Medical Proton Test Facilities (MPTFs) –

Lessons Learned on the Unique Aspects for Single Event Effects (SEE) Testing of Electronics in the 200 MeV Regime

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All photos courtesy of K. LaBel, NASA (retired)

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Acronyms

- Federal Acquisition Regulation (FAR)
- Health Insurance Portability and Accountability Act (HIPAA)
- Hampton University Proton Therapy Institute (HUPTI)
- Indiana University Cyclotron Facility (IUCF)
- Indiana University Cyclotron Facility (IUCF)
- Medical Proton Therapy Facilities (MPTF)
- Monitor Units (MUs)
- Pencil Beam Scan (PBS)
- Point of Contact (POC)
- Particle Therapy Co-Operative Group (PTCOG)
- SCRIPPS Proton Therapy Center (SCRIPPS)
- Single Event Effects (SEE)

Abstract

- **Ever since the closure of the Indiana University Cyclotron Facility (IUCF) in 2014, there has been an increasing use of medical proton therapy facilities (MPTF) for SEE testing with protons in the 200 MeV or greater regime.**
- **This talk covers some of the unique features and considerations for utilizing MPTFs including both logistical and technical aspects.**
- **The emphasis is on those facilities that are new to SEE testing and not those that were providing protons prior to the IUCF shutdown and still are.**
- ***Note: this is NOT a guideline on how to test.***

Outline

- Pre-test Considerations
  - Logistics
    - Scheduling, Contracts, Shipping/Storage, User/target Rooms, Cabling, Amenities
  - Technical
    - Beam characteristics
    - Mounting/setup, dosimetry
  - Summary Comparison of Medical Patient versus Electronics SEE Test
- On-site Test Checklist
  - Arrival
    - Check-in, Radiation Safety/Personal Dosimetry, Test Preparation, Power
  - Test Performance
    - Installing in Target Room, Beam Control Preparation, Typical Test Run Protocol, Changes of Test DUT and Related, Post Test
- Sample Good Engineering Practices
- Summary

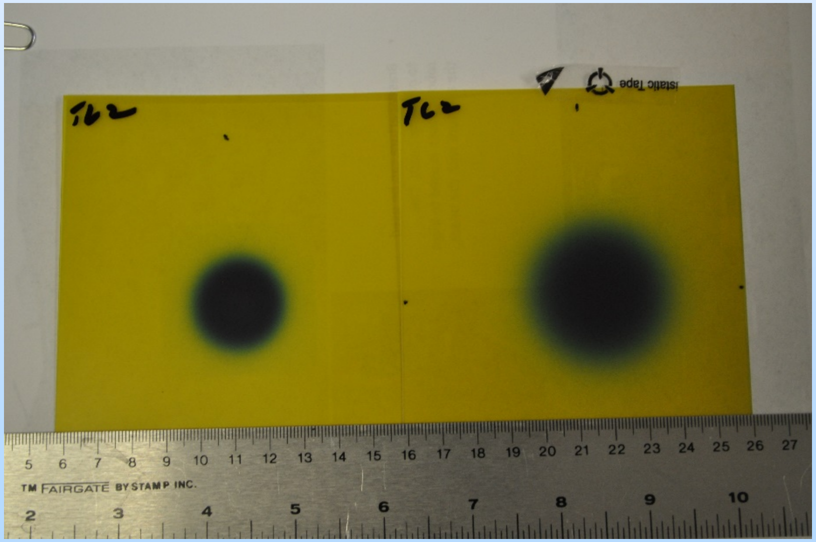
Sunset from California Protons

9730 Summers Ridge Rd, San Diego, CA 92121

Note:

Summary Table of Domestic MPTFs and Accessibility in Companion Poster

Pre-Test Considerations



Radiometric film exposure for two target locations: darkening equals dose.

Edges show drop off in uniformity.

