This is Uh, a, continuing education session on head scatter and my name is Tim Zhu. Uh, I will be talking today with Anders Ahnesjo on the preliminary results from task group, AAPM task group TG74 on the effect of the measurement interpretation of the in-air output ratio and its impact on dose calculation. And I would like to acknowledge contributions from members of the task group 74. Kwok Lam from University of Michigan, Allen Li from Medical College of Wisconsin, Charlie Ma from Fox Chase, Jatinder Palta from University of Florida, and Mike Sharpe from Princess Margaret, and Bruce Thomadsen, and we also have a consultant from RPC, Remash Tailor. And the purpose of this task group is to look at whether we can define the quantity in-air output ratio which has been quite extensively used within the community, but the physical

definition, actually has not been really finalized. So we want to look at the definition of in-air output ratio, and we want to review mostly the effect of miniphantom on how to measure this quantity since there is some confusion about how this can be measured correctly. And we also want to try to review the various approach to parameterize this quantity, and thus this purpose is because uh, for intensity modulated radiotherapy, you have to uh, account for the head scatter and the only way to account for that is to have a model that can calculate this effect for any collimator settings. And we also want to propose some methods to QA this quantity. 4.And uh, in this talk we also will look at the impact of in-air output ratio for monitor unit calculation as well as for dose calculation where Anders Ahnesjo will talk later on, on this aspect in more details, and he will also

review the various components form a theoretic aspect that what is contributing to the output ratio variation, and as well as the use of S_c data for the photon beam modeling for model-driven calculation. So, first, we look at the definition of in-air output ratio. Uh, this actually has been quite, although the task group is not finished yet, this definition is quite finalized, I think. We would define *Sc* as a ratio of primary collision water kerma, in free space per monitor unit between a collimator setting, an arbitrary collimator setting, and a reference collimator setting for the same reference condition. Uh the positions, Z, is the source-to-detector distance. And notice that we define it specifically as a kerma, so that the electron transport is eliminated, so this quantity only is quantifying the energy fluence effect, and also we use primary kerma, so that in this particular

definition, it does not say that you have to use a mini-phantom to do the measurement. You can, as long as one can determine the primary kerma, you can determine this quantity *Sc*. So with this rigorous definition, all the other experimental methods for measurement become an approximation, and that, any kind of measurement technique can be used, but they all involve different approximations. And that approximation can be corrected using some correction factors, since the quantity that we are interested in can be calculated theoretically using Monte Carlo or analytic method. And we, we would, say one recommended method, of course, is using mini-phantoms, which is actually THE methods for measurement right now. And we will say a mini-phantom is in-air equivalent if the dose ratio that's measured in a mini-phantom equals to the primary kerma ratio, and

this definition implies that one have to eliminate all the electron contaminations, electron disequilibrium in the mini-phantom. Also one have to get rid of the phantom scatter in the mini-phantom itself, uh, to get this quantity correctly, and it's relatively easy to establish in-air equivalence for this in-air output ratio measurement, and this reference gives us some Monte Carlo simulation to describe what kind of dimension of the water equivalent mini-phantom one can use to achieve this equivalencies.7. Now, form theoretical prospective, the signal that is measure in a mini-phanom actually is a dose that's measured, which involves not only the primary kerma itself, but also involves the stopping power ratio and the attenuation in the mini-phantom itself, and all these effects, attenuation in the mini-phantom, and the stopping power ratio due to the air cavity

introduced by the detector, has to be corrected, and these components here uh, is considered to be very small. So that, in reality, the measured value can very well approximate these ratio of primary collision kerma, but when we, when one use different Z material, for example high-Z material, this correction has to be considered, because particularly, this ratio will change, because the attenuation coefficient will change because of different Z material, as well as the energy of spectrum will change slightly for this calculation, because of the attenuation in the beam itself. So, a general method, really, is one can use any mini-phantom, but these additional effect has to be corrected, and they can be viewed as field size dependent.A more general definition is in-air output function, which basically is the same as this, but it's, a global reference. Since it is

