Weights of Bragg Peaks (beam current weights) can be calculated from range modulation wheel thicknesses.
- However….

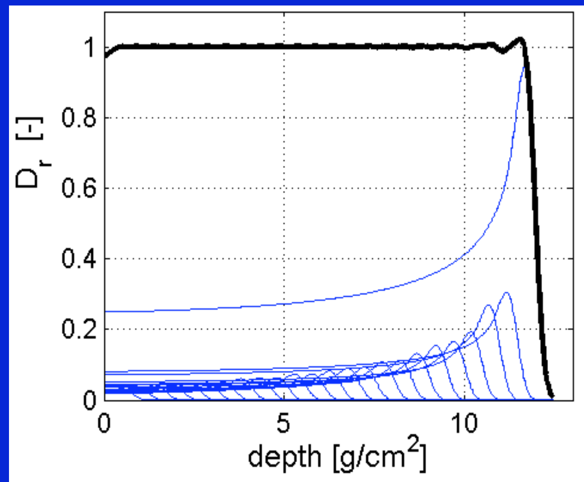




Range Modulation

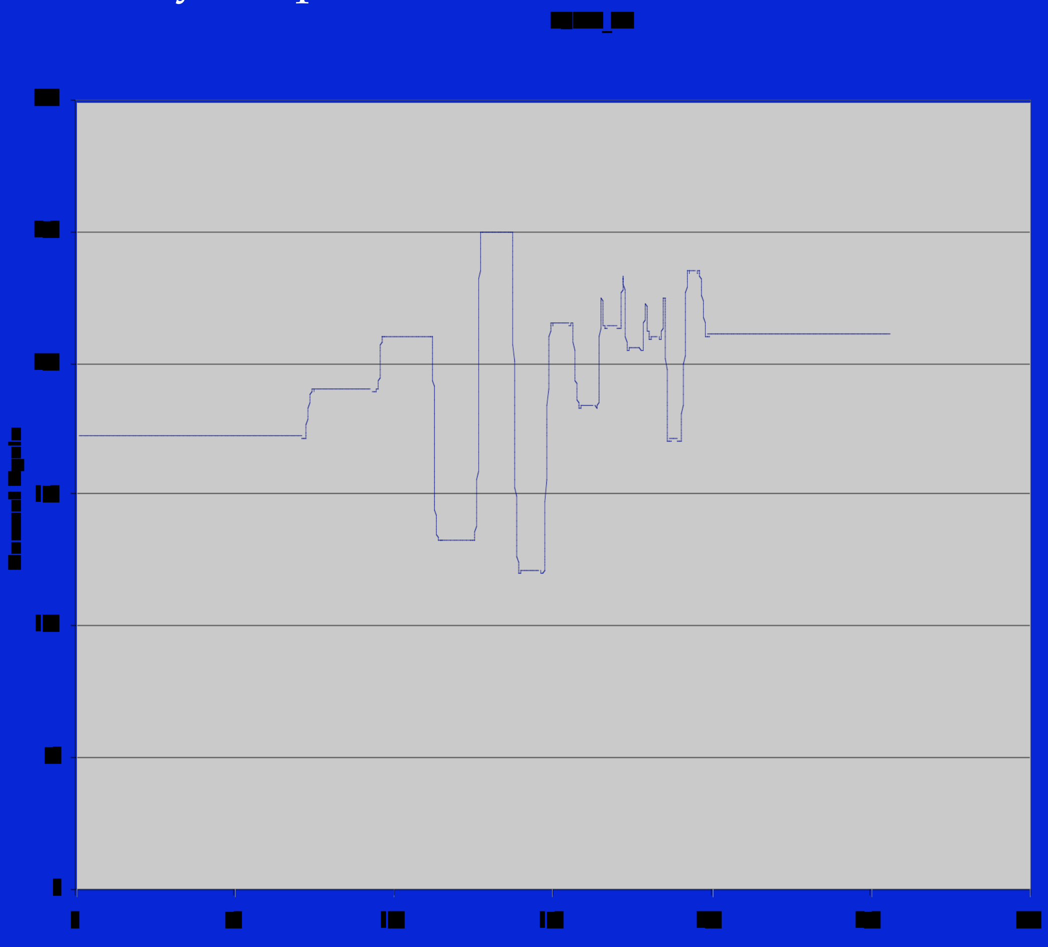
- BCM files are therefore based on beam measurements and fitted parameters.
- BCM files are stored in an Excel spreadsheet file – the ConvAlgo (Conversion Algorithm)
- ConvAlgo also specifies first scatterer, collimator, second scatterer, and other cyclotron and beam line settings (range at nozzle, beam current) for a given set of clinical beam prescription parameters (range, modulation, dose rate)

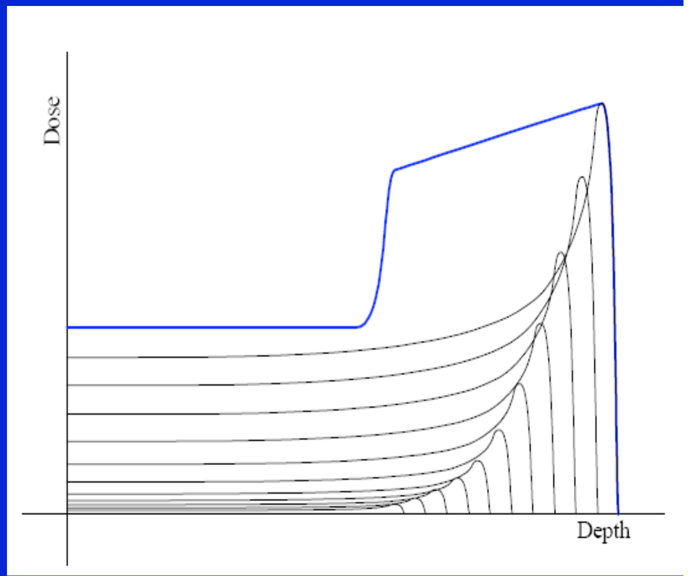




Range Modulation

- Physical thicknesses of range modulation wheel steps vary due to manufacturing process.
- Beam current modulation files (BCM) calculated from theoretical thicknesses may not produce flat SOBPs





ConvAlgo

- Validation of the ConvAlgo file is a central part in the commissioning of the IBA proton system
- Eclipse uses ConvAlgo for specification of machine settings as well
- Same ConvAlgo MUST be used in both IBA machine and Eclipse TPS