Logistics - Scheduling

- **When reaching out to the POC at the MPTF, be aware that there are a variety of scheduling models being utilized including**
  - **Weekends**
    - **One day or both days**
    - **2 weekends a month, 3 out of 4 weekends a month**
    - **6, 12, or 16 hours each day**
  - **Evenings**
    - **After patient treatments end for the day**
    - **4-8 hours (SEE testers are used to "the graves")**
  - **Interleaving during the patient treatment hours**
    - **Lowest priority patient model**
    - **Assumes "Isolation" from patient area (dedicated research room)**
    - **~15 minutes of beam per hour (in 2-3 minute blocks)**
      - **15-20 minutes of beam per hour is a sweet spot for users**
    - ***Minimizes additional staffing***
  - **Model changes if no patients are being treated with a machine (dedicated time available)**

Logistics – Contracts, Shipping, Amenities

- **Contracts**
  - **While MPTFs are used to either direct payment or medical insurance, many are now taking purchase orders or other contract vehicles.**
    - **This is not universal, however.**
  - **Be aware of potential concerns on items like "indemnity clauses" or government Federal Acquisition Regulation (FAR) that might delay finalizing contracts.**
- **Shipping**
  - **Most SEE testers either ship equipment (crates, boxes) or drive them to the MPTFs.**
  - **The MPTF requires knowledge of what is being shipped including dimensions and weight as well any storage requirements.**
- **Amenities**
  - **These are more modern sites and as a rule internet access, break rooms, etc… are available**

Logistics –
MPTF Layout, Cabling

- **MPTF Layout**
  - **It is important to gather information in advance on three areas**
    - **Staging area – where equipment is unpacked and tested upon arrival**
    - **User area – where the SEE tester sits during irradiation**
    - **Target area – where the beam hits the target**
  - **A pre-test site visit is often recommended.**
- **Cabling from target to user area**
  - **Wide variance in cable length and if patch panels exist between MPTFs (65-125 ft)**
- **Shipping**
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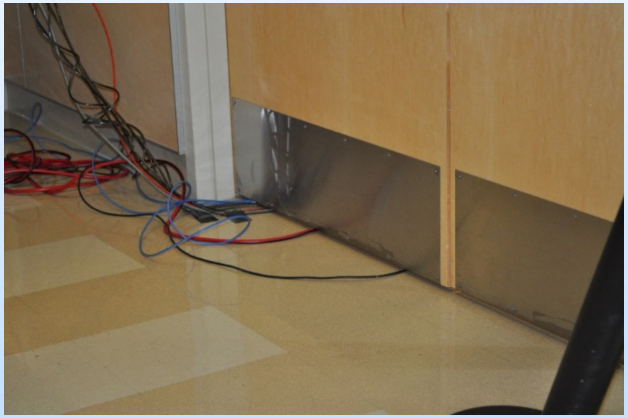


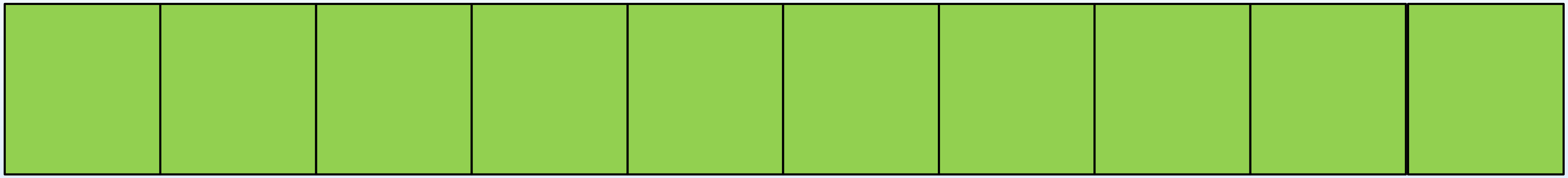
Running cables under target room door at California Protons (formerly SCRIPPS), La Jolla, CA

