

This will be more focused on the use in our operations data for, in beam modeling particularly as the basis for calculations with model labeled dose engines. And then, we will cover the easiest of clinical beam modeling and introduce some terminology of how we will label different components of the beam and parts of the dose and we will also focus quite a deal on separation of primary and scattered parts and see how the collation karma bias of the energy fluence variation estimates from the SC measurements goes in to the beam modeling and also browse through some of the components which Tim already mentioned. Feasible beam model for clinical use should be simple such that you can get conceptual understanding of what's going on by analyzing the model and it should be accurate enough results of course and the fewer and more independent the

parameters to drive it, the better it is and those parameters should preferably be possible to derive from well standardized type of measurements particularly in this scope is now in the output ratio in the profiles but one also needs other data to do a full beam modeling and it has then to also provide the needed information to the dose engines, it might be to provide terma calculations for convolution super position models or should be able to drive particle sampling if I want to have a Monte Carlo dose engine. Terminology, well we differentiate the beam into its components, direct particles, those are the particles which are not scattered anywhere in the treatment head and most directly to the patient and then we have an indirect component and that's the head scatter from various sources of head scatter and we also have the charged particle continuation and if you then look at

the dose components, we have primary dose and that is defined as the dose deposited by the electrons liberated by the first interaction and the photon has when it enters into the patient so it has two components; that's for the direct beam and that for the indirect. Similar for the scatter dose and then one can sum everything up to get the total dose. What's typically done in the beam modeling for treatment planning is that while you use the concept of energy fluence matrix to map the properties of the beam and the local energy flow is that given by the values of the pixels and the position of the pixel then gives the direction. And one can eventually then add an angular spread to that direction and the energy spectrum is usually considered a common tool pixels. One can also separate this concept to have two matrices, one for the direct beam and one for the

indirect, head scatter part of it and in doing that one can assume different sources for these and have then different angular deviations and inverse square behavior for these different components. In convolution super position dose modeling, it's a two-stage process where the first step is to retrace the energy fluence out through the patient and while doing that calculate the energy taken from the beam and supposed then to be further transported by means of the kernels to deposit the dose and one can do that by calculating the total energy released per mass terma or one can separate the terma into primary collation karma and what can nickname the terma as being the difference between the terma and the collation karma, that is the released energy which is slated to become the scatter dose and in doing this operations properly then one need to introduce

and integration over the energy demand in order to consider all the different parts of the

spectrum. The next step is to convolve or super impose the kernels to yield the dose and using the terma concept then one has to repeat this over all spectrum beams so that's quite inefficient so it's more efficient to separate into a primary dose calculation and a scatter dose calculation and this way of expressing it, all beam modeling is then actually expressed through the distribution of the collation karma and this terma and then the kernels are to the blurring and the secondary particle and transport within the patient then. So if we look somewhat more into detail how one can calculate collation karma, to do it precisely one has to do summate over the energy demand to take all spectral components and then there is the rate raise and attenuation and energy transfer coefficient, absorption coefficient but that can since this parameters varies rather slowly with the energy, one can parameterize that to an effective attenuation and the mean

energy absorption coefficient and we can manipulate this expression to include a reference value of the energy absorption coefficients such that we have here a quantity which is the energy fluence biased by the collation karma over the field width and one can also formulate the scatter part of the calculations in the same manner to be dependent on the same quantities so we see here that this is a important quantity which is directly come by table where the definition or the SC as Tim went through earlier. The other part of parameters here I don't go into the details of those but the all the directly measured one in the for the beam directly is the effective attenuation coefficient and the others can be related to that one and the variation of this one is easily taken and is shown in a paper by Taylor et. al. it varies in the same relatively manner laterally for a very broad range of

machines and all though I'm not published we have verified this also by Monte Carlo calculations. So if we look at the expression that Tim already showed, we see that we have there the same quantity as what we needed in the beam modeling for the convolution super position models and although we are not entering into it, it's also possible to use the same quantities to design sampling procedures if I want to have this beam model to drive Monte Carlo dose calculations instead. The measurement of the in air output ratios is sensitive to the measurement technique and in particular there is the data published in Report 55 has very strange behavior and the only one compared to other measurements and the only interpretation of that is that the buildup used was too thin so this data is heavily corrupted by the inclusion of electron contamination which is known

to vary strongly with the field size. The other graph here shows well, if Tim has already shown this, that we have a variation if we use the high set buildup caps and that variation with field size is larger for higher energy beams than it is for lower energy beams. The basis of beam modeling using this concept is that one take the direct beam and the head, the indirect part head scatter beam, one can express the various fluence component and if one had then the reference level then the rest can be expressed relative to that one and the in the doing modeling it's most important is to consider all your matrical effects, or how much of these various contributions we actually get in the detector's eye view up through the machine. And we know quickly browse through these various components and the reference level of the energy fluence value that is not measured, but it's derived from a

