Contents

1 Introduction

Beam modelling performs a crucial role in the procedure of oncology treatment. The very first step of beam modelling is to receive sets of photon beam data from different hospitals, which are measured from the linear accelerator (Linac) owned by these sites. Due to the similarity of the densities of water and human body, it can reasonably simulate the performance of photon beam in human bodies.

Physicists refer to the collected photon beam data to adjust different parameters in order to obtain a completed model for a particular type of machine in the hospital. The beam models aid the simulation of machine working circumstances and calculate parameters which can generate the correct dose information for patients. However the reliability of models is highly dependent on the quality of reference data collected from hospitals. Therefore it is necessary to control the accuracy. The general shapes of beam data curves are similar under the same measuring conditions. Creating a set of reference data could help physicists check whether the data collected from each site is good or not. It is an efficient way to evaluate the reliability of the use of the data.

This project aims to create a standard photon beam database for different Linacs based on sets of high quality measurements. This standard beam data will be also used as a reference library in Beam Data Tool for measurements comparison and analysis. The main tool used for data processing in this project is MATLAB. The characteristics of beam data collected by different types of detectors were quantitatively analysed, and then calculated the average of photon beam data for 4/6/10/15/18/6FFF/10FFF MV of Agility head, and 6/10 MV of MLCi2 head.

The data from sites are selected manually in advance then calculate the mean of the collection. This average of data is acting as the reference.

2 Data Types and Processing

2.1 Categories of data curves

A completed set of data is consist of open and wedge measurements that both include profile(inplane and crossplane), PDD and diagonal curves. Each type of curve is measured by the detector moving in different directions and could also with supplemented equipments such as the insertion of wedge in wedge measurement.

The profile curves mainly measure the change of dose when detector moves along the horizontal plane(X-axis and Y-axis), whereas the PDD curve is the information about dose change in the vertical direction(Z-direction) when detector changes its depth. Diagonal curves are obtained in similar way but with detector moving in the diagnose of the water tank. The 45-degree diagnose is defined as counting in clockwise direction and vice verse 135-degree is defined in anticlockwise direction.

2.2 Raw data

The raw data received in this project were stored in files of two extensions that are *.asc* and *.mcc*. Files with either extension can be opened with any application programmes which can deal with ASCII, such as Office Word or Notepad. Although the main body of the file is numerical data, there are also important information about the machine settings in header files which was written in text. In order to sort out the same type of measurements for data processing, the setting information must be extracted out as reference. It was expected to process the database in MATLAB due to its powerful functions in matrix calculation. As a result, the code should be able to extract the numerical part and the machine settings recorded in the header file in each scan.

The following paragraph introduced some of the essential features displayed in the header file of a *.asc* document. Figure 1 is one of the examples to demonstrate where the machine settings recorded in the header file. The lines were highlighted by the yellow marker are several pieces of key information that needs to be sorted out in order to classify different types of measurements.

When the physicist stored more than one scan in a file for convenience, the number of measurements tells how many measurements are combined in this document and the measurement number specifies which scan the current data is.

The next tag is the field size which tells the square area that is covered by the detector. The conventional field size range is normally from $2mm \times 2mm$ to $40mm \times 40mm$. Measurements with the same field size should be classified into one group so that there is only one independent variable.

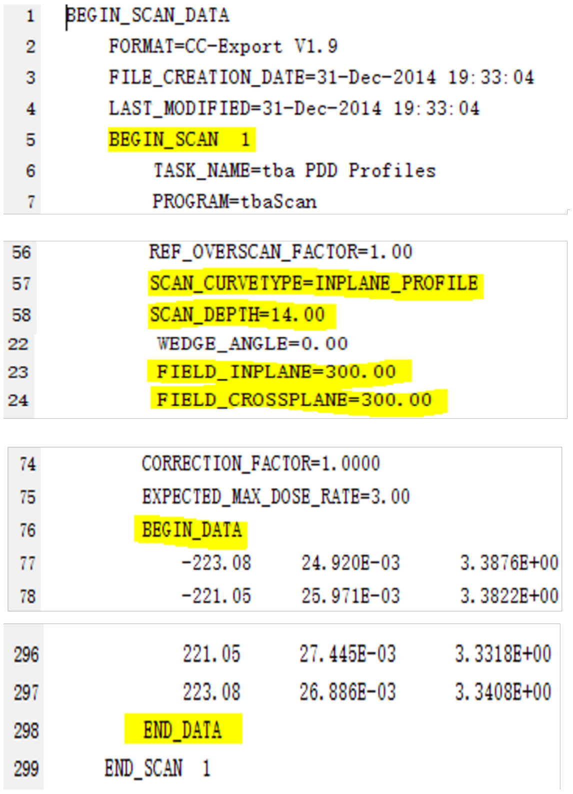
Finally line 32 and line 217 shown in Figure 1 are the indicator of the start and end locations of one measurement. They are the most important flags to tell where the MATLAB code to start storing the numerical data into a matrix and where to stop.

Features mentioned above are merely the most basic essential tags needed to be read when importing data from its original file format into MATLAB. As there might be more requirements on classifying the measurements according to some other features such as photon energy level, surface to skin distance(SSD) etc. There are other tags in the header file to read during data import.

```
1    :MSR     45   # No. of measurement in file
2    :SYS BDS 0 # Beam Data Scanner System
3    #
4    # RFA300 ASCII Measurement Dump ( BDS format )
5    #
6    # Measurement number     1
7    #
8    %VNR 1.0

14   %TIM     01:54:48
15   %FSZ     100 100
16   %BMT     PHO      6.0
17   %SSD     1000

30   #
31   #       X        Y        Z        Dose
32   #
33   =          0.0   -110.7     14.0       0.7
34   =          0.0   -109.7     14.0       1.1
35   =          0.0   -107.8     14.0       1.1

216  =       0.0    110.7    14.0      1.2
217  :EOM  # End of Measurement
218  #
219  # RFA300 ASCII Measurement Dump ( BDS format )
220  #
221  # Measurement number    2
```

Figure 1: Machine setting in asc header file

In Figure 2 shows the header file of an *.mcc* file. The information provided here is similar to that of *.acc* file but in a different way.



```
BEGIN_SCAN_DATA
    FORMAT=CC-Export V1.9
    FILE_CREATION_DATE=31-Dec-2014 19:33:04
    LAST_MODIFIED=31-Dec-2014 19:33:04
    BEGIN_SCAN  1
        TASK_NAME=tba PDD Profiles
        PROGRAM=tbaScan

        REF_OVERSCAN_FACTOR=1.00
        SCAN_CURVETYPE=INPLANE_PROFILE
        SCAN_DEPTH=14.00
        WEDGE_ANGLE=0.00
        FIELD_INPLANE=300.00
        FIELD_CROSSPLANE=300.00

        CORRECTION_FACTOR=1.0000
        EXPECTED_MAX_DOSE_RATE=3.00
        BEGIN_DATA
            -223.08    24.920E-03    3.3876E+00
            -221.05    25.971E-03    3.3822E+00

             221.05    27.445E-03    3.3318E+00
             223.08    26.886E-03    3.3408E+00
        END_DATA
    END_SCAN  1
```

Figure 2: Machine setting in mcc header file

This report will mainly focus on the processing of *.asc* file. Therefore all of the files mentioned later are of asc format. However the precessing of *.mcc* file can be easily carried out by altering several lines of the code.

