Practical Commissioning of Photon Beam Algorithms

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Introduction

The basic problem of commissioning a photon beam algorithm can be reduced to the following:

> Implementing a dose calculation system that accurately predicts the dose delivered by your accelerator for the range of clinical situations encountered in your department.

There are 2 steps in this process.

1. Verify the accuracy of the dose calculation algorithm. This does not necessarily need to be done through direct measurements in every clinic. The accuracy of an algorithm can be established once through a benchmark process. This involves a series of careful measurements which can be used to check the accuracy of the system. If a benchmark dataset consisting of both basic input data and a series of test cases is available, the accuracy of the algorithm can be verified independently of the system in your clinic. An early example of this is AAPM report 55 which presented basic input data and a series of 12 test cases. Currently AAPM TG67 is working to greatly expand the scope of that work. Also, request information on validation studies from your vendor. Check the literature for validation studies for your system. These kinds of studies will give you an idea of expected accuracy. Be careful to compare results for the same versions of software or verify the extent of any differences between versions. For each section in this presentation where literature searches are mentioned, a sample of references will be listed in the attached appendix.
2. Verify that you have implemented the algorithm properly at your clinic. This will involve the direct comparison of calculated and measured doses. Your results should be similar to those described by the studies mentioned in step 1. How many test cases to measure is a key question. A sample set will be described below.

AAPM TG67, Benchmark Datasets for Photon Beams

Currently have developed a document describing a benchmark dataset. The dataset will include the input data required for any TPS and a series of test cases covering the clinical range. Descriptions of recommended measurement techniques are also included. In the future it is planned to obtain funding to collect data for 8 beams. The resulting dataset will be available to all. Will include 6 and 18MV beams for Elekta, Siemens, and Varian. Will include one 4MV and one 10MV beam.

Understanding your algorithm

To properly evaluate an algorithm you must understand the process it uses to calculate dose for various conditions. There are 3 basic types of algorithms. Measured beam (i.e. Bently-Milan), modeled beam (pencil beam, convolution), and Monte Carlo. Detailed descriptions of these are beyond the scope of this presentation but are available in the literature. A brief list of topics to investigate for your algorithm are:

1. What type of algorithm is it?
2. What are the published references for the algorithm?
3. What is the reference condition (i.e. where is absolute output defined)?
4. How does the system account for changes in aperture?
5. How does the system account for beam modifiers (wedges, trays, compensators, etc.)?
6. How does the system calculate dose in the central portion of the beam?
7. How does the system calculate dose in the penumbra?
8. Does it include tongue and groove?
9. Does it account for rounded leaf ends?

10. How does the system calculate dose outside the field?
11. How does the system account for changes in SSD?
12. How does the system account for irregular external contours?
13. How does the system account for material inhomogeneity?
14. How are MU determined?

Your vendor should be able to provide detailed answers to these questions. Again, you can also check the literature.

System Tests

Before beginning a comparison of calculated doses to measured doses you need to verify that the calculated results you are using for comparison are those that are actually calculated by the system. This means checking the consistency of reported doses by various modules of the software. These include:

1. Doses reported by physics tools or modeling routines.
2. Point doses.
3. Isodose plots.
4. Dose matrix export (DICOM, RTOG, proprietary)

Any change in reported dose with calculation grid spacing should be investigated. Differences between calculated and measured doses could be due to improper grid spacing. Pick a small field, say 5x5cm and calculate for various grids. Start with a 10mm grid and decrease by 2mm down to a 2mm grid. The resulting changes in calculated profiles are similar to volume effects seen by scanning with increasingly smaller ion chambers. Just as you would not want to measure profiles with a farmer chamber, you would not want to use calculations from an improper grid for your comparisons.

Another dose reporting tool that is used frequently is the Dose Volume Histogram (DVH). The accuracy of this should also be checked for various structure sizes and grid sizes. A basic manual check of minimum and maximum reported doses to a structure can be done rather easily by evaluating isodose lines and point doses. A more extensive check is described in the literature.

Designing your test cases.

Now that you have reviewed vendor and published validation studies for your system and understand the dose calculation process used, you can begin to design test cases to evaluate your implementation of the algorithm.

There are basically 2 categories for these tests. Basic water scans (characterization set) and phantom tests (verification set). How these are implemented depends on the type of algorithm.

The characterization set is either the set of basic data needed for input to a system (measured beam algorithm) or the basic scans needed to verify the input parameters for a modeled beam or Monte Carlo system. These consist of water scans for basic beam configurations (square fields, standard SSD, with and without wedges). Your vendor will have a recommended set. Beyond these, you will want to scan for other types of conditions (multiple SSD's, rectangular fields, asymmetric fields, irregular fields, beamlets).

There are some basic principles that should be followed when acquiring these water scans. Make sure that a set of reference scans is taken throughout the measurement period to ensure the stability of the beam. A sample reference set would be a depth dose and profiles at dmax for a 10x10 field, 100 SSD and 40x40 profiles at dmax, 100 SSD. You may want to record pertinent beam parameters (bend magnet current, injection current, pulse height, rep rate, water temperature, etc.) during each scan. This can help you determine if any differences are due to normal experimental error or changes in the beam itself. Great care should be taken when setting up the water tank to make sure that it is level, that the scanning arms move parallel to their measurement axis, that the machine gantry is level, that the distance accuracy of the

scanning arms is better than 1mm, that a reference chamber is used, and that the background of the detectors has been properly adjusted. It is also imperative to check the dosimetric accuracy of the water scanning system by independently measuring a few point doses using a calibrated chamber and electrometer. See TG53 for a description of obtaining a self-consistent dataset. Every piece of data should be confirmed by multiple measurements and when possible compared to data from the literature or other sources.

