The EGS4/PRESTA-II electron transport algorithm: Tests of electron step-size stability

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The PRESTA algorithm [1, 2], an extension to the EGS4 Monte Carlo code system [3], was introduced in 1986 and adopted widely for medical physics applications. Introducing the physics of stable average detour corrections (*aka* path-length corrections), lateral correlations and minimal violation of transport physics in the vicinity of interfaces, the PRESTA-I algorithm became regarded as "good enough" for radiotherapy planning applications but "use with caution" for high accuracy dosimetry applications [4]. Refinement of the physics content (described in the accompanying paper) has resulted an algorithm that is "good enough" for high accuracy dosimetry applications. This is demonstrated through the step-size stability of axial and radial depth-dose profiles, stable backscatter applications and ion chamber calculations, the most difficult challenges arising within medical physics applications. (Some of these results are presented at this conference in the companion paper *New Multiple Scattering Theory and Transport Algorithm for Electron Monte Carlo Simulations* by Kawrakow and Bielajew.)

SINCE EGS4/PRESTA-I

Although many of the ideas that were incorporated into the design of PRESTA-I were taken from Berger's classic work [5], PRESTA-I was their first implementation in a general-purpose generally available Monte Carlo code. Since then there have been several similar developments as well as detailed critiques [6–12]. Current development includes a new multiple-scattering theory [13], refined longitudinal and lateral electron sub-step distributions [14], "zero-artefact" boundary crossing where an interface boundary can only be crossed in analogue Monte Carlo transport mode [15] (See Figure 1.) and randomisation of electron sub-steps to allow sub-voxel tallying.

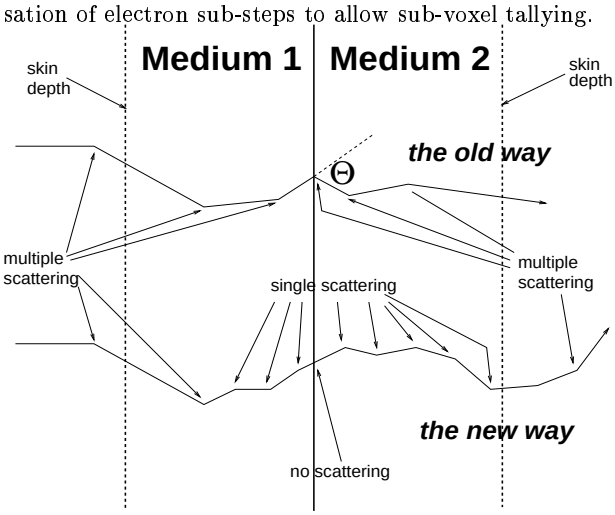

Figure 1. The new boundary algorithm described. Electrons can cross boundaries only in single-scattering mode.

Many of the essentials of these new capabilities are discussed in some detail in the companion paper.

APPLICATIONS

Although PRESTA-I improved the step-size stability of backscatter, it was recognized that this was an area that required improvement [16]. The results we obtain with the PRESTA-II algorithm indicate that the step-size dependence of backscatter calculations is solved. Two examples are shown, for 100keV and 10 MeV normally incident electrons on water in Figures 2 and 3 respectively. PRESTA-I and PRESTA-II results are shown as well as results calculated using Kawrakow's LLCA algorithm [12], a recent improvement in electron transport condensed history physics.

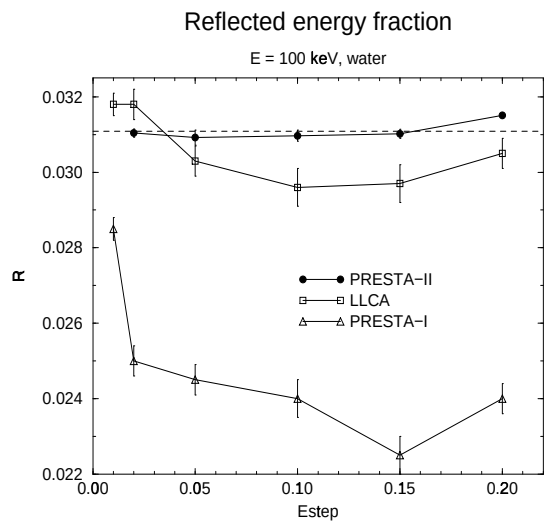

Figure 2. Fraction of energy reflected from 100 keV electrons incident on water.

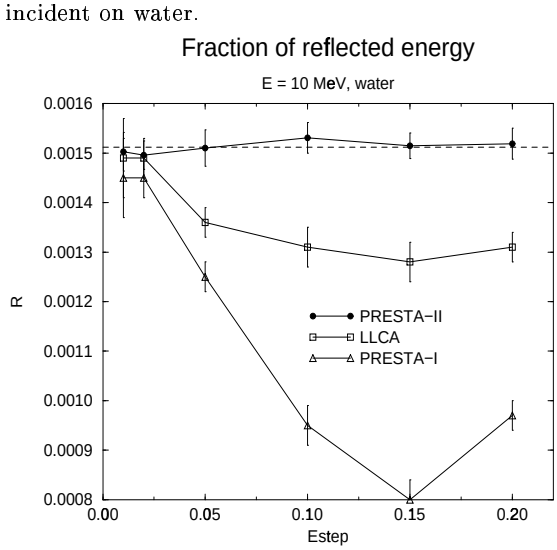

Figure 3. Fraction of energy reflected from 10 MeV electrons incident on water.