3 Data Analysis and Data Import

The raw data directly collected from hospitals was gathered together to form the original database. Physicists opened those data files in the technical software IBA to check the quality of the data. They first manually selected those sets of data with nice and smooth curves displayed in IBA and saved as a new *.asc* document. There might be circumstance that the scale of different measurements varied within a large range,it is necessary to normalise the data by dividing a number, which could be the maximum value of dose in that measurement or the value at a particular depth, usually at vertical 10 cm depth. Considering the different maximum dose might accumulate at different depths for different measurements, in this project the normalisation denominator was selected as the value at 10 cm depth. The normalised data was calculated as shown in Formula 1. Finally a collection that involved many sets of good quality measurement data were ready to be imported into MATLAB for further processing.

$$\hat{d} = \frac{d}{d_{10cm}} \tag{1}$$

From Figure 1 it was easily found that the header file contains lots of symbols such as %, #, = as delimiters and many other characters to describe what the number is. This caused a problem in numerical parts extraction. As in MATLAB most of the built-in functions used to separate text and numbers only accept one type of delimiter as input argument.

The function ***textscan*** and ***importdata*** were used to give the solution to the problem mentioned above. ***textscan*** function read formatted data from text file or string. Due to there were text and numbers mixed together in the header file, the conversion specifier ***%s*** was used as the input argument in this function and it returned cell array of strings containing the data up to the end-of-line character. The number of lines of header file for every measurement is always the same. It was possible to count the position where contains the useful information such as field size and curve type etc. in the cell array. The machine settings existing in the header file was then extracted.

The next step is to extract numerical part. ***Importdata*** imported the whole document in string format by predefining the delimiter and headerlines needed to be skipped. In this case the delimiter to indicate the separation of column in each line is space and the headerlines can be counted because of the fixed number of lines of all the header files. Lastly to convert the extracted data which is string type to number. By applying a ***for*** loop to repeat for n times, where n is the number of measurements stored in the document, and to match the machine settings extracted before for each scan and save them all together as a for*.mat* file. The example results of data import were shown as Figure 3 and Figure 4.

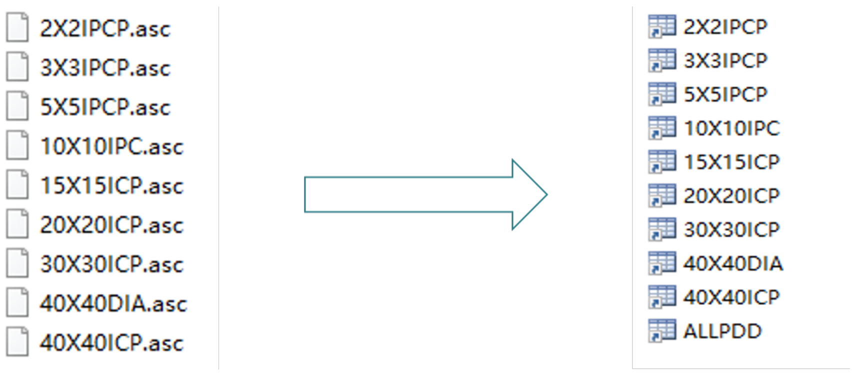


Figure 3: Data Import

Field size	Field size	X	Y	Z	Dose	Wedge
1	2	3	4	5	6	7
100	100	-125	0	14	0.9000	60
100	100	-123.9000	0	14	0.9000	60
100	100	-121.3000	0	14	0.9000	60
100	100	-120.5000	0	14	0.9000	60
100	100	-119.4000	0	14	0.9000	60
100	100	-118.4000	0	14	0.9000	60
100	100	-117.6000	0	14	0.9000	60
100	100	-116	0	14	1	60
100	100	-114.8000	0	14	1	60
100	100	-113.5000	0	14	1	60
100	100	-112.4000	0	14	0.9000	60
100	100	-111.2000	0	14	1.1000	60

Figure 4: Data Import Details: The final database was an $N \times 7$ matrix. The first two columns was field size. Column 3, 4 and 5 were the coordinates of X, Y and Z three axes. Column 6 was dose information at that position. The last column told whether the scan was measured with wedge or not for convenience of further processing— 60 for wedge and 0 for open.

4 Data Classification

Imported data with the same measuring conditions needed to be classified into different groups for further calculation. The classification was to mainly distinguish the curve type, field size and wedge scans. Field size and wedge scans can be recognised from the first two and the last columns directly. However to clarify the curve type requires some observations and even calculations on the values of three axes.

Theoretically when profile scans are carried out, the coordinate of Z axis must be zero as the detector is only moving in the horizontal plane. Similarly in any PDD scans the coordinates of X and Y axis must be 0 as well. However in most of the experiment environments, the absolute accurate 0 origin can not be guaranteed. Consequently there are lots of systematic errors which caused that the condition of a certain axis equal to 0 cannot be simply applied as the argument of *if* statement. Furthermore, the point which exactly passed through the origin $(0, 0, Z)$ where Z is whatever the depth of that measurement can be also confused to distinguish from the three curve types. In this case, if subtraction is applied to the whole column of an axis and obtain the answer 0, it can prove that there is no movement along this axis. Therefore the curve type can be clarified as shown in Table 1.

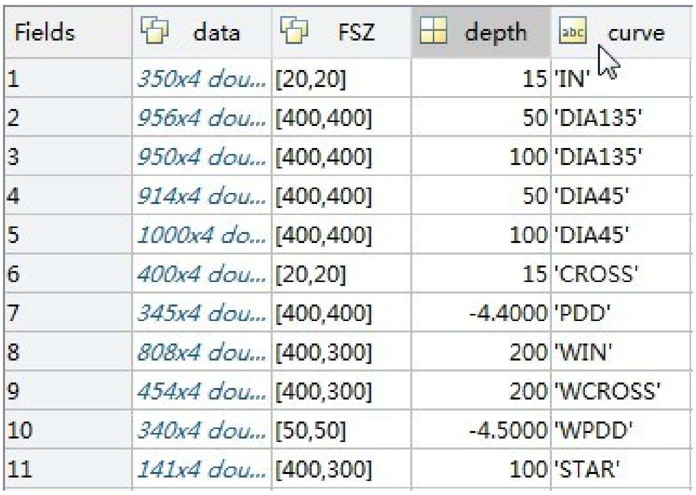
$Difference_X$	$Difference_Y$	$Difference_Z$	Curve type
Non zero	0	0	Crossplane
0	Non zero	0	Inplane
0	0	Non zero	PDD

Table 1: Curve Type Matching Table

In the diagonal measurements, there was no information in the header file to indicate the angle of diagnose. When the value of both X and Y axis are non zero, according to trigonometry tangent calculation the angle can be worked out as well.

The sorted measurements were stored as a temporary *struct* variable in MATLAB. In order to improve the code efficiency, it should reduce the use of *for* loop. To create a *struct* variable can store all the sorted information via one *for* loop rather than each loop only clarify one scan.

The *struct* variable contained four fields which can fully describe the characteristics of each measurement. The content of the *struct* was shown in Figure 5.