Output factors and Scatter factors
- Find refs for your accelerator
- Compare your phantom scatter values to Storchi

Transmission factors
- Find refs for your accelerator and wedge type
- RPC had a poster several years ago with a very nice compilation

PDD and TMR
- Find refs for your accelerator (match within 1-2%)
- BJR data (match within 2-3%)

Also take care that proper dosimeters are used, especially so that high gradient areas are properly characterized. Many references have reported comparisons of various dosimeters. In sorting through these, a set of recommendations can be developed as shown below.

Type of measurement	Recommended dosimeter
Depth dose	Small ion chamber (0.05 – 0.125 cc)
Profile	Diamond detector (properly corrected), diode
Soft Wedge (dynamic, virtual)	EDR film, Radiochromic film, ion chamber array, diode array (verify accuracy outside field)
Point dose	Small ion chamber (~0.05 cc)

You can use a wide variety of dosimeters but just be sure to validate whatever dosimeters you use.

The verification set should include a few basic test cases that address the typical clinical situations; different SSD's, beam obliquity, flash, and irregular contours. The first two can easily be checked with water phantom scans. Flash can also be checked with water scans but most easily with the gantry at 90 degrees. Alternatively scans can be taken up to the edge of the water tank but no data can be obtained in the phantom walls, typically ~1cm. This is perhaps the area of most interest. Irregular contours are more easily checked using solid phantoms and point dosimeters and film dosimeters. When using film of any type with solid phantoms, comparisons should be made with water scans to establish the accuracy of the method. This should be done at each clinic to verify that the dosimetry is being done properly.

Monitor Units

Don't forget to verify monitor unit accuracy for all test cases and for the characterization set as well. This may seem like a simple task, but it is surprising how often it is overlooked. See the Starkschall reference from The Journal of Applied Clinical Medical Physics, summer 2000 (http://ojps.aip.org/acm/).

Inhomogeneity

The inclusion of inhomogeneity test cases should be very carefully considered because these are difficult to measure accurately. Also, it is even more difficult to determine a methodology to implement clinical changes in treatment plans based on the resultant dose distributions. If you do decide to implement inhomogeneity corrections, there are 5 areas to check.

1. Doses proximal to inhomogeneity.
2. Doses within inhomogeneity.
3. Doses at the interfaces.
4. Doses distal to inhomogeneity.
5. Doses lateral to inhomogeneity.

It is very unclear as to how to perform accurate measurements for 2 and 3. At distances of 1cm or greater from the inhomogeneity, ion chamber measurements will be accurate. At closer distances and within the inhomogeneity, the results must be very carefully examined due to equilibrium effects and some spectrum changes.

Sample Verification Set

A sample set of test cases is shown below. Absolute dose at a point, water scans (PDD and profiles at dmax, 5cm, 10cm, 20cm, 30cm) at 90cm SSD, and film dosimetry perpendicular to beam at 100cm.

1. Rectangular fields (2x10, 5x10, 5x20, 20x5, 5x30)
2. Asymmetric fields (10x20 with center at 2.5 and 5cm off axis, open and wedged)
3. Irregular fields listed in TG53 plus several common to your clinic
4. Oblique beam from TG53
5. 15x15 field with 2.5cm flash
6. 2x2cm beamlet centered at 5 locations (cax, 5 and 10cm off axis inplane and crossplane) (mainly for IMRT)

If you decide to utilize inhomogeneity corrections, test for bone and lung equivalent. Use film and ion chamber to measure a 5x5 and 10x10 cm fields for 15cm wide and 5cm thick slab inhomogeneity. Film planes should be 1cm proximal to inhomogeneity, at proximal interface, at the middle of the inhomogeneity, at the distal interface, 1cm distal, and 2cm distal to the inhomogeneity. Ion chamber measurements should be made at each film plane to confirm absolute doses. The measurement point should be at least 1cm from the inhomogeneity which will require the point to be lateral to the inhomogeneity for the interface planes and the plane through the middle of the inhomogeneity.

Tools for dose comparisons

There are commercial systems (RIT, Med-Tec, PTW, Scanditronix-Wellhofer,) that allow you to import measured and calculated dose distributions and perform various analytical comparisons. There is a freeware program from MD Anderson that will also do this. Modeled beam planning systems (CMS, ADAC) have built in modules for evaluating model parameters by comparison to water scans. These are generally relative comparisons and absolute dose verification (MU) still needs to be done through the main software routines. Some treatment planning systems have built in comparison modules for test cases as well (Corvus). Alternatively, it is straightforward to import measured and calculated profiles into spreadsheets for comparison. Whichever method you use for comparison, you need to determine what is an acceptable limit for differences. Van Dyk describes a set of criteria that varies by dose region type. They are:

1. High dose/low gradient (Inner), 1-2%
2. High gradient (Penumbra), 2mm
3. Low dose/low gradient (Outer), 2-5%
4. Low dose/high gradient (Build-up), 20-40%

Low has described a method for combining two commonly used methods for comparison, percent difference at a point and distance to dose agreement between measured and calculated doses. This parameter, called gamma, is a very useful way to easily visualize the differences. It is incorporated in many software packages.

The final report

When all the comparisons are done and you have decided you are ready to begin using the system clinically, it is helpful to generate a commissioning report. This should state the accuracy achieved for the characterization set, the accuracy of the test cases, the accuracy of any special clinical situations (surface dose, build up region, inhomogeneity, etc.), and a discussion of the expected level of accuracy overall. The discussion of overall accuracy should also include a review of the reference scans taken throughout the data acquisition process. The range of data seen in these scans is an indication of the stability of the beam.

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Beam Spectra

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