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Calculation of Percentile-Distance Ratios and Scaled Absorbed-Dose Distributions for 0.05- to 30-keV Primary Electrons

W. E. Wilson
W. D. Reece, Jr.

October 1991

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the U.S. Department of Energy
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Pacific Northwest Laboratory
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CALCULATION OF PERCENTILE-DISTANCE RATIOS AND
SCALED ABSORBED-DOSE DISTRIBUTIONS FOR
0.05- TO 30-keV PRIMARY ELECTRONS

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SUMMARY

This document reports the results of computing Berger-type point kernels for 0.05- to 30-keV monoenergetic electrons in a water medium. A detailed-histories Monte Carlo method was used in contrast to the condensed-histories methods used by others. Good agreement with other work was found, over the common energy region. The study was performed at Pacific Northwest Laboratory as an exploratory research project.

CONTENTS

SUMMARY	iii
INTRODUCTION	1
COMPARISON OF ELECTRON POINT KERNELS	2
PERCENTILE-DISTANCE RATIOS	4
SCALED ABSORBED-DOSE DISTRIBUTIONS	4
REFERENCES	13

FIGURES

1	Ninety-Percentile Distances as a Function of Primary Electron Energy	2
2	Percentile-Distances Ratios for 20-, 25-, and 30-keV Primary Electrons	3
3	Percentile-Distances Ratios for 30-, 25-, and 20-keV Primary Electrons	5
4	Percentile-Distances Ratios for 15-, 10-, and 5-keV Primary Electrons	5
5	Percentile-Distances Ratios for 2-, 1-, and 0.5-keV Primary Electrons	6
6	Percentile-Distances Ratios for 0.2-, 0.1-, and 0.05-keV Primary Electrons	6
7	Scaled Absorbed-Dose Distributions for 30-, 25-, and 20-keV Primary Electrons	9
8	Scaled Absorbed-Dose Distributions for 15-, 10-, and 5-keV Primary Electrons	9
9	Scaled Absorbed-Dose Distributions for 2-, 1-, and 0.5-keV Primary Electrons	10
10	Scaled Absorbed-Dose Distributions for 0.2-, 0.1-, and 0.05-keV Primary Electrons	10

TABLES

1	Percentile-Distance Ratio, X/X_{90} , in Water	7
2	Scaled Absorbed-Dose Distribution, $F(X/X_{90}, E_0)$	11

INTRODUCTION

Internal dosimetry methods rely heavily on the formalism adopted by the Medical Internal Radiation Dose Committee (MIRD) of the Society of Nuclear Medicine. The MIRD protocol (Loevinger and Berman 1968) defines the specific absorbed fraction, Φ , to be the fraction of emitted energy deposited in a target volume divided by the target mass. For a point source emitting isotropically, Φ is radially symmetric with a singularity at the point of emission. A more tractable quantity is obtained by defining a scaled dose kernel as

$$F(X/X_s) = 4\pi X^2 \rho X_s \Phi(X).$$

X_s is a predefined scaling distance and ρ is the density of the medium. Berger has computed $F(X/X_s)$, which he calls a point kernel, for several beta emitters and monoenergetic electrons in a water media. The scaling factor X_s favored by Berger is the distance from the source within which 90% of the energy is absorbed, X_{90} . His published computations for monoenergetic electrons covered the energy range from 4 MeV to 25 keV (Berger 1971) and were later supplemented in an unpublished report that extended them down to 500 eV (Berger 1973). Berger's computational methods employed multiple-scattering theory (Berger 1971; Spencer 1959) and Monte Carlo condensed histories (Berger 1973).

It has been pointed out (Rodgers and Bielajew 1986) that the Vavilov distribution was improperly sampled to produce secondary electron energies in some of the pre-1986 condensed-histories work. Therefore, it is timely to recalculate at least some of the point kernels, preferably by an entirely independent method.

We have done this, using a detailed-histories, Monte Carlo method for electron transport (slowing down of electrons is followed by computing every elastic and inelastic interaction) (Paretzke 1987; Wilson et al., 1988); the Vavilov distribution is not used. It is not computationally tractable to compute in the MeV electron energy range with detailed histories, however. On the other hand, it is possible to transport electrons of much lower energy than can be reasonably done with the condensed-histories methods, so that point kernels can be computed for lower energy electrons.

This document reports the results of calculations to compare the two methods over a common energy range and to extend the Berger point kernel tables downward in energy to 50 eV.

COMPARISON OF ELECTRON POINT KERNELS

Point kernels for low-energy electrons (30 keV to 50 eV) were calculated by Monte Carlo simulation and compared with Berger's computations. The MOCA code system (Paretzke 1987; Wilson et al., 1988) was used for the computations.