Fields	data	FSZ	depth	curve
1	350x4 dou...	[20,20]	15	'IN'
2	956x4 dou...	[400,400]	50	'DIA135'
3	950x4 dou...	[400,400]	100	'DIA135'
4	914x4 dou...	[400,400]	50	'DIA45'
5	1000x4 do...	[400,400]	100	'DIA45'
6	400x4 dou...	[20,20]	15	'CROSS'
7	345x4 dou...	[400,400]	-4.4000	'PDD'
8	808x4 dou...	[400,300]	200	'WIN'
9	454x4 dou...	[400,300]	200	'WCROSS'
10	340x4 dou...	[50,50]	-4.5000	'WPDD'
11	141x4 dou...	[400,300]	100	'STAR'

Figure 5: The structure of *struct* variable

5 Data Interpolation

From Figure 5 it can be observed that in the *data* field, the lengths of scans are different from one another. This might be due to the precision of the detectors in hospitals are different. In the average calculation it was expected to average over the values at the same position. With the purpose of obtaining every piece of data of the same length, the raw data needed to be extended with increment of the smallest digit, in which case 0.1. Finally to define a range that is a union to all the extended data and average over that section.

There are MATLAB built-in functions which can interpolate the coordinates meanwhile reasonably estimate dose at the interpolated point. The interpolation function interpolates to find a new vector *ynew*, the values of the underlying function $y = F(x)$ at the query points x. When an input was given, there would an one-one mapping output be estimated by several alternative methods [1]. As there were only one axis needed to be interpolated, function *interp1* which is an 1-D interpolation was used in this case.

The syntax of *interp1* is *ynew=interp1(x,y,xnew)*. There are three input arguments which are the raw data x and y and the vector of query points *xnew*. X and y are sample points which are used to define the underlying function and they must be two vectors of the same length. *Xnew* gives where the new output *ynew* is expected to be interpolated at. With the increment of 0.1,the suedo code was shown as Figure 6

Algorithm I Function: ynew=interp1(x,y,xnew)

$x = axis;$
$y = dose;$
$xnew = x(1) : 0.1 : x(end);$
$ynew = interp1(x, y, xnew, 'method');$

Figure 6: Suedo code of *interp1* function application

However there was a common warning when applying *interp1* function as shown in Figure 7:

```
Error using griddedInterpolant
The grid vectors are not strictly monotonic increasing.

Error in interp1 (line 161)
        F = griddedInterpolant(X,V,method);
```

Figure 7: Warning of *interp1* function

This warning mainly reflected in the repeated scan at a particular position. To ensure the input vectors are strictly monotonic increasing or decreasing, *unique* or *diff* functions can be used to check the repetition and then delete the repeated row.

The third input argument of *interp1* is the method of interpolation. MATLAB provides several built-in methods as shown in Figure 8:

Method	Description	Continuity	Comments
'linear'	Linear interpolation. The interpolated value at a query point is based on linear interpolation of the values at neighboring grid points in each respective dimension. This is the default interpolation method.	C^0	• Requires at least 2 points. • Requires more memory and computation time than nearest neighbor.
'nearest'	Nearest neighbor interpolation. The interpolated value at a query point is the value at the nearest sample grid point.	Discontinuous	• Requires at least 2 points. • Modest memory requirements • Fastest computation time
'next'	Next neighbor interpolation. The interpolated value at a query point is the value at the next sample grid point.	Discontinuous	• Requires at least 2 points. • Same memory requirements and computation time as 'nearest'.
'previous'	Previous neighbor interpolation. The interpolated value at a query point is the value at the previous sample grid point.	Discontinuous	• Requires at least 2 points. • Same memory requirements and computation time as 'nearest'.
'pchip'	Shape-preserving piecewise cubic interpolation. The interpolated value at a query point is based on a shape-preserving piecewise cubic interpolation of the values at neighboring grid points.	C^1	• Requires at least 4 points. • Requires more memory and computation time than linear.
'cubic'	Same as 'pchip'.	C^1	This method currently returns the same result as 'pchip'. In a future release, this method will perform cubic convolution.
'v5cubic'	Cubic convolution used in MATLAB® 5.	C^1	Points must be uniformly spaced. 'cubic' will replace 'v5cubic' in a future release.
'spline'	Spline interpolation using not-a-knot end conditions. The interpolated value at a query point is based on a cubic interpolation of the values at neighboring grid points in each respective dimension.	C^2	• Requires at least 4 points. • Requires more memory and computation time than 'pchip'.

Figure 8: Methods of interpolation in *interp1* function

Methods like *nearest*, *zero* and *previous* are discontinuous methods that simply depend on the neighbour values of query point and copy that to the interpolated point. These kind of methods are efficient in computational aspect but lack of smoothness and accuracy of estimation. An alternative approach to using a single (n-1)th order polynomial to interpolate between n points called *spline* is to break it down to many lower-order polynomials in a piecewise fashion to subsets of data points [2]. The connections of those lower-order polynomials can better fit the original curve and therefore minimize oscillations and reduce round-off error due to their lower-order nature. According to the complexity quadratic or cubic equations can be applied.

An easier way is linear method. As the name suggested, this method connects two sample points together by a straight line and interpolates according to the point lying on the line.

The results of several basic interpolation methods was shown in Figure 9:

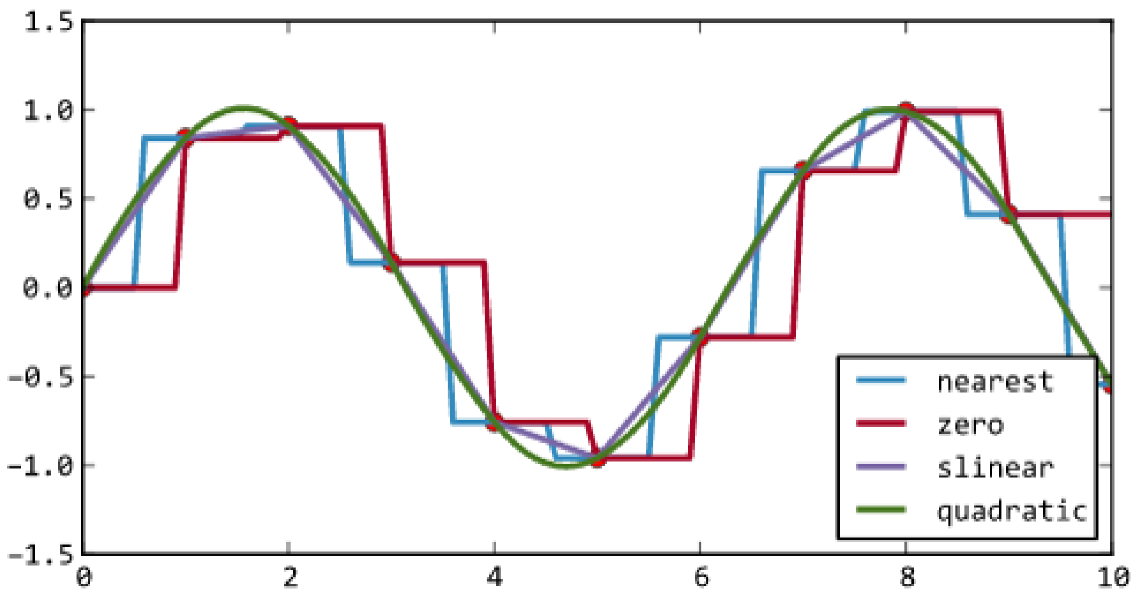
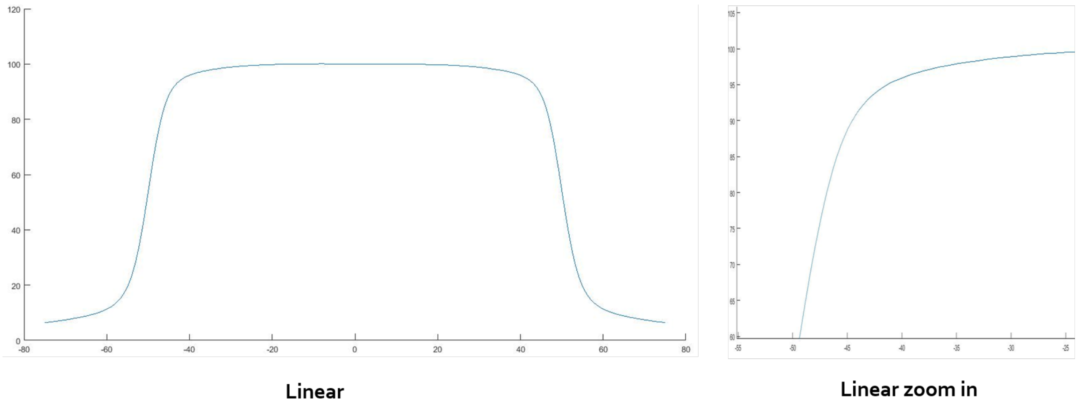


