High Dose, Small Field Radiation Therapy: Lessons from the HyTEC Project and the ICRU 91 Report

Part 1: Small Field Dosimetry

Jan Seuntjens, Ph.D, FCCPM, FAAPM, FCOMP
Director and Professor, Medical Physics
McGill University, Montréal, Canada

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• I am working with Sun Nuclear Corporation and Lifeline Software Inc on technology commercialization projects
• I am working with RefleXion Medical on a small field dosimetry project
• Some brand names of commercial products are mentioned in this presentation. This does not represent any endorsement of one product or manufacturer over another

In ICRU91: SRT = (SBRT/SABR, SRS)

• Reference frame (physical or imaging only)
• Precision < 1 mm (real-time tracking, repositioning)
• Multiple SMALL beams (non-coplanar)
• Specific dose distribution (+ MC ?)
• Limited target volume = High dose (> 5 Gy)/few fractions (1, 5, 10, …)

• SBRT: B = body, fractionated?
• SABR: A= Ablative: not always, dose per fraction, different biology?
• SRS: RS= radiosurgery: single fraction, brain only?
Why ICRU?

- Need for a common language
  - Within the department of radiation oncology
  - Within the hospital between health professionals
  - Between institutions locally and internationally
- Importance of harmonizing prescribing, recording and reporting
  - Is the prescription volume the same from one institution to another?
  - Is the prescribed dose delivered in a homogeneous and identical manner between one clinic and another?
- What is dose homogeneity?
  - What are the parameters describing the treatment?

A technology driven field

- CyberKnife
- C-arm SRT accelerator
- TomoTherapy
- Vars
- GammaKnife

Radiation fields are small and the dose per fraction is high!

Volumetric precision


\[ D_{100} = 18.4 \text{ Gy} \]
\[ D_{80} = 14.4 \text{ Gy} \]
\[ V_{16\text{Gy}} = 17.2 \text{ cm}^3 \]
Measured Output Factors among users / machines

Situation in the mid-2000's!

New-generation dose calculation algorithms

Radioresistant tumours

- Biology of high dose / fraction: *BED > 100 Gy*
- Melanoma
- Renal tumours
- Sarcomas
- …
ICRU Reports on Prescribing, Recording & Reporting of EBRT

ICRU Report 91 - Table of Contents

- Section 1: Introduction
  - History
  - Definitions
  - Similarities and Differences Between 3D-CRT, IMRT and SRT
  - Radiobiological considerations - Issues and Challenges
  - Clinical experience
- Section 2: Small Field Dosimetry
- Section 3: Definition of Volumes
- Section 4: Treatment Planning Algorithms
- Section 5: Image Guided Beam Delivery
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- Appendix: Clinical Examples

2009 - 2017
122 pages excluding references!
Section 2: Small field dosimetry

- Setting up a program for SRT requires dedicated team involving all professions related to the radiation planning & delivery!!
- Small fields - radiation dosimetry is prone to errors – expert knowledge required!!
- ICRU 91 strongly discourages the use of high energies, i.e., for SRT, E ≤ 10 MV!!

Small field dosimetry à la ICRU 91 follows verbatim the IAEA-AAPM TRS 483

Which problems needed to be solved?

- Characteristics that lead to dosimetric issues of two kinds:
  - Reference dose calibration
    - Reference fields are not 10 x 10 cm², SSD/SAD is not 100 cm, etc.; they are machine-specific reference fields (msr)
  - Flattening filter-free beams, beam quality specification
- Output factors
- Small fields
- Detector correction factors
- Problem that was put on the backburner: calibration of composite fields

The “Alfonso” paper (2008)
What constitutes small-field conditions?

- Beam-related small-field conditions
- the existence of lateral charged particle disequilibrium
- change in photon fluence spectrum → beam quality
- partial geometrical shielding of the primary photon source as seen from the point of measurement
- Detector-related small-field condition
- detector size compared to field size

Lateral charged particle loss

In small fields there is no depth in which $D \approx K_{\text{coll}}$.

Concept of the $msr$ field

Route 1

$D'_{\text{ref}} = M'_{\text{ref}} \cdot N_{\text{ref}}'_{\text{ref}}$

Route 2

$D'_{\text{ref}} = M'_{\text{ref}} \cdot N_{\text{ref}}'_{\text{ref}} \cdot (k'_{\text{ref}} / 0) \cdot Q_{\text{ref}}$

Route 3

$D'_{\text{ref}} = M'_{\text{ref}} \cdot N_{\text{ref}}'_{\text{ref}} \cdot (k'_{\text{ref}} / 0) \cdot Q_{\text{ref}} \cdot k'_{\text{ref}} / 0$
Equivalent square fields $msr$

$$s = \frac{1}{2\pi} \int \int \left( \frac{\mu_0 e^{-\mu s}}{\mu_0 e^{-\mu s} + \mu_1 e^{-\mu_1 s}} \right) P(x) dx$$

Make the scattering component equivalent!