dose measurement, it derived from the dose reference calibration of the machine, taking that measured value which is dose per monitor unit and divide it by exactly the same conditions calculated dose per energy fluence and then the dose cancels and then we are getting then the energy fluence per monitor units. A little complication is that we have the back scatter to the monitor from the collimators and if I want to include that which I think one should, then one need a model or one need measurements to estimate that small component and the modeling is rather easy just to consider the geometry of the back scattering area, how much the monitor sees of the back scattering blocks and then one can formalize that to include only one empirical coefficient. Modulation of the direct beam can be done by blocking or one can calculate if I need to use a wedge one can calculate or

one can measure what would be the modulation of that part too. What one then need to estimate is also the effects of changing the spectrum and here is a graph that shows how the collation karma and scarma components various with that for a lead attenuator for two different energies, it's not large variation for lower energies than it is for higher energies so one has to be very careful when one design, for instance, factor based calculations and introduce wedges, then one has to be very careful of how output ratios in air are introduced into that machine in order to not be biased the wrong way or the beam quality changes. The open beam distribution the relative lateral distribution I already have that as part of the collation karma calculations in beam modeling and one can actually use an in air measurements to characterize that one and the collation karma bias is actually then

consistent with the beam modeling based on separation of the primary and scatter dose parts. Then we have the head scatter components and the driving force in any kind of parameterization here is of course the in air ratio measurements and the modeling aspect has to be based on what views one get through the geometry of the machine and the most complicated factor here is actually the thickness of the collimator that can make this kind of geometry modeling quite complicated and the blocking of the scatter from the flattening field directs planes, most of the characteristics one get of the in air output ratios and this graph shows for the machine geometry we have the here to the right, the variation in head scatter fluence or flattening filter fluence when the collimate, then we would change the size of the field and this are no rectangular field wide open in one

direction and the other is varied and in this three curves it's the inner pair of collimator which is varied and in this three curves it's the outer pair of collimators which is varies and we get a more rapid variation for the outer pair because just the geometrical properties while looking upwards into the treatment head and these graphs up here shows how much one see at each position for each field size of respectively collimator pair how much one see of the flattening filter. And this is on the beam axis and here is the same kind of this \_\_\_ but we are now going to off-axis position, we are looking up into the flattening field from various off-axis positions and we see then what is the different part of the flattening filter and the amount of scatter here is modeled with three different distributions, three different shapes of the flattening filter scatter; it's the triangular,

looking like that, or Galcion or just flat. They are all having the same integrated value

and we see that for some instances we get the difference according to which shape it shows but mostly it's relatively shape independent. There is some situations where we get more rapid variation than others and that is if we have a blocking which pre-acts directly onto the most intense part of the scattering area of the flattening filter, now that is typically for having asymmetric beam and put a collimator at the central axis and then we get the wedge-like effect introduced into the beam through the very steep variation of the flattening filter scatter we get under these conditions. Collimator scatter is of minor influence, it's usually of the same order as monitor back scatter and here shows the distributions calculated of collimator scatter for some different field sizes and we never reach the level of 1% so it can be modeled by use of pre-calculated collimator scatter kernels or one can fudge this part into other, the other sources of the treatment head. The

primary collimator is an exception but that is located so close to the flattening filter so common practice one fudge the primary collimator scatter into the distribution of the flattening filter scatter. Adding scatter from modulators like your age finally the can be calculated by using first scatter models and the thick of the wedge, the more scatter is produced but there is also more scatter self-absorbed into the wedge itself, sorry. So it means that we get the kind of maximum of scatter production from a modulator if we're having modulation value, which is approximately around 50% or 60%. Here shows examples of how one can design head scatter models and derive those from SC measurements so what's shown here is all the dots are the measurements and the taken in air and then we have the parameterization using this kind of head scatter models and we

do have this dominant effect of the view blocking of the flattening filter at smaller field sizes and when we go to larger field sizes we have a remaining slope there which is driven by the combination of collimator scatter and back scatter to the monitor. So in conclusion, accurate beam modeling, it needs to be verified of course and head scatter modeling is essential for all accurate dose calculations and the head scatter part relies heavily on the SC data both for parameterization and for verification and off-axis fluence profiles can be measured by a similar technique and using buildup caps in air as long as one is thick enough to take away the electron contamination, the measured quantity from those is the relative distribution of the energy fluence biased by the collation karna ratio and that is consistent with beam modeling at least all types of beam modeling which is

based on separation of the primary and scatter parts in the patient. So, that concludes so thank you very much for listening.