Technical – Proton Beam for SEE Testing

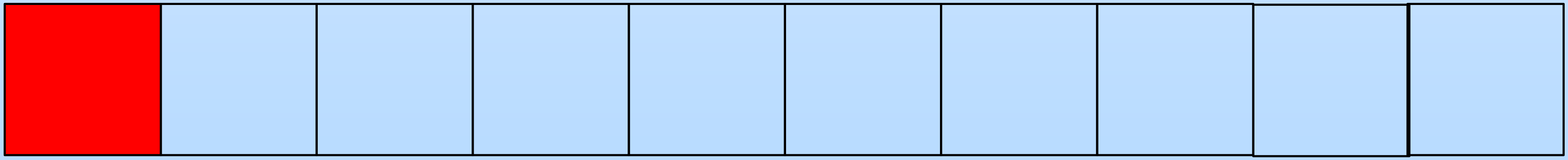
- **There are two types of accelerator beam structures being used for proton cancer therapy:**
  - **Cyclotrons (continuous beam), and,**
  - **Synchrotrons (beam spills or pulses).**
- **In addition, there are three types of delivery methods used.**
  - **Scatter,**
  - **Wobble/uniform scan, and,**
  - **Pencil beam scan (PBS).**
- ***IUCF was a cyclotron and utilized a scatter beam delivery system.***
  - ***Random particle impact over a uniform geometry***
  - ***Random particle impact over a uniform time period***

Cyclotron versus Synchrotron Beam Structure

- **Cyclotron is relatively continuous over time**
  - **Flux (particles/second) is fairly constant**



- **Synchrotron is pulsed with a ~ 10% duty cycle (usually)**
  - **Instantaneous flux is 10x higher during pulse (beam spill) versus the average flux over a 1 second period**

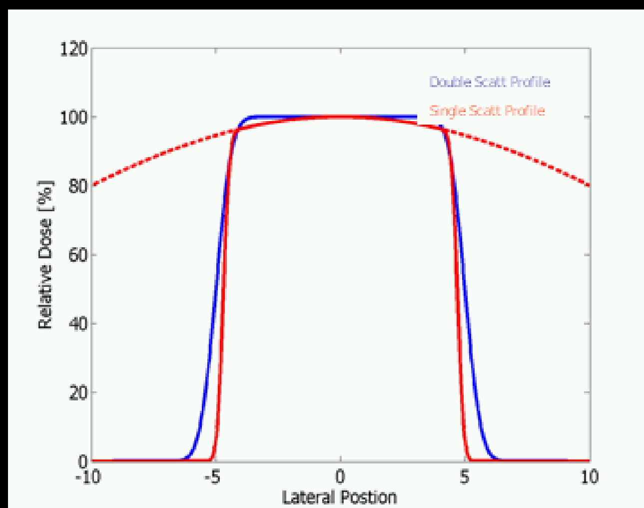


Dead time and instantaneous flux vs average flux may impact results.

Old School Proton Therapy Beams – IUCF-like (passive scatter)

Lateral spreading / single scattering

Flat scatterer spreads the beam to a large Gaussian profile, of which all protons outside the central 'flat' region are collimated.



Advantages:

- simple
- sharp lateral fall-off

Disadvantages:

- inefficient
- small field size

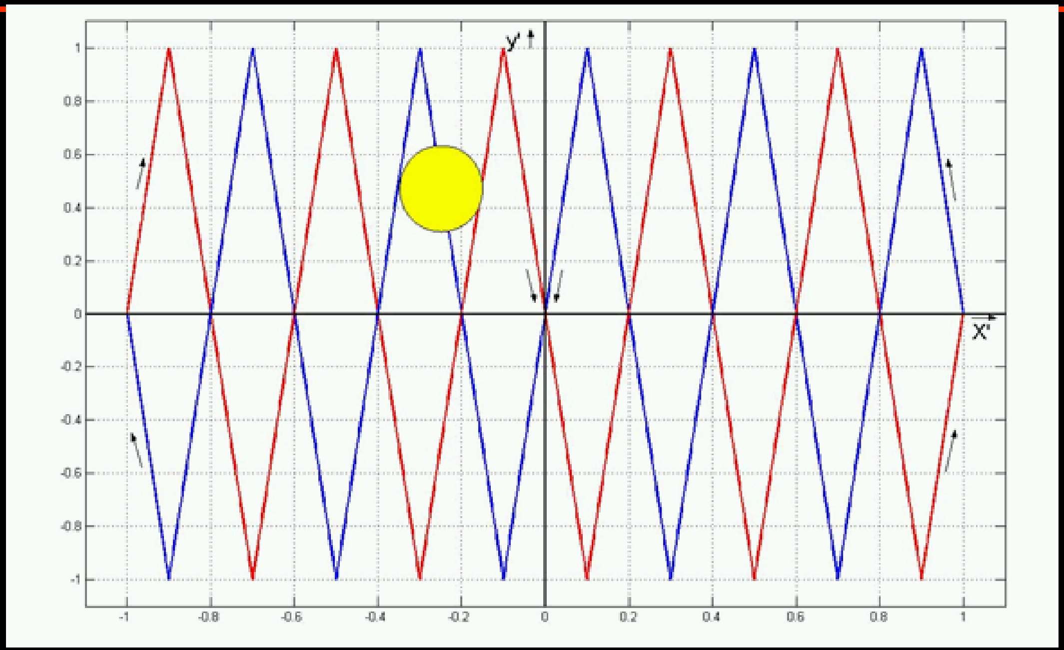
After Zuofeng Li, Beam Delivery Techniques: Passive Scattering Proton Beams PTCOG49 Educational Workshop, NIRS, Chiba & GHMC, Maebashi, Japan, May 2010

There are also double scatter systems in use.

Both provide uniform irradiation of a target geometry.

Uniform Scanning Beam (aka Wobble)

- Much like a raster scan with a small beam spot
- Energy is constant per scan
- A tumor shaped collimator of varying thickness is used to stop the beam in the patient
  - The Bragg peak is placed within the tumor.