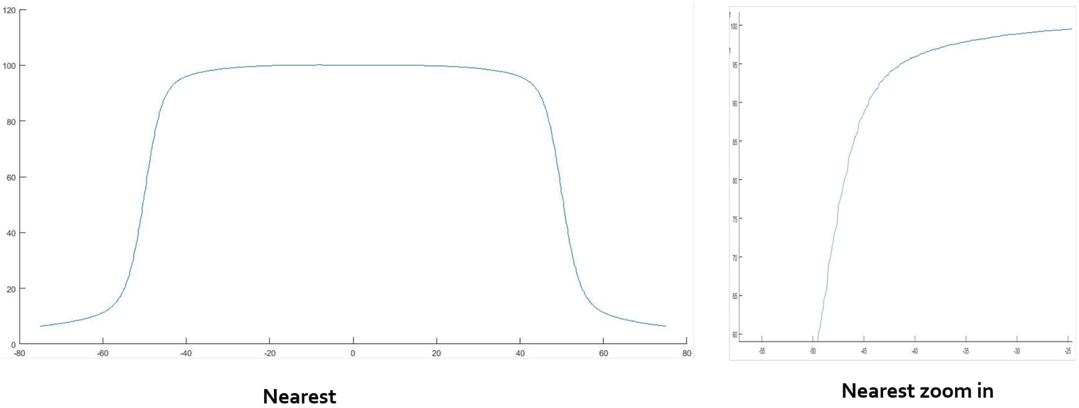
Figure 9: Demonstration of basic interpolation methods [3] [4]

From the Figure 9 it is obvious that the linear curve roughly follows the trend of query points and the oscillation converged to every data point but lack of smoothness. The quadratic spline method has great smoothness and seems fits the data points better so that minimise oscillations. However it requires more computational memory and relatively time consuming. For all concerned, *linear* method was applied in this project because generally after interpolation, there were at least more than 900 points for each measurement, in large-field-size measurements there were even more 3000 points. Due to the sufficient amount of sample points, the lack of smoothness of *linear* method can be compromised.

Figure 10 showed the comparison between *linear* method which is continuous and *nearest* method, which is discontinuous.



(a) Linear

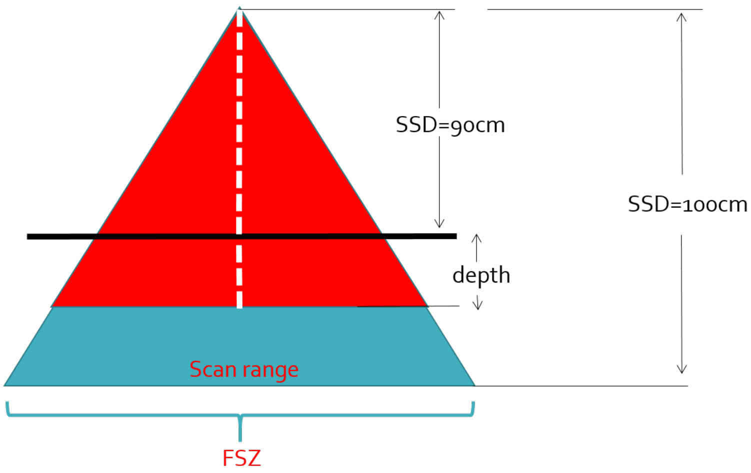


(b) Nearest

Figure 10: the comparison between *linear* and *nearest*. Linear interpolation gave smoother result than nearest interpolation

6 Data Range Selection and Average Calculation

After interpolation, the length of each measurement data was extended a lot. However the length of different measurements were still inconsistent. There must be a way to pick out a range that all measurements contained. The calculation of profile range was shown in Figure 11.



$$\frac{90 + depth}{range} = \frac{100}{FSZ} + 2.5$$

Figure 11: Profile range selection

According to similar triangles the sides of two triangles in Figure 11 are in ratio. By applying the formula on the left, the theoretical scan range can be calculated. The range of PDD is much easier to decide. To gather all the PDD measurements and then find out the shortest scan range (depth) in the set of data. However if the measurement scan depth was less than 30 cm, it would be regarded as a bad quality scan which could not be selected as reference data for the calculation. Figure 12 showed an example result of a set of averaged PDD data. It clearly showed that every curves started and ended at the same depth.

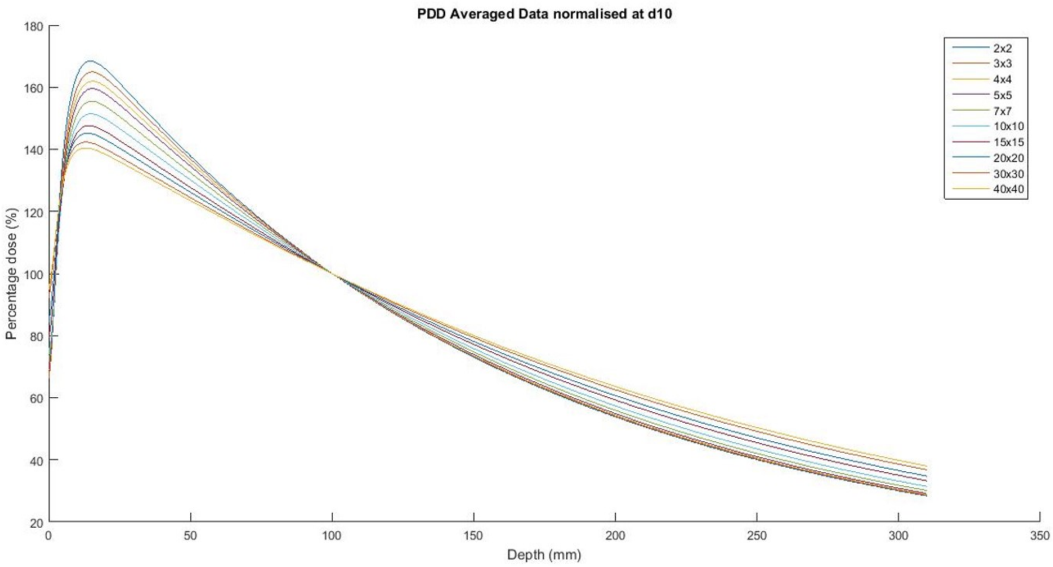


Figure 12: Averaged PDD curves

Final elected data was eventually put together and averaged along row as shown in Figure 13.