referenced to a open beam, so you can actually make a measurement of wedge beam referenced to open beam as the reference condition, and, uh, that definition actually is corresponding to a quantity that can be used to determine a in-air profile and wedge factors, and we actually introduced this quantity in the task group report, but we didn't really go into detail about how this quantity can be measured, since it's harder to actually make these corrections, because of larger change of energy spectrum between different conditions.8. . So what is the basic characteristics of, uh, *Sc* that's measured, uh, in a mini-phantom? It's almost independent of SSD. That's summarized in the literature, and itdoes not depend on the mini-phantom depths, as long as the depths in the mini-phantom is thick enough that is beyond the range of contaminate electrons, and also the *Sc* is only

a function of collimator setting, it's not a function of depths or uh, other, field size in the phantom, so this really is characterizing the incident energy influence. And the ratio *Sc,p divided by Sc, Sp* is another phantom scatter factor, and that becomes a function of nominal energy only, and uh, so that the importance of *Sc* is it really characterize the incident energy influence change due to the accelerator itself. There's various methods used to determine *Sc*. One direct method is using a mini-phantom, and the advantage of this method is, it has a wider range of application, uh, that you can use to make measure the *Sc*. For example, one can measure the Sc at off axis positions in and outside of beam collimation, and it provides more accurate result because it is a measured quantity. Thedisadvantage, of course, is the mini-phantom material and shape is important, which

affects the result, so the correction, proper correction, is needed. Uh, there's the other method. For example, one method is called in-water phantom determination proposed by University of Michigan which says one can use in-water measurement directly and divided out the data by phantom scatter Sp, so one does not need to have a mini-phantom measure for that, but that method, of course, has required a complete knowledge of Sp calculation, because any error of Sp calculation will effect the *Sc*. Now, we look the influence of mini-phantom on *Sc*. Experimentally, there's quite a large body of literature which describes that effect. The van Gasteren actually has established that if you use the water equivalent mini-phantoms, you can get reliable results for *Sc*, reproducible results. And you, one have to use low-Z material, like polystyrene, acrylic, solid-waters, uh, that

has to have a minimum sufficiently large dimensions to eliminate electron contamination, as well as electron disequilibrium. Uh, some theoretical study has looked at the requirement of the dimension for the mini-phantom, and uh, this one published in 1995 by Allen Lee, find out that the minimal lateral dimension has to be 4 gram per centimeter square water equivalent depth, and that is sufficient for energies up to about 25 MV, that's all the clinic range that we are using, and also they found out that you can use brass actually to get similar result as other low-Z material. 12 And Lars webber and Anders Ahnesjo, their group has published the measured results for a range of mini-phantom materials. In this case, it's lead and brass, and they're basically showing the effect of mini-phantom material produced less than 1% of error, and this change can be

considered as a correction factor, which as you can see is a field size dependent correction factor, so if you correct it, it's all normalized to uh, water equivalent mini-phantom. I think it's graphite. Uh, that is right. Now there are some controversal results exist in the literature, other method, for example, by Jursinic and Thomadsen which shows, they use a wider range of mini-phantom materials. Uh, they found out actually, for 18 MV photon beams, the difference can be go up to 5%, And, uh, I think we have more understanding about this discrepancy now in our task group. We actually found out that they were using the depth is at D-maximum, so it potentially is caused by the electron contamination that introduce additional field size dependence. 15. And here is a list of recommended mini-phantom. You can see that most can be water equivalent,

like acrylic or graphite, and the chamber orientation actually has been found to be not that important for getting the consistent result. You can go make the chamber perpendicular or uh, uh, parallel to the incident radiation, or you can use a brass. Actually, that's one compromise, although there is some, uh, effect from brass, uh, it's relatively small, so in general, we have to apply for correction, but that can be used, uh, very nicely for small field, especially for IMRT. 16. And next, I will talk about the different, briefly, different components that affect the *Sc* which is basically three effects: Source obscuring effects which is due to the blocking of x-ray source itself, head scatter in the accelerator itself, and monitor back scatter. 17. So source obscuring effect is if you make a measurement of in-air output ratio to very small field size, what one found out is the result suddenly

drops, and this portion of data is independent of the scatter material used in the beam. For example, this red data is for wedge beam, 60° wedge from SL75/5, and this yellow data is from an open beam so you can see that for small field sizes, really this portion is independent of head scatter at all, but this portion, this sudden drop, is really due to the x-ray source itself has been blocked by the collimator jaws for this small field sizes. 18.