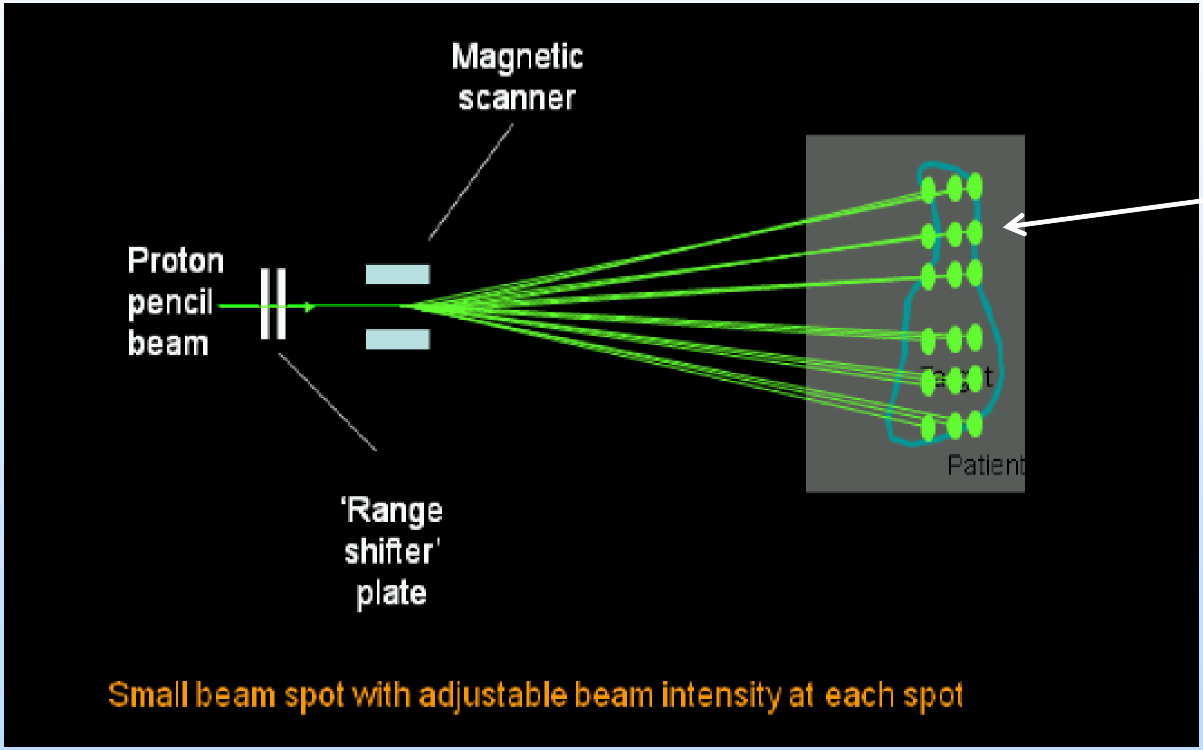


Scanning pattern created by the two perpendicular dipoles, one operating at a frequency of 3 Hz the other at 30 Hz.

After R. Slopsema, Dosimetric Comparison of Proton Delivery Techniques: Double-Scattering and Uniform-Scanning, The International Journal of Medical Physics Research and Practice, July 2008

Pencil Beam Scanning (PBS)

- **PBS method allows modulation of the proton beam at each spot during a scan (pass)**
  - **Each spot can have a differing energy/modulation (intensity).**



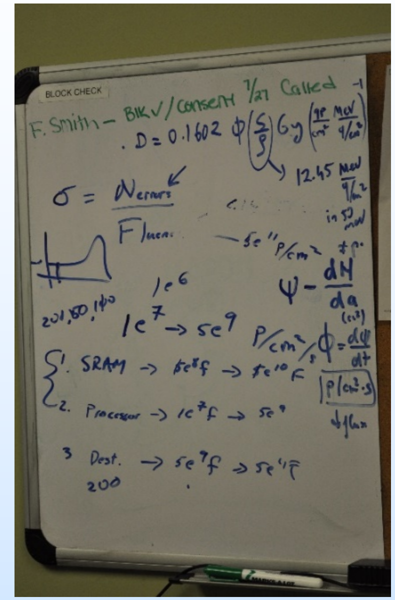
"Paint" a complex pattern at each layer (energy)

After T. Lomax, State-of-the-art proton therapy: The physicist's perspective, PTCOG47, Jacksonville, FL, May 2008

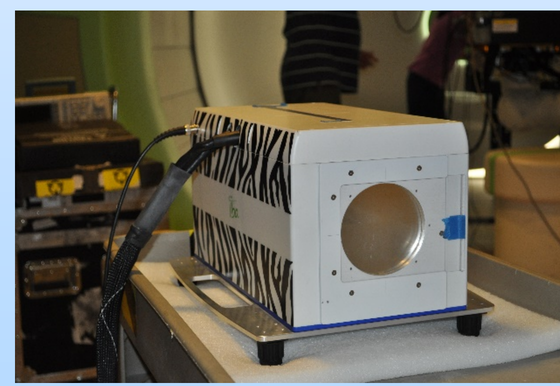
Scan beams can be set for a small fixed beam spot or with an added scatter for a larger uniform field

Technical – Available Beam Characteristics and Control

- **Proton energy**
  - **Depending on the MPTF, desired incident test energy may be set from either via tuning or by degradation of a higher energy**
    - **This may be as simple as setting a parameter in software or by adding material shielding (with potential energy straggle/secondary particles)**
- **Beam intensity**
  - **What SEE testers use: flux, fluence, dose (SiO_2)**
  - **What MPTF physicists use: dose (H_2O or tissue) or monitor units/counts**
    - **Conversion of factors and how to specify for test runs and tracking of dosimetry should be planned in advance**
  - ***Note: some MPTFs limit proton irradiation levels allowed***
- **Dosimetry**
  - **Dose delivered is very precise, but the dosimetry systems are focused on biology**
  - **Ion chambers, film, ?**