Clinical parameters (input)						
Range in patient:	10	g/cm^2				
Range Modulation:	10	g/cm^2				
Field Radius:	6.0	cm				
Dose:	100	MU				
Dose rate:	2	Gy/min				
ExpectedIrradTime (*):	100	sec	(suggested:		4.9	sec)
Range compensator length:	5.0	cm				
Equipment settings (output 1)						
a) Cyclo:						
Range @ nozzle entrance:	19.54	g/cm^2				
Beam current @ cyclo exit:	64	nA				
b) ESS:						
Slits opening:	40	mm				
B12:	1.330873	T				
c) Nozzle:						
Option #:	B4	-				
FS thickness:	1.465	mm				
FS thickness:	1.663	g/cm^2				
FS setting:	9	6	2	5	4	X
RM #:	5	-				
RM track:	5	-				
Stop position:	254	digit				
BCM filename:	bcmb4_lo_5	-				
SS #:	8	-				
SS position:	2	-				
VC x:	9.8	cm				
VC y:	9.7	cm				
presetCountIC2:	30000	cts				
presetCountIC3:	29784	cts				
Snout axial position:	5.0	cm				
Phantom position:	45.0	cm				
Misc. information (output2)						
RM derivative:	1.3	digit/(g/cm^2)				
RV max channel:	12.8	-				
BoxBWidth:	97.8	msec				
Beam current @ nozzle entrance:	7	nA				
ESS efficiency:	11.36%	%				
ExpectedCountperCycle_IC2:	30.0	counts				
Beam energy:	170.67	MeV				
rho: effective Radius of B12:	1.480	m				
DoseRate:	1.000	MU/sec				
Dose constant:	0.0081	Gy/MU				
Stop angle RM:		degree				

Other Considerations

- Global, “black box” tests of overall dosimetry characteristics can be performed
- *Most of the failure modes can be monitored by measurements of output, range, modulation, SOBP, and lateral profiles*

Mechanical Accuracy Test

- All mechanical accuracy tests must be considered in the context of image-guided proton therapy
- Special functions of PPS (tabletop sag correction, gantry sag correction) need to be tested if clinically used
  - Test performed by use of DIPS imaging of box phantom

Digital Imaging Positioning System (DIPS)

Imaging Accuracy Test

- Cross-hair manually installed on snouts to represent beam isocenter
  - Coincidence of X-ray isocenter to lasers
  - Coincidence of X-ray isocenter and proton beam isocenter

Periodic QA @ UFPTI: Daily QA

Daily QA	Comments
Review operator's cyclotron and gantry startup checklists	Operator checks machine operating parameters daily
Safety interlocks, indicator lights, neutron detector, A/V systems	
kV imaging and laser accuracy	Orthogonal x-ray cross hair and laser alignment to agree to within 1 mm
Output constancy check for reference field	Output measurements in plastic phantom
Range verifier reading constancy check for reference field	Range verifier reading constancy for the reference field has been established during machine commissioning
Range modulation wheel signal timing constancy check	Variations in these timing readings may indicate range and modulation delivery discrepancies

Proton Gantry 1 / Daily QA

QA performed by: Liyong Lin   Date: Day#:

1. Record temperature and pressure correction:

Air temperature [°C]: 22.0   Air pressure [hPa]: 1008.0   TCS PT correction: 1.005

Water temperature [°C]: 22.0   Chamber PT correction: 1.005

$$k_{PT} = \frac{(273.15+T)}{(273.15+22)} \frac{1013.25}{P}$$

2. Measure output QA field 1:

Detector: PPC05-407   Electrometer: DOSE1-05-10092

Detector cal factor [Gy/C]: 6.41E+08   Electrometer cal factor [-]: 1.000

Phantom type: Solid water   Background [C/s]: 0.00E+00

Dose MU	Charge [C*10^{-9}]	Time [s]	Output [cGy/MU]	Doserate [MU/s]
2.3				
103.5	1.487	38	0.947	2.7
205.5	1.521	38	0.961	2.7
305.1	1.486	39	0.962	2.6
		average	**0.957**	2.6
		stdev	0.008	0.1

Comments: Shuichi did

Measured output at mid-SOBP [cGy/MU]: 0.957   Exp. Value: 0.962   % Deviation: -0.6

3. Record Range Verifier QA field 1:

Range verifier reading [cm]: 15.13   Difference from expected [cm]: 0.03

4. Record RM timings:

10Hz signal period [ms]: 99.9   RE to FE BoxB [ms]: 71.9

Delay FE 10Hz to RE BoxB [ms]: 0.8   FE 10Hz signal to photocell [ms]: 3.2

5. Record position iso-align device center and check distance to crosshair:

Iso marker locations [pixels]: rad-A x 574   rad-A y 805   rad-B x 535   rad-B y 775

Dist. marker to xhair ≤1mm?: rad-A ☐   rad-B ☑   Leveling lasers parallel? : ☑

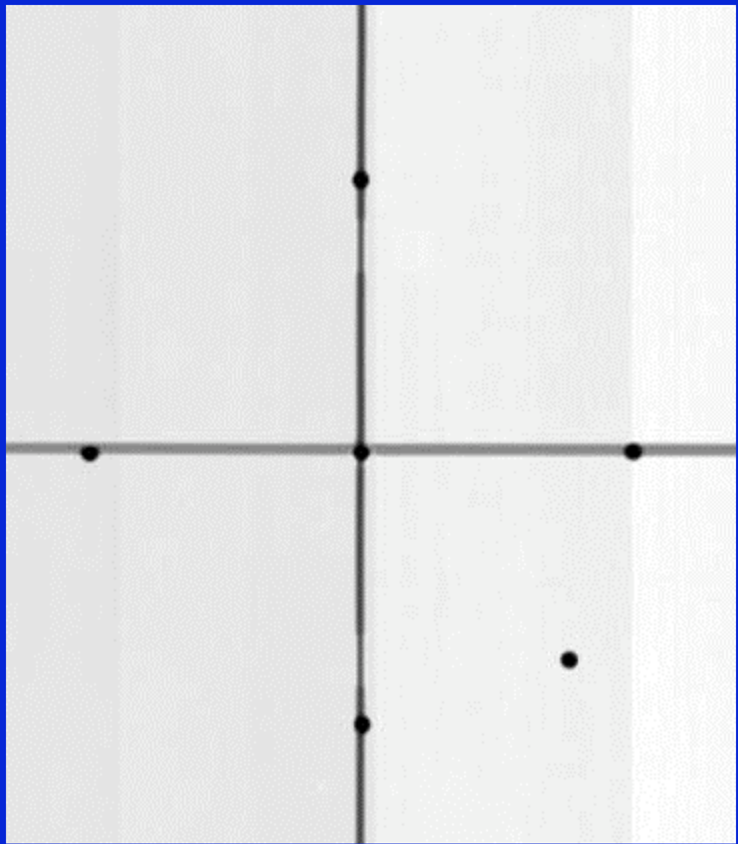
6. Test saftey interlocks and devices:

Door warning lights: ☑   Audio intercom/Video: ☑   Door interlock: ☑   Room search chime: ☑

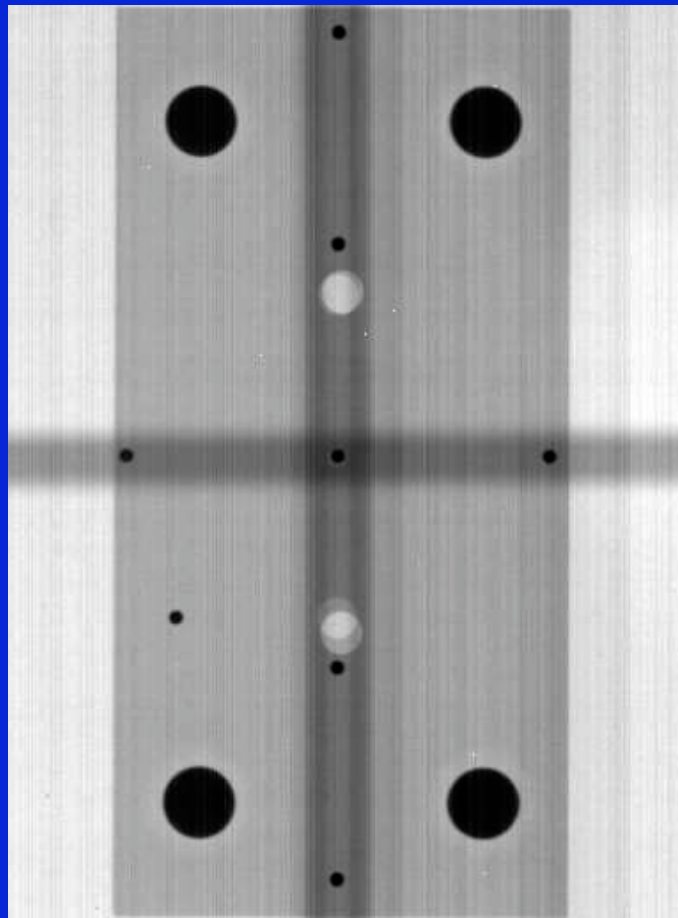
DCEU reset: ☑   Beam pause: ☑   Neutron detector: ☑

Daily QA RC Phantom

Laser vs. DIPS Imaging Crosshair Agreement



RAD-A



RAD-B

Periodic QA: Weekly QA

Weekly QA	Comments
Review daily QA results	
Output measurements in water phantom for two fields	**With increased use of MU calculation model, measure output of a random patient treatment field**
SOBP measurements for two fields	
Total first-scatterer water-equivalent thickness constancy check	**First-scatterers are subject to mechanical wear and tear**
Light / X-ray / Proton radiation field agreement	**x-ray and proton double exposure film taken to evaluate x-ray cross hair agreement with proton field. Different snouts used each weekly**

Proton Gantry 1 / Weekly QA

QA performed by: Liyong Lin | Date: Thursday, May 15, 2008 | Week#: 92

1. Temperature and pressure correction:

Air temperature [°C]: 22.2 | Air pressure [hPa]: 1015.0 | TCS PT correction: 0.999

Water temperature [°C]: 22.2 | Chamber PT correction: 0.999 | $k_{PT} = \frac{(273.15+T)}{(273.15+22)} \frac{1013.25}{P}$

2. Measured pdd and output QA fields 1 & 2, and one additional field:

Detector: PPC05-408 | Electrometer: DOSE1-05-10092

Detector cal factor [Gy/C]: 6.32E+08 | Electrometer cal factor [-]: 1.000

Snout size: 10-cm | Background [C/s]: 0.00E+00

a. Field 1 : Range = 15.1 cm, Modulation = 10.4 cm, Output @ 10 cm in water

Number of MU's for tuning: 2.5 | Offset: PPC05 → 0.16 cm

Depth D_{90} [cm]: 14.97 | Measured range [g/cm²]: 15.13

Distance P_{90}-D_{90} [cm]: 10.59 | Measured modulation [g/cm²]: 10.59

Dose MU	Charge [C*10⁻⁹]	Time [s]	Output [cGy/MU]	Doserate [Gy/min]
100.0				
195.7	1.466	35	0.967	1.6
285.6	1.382	33	0.971	1.6
		average	**0.969**	1.6
		stdev	0.002	0.0

Measured output at mid-SOBP [cGy/MU]: 0.969 | Exp. Value: 0.972 | % Deviation: -0.3

Range verifier reading [cm]: 15.12

b. Field 2 : Range = 25 cm, Modulation = 12 cm, Output @ 19 cm in water

Number of MU's for tuning: 2.2 | Offset: PPC05+5cmPA → 5.37 cm

Depth D_{90} [cm]: 19.77 | Measured range [g/cm²]: 25.14

Distance P_{90}-D_{90} [cm]: 11.92 | Measured modulation [g/cm²]: 11.92

Dose MU	Charge [C*10⁻⁹]	Time [s]	Output [cGy/MU]	Doserate [Gy/min]
2.2				
96.8	2.085	42	1.392	1.9
184.6	1.938	39	1.394	1.9
		average	**1.393**	1.9
		stdev	0.001	0.0

Measured output at mid-SOBP [cGy/MU]: 1.393 | Exp. Value: 1.387 | % Deviation: 0.4

Range verifier reading [cm]: 25.07

c. Measure pdd, output, and RV for patient-QA field (either actual Tx field or field with negative QA#)

QA#: 756 | *Note: print patient-QA form and attach to this form.*

3. Fixed scatterer lollipop check (in service mode):

a. No lollipops - Range verifier reading [cm]: 25.78 | Expected difference: 2.05

b. All lollipops in - Range verifier reading [cm]: 23.92 | Diff in RV All-in to All-out: **1.86**