The ninety-percentile distances, X_{90} , obtained in this study are plotted and compared with Berger's results in Figure 1. The excellent agreement between these two computations shows that the two quite different methods agree on extrapolated ranges for low-energy electrons.

FIGURE 1. Ninety-Percentile Distances as a Function of Primary Electron Energy (Berger 1973)

A further comparison with Berger's results is shown in Figure 2. The percentile-distance ratio, X/X_{90} , computed at 20, 25, and 30 keV is compared with Berger's calculation at 25 keV. Agreement is reasonably good; however, there is a systematic difference indicating that detailed histories predicts a slightly greater spatial variation in the energy deposition within the ninety-percentile spheres. The Berger results shown in Figure 2 are from Table 8 of Berger (1971). It is not clear at this time if the exhibited systematic difference arises from the reported sampling error in the pre-1986 results. Further investigation will be required to resolve this point.

FIGURE 2. Percentile-Distance Ratios for 20-, 25-, and 30-keV Primary Electrons (Berger 1971)

PERCENTILE-DISTANCE RATIOS

A primary objective of this project was to compute percentile-distance ratios, X/X_{90} , down to very low electron energies, effectively extending Table 8 of Berger (1971). These results are presented in graphical form in the following Figures 3 through 6 and further tabulated in Table 1. Table 1 of this document corresponds to Table 8 in Berger (1971).

SCALED ABSORBED-DOSE DISTRIBUTIONS

Another objective was to obtain the scaled absorbed-dose distribution, $F(X/X_{90}, E_0)$, as an extension of Table 11 of (Berger 1971) down to lower primary electron energies. Those results are presented in graphical form in the following Figures 7 through 10 and in tabular form in Table 2.

FIGURE 3. Percentile-Distance Ratios for 30-, 25-, and 20-keV Primary Electrons

FIGURE 4. Percentile-Distance Ratios for 15-, 10-, and 5-keV Primary Electrons

FIGURE 5. Percentile-Distance Ratios for 2-, 1-, and 0.5-keV Primary Electrons

FIGURE 6. Percentile-Distance Ratios for 0.2-, 0.1-, and 0.05-keV Primary Electrons

TABLE 1. Percentile-Distance Ratio, X/X_{90} , in Water

P(%)	E_0 (keV)					
	30	25	20	15	10	5
5	0.102	0.105	0.104	0.104	0.103	0.105
10	0.192	0.197	0.190	0.189	0.193	0.192
15	0.269	0.277	0.266	0.267	0.270	0.268
20	0.341	0.348	0.335	0.336	0.341	0.336
25	0.401	0.409	0.400	0.396	0.402	0.398
30	0.454	0.464	0.457	0.448	0.454	0.453
35	0.502	0.514	0.506	0.494	0.502	0.501
40	0.549	0.562	0.551	0.538	0.547	0.545
45	0.595	0.606	0.594	0.581	0.591	0.587
50	0.639	0.648	0.637	0.623	0.635	0.628
55	0.681	0.688	0.678	0.665	0.677	0.668
60	0.722	0.727	0.718	0.707	0.719	0.708
65	0.762	0.766	0.758	0.749	0.759	0.748
70	0.802	0.805	0.798	0.791	0.800	0.789
75	0.843	0.846	0.840	0.835	0.842	0.833
80	0.888	0.889	0.886	0.882	0.887	0.880
85	0.939	0.939	0.938	0.936	0.938	0.934
90	1.00	1.00	1.00	1.00	1.00	1.00
95	1.08	1.09	1.08	1.09	1.08	1.09

TABLE 1. (continued)

P(%)	E ₀ (keV)					
	2	1	0.5	0.2	0.1	0.05
5	0.105	0.103	0.100	0.0931	0.0794	0.0683
10	0.191	0.186	0.168	0.155	0.136	0.119
15	0.264	0.255	0.226	0.207	0.185	0.164
20	0.327	0.320	0.278	0.253	0.229	0.203
25	0.383	0.375	0.327	0.296	0.271	0.243
30	0.435	0.423	0.375	0.337	0.310	0.282
35	0.483	0.467	0.421	0.377	0.349	0.319
40	0.527	0.509	0.466	0.417	0.388	0.358
45	0.569	0.549	0.510	0.457	0.428	0.398
50	0.609	0.589	0.552	0.498	0.470	0.439
55	0.649	0.629	0.595	0.541	0.514	0.482
60	0.689	0.670	0.638	0.586	0.560	0.527
65	0.730	0.712	0.683	0.634	0.610	0.576
70	0.774	0.757	0.730	0.687	0.664	0.632
75	0.819	0.805	0.781	0.746	0.725	0.696
80	0.870	0.859	0.840	0.813	0.796	0.773
85	0.928	0.922	0.910	0.894	0.884	0.871
90	1.00	1.00	1.00	1.00	1.00	1.00
95	1.10	1.11	1.14	1.17	1.19	1.20