And some method has been introduced in the literature by our group that shows that you can use this property by doing some slit measurement to actually plot out what is the source shape, so this is a results for two different accelerators. One is SF-75 which has a relatively big source. For example, here you can see the source is 4 mm, 50%, and then there's another SL25 as a smaller source size, about 2 mm. 19. Uh, the other effect, of

course, is head scatter, and that is caused by the scattering by various structures, most dominantly by the material that intersect in the beam, flattening filter, **wedge,** and the other material like, collimator jaws, that is uh, smaller effect, because they don't intersect the beam. 20. And a quantity of that is for open beams, the majority of that is caused by the flattening filter and uh, to some degree caused by the primary collimator. Wedge beams, the majority of head scatter is caused by flattening filter and **wedge,** and the measurement, of course, can not separate what is the contribution form different components, so we found out that Monte Carlo simulation is a very useful tool that will tell you relative contributions from various components. 21. And here is one example that shows why the flattening filter is important. Uh, some data! The measurement is

done for accelerator that one takes out the flattening filter. Once it's taken out, you found out that to the variation over the entire range form 3x3 to…oh, this is actually, yah 20x20, this, the variation is less than actually 1% for the entire range. While, with the flattening filter for regular open beam, this variation can go up to 4%. 22. And here is some preliminary results of measurement for 6 different linear accelerators, and you can see that they're different for about 2% between the different accelerators, and they generally increase with field size with a shape looks like this, and one disclaimer is this measurement actually does not include measurement for small field sizes, so for smaller field size, actually, one expects, this data should go down to zero. 23. And if a wedge is used, additional head scatter is introduced, so here is the result for, uh, head scatter from

wedge beam itself, and this is for internal wedge, like, uh, uh, Elekta machine, and this is for external wedge measured for Varian machine, and they have different shapes, but on average, they introduce an additional 8% of the variation of output. 24. And the last effect is monitor-backscattering, which is caused by photons and electrons that scatter from the collimator jaw back into the monitor chamber, which thus increase the ionization current to the ionization chambers, especially for small collimator settings. As a result of that, the incident influence per monitor unit will increase with the collimators opening, and the modeling experimentally generally found that this effect produce a linear term that is proportional to the collimator settings. 25. And some comment about that, the scattering is probably mostly caused by electron scattering, because what we

found out is that if you use a mm thick plate, you can eliminate that, and that can only be caused by electrons. Photon effect can not be eliminated that way. And the magnitude Monte Carlo studies shows that is 2-3% in the entire range. Experimentally, this effect is slightly bigger; can go up to 3-5%; some of earlier measurements give up to 6% of variation depending on machines structures. And uh, various method has been introduced to measure it. Telescopic method and dose rate method. These two methods is the most commonly used, because no additional equipment is needed. Uh, well, no additional modification of accelerator itself is needed, but the target charge method is also used. 26. So we change gear to primitization of *Sc*, because that's important for clinic applications. For that purpose, we will only monitor the head scatter and the monitor back scattering,

and the various methods existed like analytic method, empirical method, or Monte Carlo. They all can produce a parameter set that you can fit to the measured data to get those parameters. 27 And uh, they all assume, the dominant head scatter source is the flattening filter and the primary collimator for open beams, and the Gaussian source shape is most commonly used. But other source shape exist like uh, uh, rational function by Yu; and Anders Ahnesjo who has a triangle function.28 And, uh, this is one example is a Gaussian source model. The *Sc* for square field can be expressed by 3 parameters: a_1 express the monitor back scattering, a_2 that account for the total head scatters, λ is the spread of head scatter, and H_0 is not a free parameter, it can be determined from all the other factors. So there's 3 parameter of the model. 29. And for rectangular beams