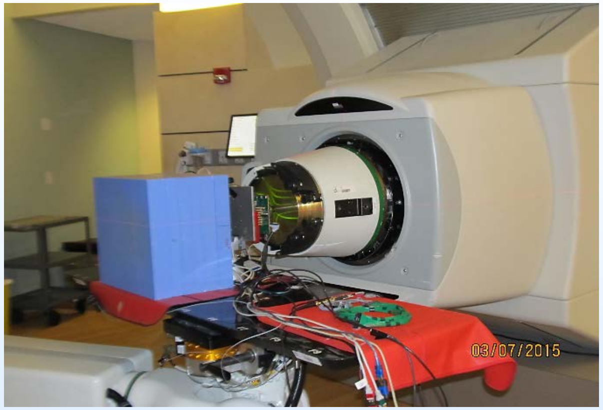
Scratching out units conversions to flux/fluence at Hampton University Proton Therapy Institute (HUPTI), Hampton, Va



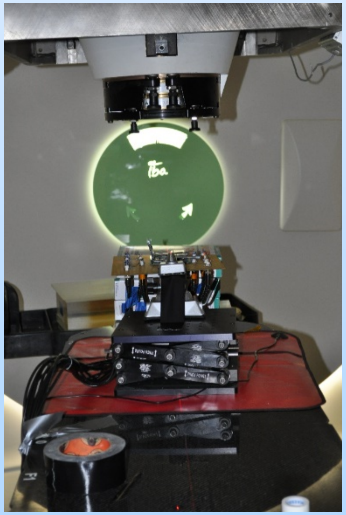
Ion Chamber at HUPTI

Technical – More Beam Stuff

- Spot Size
  - Fixed point beam (no scan, no scatter foil)
    - Widens by a factor of r^2, where r is distance from the nozzle.
    - Known spot size preferred in advance allows target location to be set in advance
  - Scattered beam (no scan, scatter foil)
    - Same factor of r^2 from the nozzle
  - Collimation: in some cases, making the beam smaller is desired
    - Facility may or may not have a means for collimation and user may need to bring to site
- Protons impacting with materials may raise the background neutrons in the target area
  - This may cause neutron SEE on equipment or impact MPTF monitoring systems
- Protons go through the target and may require a beam stop (SEE tests avoid the Bragg peak)



Big blue beam stop at Northwestern Medicine Chicago Proton Center, Warrenville, IL



Vertical gantry system used the earth as beam stop at HUPTI

Technical – Shielding

- **Protons scatter secondary neutrons when they interact with materials including scattering foils, collimators, and target hardware**
  - **Below are examples of means to reduce neutron impacts**

