Re-Evaluation of Absorbed Fractions for Photons and Electrons in Spheres of Various Sizes

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Absorbed fractions for unit density spheres in an infinite unit density medium, previously calculated for photon emitters and electron emitters, were reevaluated with the Monte Carlo codes EGS4 and MCNP4B. **Methods:** Activity was assumed to be distributed uniformly throughout the spheres, and absorbed fractions for self-irradiation were calculated at discrete photon and electron energies. **Results:** For electrons, the codes were in very good agreement with each other (±5%) and with published values, except at higher energies in the very smallest spheres, where some differences exceeded 10%. For photons, the codes were again in good agreement with each other but produced results that varied considerably from published MIRD values. For energies <1 MeV and sphere sizes <50 g, the absorbed fractions determined using the Monte Carlo codes were typically 20%–40% higher than values in MIRD 3 and 8. For energies >1 MeV, the Monte Carlo values were sometimes lower than those in the MIRD documents. Recommended values, generally the average results from the 2 Monte Carlo codes, are given for all sphere sizes and energies for both electrons and photons. **Conclusion:** The absorbed fractions calculated using the Monte Carlo codes should replace the older values and are helpful in evaluating tumor doses, doses to small organs, and other situations in which a uniform distribution of activity throughout a spherical structure of unit density can be assumed.

Key Words: radiation dosimetry; Monte Carlo; β- and photon-emitting radionuclides

J Nucl Med 2000; 41:149–160

Absorbed fractions for self-absorption in unit-density spheres (which could represent tumors, organs, or other objects) have been published for photons in *MIRD Pamphlets 3* and *8* and for electrons and β particles (*1–3*). These values were calculated either by Monte Carlo methods, the use of published point-kernels, or other analytical methods. We sought to reevaluate and update these data using results from 2 modern and well-supported Monte Carlo codes, EGS4 and MCNP4B (*4,5*).

METHODS

Sources were assumed to be uniformly distributed throughout homogeneous spheres of unit density and tissue-equivalent composition located within a unit-density scattering medium. To facilitate comparison, the tissue compositions of the original studies were used, instead of compositions more commonly encountered today. The differences between these tissue compositions and more recently cited compositions are quite minor and should not significantly affect the numeric values of the absorbed fractions calculated. The Monte Carlo codes were run for photons and electrons for the sphere sizes and initial particle energies used by the original authors. Values were not calculated for some very low-energy electrons, because all absorbed fractions were close to unity. Comparisons were made between each code's results and those of the original authors, as well as between the 2 codes. Recommended values were calculated, using average results from the 2 Monte Carlo codes. All values had very low errors, typically 1% or less. Weighting according to the inverse of the variance or other statistical parameters was not thought necessary.

RESULTS

Absorbed fractions for electrons are given in Table 1. Values for smaller spheres [comparable with those from *MIRD Pamphlet 8* (*1*)] are given in Table 2, and those for larger spheres [comparable with those from *MIRD Pamphlet 3* (*2*)] are given in Table 3. Note that in Table 2, values were calculated at 0.02 MeV, although they were not included in the MIRD pamphlet. These values were provided for assistance in extrapolation to low energies, because the rate of change of absorbed fraction with energy can be very rapid in this area. Figures 1–4 show results for photons and electrons from the 2 codes as a function of initial particle energy for families of curves representing different sphere masses. Figure 1 shows photon results from EGS4; Figure 2 shows photon results from MCNP; Figure 3 shows electron results from EGS4; and Figure 4 shows electron results from MCNP. Figures 5 and 6 show comparisons of both codes against the results of either Siegel and Stabin (*3*) or *MIRD Pamphlets 3* and *8* (*1,2*) for selected particle energies, as a function of mass. Note that in these figures the results from the 2 Monte Carlo codes are sometimes very close, and the symbols may overlap, obscuring some results.

DISCUSSION

The tissue compositions suggested by the authors of *MIRD Pamphlets 3* and *8* (*1,2*) were used to facilitate direct comparison with the results of the 2 Monte Carlo codes. Although these tissue compositions are somewhat different

Received Jan. 19, 1999; revision accepted Jun. 21, 1999.