We note an order of magnitude improvement in the step-size stability of backscatter results. The small discrepancy at 20% energy loss for the 100 keV case may be resolved through improved handling of energy loss. This is currently under investigation. The PRESTA-I results either do not show any convergence or convergence only for the small step-sizes. The LLCA algorithm, while a significant improvement over PRESTA-I still shows some residual step-size dependence.

A radial distribution is shown in Figure 4 for one of the most extreme cases encompassed by our condensed history method. This is the differential radial distribution for 128 keV electron in Au undergoing a pathlength of 10 elastic scattering mean free paths.

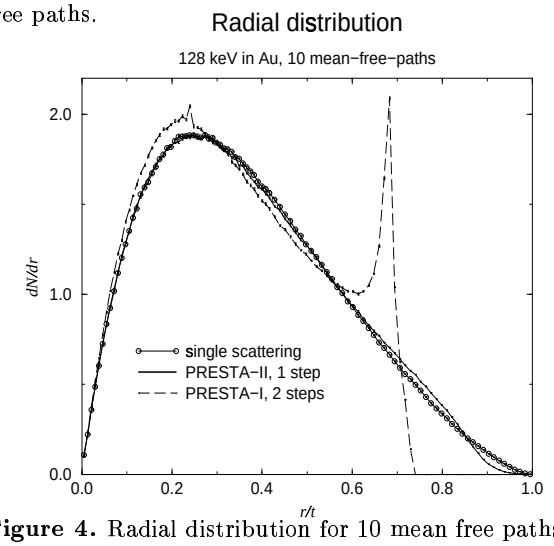

Figure 4. Radial distribution for 10 mean free paths in Au.

The ion chamber backscatter experiment described by Andreo [17] is shown in Figure 5. Here we see greater agreement between measurement and PRESTA-II results, particularly for large Z where the discrepancies were worse. Although the PRESTA-I results appear to be better for small Z it should be remarked that the agreement between PRESTA-I and measurement may have been spurious in light of Rogers' [18] work, indicating that $\pm 2\%$ variations may be expected depending on the simulation conditions employed in PRESTA-I.

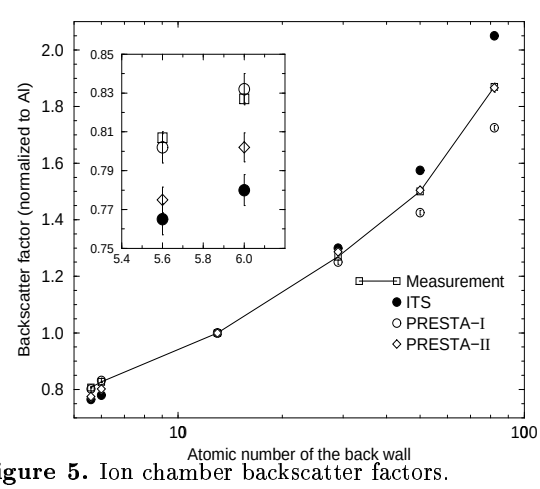

Figure 5. Ion chamber backscatter factors.

CONCLUSIONS

The aim of the current research is to develop algorithms that may be employed with full confidence by non-Monte Carlo specialists, to be able to employ the calculations as a "black box". The EGS4/PRESTA-I algorithm achieved this with some moderate success for "radiotherapy-class" problems, *i.e.* energy deposition in O(mm) structures. Thus EGS4/PRESTA-I became known as "good enough" for radiotherapy planning applications but potentially problematic for the high-accuracy demands of some dosimetry applications [4]. In some cases, even the use of EGS4/PRESTA-I with very small electron step-sizes could not guarantee convergence to a sensible result [18]. We know now that this was because the underlying physics' modeling was inadequate. The PRESTA-II results presented herein give preliminary indication that it is "good enough" even for the demands of high accuracy dosimetry applications, as shown by its good performance on backscatter calculations, the toughest test for this class of Monte Carlo codes. The next few years will allow EGS4/PRESTA-II to be tested against a myriad of stringent tests and benchmarking trials. If successful, a significant goal will have been achieved. If our algorithms prove to be robust and faithful as these preliminary results suggest, a disagreement between experiment and Monte Carlo can have one of only two causes: 1) either the interpretation of the experiment is wrong or, 2) the underlying cross sections employed by the Monte Carlo, a primary output of basic physics research, are wrong. It appears that the problem of inadequate transport algorithms, at least for the class of problems that concern the entire scope medical physics, is finally at an end.

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