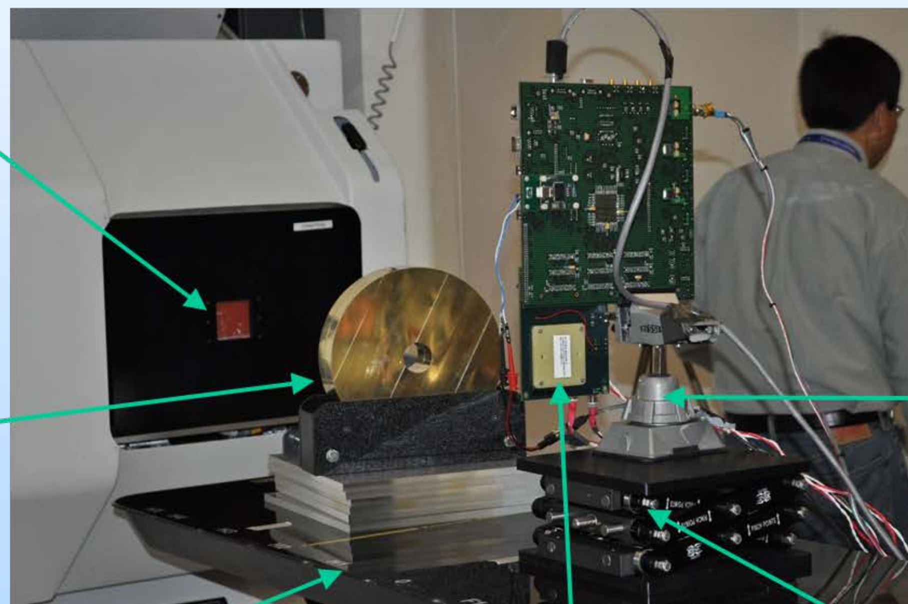
Additional polyethylene material supplied by SCRIPPS used to partially shield non-DUT electronics from secondary neutrons

Test Fixture at California Protons

Borax used to partially shield test equipment in the chamber from secondary neutrons (NASA supplied)

Technical – Target Mounting

- MPTF may or may not have a means of mounting target hardware
  - Base for mounting
    - May use patient sled, rolling cart, or table
  - User may need to bring board clamps, table jacks, etc… all depending on specific MPTF



A Few More Considerations

Patient	Electronics (Typical)
Measurement: dose in tissue/water	Measurement: dose (material – Si, SiO_2, GaAs, etc.) and particle rates (fluence – protons/cm^2 and flux – protons/cm^2/s)
Beam penetration: use Bragg peak to stop the beam in the patient	Beam penetration: beam goes through the target with a beam stop behind the target
Exposure stop: cumulative dose	Exposure stop: cumulative dose, fluence, number of recorded events, degradation, or an unanticipated event / failure. When an unanticipated event occurs, the beam stop may be manual, automatic, or via verbal command such as “stop”. Coordinating “beam on” with device under test operation is important as well.
Target size: tumor	Target size: single device / chip (1 cm x 1 cm) to a full assembly (20 cm x 20 cm or larger)
Beam delivery: pencil beam, wobble, uniform scan, or fixed point/scatter	Beam delivery: prefer fixed point / scatter
Beam timing structure: less important	Beam timing structure: when particle arrives versus electronics operation can be important, but not always
Patient exposure: a few minutes	Target exposure: flexible, seconds to minutes, depending on stop criteria. There are often many exposures (test runs) per target (10s to 100s)
Beam movement: gantry or fixed	Beam movement: fixed

On-site Test Checklist

Front Entrance at
California Proton Center

Arrival to the MPTF

- **Check-in**
  - **SEE Testers must remember that these are medical facilities**
    - **Patient privacy and concerns come first**
      - **The Health Insurance Portability and Accountability Act (HIPAA) enacted in 1996 form may be required to be signed at some MPTFs**
    - **It's important to know when SEE test teams are allowed to arrive pre-test and where they may enter**
      - **It's always a good idea to visit the site in advance when possible**
- **Radiation Safety/Personal Dosimetry**
  - **Radiation training is likely (and usually fairly quick)**
  - **While some MPTFs will provide/require personal dosimetry for each team member, some may utilize "shared" devices (e.g., 1 per 3 team members)**
- **Test Preparation (pre-installation in target area)**
  - **Unpacking of equipment**
  - **Connecting test setup**
  - **Validating functional operation of test setup**
  - **Verifying power (where available, proper voltage, cleanliness)**

