Small-Field Dosimetry

Indra J. Das, PhD, FACR
Department of Radiation Oncology
Indiana University School of Medicine
Indianapolis, IN, USA

TG-155: Small Fields and Non-Equilibrium Condition
Photon Beam Dosimetry

Indra J. Das (Chair)
Indiana University School of Medicine, Indianapolis, IN 46202

Paolo Francescon (Co-chair)
Ospedale Di Vicenza, Viale Rodolfi, Vicenza 36100, Italy

Anders Ahnesjo
Uppsala University & Swedish Cancer Society, JHB, 751 87 Uppsala, Sweden

Maria M. Aspradakis
Department of Radiation Oncology, Kantonsspital Graubünden, Chur, Switzerland

Chee-Wai Cheng
Midwest Proton Radiotherapy Institute, Bloomington & Indiana University School of Medicine, Indianapolis, IN, 46202

George X. Ding
Vanderbilt University Medical Center, Nashville, TN 37242

Geoffrey S. Ibbott
Radiological Physics Center, MD Anderson Cancer Center, Houston, TX 77030

Iwan Kawrakow
Ionizing Radiation Standards, National Research Council of Canada, Ottawa, ON K1A 0R6, Canada

Mark Oldham
Duke University Medical Center, Durham, NC 27710

M. Saiful Huq
University of Pittsburgh Medical Center, Pittsburgh, PA 15232

Chester S. Reft
University of Chicago, Chicago, IL 60637

Treatment Fields

Magna-Fields
200x200 cm²

Traditional Fields
40x40 cm²

Small Field
4x4 cm²

SRS/SRT
Gamma Knife
Cyber-Knife
Tomotherapy
IMRT

What is a Small Field?

- Lack of charged particle
  - Dependent on the range of secondary electrons
- Photon energy
- Collimator setting that obstructs the source size
- Detector is comparable to the field size
Definition of Small Fields

Dosimetry
- Absolute
  - Dose
- Relative
  - Depth Dose \( [D(r)/D(r, dm)] \)
  - TMR
  - Profiles
  - Output, \( S_{\text{ref}} \) (total scatter factor), \( [D(r)/D(\text{ref})] \)

IAEA/AAPM proposed pathway

Small Field Dosimetry Problem

Institutional variability in 6 MV Radiomics SRS dosimetry
Dosimetric Variation with Detectors

- Charged particle equilibrium or electronic equilibrium
  - Range of secondary electrons
  - Medium (tissue, lung, bone)
- Photon energy and spectrum
  - Change in spectrum
  - Field size
  - Off axis points like beamlets in IMRT
- Detector size
  - Volume
  - Signal to noise ratio

CPE & Electron Range

- CPE, Charged Particle Equilibrium
- Electron range $= d_{\text{max}}$ in forward direction
- Electron range in lateral direction
  - Nearly energy independent
  - Nearly equal to penumbra (8-10 mm)
- Field size needed for CPE
  - Lateral range

Dosimeters & Associated Problems

- Ion Chambers
  - Diameter, volume, and window thickness
  - Wire, $S_{\text{nuc}}$, $\alpha_{\text{eff}}$
  - Perturbation
- Films
  - Silver bromide films
    - High Z, sensitivity, thickness
  - GAFchromic polymer films
    - Sensitivity, thickness, polymerization at low energy
- TLD/OSL (sensitivity at low energy, F center)
  - Size 10-15 mm, difficulty of handling
- Fricke Dosimeter (G value)
  - Size (Size and dose)
- MOSFET (thickness, dose rate, burnout, life, cost)
- Monte Carlo (benchmarking, expertise, reliability)
Ratio of Readings?

\[ D = \int_0^\infty \frac{d^2 \Omega}{d \Omega d\Omega} \left( \frac{\mu(E)}{\rho} \right) E \exp(-\mu(E)r) d(E) \]

\[ D_e = \left( \frac{Q_e}{m} \right) \left( \frac{W_e}{c} \right) \left( \frac{s}{p} \right) \]

\[ D(\omega) = \left( \frac{Q(\omega)}{Q_{ref}} \right) \left( \frac{W(\omega)}{W_{ref}} \right) \left( \frac{s}{p} \right) \]

\[ Q(E,E') = Q_{P_{tot}} P_{ref} P_{n Ref} P_{ref} P_{ref} \]

\[ D_{ref} = \left( \frac{Q_{ref}}{Q_{tot}} \right) \cdot CF_{ref} \]

Spectra & Effective Energy from SRS Cones (0.5-5 cm)

Ionization chamber dosimetry of small photon fields: a Monte Carlo study on stopping-power ratios for radiosurgery and IMRT beams

Radiological Parameters

\[ E (MeV) \]

\[ (r, \theta, \phi) \]

\[ (E, r) = Q_{ref} P_{ref} P_{ref} P_{ref} P_{ref} P_{ref} \]

\[ V (\text{MeV}) \]

\[ \text{Average Energy} \]

\[ \text{Spec tra & Effective Energy from SRS Cones (0.5-5 cm)} \]


Correction Factors

Correction Factor depends on:
- Field size
- Source size (FWHM)
- Detector type


Issues with IMRT Dose Delivery

- About 50% of the total MU contributes to ~95% of the dose and 30% of the total MU contributes <0.5% to isocenter due to small beamlets
- With insufficient lateral equilibrium in at least one direction, the absorbed dose never reaches the equilibrium value, and can be significantly lower for very small field sizes
- The large difference between 0.6cm³ and the 0.015 cm³ ion chamber data is due to the under sampling of the 0.6 cm³ data because of the detector size.

Cheng, Das, Huq, Med Phys. 30(11), 2959-2968, 2003
Dependence on Chamber Volume

Field Size Limit for Accurate Dose Measurements with Available Detectors

Profiles with different detectors

Effect of Inhomogeneity

- Range of secondary electrons
  - Simple scaling based on density
  - Perturbations of the detector
Conclusions

- Small volume detector should be used that has minimum energy, dose and dose rate dependence.
- Micro-ion chambers are best suited for small field dosimetry; however, signal to noise should be evaluated.
- Stereotactic diode with micron size detector could be suitable for radiosurgery beam.
- If field size is small compared to detector and electronic equilibrium could be compromised, measurements should be performed at greater source to surface distance with proper correction.

Energy spectrum does vary in small fields such as SRS, and IMRT, however, its impact is not significant.
- Stopping power ratio in small fields for most ion chambers is relatively same as the reference field.
- Spot check and verification of smaller fields should be carried out with at least another independent method (TLD, film, MC, etc).
TG-155 Approved Task

1. Collaborate with the new task group (Non-compliant IAEA) on absolute dosimetry to ensure that there is no overlap between the two task groups, but rather are complementary to each other.
2. Review and synthesize literature on dosimetry of small fields irrespective of the origin and treatment modality.
3. Provide overview of the issue of OPE for the small field dosimetry in homogeneous and inhomogeneous media.
4. Provide meaningful information on the spectrum and shift in beam energy from Monte Carlo.
5. Provide radiation parameters (mens, S/R, etc) for small field dosimetry from published literature from Monte Carlo.
6. Provide suitability of specific detectors with respect to perturbations and signal to noise ratio.
7. Provide available information on the correction and perturbation factors in detectors.
8. Provide guidelines in measurement methods for modeling the treatment planning systems for small fields.
9. Provide suitability of algorithms based on measurement for beam modeling in small fields especially in inhomogeneous medium.
10. Provide error analysis and limit of uncertainty in the measurements.
11. Provide guidelines and recommendations for accurate determination of dosimetric data for small fields.