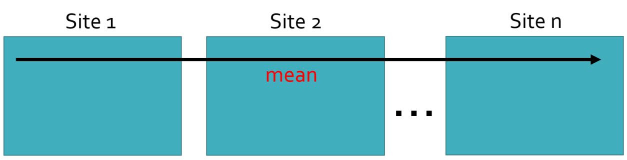
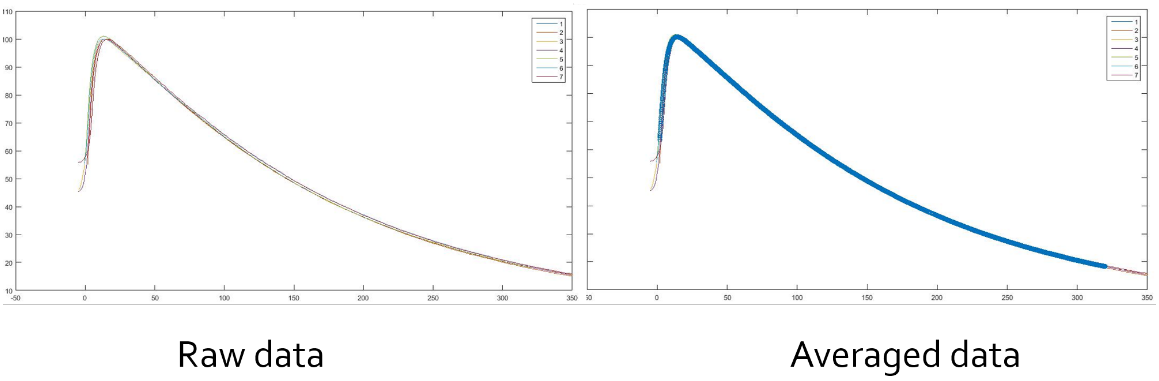
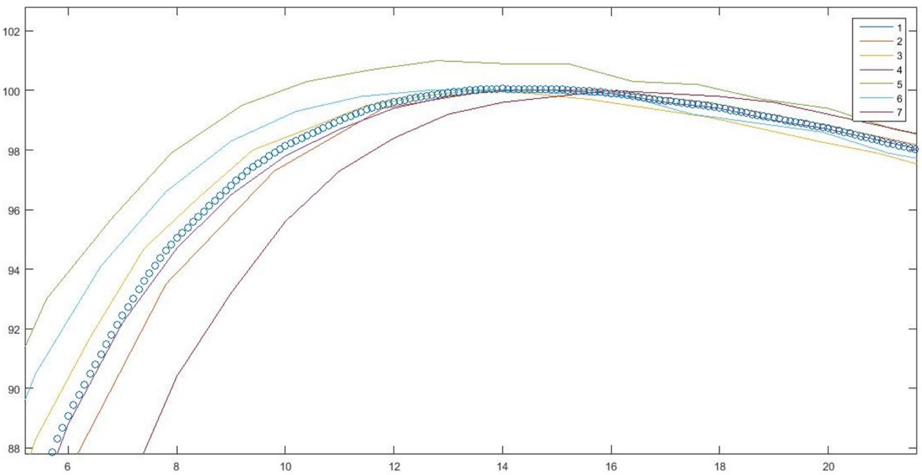


Figure 13: Average calculation

A comparison between an example set of averaged data and raw data was shown in Figure 14. From the plot it was clear that the averaged curve reasonably superposed on the raw data curves and after zoomed in the averaged curve lied in the middle of the other raw data curves.



(a) Comparison



(b) Zoom in

Figure 14: A comparison between averaged data and raw data: Lines with colours are plots of raw data; The curve plotted with blue circles are averaged data

7 Evaluation and Improvement

The reference database was evaluated and selected manually from the raw data collected directly from hospitals from all over the world. The filtered data was grouped according to different energy levels. The first part of MATLAB code written for this project can successfully import data in text format into MATLAB matrix and sort out any measurement by given conditions as long as there are tags existing in header file (field size, scan curve type, open or wedge). However because to obtain the information from header file must be using *for* loop, it caused the low efficiency when importing large amount of data.

The second part of code can accurately sort out measurements with the same scan conditions and gather them together to carry out the interpolation and average calculation. The interpolation method *linear* was chosen from MATLAB built-in method after comparisons. This method can produce reasonable interpolated values as well as make sure the computational memory and speed not beyond tolerance.

The numbers of measurements used to calculate the average data for each type of scans were shown in the Appendix.

However in the data import step, as the data was reformed in text format first and then encoded to numbers by following the conversion between ASCII code table, it was not possible to encode exactly the same number as saw in the original document. Those encoded numbers were either smaller or greater than the actual numbers but close enough. This might cause problem when using *find* function to sort out a particular kind of measurements. It can be solved by rounding the numbers or doing an addition and subtraction to give a reasonable range which only includes the value expected.

Sanity check is necessary in order to ensure the correct interpolation was carried out. To find the dose corresponding to the axis in the raw data from interpolated dataset and simply subtract these two sets to evaluate whether the result is zero.

For the purpose of increasing computational efficiency and quality of the reference data, it is worth to considering applying machine learning methods and regard this as a regression problem. By evaluating the cost function of different algorithms to choose the best one. The more high quality reference data is selected, the more reliable the averaged data is.

Reference

[1] "1-d data interpolation (table lookup) - matlab interp1 - mathworks united kingdom." http://uk.mathworks.com/help/matlab/ref/interp1.html. (Accessed on 09/29/2016).

[2] B. Chen, "Splines and piecewise interpolation." http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.713.6275&rep=rep1&type=pdf. (Accessed on 09/29/2016).

[3] "python - ." http://www.voidcn.com/blog/huozi07/article/p-4987298.html. (Accessed on 09/29/2016).

[4] "Python." http://zqdevres.qiniucdn.com/data/20150507214117/index.html. (Accessed on 09/29/2016).

Appendix I: Agility								
6MV		Open			Wedge			
		Curve type	Depth	No. Measurements	Curve type	Depth	No. Measurements	
Field Size	2x2	CROSS	50	36	CROSS	50	-	
			100	36		100		
			200	20		200		
			dmax	36		dmax		
		IN	50	35	IN	50		
			100	35		100		
			200	34		200		
			dmax	19		dmax		
	3x3	CROSS	50	36	CROSS	50		
			100	37		100		
			200	37		200		
			dmax	19		dmax		
		IN	50	34	IN	50		
			100	35		100		
			200	34		200		
			dmax	19		dmax		
	5x5	CROSS	50	33	CROSS	50	23	
			100	33		100	23	
			200	33		200	23	
			dmax	17		dmax	13	
		IN	50	33	IN	50	24	
			100	33		100	24	
			200	34		200	24	
			dmax	18		dmax	13	
	10x10	CROSS	50	25	CROSS	50	33	
			100	25		100	33	
			200	25		200	33	
			dmax	15		dmax	17	
		IN	50	33	IN	50	24	
			100	33		100	24	
			200	33		200	24	
			dmax	18		dmax	13	
	15x15	CROSS	50	33	CROSS	50	23	
			100	33		100	23	
			200	33		200	23	
			dmax	18		dmax	13	
		IN	50	32	IN	50	24	
			100	32		100	24	
			200	32		200	24	
			dmax	18		dmax	13	
	20x20	CROSS	50	33	CROSS	50	13	
			100	34		100	13	
			200	34		200	13	
			dmax	18		dmax	9	
		IN	50	33	IN	50	23	
			100	32		100	23	
			200	33		200	23	
			dmax	18		dmax	14	