Test Performance

Em = Proton Energy from machine=				?	MeV		Proton Charge =	1.60E-19	Coulombs					
Ed = Proton Energy at DUT=				198.5	MeV									
Dose(Water) per MU=			8.62E-03	Gy(Water)	or	53801.8105	MeV/mg(Water)	or	0.000862	krad(Water)		1 Gy =	6241509.34	M eV/mg
Fluence (p's/sq cm)/MU = (Dose(Water)/MU)/LET(Water, Ed)=						#NAME?	p's/cm^2							
							Conversion =	1.60E-08	# krads/MeV/mg					
Specified Fluence (p's/cm^2) =			2.61E+11	p's/cm^2									HUPTI Energies	
Dose Water (MeV/mg) =			#NAME?	MeV/mg		LET(Water)=		#NAME?	MeV/mg/cm^2				MeV	
Specified # MU's =			#NAME?	MU's		LET(Si)/LET(H2O)=		#NAME?					198.5	
Specfied Run length (sec) =			1338	sec									149	
Specified MU rate =			#NAME?	MU's/sec	or	#NAME?	Gy/min						98.5	
Specified Flux =			1.95E+08	p's/cm^2/sec										
Diameter of Spot at DUT =			NA	cm	Area of Spot at DUT =		100	cm^2						
Fraction of beam at DUT =			1											
Beam Current Required =			3.12E+00	nanoamps										

Converting MUs to dose, flux, fluence during one test trip

Test Performance - 1

- Setting Up (Test Day or Sometimes Test Day-1)
  - Dosimetry check
  - Mounting the test fixture
  - Beam area/collimation
  - Cabling
  - User area
  - Training on entry/exit from beam room and beam control
- Preparing to Irradiate (Test Day)
  - Setting beam parameters for the test run(s) (energy, flux, fluence, time, etc.)
  - Converting monitor units (MUs) or Dose to flux/fluence
  - Start/stop methods (fluence, time, event)

Test Performance - 2

- Typical Test Run Protocol (Test Day)
  - Verify electrical test operation
  - Verify beam parameters (check that run numbers are the same on test system and beam control)
  - Start test system
  - Start beam
  - Stop beam (on set time, fluence, or event)
  - Log test results; log run dosimetry (flux, fluence, time, dose) – ensure run numbers match
  - Repeat or modify as needed

Test Performance - 3

- Changing Things (Test Day)
  - Replacing parts or new boards
  - Activation check and irradiated part storage
    - Proton exposure will activate materials (metals). Work with the facility on proper protocol for surveying irradiated hardware prior to removal from the beamline. This includes changing out socketed devices.
  - A proper location for storage of activated hardware should be discussed with the MPTF.
  - Changing energy, flux, etc.
  - Changing angles (usually not necessary for standard proton SEE testing)

Post Test

- **Post-Test (Test Day or Post-Test Day)**
  - **Confirm all logs are stored and saved (backups are good)**
  - **Check hardware activation**
  - **Return shipping coordinated with facility (paid by user)**
    - **While the half-life of the typical exposed SEE test hardware may be short (at most overnight to return to background levels), some hardware such as custom collimators may stay activated longer.**
    - **Shipping is contingent on ensuring appropriate radiation safety practices.**
    - **Discuss storage with MPTF.**

Good Ideas

- **Canary test**
  - **Have a part with known susceptibility to check for consistency with other test sites.**
  - **Alternately, bring independent equipment for dosimetry check**
- **"Blank" test**
  - **Point beam at "empty" spot for a test run: i.e. not on target or on any test electronics. This often looks for issues with secondary neutrons or coupled power noise.**
- **Have backup plans**
  - **Some test fixtures decide that they want to be finicky or the errors being observed are not as expected.**
  - **When this happens, debugging while in the target area wastes resources and having a backup test to swap out test articles should be considered.**

Summary

- **An overview of lessons learned for SEE testing at MPTFs has been shared.**
  - **Unlike research facilities which are used regularly for electronics testing, not all MPTFs are familiar with "our" test needs and this was an attempt to educate the test community on differing expectations.**
- **A companion poster is available for snapshot status on domestic proton high energy test access with COVID update as of 1-June 2020.**