4. Irradiate X-ray/proton double exposure film:

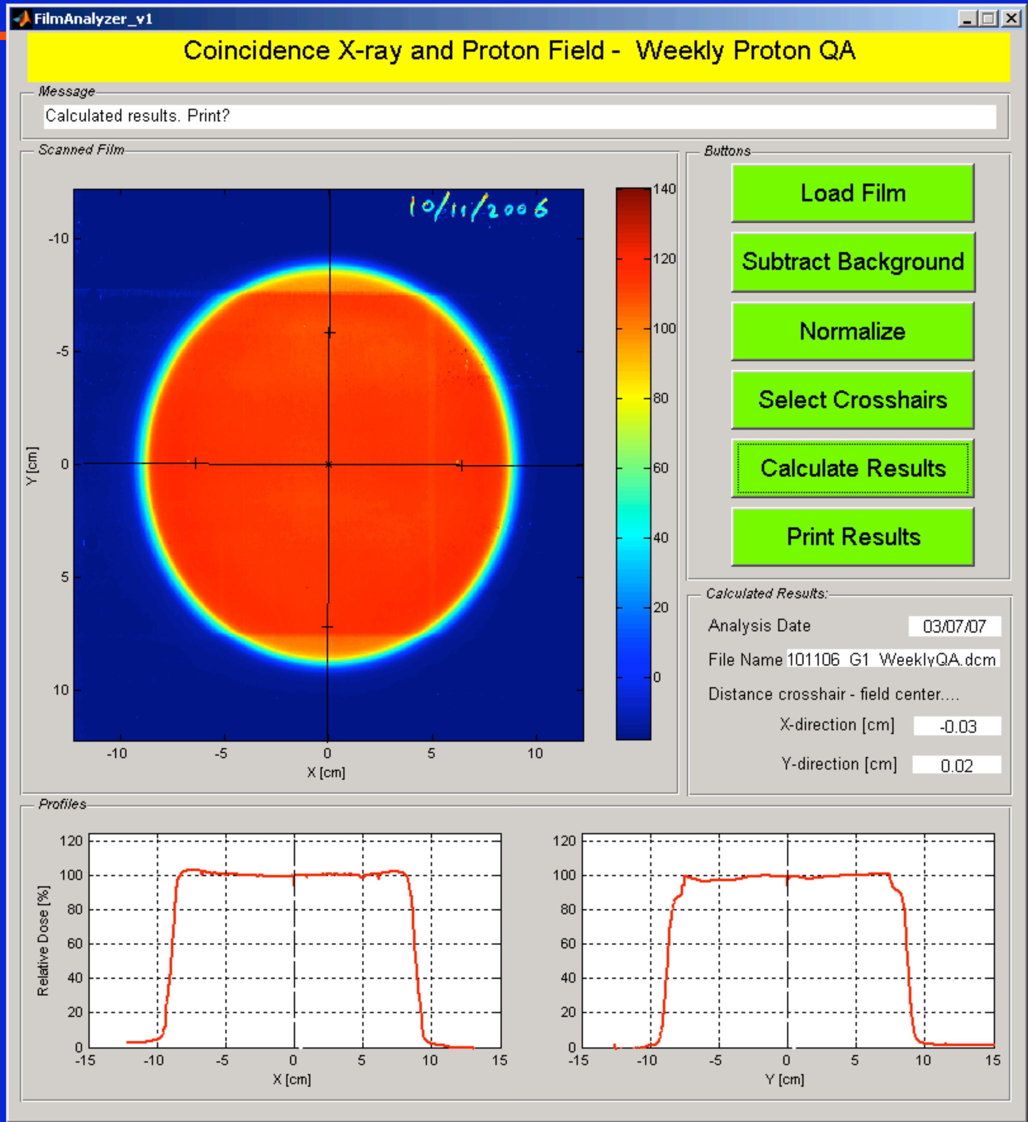
Snout size:

Dist. x-hair to proton / inline (x) mm

Dist. x-hair to proton / crossline (y) mm | Dist x-hair to proton: mm

5. Review daily QA sheets for last 5 days: Done? ☐

Weekly QA Film Analyzer



Periodic QA: Monthly QA

Monthly QA	Comments
Review weekly QA results	
Complete weekly QA	
Dose profile symmetry and flatness measurement for two fields	MATRIX ion chamber array used
Pristine peak depth dose measurement for two fields	Verify pristine peak beam energy spectrum constancy to rule out beam steering and centering errors
Gantry and treatment table movement accuracy, x-ray imaging patient shift calculation accuracy	Mechanical accuracy tests combined with x-ray imaging shift calculation accuracy test, by comparing artificially introduced and measured phantom shifts and rotations

Monthly QA Gantry 1

20-May-08

Month: Select...
Year: 2007
Physicist: Who are you?

1. Perform weekly QA (use the weekly form)

Snout used: Pick snout
Is weekly QA OK? ☑

2. Profiles

QA Field 1 (R=15.1 cm, M=10.4 cm):

Inline flatness: ___ %
Inline symmetry: ___ %
Crossline flatness: ___ %
Crossline symmetry: ___ %

QA Field 2 (R=25 cm, M=12 cm):

Inline flatness: ___ %
Inline symmetry: ___ %
Crossline flatness: ___ %
Crossline symmetry: ___ %

Profile instructions

3. Pristine peaks (Add WET of chamber wall to range)

PP Field 1 (R=15.53 cm):

Range PP Field1: ___ cm
90-90% Width Field1: ___ cm

PP Field 1 (R=24.50 cm):

Range PP Field2: ___ cm
90-90% Width Field2: ___ cm

Pristine peaks instructions

4. DIPS

Gantry at 270°:

Box @ iso:	New PPS position:	Position difference:	DIPS corrections:
PPS x:	PPS x:	PPS x:	PPS x:
PPS y:	PPS y:	PPS y:	PPS y:
PPS z:	PPS z:	PPS z:	PPS z:

Gantry at 315°:

Box @ iso:	New PPS position:	Position difference:	DIPS corrections:
PPS x:	PPS x:	RadA x:	RadA x:
PPS y:	PPS y:	RadA y:	RadA y:
PPS z:	PPS z:	RadB x:	RadB x:
		RadB y:	RadB y:

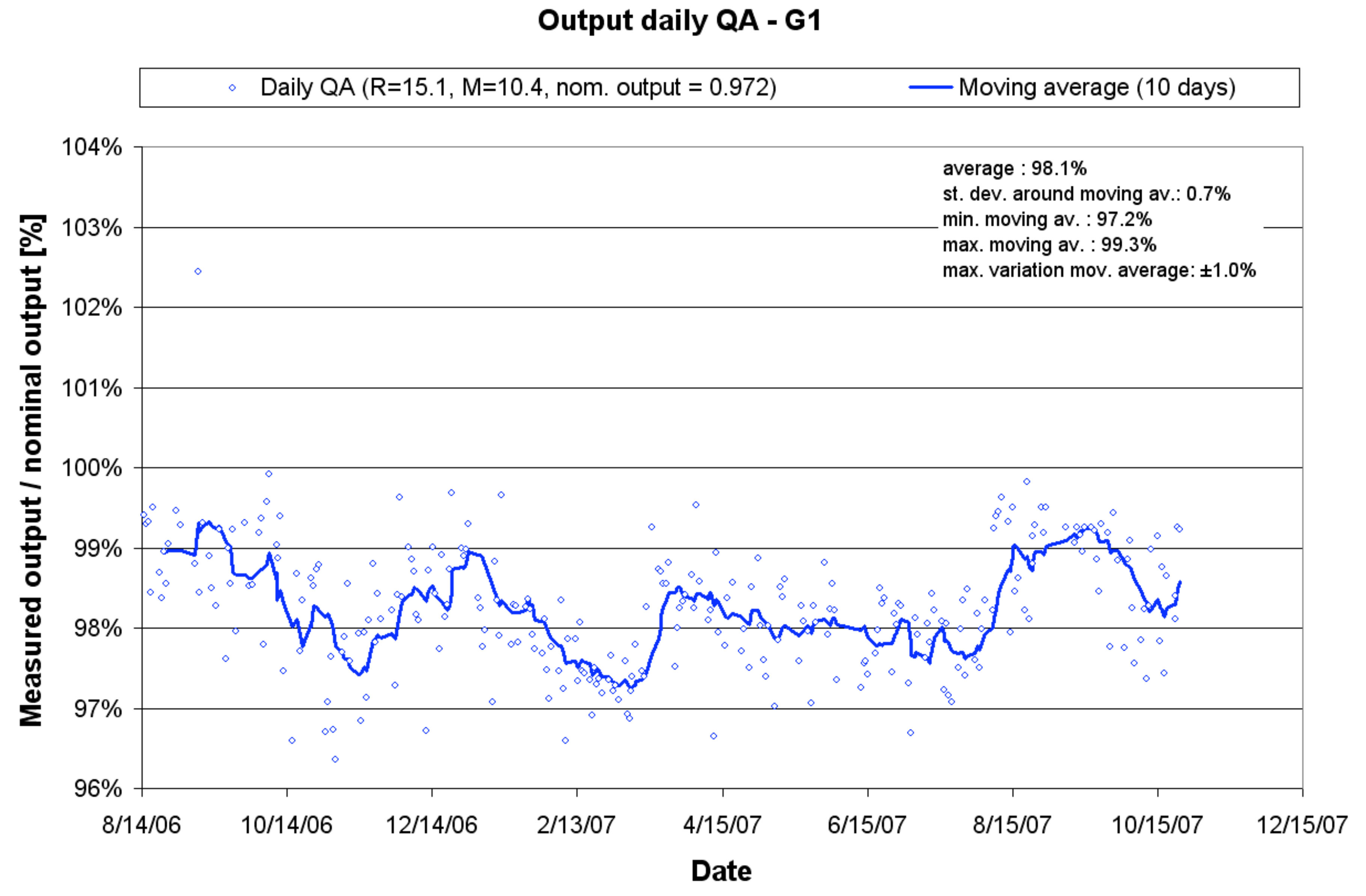
DIPS instructions

Periodic QA: Annual QA

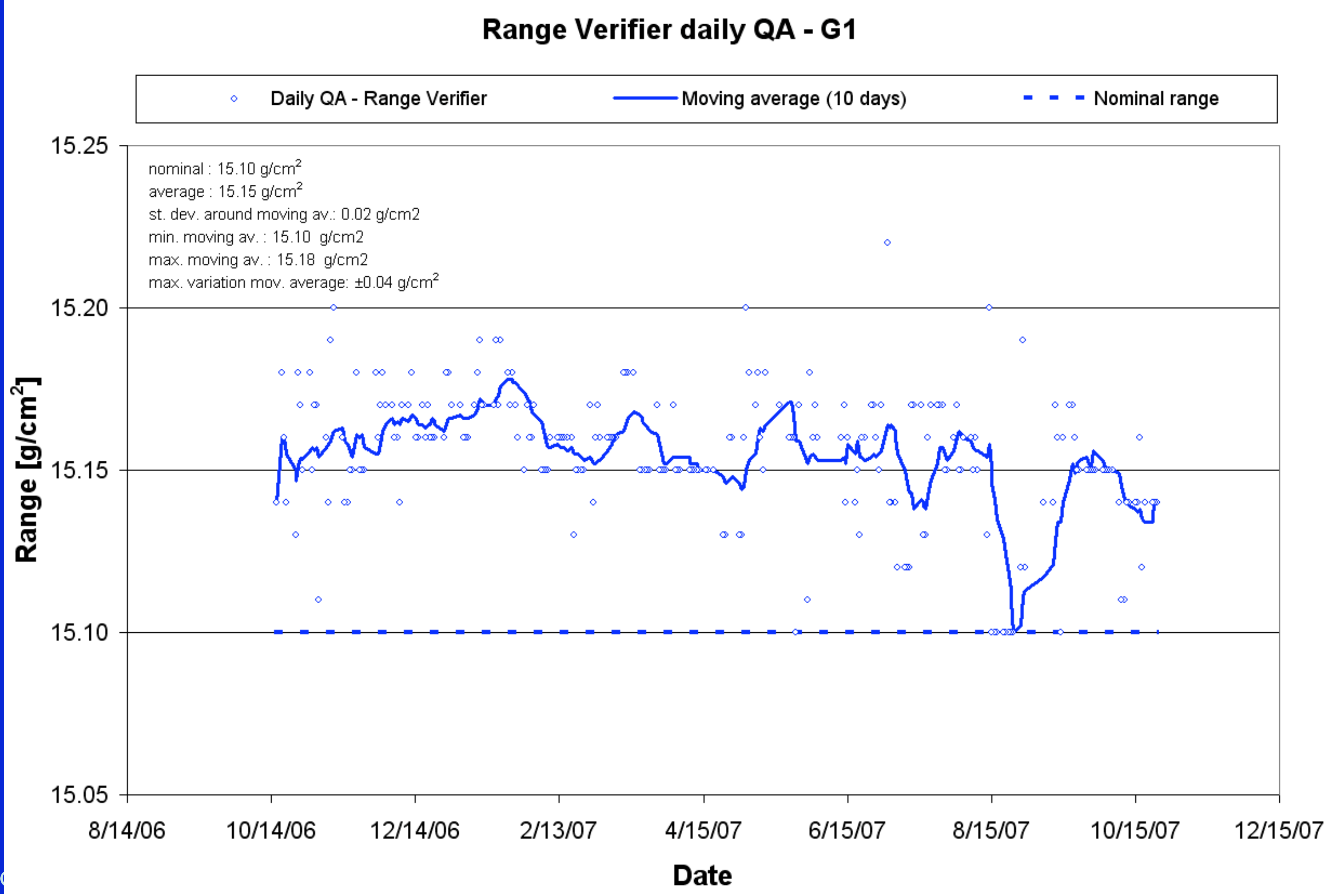
A "mini" commissioning exercise

Contents

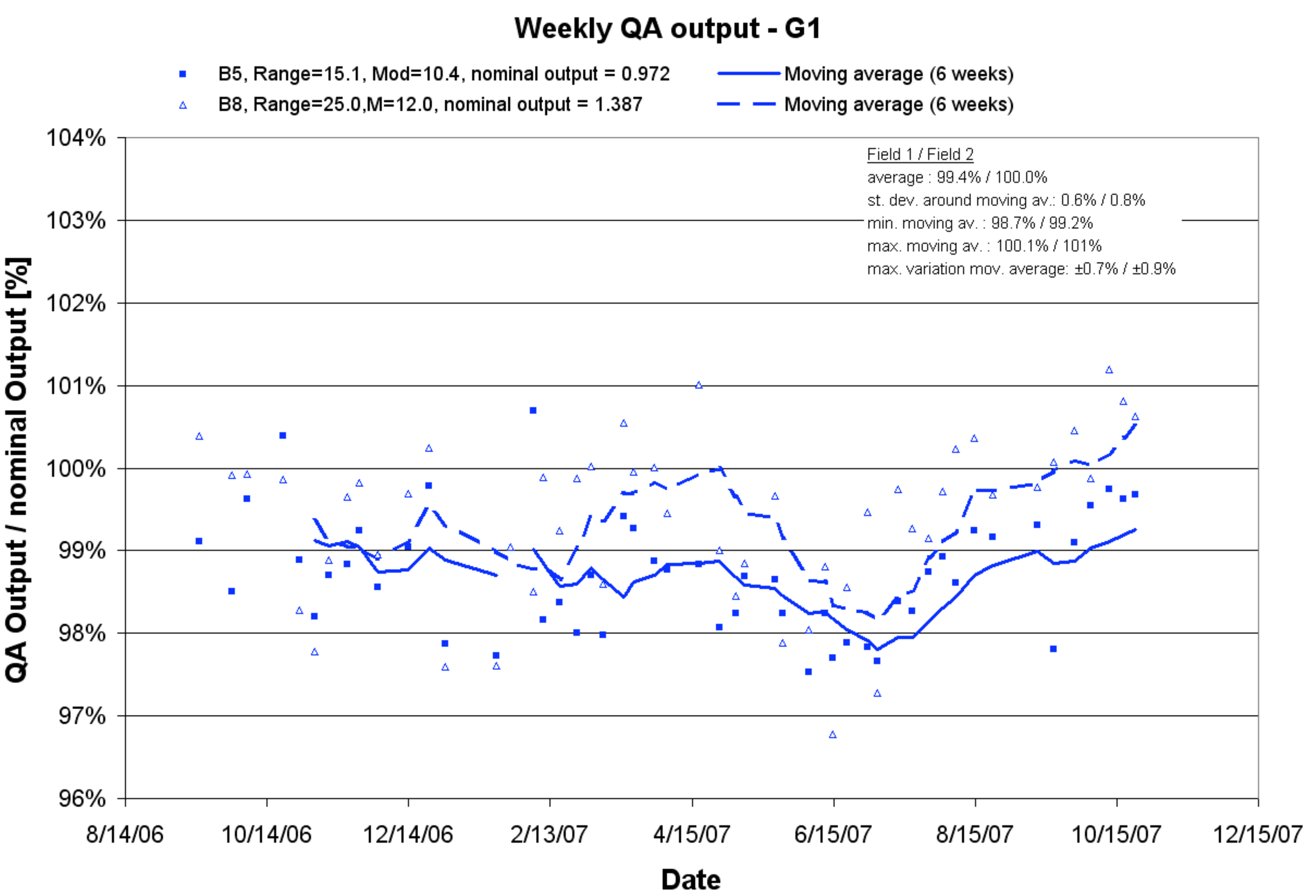
Results: Daily Output



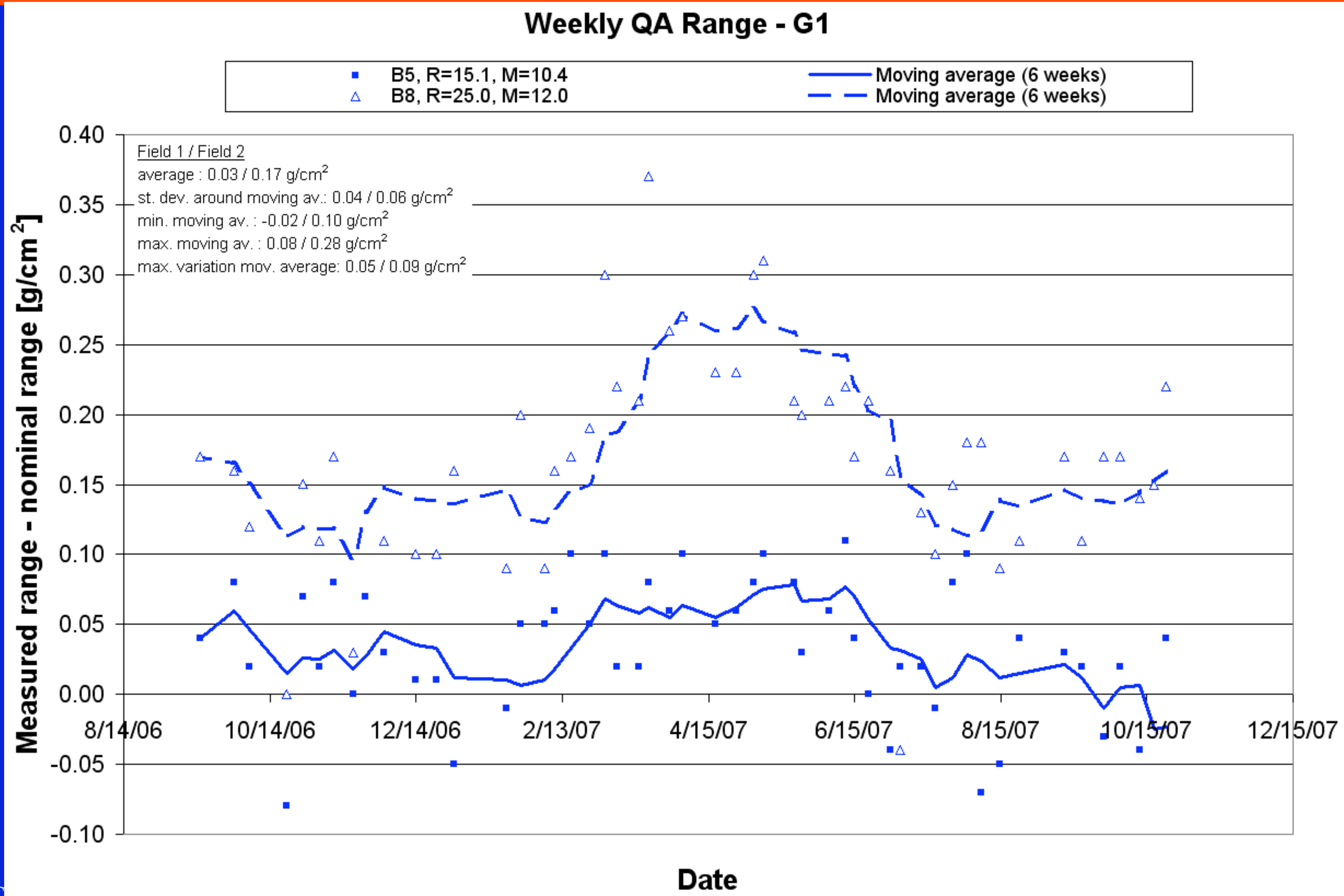
Results: Daily Range Verifier Readings



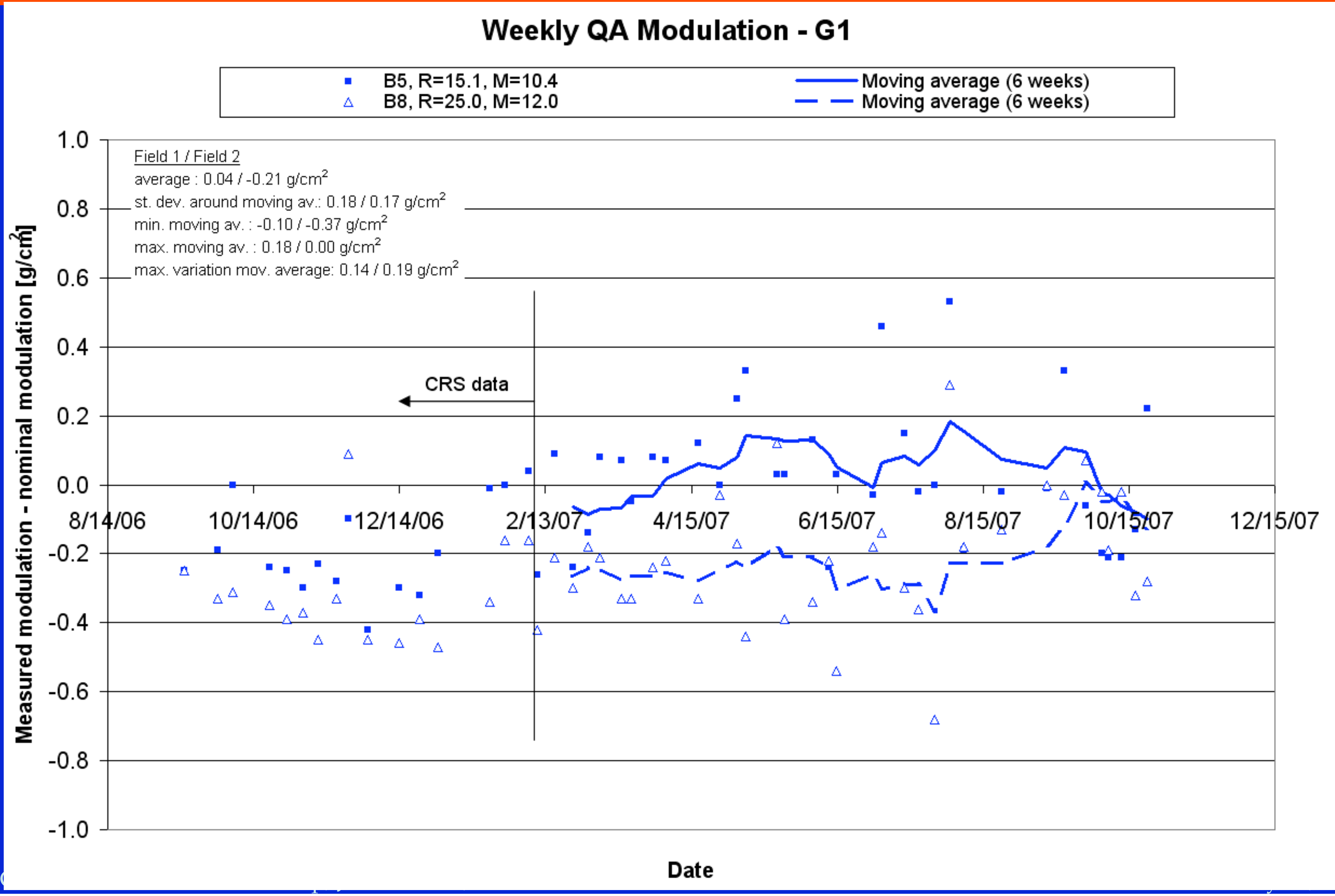
Results: Weekly Output



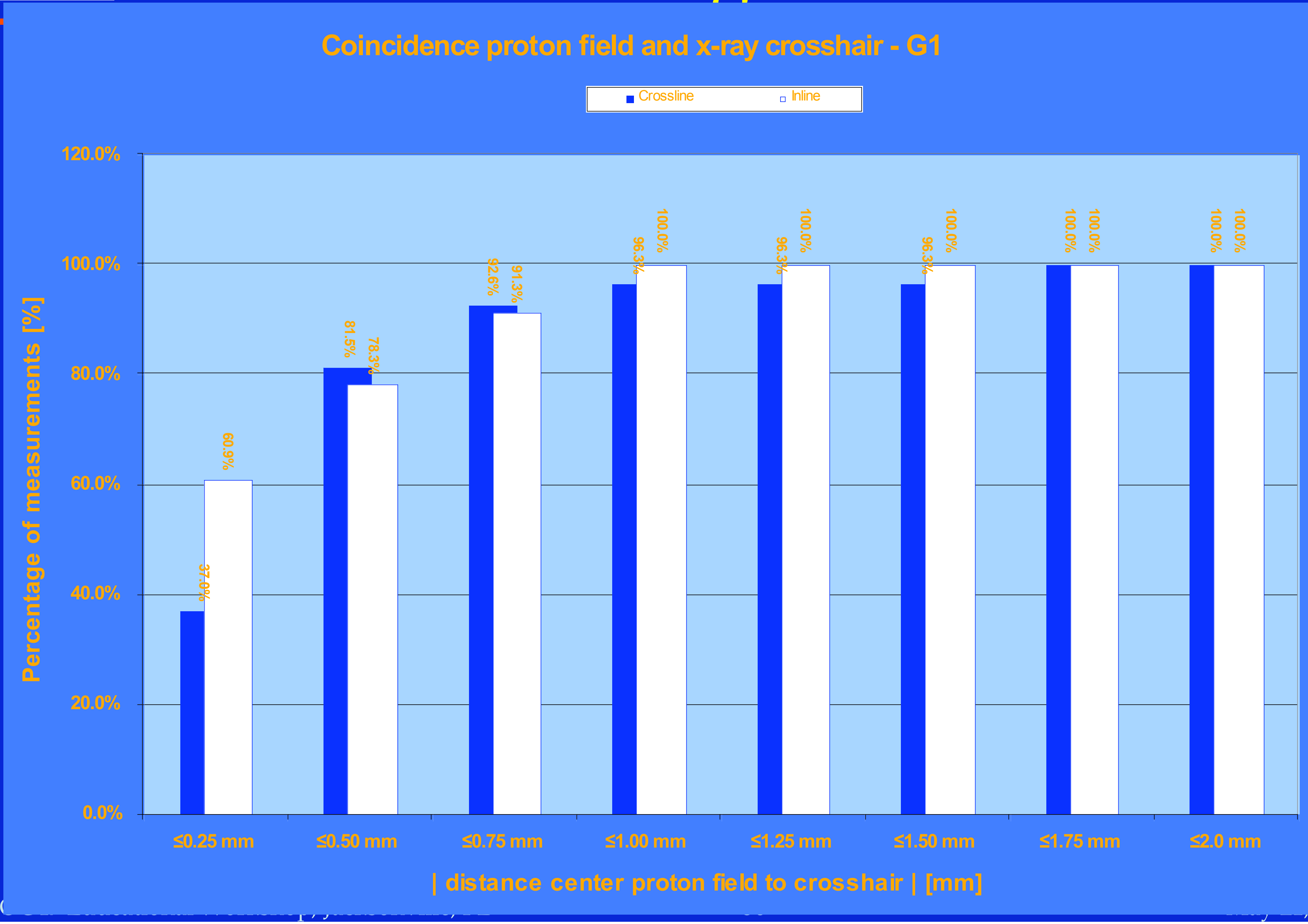
Results: Weekly Range



Results: Weekly Modulation



Results: Weekly X-ray, Proton, Light Field Agreement



Results: Output Calibration

RPC Radiological Physics Center
Excellence through Quality Assurance

7515 South Main Street, Suite 300, Houston, TX 77030 • Tel. (713) 745-8989