equivalent square function can be used to calculate what is the equivalent square that is used in that model. 30. Uh, for off-set field there is some publications. This afternoon there's a look at uh what is the effect at off-axis point on these parameters, and that one can use, one have to introduce a penumbra function after here when the point of interest is in the penumbra region, 31 And uh, this is basically uh, beam's detector'seyes-view of this model. You basically look through the detector, look at the how much head scatter source is dropped. 32 And uh, this algorithm can predict *Sc* for MLC shaped irregular field to about 1% for all other existing accelerators that we know of; the 3 major ones: Varian, Siemens, Elekta. And uh, for Varian machine actually it's something special there that it can be approximated by using secondary collimators that is sufficiently to

get the result. 33. So if the *Sc* is measured at an off-axis field (or off-set field) at the center of it, one found out that this *Sc* change by about 1% experimentally, provided, of course the off-axis ratio is taken out. And, uh, more recent studies show that the parameter that describes the previous parameter itself does not change very much with off-set.34. And uh, if one use another field that's off-set from the center axis, you found out a larger effect. Some measure experiment results have shown a 4% change.35. and if one make a measurement at the off-set position outside beam collimation, you will see of course a larger variation, and these can be modeled with uh, proper parameterizations.36 And for enhanced dynamic wedge, one actually found out once one has taken out the moderation terms, the variation of in-air output ratio with field sizes is approximately the

same as the open beam, within a percent, so basically they can be modeled easily with once we know the open beam parameter. 37. And uh, so, what is the impact of Sc for factor-based *MU* calculation? Well, uh, the dose actually can be expressed in general in this formulism. Then effect of *Sc* is basically introduced by this effect. *Sc* here, and uh, it will produce up to 12% for open beams within all the range, and uh, for wedge beams and additional 5-7%. 38. And the one actually can, now we change gear to QA. Because for a wide range of machine, these parameters has been determined, they can be used to QA the in-air output ratio to see in a particular measurement whether it fits into these patterns basically, so they gave you the a_1 range and a_2. For example, a_2 that express the total amount of head scatter changes from 6% to all the way to about 14, or 12%, and the

range ofλ here, sorry for the mistake here, uh, changes from about 8 to 9, so these quantity actually has a pretty narrow range that can be used.39. So one example for that is if you look at one measurement that give you some bad data here. And if you fit the data, one set of bad measurement, one set of good measurement, you found out that a_2, for example, for the bad data set, it give you widely different, very large a_2, and that's almost impossible. If one look at the data to really find out this is actually indeed caused by the measurement for small field size actually is different; is not right. 40. And if you look at another set of measurement for 18 MV beams, you also found out this a_2 is uh, 20%. That's impossible, and if you look at data itself uh, they actually is almost 10% different from a good set, and that's really caused by the uh, uh, not sufficient buildup, actually,

for this particular measurement in the mini-phantom. 41. So in summary, the S_c characterized variation of collision water kerma per monitor unit, and it's, as a result it's critical for *MU* calculation. Electron contamination, lateral electron equilibrium, disequilibrium, are not part of the *Sc*. A former definition of *SC* is given which allows the theoretic calculations, Monte Carlo or analytic, and analyze various experimental approximations, mostly for different high-Z material mini-phantoms, and uh, uh, three components that cause *Sc* source obscuring effect, head scatter, and monitor back-scattering, now we also recommend a range of mini-phantom material that can be used for this measurement provided proper correction is used, 42. And a general…a great deal of progress made to parameterize this factors, uh, most the head scatter and monitor back

scattering for wide range of linear accelerators, and *Sc* off-axis points inside/outside collimation is important for those calculation QA for IMRT. Uh, sufficient information about *Sc* exists to develop a QA method for *Sc*. So this is my part of talk, and now I invite Dr. Ahnesjo to give a talk on the theoretic aspect of this quantity.