**WFF beams:**
BJR 25 - equivalent field size is energy independent

**FFF beams:**
equivalent field size is energy dependent; Tables are provided for 6 MV and 10 MV

Getting the beam quality in non-standard reference fields

$$TPR_{20,10} = TPR_{20,10}$$

$$TPR_{20,10}(10) = \frac{TPR_{22,11}(10) + c(10-s)}{1+c(10-s)}$$

$$\%dd(10,10) = \frac{\%dd(10,10)X + 80c(10-s)}{1+c(10-s)}$$

Note!:
- FFF beams → use the Pb filter and equations in TG-51 to get $\%dd(10,10)$

Source occlusion

FWHM > geometric field size

Small field dosimetry-related parameters must be specified as a function of FWHM
Spectral changes

- The photon fluence spectrum is modified as a function of field size

Magnitude of \( p \) correction factors on- and off-axis

8 mm \( \times \) 8 mm field, 10 cm depth (0.4 mm, 2 mm spot sizes)

Concept of field output correction factors

- Field output factor relative to reference field (ref stands here for a conventional reference or mss field)

\[
\frac{E_{\text{ref}}}{E_{\text{clin}}} \frac{M_{\text{ref}}}{M_{\text{clin}}} \frac{k_{\text{ref}}}{k_{\text{clin}}}
\]

- Field output factor relative to reference field using intermediate field or 'daisy chaining' method

\[
\frac{E_{\text{ref}}}{E_{\text{det}}} \frac{M_{\text{ref}}(\text{det})}{M_{\text{clin}}(\text{IC})} \frac{M_{\text{clin}}(\text{IC})}{M_{\text{clin}}(\text{ref})} \frac{k_{\text{ref}}}{k_{\text{clin}}}
\]

where

\[
K_{\text{ref}} = K_{\text{clin}}(\text{det}) - K_{\text{ref}}(\text{IC})
\]

Output factors are DOSE RATIOS not reading ratios!!
Small field output correction factors

Field size specification

\[ S_{\text{cin}} = \sqrt{A \cdot B} \]

\[ 0.7 < A/B < 1.4 \]

\[ S_{\text{cin}} = r \cdot \sqrt{\pi} \]

- There are large corrections to reading of virtually any type of detector
- For air-filled chambers: large upwards correction factors in small fields
- For solid state detectors: correction factors depend on the construction, density, Z and size of the sensitive volume

ICRU 91 detector suitability criteria for small fields

- the sensitive region of the detector is close to water equivalent in terms of radiation absorption characteristics;
- the density of the sensitive region is close to the density of water; and
- the size of the sensitive region can be made small compared to the field size while keeping noise levels under control.

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Section 4: Treatment Planning Algorithms

- **Factor based**
  - Successfully used in cranial SRS

- **Model based**
  - Beam model
    - Coupled angular-energy distribution of a representative set of particles in the beam (photons and contamination particles).
    - Source parameters: TPS parameterizes the source size — impact on dose calculation accuracy
    - Calibration system: Backup calibration, alignment of different collimation systems
  - Patient model
    - Type A (or category 1)
      - Equivalent path-length scaling for inhomogeneity corrections
    - Type B (or category 2)
      - Dosimetric effects of dose transport are considered in some fashion
    - Advanced type B: MC or deterministic transport algorithms

Variability in source intensity distribution. Spot sizes range between 2.5 mm and 4.6 mm and the typical spot size is also not perfectly circular.

Beam models suitable for SRT planning algorithms are accelerator spot size dependent.

Special care must be taken to commission and validate the beam models in the TPS for use with SRT!

![Figure 4.5 Monte Carlo-calculated central-axis depth-dose profiles for a lung slab phantom geometry irradiated by a 6 MV and a 18 MV beam (3 x 3 cm² field size) with a 1 x 1 x 1 cm³ tumour embedded in the lung, with decreasing lung slab density. From Disher et al. (Disher et al., 2012) with permission.](image)
ICRU Report 91 mandates the use of advanced type b model-based dose calculation algorithms (Monte Carlo, etc).

Considerations for Clinical Prescription Using Category 2 Dose Calculation Algorithms in Small Fields

Take home

- ICRU 91 covers
  - the clinical context of SRT
  - small field physics → IAEA-AAPM recommendations
  - TPS dose calculation algorithms
  - IGRT and QA
  - volumes and prescription, recording and reporting
- Does not dive into radiobiology of high dose per fraction nor normal tissue response models
- Tries to systematize and document how SRT is performed clinically
ICRU 91 Reporting

Level 1: Basic Techniques
- Dose at ICRU reference point

Level 2: Advanced Techniques
- DVHs calculated
- PTV: D_{50}, D_{mean}, D_{95}, D_{10}
- GTV/CTV/ITV: Doses must for Lung OAR/PRV: Vol, D_{mean}, V_{D}, D_{2%}
- Dose Homogeneity and Conformity and Gradient Index

Level 3: Developmental Techniques
- In addition: Integral Dose
- Biology based evaluation metrics