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TABLE 1
Absorbed Fractions for All Energies and Sphere Sizes for Electrons: Results from EGS4 and MCNP, with Comparisons with Each Other and Values of Siegel and Stabin

Sphere mass (g)	Sphere radius (cm)	EGS4 ϕ	MCNP ϕ	SS ϕ	EGS4/ SS	MCNP/ SS	EGS4/ MCNP	Recommended value
Energy: 0.1 MeV								
0.01	0.13	0.960	0.964	0.97	0.99	0.99	0.996	0.962
0.1	0.29	0.981	0.983	0.99	0.99	0.99	0.998	0.982
0.5	0.49	0.989	0.989	1.0	0.99	0.99	1.00	0.989
1	0.62	0.991	0.992	1.0	0.99	0.99	0.999	0.992
2	0.78	0.993	0.993	1.0	0.99	0.99	1.00	0.993
4	0.98	0.994	0.994	1.0	0.99	0.99	1.00	0.994
6	1.13	0.995	0.995	1.0	0.99	0.99	1.00	0.995
8	1.24	0.995	0.995	1.0	1.0	1.0	1.00	0.995
10	1.34	0.995	0.996	1.0	1.0	1.0	1.00	0.996
20	1.68	0.997	0.996	1.0	1.0	1.0	1.00	0.997
40	2.12	0.997	0.997	1.0	1.0	1.0	1.00	0.997
60	2.43	0.998	0.997	1.0	1.0	1.0	1.00	0.997
80	2.67	0.998	0.997	1.0	1.0	1.0	1.00	0.998
100	2.88	0.998	0.998	1.0	1.0	1.0	1.00	0.998
300	4.15	0.998	0.998	1.0	1.0	1.0	1.00	0.998
400	4.57	0.998	0.998	1.0	1.0	1.0	1.00	0.998
500	4.92	0.999	0.998	1.0	1.0	1.0	1.00	0.998
600	5.23	0.999	0.998	1.0	1.0	1.0	1.00	0.999
1000	6.20	0.999	0.998	1.0	1.0	1.0	1.00	0.999
Energy: 0.2 MeV								
0.01	0.13	0.873	0.855	0.89	0.98	0.96	1.02	0.864
0.1	0.29	0.942	0.933	0.96	0.98	0.97	1.01	0.937
0.5	0.49	0.965	0.960	0.98	0.98	0.98	1.01	0.962
1	0.62	0.974	0.968	0.99	0.98	0.98	1.01	0.971
2	0.78	0.978	0.975	0.99	0.99	0.98	1.00	0.976
4	0.98	0.983	0.981	1.0	0.98	0.98	1.00	0.982
6	1.13	0.984	0.983	1.0	0.98	0.98	1.00	0.984
8	1.24	0.986	0.985	1.0	0.99	0.99	1.00	0.985
10	1.34	0.987	0.986	1.0	0.99	0.99	1.00	0.987
20	1.68	0.989	0.989	1.0	0.99	0.99	1.00	0.989
40	2.12	0.991	0.991	1.0	0.99	0.99	1.00	0.991
60	2.43	0.993	0.992	1.0	0.99	0.99	1.00	0.992
80	2.67	0.994	0.992	1.0	0.99	0.99	1.00	0.993
100	2.88	0.994	0.993	1.0	0.99	0.99	1.00	0.993
300	4.15	0.996	0.995	1.0	1.0	1.0	1.00	0.995
400	4.57	0.996	0.996	1.0	1.0	1.0	1.00	0.996
500	4.92	0.996	0.996	1.0	1.0	1.0	1.00	0.996
600	5.23	0.996	0.996	1.0	1.0	1.0	1.00	0.996
1000	6.20	0.996	0.997	1.0	1.0	1.0	0.999	0.996
Energy: 0.4 MeV								
0.01	0.13	0.658	0.630	0.67	0.98	0.94	1.04	0.644
0.1	0.29	0.837	0.827	0.85	0.98	0.97	1.01	0.832
0.5	0.49	0.903	0.896	0.92	0.98	0.97	1.01	0.900
1	0.62	0.924	0.917	0.94	0.98	0.98	1.01	0.921
2	0.78	0.940	0.932	0.95	0.99	0.98	1.01	0.936
4	0.98	0.951	0.945	0.96	0.99	0.98	1.01	0.948
6	1.13	0.957	0.951	0.97	0.99	0.98	1.01	0.954
8	1.24	0.961	0.955	0.97	0.99	0.98	1.01	0.958
10	1.34	0.963	0.959	0.98	0.98	0.98	1.00	0.961
20	1.68	0.971	0.967	0.98	0.99	0.99	1.00	0.969
40	2.12	0.976	0.974	0.99	0.99	0.98	1.00	0.975
60	2.43	0.979	0.977	0.99	0.99	0.99	1.00	0.978
80	2.67	0.980	0.978	0.99	0.99	0.99	1.00	0.979
100	2.88	0.983	0.980	1.0	0.98	0.98	1.00	0.982
300	4.15	0.987	0.986	1.0	0.99	0.99	1.00	0.987
400	4.57	0.988	0.987	1.0	0.99	0.99	1.00	0.988
500	4.92	0.989	0.988	1.0	0.99	0.99	1.00	0.988
600	5.23	0.990	0.989	1.0	0.99	0.99	1.00	0.989
1000	6.20	0.992	0.991	1.0	0.99	0.99	1.00	0.991

TABLE 1 (*Continued*)