FIGURE 7. Scaled Absorbed-Dose Distributions for 30-, 25-, and 20-keV Primary Electrons

FIGURE 8. Scaled Absorbed-Dose Distributions for 15-, 10-, and 5-keV Primary Electrons

FIGURE 9. Scaled Absorbed-Dose Distributions for 2-, 1-, and 0.5-keV Primary Electrons

FIGURE 10. Scaled Absorbed-Dose Distributions for 0.2-, 0.1-, and 0.05-keV Primary Electrons

TABLE 2. Scaled Absorbed-Dose Distribution $F(X/X_{90}, E_0)$

X/X_{90}	E_0 (keV)					
	30	25	20	15	10	5
0.00	0.339	0.484	0.515	0.499	0.404	0.438
0.05	0.433	0.505	0.530	0.502	0.458	0.463
0.10	0.527	0.526	0.545	0.505	0.512	0.488
0.15	0.567	0.535	0.613	0.622	0.569	0.577
0.20	0.621	0.594	0.596	0.607	0.603	0.610
0.25	0.663	0.635	0.713	0.671	0.673	0.694
0.30	0.685	0.686	0.718	0.723	0.693	0.737
0.35	0.783	0.763	0.739	0.801	0.771	0.780
0.40	0.902	0.859	0.815	0.909	0.900	0.850
0.45	0.985	0.937	0.948	1.03	1.00	0.969
0.50	1.044	0.997	1.07	1.12	1.08	1.09
0.55	1.08	1.07	1.13	1.17	1.12	1.18
0.60	1.12	1.16	1.17	1.18	1.14	1.23
0.65	1.17	1.23	1.21	1.19	1.17	1.25
0.70	1.23	1.27	1.25	1.20	1.21	1.25
0.75	1.26	1.29	1.26	1.20	1.24	1.23
0.80	1.23	1.26	1.22	1.16	1.22	1.17
0.85	1.15	1.19	1.13	1.08	1.14	1.08
0.90	1.02	1.06	0.998	0.959	1.01	0.946
0.95	0.878	0.885	0.857	0.826	0.862	0.801
1.00	0.734	0.709	0.715	0.694	0.715	0.663
1.05	0.584	0.553	0.571	0.562	0.573	0.533
1.10	0.431	0.417	0.425	0.429	0.435	0.411
1.15	0.292	0.301	0.289	0.300	0.303	0.297

TABLE 2. (continued)

X/X_{90}	E_0 (keV)					
	2	1	0.5	0.2	0.1	0.05
0.00	0.241	0.192	0.266	0.432	0.505	0.587
0.05	0.507	0.494	0.457	0.538	0.676	0.858
0.10	0.510	0.530	0.688	0.723	0.850	1.01
0.15	0.594	0.576	0.747	0.873	0.973	1.18
0.20	0.628	0.726	0.877	1.03	1.13	1.25
0.25	0.726	0.729	0.961	1.12	1.20	1.29
0.30	0.807	0.782	1.01	1.21	1.29	1.32
0.35	0.878	0.918	1.05	1.25	1.29	1.29
0.40	0.952	1.05	1.08	1.25	1.25	1.23
0.45	1.03	1.15	1.12	1.23	1.19	1.17
0.50	1.12	1.21	1.16	1.20	1.13	1.11
0.55	1.20	1.24	1.17	1.13	1.06	1.02
0.60	1.25	1.25	1.17	1.05	0.987	0.913
0.65	1.25	1.23	1.14	0.963	0.901	0.807
0.70	1.22	1.17	1.07	0.878	0.807	0.709
0.75	1.17	1.10	0.980	0.794	0.718	0.620
0.80	1.08	1.00	0.875	0.711	0.634	0.542
0.85	0.974	0.887	0.770	0.626	0.556	0.475
0.90	0.855	0.771	0.665	0.542	0.484	0.419
0.95	0.734	0.660	0.561	0.463	0.418	0.372
1.00	0.612	0.552	0.465	0.393	0.359	0.328
1.05	0.488	0.449	0.382	0.331	0.306	0.286
1.10	0.370	0.357	0.310	0.278	0.259	0.246
1.15	0.271	0.276	0.251	0.232	0.218	0.207

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