	30x30	CROSS	50	34	CROSS	50	-
			100	34		100	
			200	34		200	
			dmax	18		dmax	
		IN	50	33	IN	50	
			100	32		100	
			200	33		200	
			dmax	18		dmax	
	40x40	CROSS	50	34	CROSS	50	
			100	33		100	
			200	33		200	
			dmax	18		dmax	
		IN	50	32	IN	50	
			100	33		100	
			200	34		200	
			dmax	18		dmax	
	40x30	DIA45	50	20	DIA45	50	-
			100	19		100	
		DIA135	50	13	DIA135	50	
			100	13		100	
	2x2	PDD	-	29	PDD	-	-
	3x3			29			
	4x4			29			
	5x5			28			24
	7x7			30			-
	10x10			30			25
	15x15			30			25
	20x20			30			25
	30x30			30			-
	40x40			30			
Total No. of Measurements:				**3354**			

4MV		Open			Wedge		
		Curve type	Depth	No. Measurements	Curve type	Depth	No. Measurements
Field Size	2x2	CROSS	50	18	CROSS	50	-
			100	18		100	
			200	18		200	
			dmax	4		dmax	
		IN	50	17	IN	50	
			100	17		100	
			200	17		200	
			dmax	4		dmax	
	3x3	CROSS	50	18	CROSS	50	
			100	18		100	
			200	18		200	
			dmax	4		dmax	
		IN	50	15	IN	50	
			100	17		100	
			200	17		200	
			dmax	4		dmax	
	5x5	CROSS	50	18	CROSS	50	14
			100	18		100	14
			200	13		200	14
			dmax	2		dmax	2
		IN	50	17	IN	50	13
			100	15		100	13
			200	17		200	13
			dmax	4		dmax	2
	10x10	CROSS	50	18	CROSS	50	14
			100	18		100	14
			200	18		200	14
			dmax	4		dmax	2
		IN	50	17	IN	50	13
			100	15		100	13
			200	17		200	13
			dmax	4		dmax	2
	15x15	CROSS	50	16	CROSS	50	15
			100	18		100	15
			200	18		200	15
			dmax	4		dmax	2
		IN	50	17	IN	50	13
			100	15		100	13
			200	17		200	13
			dmax	4		dmax	2
	20x20	CROSS	50	17	CROSS	50	14
			100	17		100	14
			200	17		200	14
			dmax	4		dmax	2
		IN	50	15	IN	50	13
			100	15		100	13
			200	17		200	13
			dmax	4		dmax	2

	30x30	CROSS	50	18	CROSS	50	-
			100	18		100	
			200	18		200	
			dmax	4		dmax	
		IN	50	17	IN	50	
			100	15		100	
			200	17		200	
			dmax	4		dmax	
	40x40	CROSS	50	18	CROSS	50	
			100	18		100	
			200	18		200	
			dmax	4		dmax	
		IN	50	17	IN	50	
			100	15		100	
			200	17		200	
			dmax	4		dmax	
	40x30	DIA45	50	12	DIA45	50	-
			100	12		100	
		DIA135	50	8	DIA135	50	
			100	8		100	
	2x2	PDD	-	16	PDD	-	-
	3x3			17			
	4x4			17			
	5x5			17			15
	7x7			17			-
	10x10			17			15
	15x15			17			14
	20x20			17			14
	30x30			17			-
	40x40			16			
Total No. of Measurements:				**1813**			

10MV		Open			Wedge		
		Curve type	Depth	No. Measurements	Curve type	Depth	No. Measurements
Field Size	2x2	CROSS	50	33	CROSS	50	-
Field Size	2x2	CROSS	100	33	CROSS	100	-
Field Size	2x2	CROSS	200	33	CROSS	200	-
Field Size	2x2	CROSS	dmax	8	CROSS	dmax	-
Field Size	2x2	IN	50	33	IN	50	-
Field Size	2x2	IN	100	33	IN	100	-
Field Size	2x2	IN	200	32	IN	200	-
Field Size	2x2	IN	dmax	8	IN	dmax	-
Field Size	3x3	CROSS	50	32	CROSS	50	-
Field Size	3x3	CROSS	100	33	CROSS	100	-
Field Size	3x3	CROSS	200	32	CROSS	200	-
Field Size	3x3	CROSS	dmax	11	CROSS	dmax	-
Field Size	3x3	IN	50	33	IN	50	-
Field Size	3x3	IN	100	33	IN	100	-
Field Size	3x3	IN	200	32	IN	200	-
Field Size	3x3	IN	dmax	11	IN	dmax	-
Field Size	5x5	CROSS	50	34	CROSS	50	20
Field Size	5x5	CROSS	100	34	CROSS	100	20
Field Size	5x5	CROSS	200	33	CROSS	200	20
Field Size	5x5	CROSS	dmax	11	CROSS	dmax	5
Field Size	5x5	IN	50	32	IN	50	20
Field Size	5x5	IN	100	32	IN	100	20
Field Size	5x5	IN	200	33	IN	200	20
Field Size	5x5	IN	dmax	11	IN	dmax	5
Field Size	10x10	CROSS	50	22	CROSS	50	21
Field Size	10x10	CROSS	100	22	CROSS	100	21
Field Size	10x10	CROSS	200	22	CROSS	200	21
Field Size	10x10	CROSS	dmax	9	CROSS	dmax	5
Field Size	10x10	IN	50	33	IN	50	19
Field Size	10x10	IN	100	33	IN	100	19
Field Size	10x10	IN	200	34	IN	200	19
Field Size	10x10	IN	dmax	11	IN	dmax	5
Field Size	15x15	CROSS	50	32	CROSS	50	21
Field Size	15x15	CROSS	100	32	CROSS	100	21
Field Size	15x15	CROSS	200	33	CROSS	200	21
Field Size	15x15	CROSS	dmax	11	CROSS	dmax	5
Field Size	15x15	IN	50	33	IN	50	19
Field Size	15x15	IN	100	33	IN	100	19
Field Size	15x15	IN	200	34	IN	200	19
Field Size	15x15	IN	dmax	11	IN	dmax	5
Field Size	20x20	CROSS	50	32	CROSS	50	21
Field Size	20x20	CROSS	100	31	CROSS	100	21
Field Size	20x20	CROSS	200	31	CROSS	200	20
Field Size	20x20	CROSS	dmax	8	CROSS	dmax	5
Field Size	20x20	IN	50	32	IN	50	19
Field Size	20x20	IN	100	32	IN	100	19
Field Size	20x20	IN	200	31	IN	200	19
Field Size	20x20	IN	dmax	9	IN	dmax	5

	30x30	CROSS	50	33	CROSS	50	-
			100	35		100	
			200	32		200	
			dmax	11		dmax	
		IN	50	32	IN	50	
			100	32		100	
			200	31		200	
			dmax	11		dmax	
	40x40	CROSS	50	35	CROSS	50	
			100	35		100	
			200	33		200	
			dmax	9		dmax	
		IN	50	0	IN	50	
			100	33		100	
			200	33		200	
			dmax	9		dmax	
	40x30	DIA45	50	19	DIA45	50	-
			100	19		100	
		DIA135	50	13	DIA135	50	
			100	13		100	
	2x2	PDD	-	31	PDD	-	-
	3x3			31			
	4x4			30			
	5x5			32			19
	7x7			31			-
	10x10			31			19
	15x15			31			19
	20x20			31			19
	30x30			31			-
	40x40			31			
Total No. of Measurements:				**3202**			