rpc@mdanderson.org • http://rpc.mdanderson.org • Fax: (713) 794-1364

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RESULTS OF TLD CHECK OF PROTON BEAM

v8.0.2

Institution:	Univ of Florida Proton Therapy Institute, Jacksonville, FL
RTF Number:	3180
Person irradiating dosimeters:	Zuofeng Li, D.Sc.
Radiation Machine:	IBA Cyclotron (Gantry 1)
Distance from source to reference point:	222.0 cm

OUTPUT VERIFICATION:

Proton Energy	Date of Irradiation	Dose determined by RPC:*	Dose determined by institution:*	**Ratio of absorbed dose determined by RPC to that stated by institution: TLD/INST**
79.2 MeV	03/09/2008	289 cGy to muscle	289 cGy to water	1.00

Radiation Machine:	IBA Cyclotron (Gantry 2)
Distance from source to reference point:	222.0 cm

OUTPUT VERIFICATION:

Proton Energy	Date of Irradiation	Dose determined by RPC:*	Dose determined by institution:*	**Ratio of absorbed dose determined by RPC to that stated by institution: TLD/INST**
79.2 MeV	03/09/2008	289 cGy to muscle	291 cGy to water	0.99

Person irradiating dosimeters:	Zuofeng Li, D.Sc.
Radiation Machine:	IBA Cyclotron (Gantry 3)
Distance from source to reference point:	222.0 cm

OUTPUT VERIFICATION:

Proton Energy	Date of Irradiation	Dose determined by RPC:*	Dose determined by institution:*	**Ratio of absorbed dose determined by RPC to that stated by institution: TLD/INST**
79.2 MeV	03/08/2008	291 cGy to muscle	294 cGy to water	0.99

Miscellaneous Results

- Ion chamber malfunctions: detected in daily QA output measurements
- First scatter failures: detected in daily QA output measurements and range verifier readings
- TCS software failure to upload BCM profiles: detected in daily QA output measurements

Summary

- Many proton therapy system failure modes can be monitored by standard dosimetric measurements, such as output, beam range and modulation, SOBP flatness, lateral profile flatness, etc
- Additional system-specific tests may need to be identified and implemented
- Design of a periodic QA program for proton therapy is a continuing process, with additions and/or deletions of specific tests determined by a comprehensive review of system performance over time