15MV		Open			Wedge		
		Curve type	Depth	No. Measurements	Curve type	Depth	No. Measurements
Field Size	2x2	CROSS	50	9	CROSS	50	-
			100	9		100	
			200	9		200	
			dmax	3		dmax	
		IN	50	14	IN	50	
			100	14		100	
			200	13		200	
			dmax	5		dmax	
	3x3	CROSS	50	15	CROSS	50	
			100	14		100	
			200	15		200	
			dmax	5		dmax	
		IN	50	14	IN	50	
			100	15		100	
			200	14		200	
			dmax	5		dmax	
	5x5	CROSS	50	17	CROSS	50	11
			100	17		100	11
			200	15		200	11
			dmax	4		dmax	4
		IN	50	15	IN	50	10
			100	16		100	10
			200	16		200	10
			dmax	5		dmax	4
	10x10	CROSS	50	16	CROSS	50	11
			100	15		100	11
			200	16		200	11
			dmax	7		dmax	4
		IN	50	15	IN	50	10
			100	16		100	9
			200	16		200	10
			dmax	7		dmax	4
	15x15	CROSS	50	17	CROSS	50	16
			100	17		100	16
			200	17		200	16
			dmax	6		dmax	5
		IN	50	16	IN	50	10
			100	17		100	10
			200	17		200	10
			dmax	6		dmax	4
	20x20	CROSS	50	16	CROSS	50	6
			100	15		100	6
			200	16		200	5
			dmax	5		dmax	3
		IN	50	15	IN	50	10
			100	16		100	10
			200	16		200	10
			dmax	5		dmax	4

	30x30	CROSS	50	16	CROSS	50	-
			100	15		100	
			200	16		200	
			dmax	5		dmax	
		IN	50	15	IN	50	
			100	16		100	
			200	15		200	
			dmax	5		dmax	
	40x40	CROSS	50	15	CROSS	50	
			100	15		100	
			200	16		200	
			dmax	5		dmax	
		IN	50	0	IN	50	
			100	15		100	
			200	16		200	
			dmax	5		dmax	
	40x30	DIA45	50	9	DIA45	50	-
			100	8		100	
		DIA135	50	8	DIA135	50	
			100	7		100	
	2x2	PDD	-	15	PDD	-	-
	3x3			15			
	4x4			15			
	5x5			15			12
	7x7			15			-
	10x10			15			10
	15x15			15			12
	20x20			15			11
	30x30			15			-
	40x40			15			
Total No. of Measurements:				**1541**			

18MV		Open			Wedge		
		Curve type	Depth	No. Measurements	Curve type	Depth	No. Measurements
Field Size	2x2	CROSS	50	3	CROSS	50	-
			100	3		100	
			200	3		200	
			dmax	2		dmax	
		IN	50	3	IN	50	
			100	3		100	
			200	3		200	
			dmax	2		dmax	
	3x3	CROSS	50	3	CROSS	50	
			100	3		100	
			200	3		200	
			dmax	2		dmax	
		IN	50	3	IN	50	
			100	3		100	
			200	3		200	
			dmax	2		dmax	
	5x5	CROSS	50	3	CROSS	50	3
			100	3		100	3
			200	3		200	3
			dmax	2		dmax	2
		IN	50	4	IN	50	3
			100	4		100	3
			200	4		200	3
			dmax	2		dmax	2
	10x10	CROSS	50	4	CROSS	50	3
			100	4		100	3
			200	4		200	3
			dmax	2		dmax	2
		IN	50	4	IN	50	3
			100	4		100	3
			200	4		200	3
			dmax	2		dmax	2
	15x15	CROSS	50	3	CROSS	50	3
			100	3		100	3
			200	3		200	3
			dmax	2		dmax	2
		IN	50	3	IN	50	3
			100	3		100	3
			200	3		200	3
			dmax	2		dmax	2
	20x20	CROSS	50	4	CROSS	50	3
			100	4		100	3
			200	4		200	3
			dmax	2		dmax	2
		IN	50	4	IN	50	3
			100	4		100	3
			200	4		200	3
			dmax	2		dmax	2

	30x30	CROSS	50	3	CROSS	50	-
			100	3		100	
			200	3		200	
			dmax	2		dmax	
		IN	50	3	IN	50	
			100	3		100	
			200	3		200	
			dmax	2		dmax	
	40x40	CROSS	50	3	CROSS	50	
			100	3		100	
			200	3		200	
			dmax	2		dmax	
		IN	50	3	IN	50	
			100	3		100	
			200	3		200	
			dmax	2		dmax	
	40x30	DIA45	50	4	DIA45	50	-
			100	5		100	
		DIA135	50	2	DIA135	50	
			100	3		100	
	2x2	PDD	-	3	PDD	-	-
	3x3			3			
	4x4			3			
	5x5			4			3
	7x7			3			-
	10x10			4			3
	15x15			4			3
	20x20			4			3
	30x30			3			-
	40x40			3			
Total No. of Measurements:				**368**			

Appendix II: Agility-FFF							
6MV		Open			Wedge		
		Curve type	Depth	No. Measurements	Curve type	Depth	No. Measurements
Field Size	2x2	CROSS	50	5	CROSS	50	-
			100	5		100	
			200	5		200	
			dmax	1		dmax	
		IN	50	5	IN	50	
			100	5		100	
			200	5		200	
			dmax	1		dmax	
	3x3	CROSS	50	4	CROSS	50	
			100	5		100	
			200	5		200	
			dmax	1		dmax	
		IN	50	4	IN	50	
			100	5		100	
			200	4		200	
			dmax	1		dmax	
	5x5	CROSS	50	5	CROSS	50	-
			100	5		100	
			200	5		200	
			dmax	1		dmax	
		IN	50	5	IN	50	
			100	4		100	
			200	5		200	
			dmax	1		dmax	
	10x10	CROSS	50	4	CROSS	50	
			100	5		100	
			200	5		200	
			dmax	1		dmax	
		IN	50	4	IN	50	
			100	5		100	
			200	5		200	
			dmax	1		dmax	
	15x15	CROSS	50	4	CROSS	50	
			100	5		100	
			200	5		200	
			dmax	1		dmax	
		IN	50	4	IN	50	
			100	5		100	
			200	5		200	
			dmax	1		dmax	
	20x20	CROSS	50	5	CROSS	50	
			100	5		100	
			200	5		200	
			dmax	1		dmax	
		IN	50	4	IN	50	
			100	4		100	
			200	5		200	
			dmax	1		dmax	

	30x30	CROSS	50	*5*	CROSS	*50*	-
			100	5		100	
			200	5		200	
			dmax	1		dmax	
		IN	50	4	IN	50	
			100	4		100	
			200	4		200	
			dmax	1		dmax	
	40x40	CROSS	50	5	CROSS	50	
			100	5		100	
			200	4		200	
			dmax	1		dmax	
		IN	50	1	IN	50	
			100	4		100	
			200	5		200	
			dmax	1		dmax	
	40x30	DIA45	50	5	DIA45	50	-
			100	5		100	
		DIA135	50	4	DIA135	50	
			100	4		100	
	2x2	PDD	-	5	PDD	-	-
	3x3			5			
	4x4			5			
	5x5			5			
	7x7			5			
	10x10			5			
	15x15			5			
	20x20			5			
	30x30			5			
	40x40			5			
Total No. of Measurements:				**385**			

10MV		Open			Wedge		
		Curve type	Depth	No. Measurements	Curve type	Depth	No. Measurements
Field Size	2x2	CROSS	50	2	CROSS	50	-
			100	2		100	
			200	3		200	
			dmax	1		dmax	
		IN	50	2	IN	50	
			100	3		100	
			200	2		200	
			dmax	1		dmax	
	3x3	CROSS	50	3	CROSS	50	
			100	2		100	
			200	3		200	
			dmax	1		dmax	
		IN	50	3	IN	50	
			100	2		100	
			200	3		200	
			dmax	1		dmax	
	5x5	CROSS	50	2	CROSS	50	-
			100	2		100	
			200	3		200	
			dmax	1		dmax	
		IN	50	3	IN	50	
			100	3		100	
			200	3		200	
			dmax	1		dmax	
	10x10	CROSS	50	2	CROSS	50	
			100	3		100	
			200	3		200	
			dmax	1		dmax	
		IN	50	3	IN	50	
			100	2		100	
			200	3		200	
			dmax	1		dmax	
	15x15	CROSS	50	2	CROSS	50	
			100	3		100	
			200	3		200	
			dmax	1		dmax	
		IN	50	3	IN	50	
			100	2		100	
			200	3		200	
			dmax	1		dmax	
	20x20	CROSS	50	3	CROSS	50	
			100	2		100	
			200	3		200	
			dmax	1		dmax	
		IN	50	3	IN	50	
			100	2		100	
			200	3		200	
			dmax	1		dmax	

	30x30	CROSS	50	3	CROSS	50	-
			100	2		100	
			200	3		200	
			dmax	1		dmax	
		IN	50	2	IN	50	
			100	3		100	
			200	3		200	
			dmax	1		dmax	
	40x40	CROSS	50	3	CROSS	50	
			100	2		100	
			200	3		200	
			dmax	1		dmax	
		IN	50	1	IN	50	
			100	3		100	
			200	3		200	
			dmax	1		dmax	
	40x30	DIA45	50	2	DIA45	50	-
			100	3		100	
		DIA135	50	3	DIA135	50	
			100	3		100	
	2x2	PDD	-	3	PDD	-	-
	3x3			3			
	4x4			3			
	5x5			3			
	7x7			3			
	10x10			3			
	15x15			3			
	20x20			3			
	30x30			3			
	40x40			3			
Total No. of Measurements:				**232**			

Appendix III: MLCi2								
6MV		Open			Wedge			
		Curve type	Depth	No. Measurements	Curve type	Depth	No. Measurements
Field Size	2x2	CROSS	50	9	CROSS	50	-
			100	9		100	
			200	9		200	
			dmax	7		dmax	
		IN	50	9	IN	50	
			100	9		100	
			200	9		200	
			dmax	7		dmax	
	3x3	CROSS	50	10	CROSS	50	
			100	10		100	
			200	10		200	
			dmax	8		dmax	
		IN	50	10	IN	50	
			100	10		100	
			200	10		200	
			dmax	8		dmax	
	5x5	CROSS	50	10	CROSS	50	5
			100	10		100	5
			200	10		200	5
			dmax	8		dmax	3
		IN	50	9	IN	50	4
			100	9		100	5
			200	9		200	4
			dmax	6		dmax	3
	10x10	CROSS	50	10	CROSS	50	5
			100	10		100	5
			200	10		200	5
			dmax	8		dmax	3
		IN	50	9	IN	50	5
			100	9		100	5
			200	9		200	5
			dmax	6		dmax	3
	15x15	CROSS	50	10	CROSS	50	5
			100	10		100	5
			200	10		200	5
			dmax	8		dmax	3
		IN	50	9	IN	50	6
			100	9		100	6
			200	9		200	6
			dmax	6		dmax	3
	20x20	CROSS	50	10	CROSS	50	5
			100	10		100	5
			200	10		200	5
			dmax	8		dmax	3
		IN	50	9	IN	50	5
			100	9		100	5
			200	9		200	5
			dmax	6		dmax	3

	30x30	CROSS	50	10	CROSS	50	-
			100	10		100	
			200	10		200	
			dmax	8		dmax	
		IN	50	8	IN	50	
			100	8		100	
			200	8		200	
			dmax	6		dmax	
	40x40	CROSS	50	10	CROSS	50	
			100	10		100	
			200	10		200	
			dmax	8		dmax	
		IN	50	8	IN	50	
			100	8		100	
			200	8		200	
			dmax	6		dmax	
	40x30	DIA45	50	3	DIA45	50	-
			100	6		100	
		DIA135	50	6	DIA135	50	
			100	6		100	
	2x2	PDD	-	9	PDD	-	-
	3x3			9			
	4x4			10			
	5x5			10			8
	7x7			9			-
	10x10			10			8
	15x15			11			8
	20x20			10			8
	30x30			9			-
	40x40			10			
Total No. of Measurements:				**973**			

10MV		Open			Wedge		
		Curve type	Depth	No. Measurements	Curve type	Depth	No. Measurements
Field Size	2x2	CROSS	50	5	CROSS	50	-
			100	5		100	
			200	5		200	
			dmax	2		dmax	
		IN	50	5	IN	50	
			100	5		100	
			200	5		200	
			dmax	2		dmax	
	3x3	CROSS	50	6	CROSS	50	
			100	6		100	
			200	6		200	
			dmax	2		dmax	
		IN	50	6	IN	50	
			100	6		100	
			200	6		200	
			dmax	2		dmax	
	5x5	CROSS	50	5	CROSS	50	6
			100	5		100	6
			200	5		200	6
			dmax	2		dmax	1
		IN	50	5	IN	50	4
			100	5		100	4
			200	5		200	4
			dmax	2		dmax	1
	10x10	CROSS	50	5	CROSS	50	6
			100	5		100	6
			200	5		200	6
			dmax	2		dmax	1
		IN	50	5	IN	50	4
			100	5		100	4
			200	5		200	4
			dmax	2		dmax	1
	15x15	CROSS	50	5	CROSS	50	6
			100	5		100	6
			200	5		200	6
			dmax	2		dmax	1
		IN	50	5	IN	50	4
			100	5		100	4
			200	5		200	4
			dmax	2		dmax	1
	20x20	CROSS	50	5	CROSS	50	6
			100	5		100	6
			200	5		200	6
			dmax	2		dmax	1
		IN	50	5	IN	50	4
			100	5		100	4
			200	5		200	4
			dmax	2		dmax	1

	30x30	CROSS	50	5	CROSS	50	-
			100	5		100	
			200	5		200	
			dmax	2		dmax	
		IN	50	5	IN	50	
			100	5		100	
			200	5		200	
			dmax	2		dmax	
	40x40	CROSS	50	5	CROSS	50	
			100	5		100	
			200	5		200	
			dmax	2		dmax	
		IN	50	5	IN	50	
			100	5		100	
			200	5		200	
			dmax	2		dmax	
	40x30	DIA45	50	5	DIA45	50	-
			100	5		100	
		DIA135	50	5	DIA135	50	
			100	5		100	
	2x2	PDD	-	6	PDD	-	-
	3x3			6			
	4x4			6			
	5x5			7			2
	7x7			6			-
	10x10			6			3
	15x15			6			3
	20x20			6			3
	30x30			6			-
	40x40			6			
Total No. of Measurements:				**612**			