Sphere mass (g)	Sphere radius (cm)	EGS4 ϕ	MCNP ϕ	SS ϕ	EGS4/ SS	MCNP/ SS	EGS4/ MCNP	Recommended value
Energy: 0.7 MeV								
0.01	0.13	0.359	0.320	0.36	1.0	0.89	1.12	0.339
0.1	0.29	0.665	0.646	0.67	0.99	0.96	1.03	0.656
0.5	0.49	0.798	0.783	0.80	1.0	0.98	1.02	0.790
1	0.62	0.841	0.824	0.85	0.99	0.97	1.02	0.832
2	0.78	0.872	0.859	0.88	0.99	0.98	1.02	0.865
4	0.98	0.898	0.888	0.91	0.99	0.98	1.01	0.893
6	1.13	0.909	0.902	0.92	0.99	0.98	1.01	0.906
8	1.24	0.918	0.909	0.93	0.99	0.98	1.01	0.914
10	1.34	0.925	0.916	0.93	0.99	0.99	1.01	0.920
20	1.68	0.938	0.932	0.95	0.99	0.98	1.01	0.935
40	2.12	0.952	0.946	0.96	0.99	0.99	1.01	0.949
60	2.43	0.958	0.954	0.97	0.99	0.98	1.00	0.956
80	2.67	0.960	0.957	0.97	0.99	0.99	1.00	0.958
100	2.88	0.964	0.960	0.97	0.99	0.99	1.00	0.962
300	4.15	0.974	0.970	0.98	0.99	0.99	1.00	0.972
400	4.57	0.977	0.973	0.99	0.99	0.98	1.00	0.975
500	4.92	0.978	0.974	0.99	0.99	0.98	1.00	0.976
600	5.23	0.979	0.976	0.99	0.99	0.99	1.00	0.978
1000	6.20	0.982	0.979	0.99	0.99	0.99	1.00	0.980
Energy: 1.0 MeV								
0.01	0.13	0.209	0.183	0.20	1.0	0.91	1.15	0.196
0.1	0.29	0.502	0.472	0.50	1.0	0.94	1.06	0.487
0.5	0.49	0.692	0.668	0.70	0.99	0.95	1.03	0.680
1	0.62	0.751	0.733	0.76	0.99	0.97	1.02	0.742
2	0.78	0.802	0.786	0.81	0.99	0.97	1.02	0.794
4	0.98	0.840	0.827	0.85	0.99	0.97	1.02	0.834
6	1.13	0.861	0.850	0.87	0.99	0.98	1.01	0.855
8	1.24	0.874	0.863	0.88	1.0	1.0	1.01	0.869
10	1.34	0.880	0.873	0.89	0.99	0.98	1.01	0.877
20	1.68	0.904	0.899	0.91	0.99	0.99	1.00	0.901
40	2.12	0.921	0.919	0.93	0.99	0.99	1.00	0.920
60	2.43	0.933	0.929	0.94	0.99	0.99	1.00	0.931
80	2.67	0.940	0.935	0.95	0.99	0.98	1.01	0.938
100	2.88	0.943	0.939	0.95	0.99	0.99	1.00	0.941
300	4.15	0.961	0.958	0.97	0.99	0.99	1.00	0.959
400	4.57	0.963	0.961	0.97	0.99	0.99	1.00	0.962
500	4.92	0.966	0.963	0.98	0.99	0.98	1.00	0.964
600	5.23	0.968	0.965	0.98	0.99	0.98	1.00	0.967
1000	6.20	0.973	0.970	0.98	0.99	0.99	1.00	0.971
Energy: 2.0 MeV								
0.01	0.13	0.090	0.082	0.093	0.97	0.88	1.10	0.086
0.1	0.29	0.209	0.192	0.21	0.99	0.92	1.08	0.200
0.5	0.49	0.391	0.361	0.39	1.0	0.93	1.08	0.376
1	0.62	0.485	0.460	0.49	0.99	0.94	1.06	0.473
2	0.78	0.581	0.555	0.58	1.0	0.96	1.05	0.568
4	0.98	0.657	0.637	0.66	1.0	0.97	1.03	0.647
6	1.13	0.698	0.680	0.70	1.0	0.97	1.03	0.689
8	1.24	0.726	0.708	0.73	1.0	0.97	1.03	0.717
10	1.34	0.744	0.728	0.75	0.99	0.97	1.02	0.736
20	1.68	0.799	0.779	0.80	1.0	0.97	1.03	0.789
40	2.12	0.830	0.822	0.84	0.99	0.98	1.01	0.826
60	2.43	0.852	0.843	0.86	0.99	0.98	1.01	0.847
80	2.67	0.870	0.855	0.87	1.0	0.98	1.02	0.863
100	2.88	0.875	0.866	0.88	0.99	0.98	1.01	0.871
300	4.15	0.913	0.904	0.91	1.0	0.99	1.01	0.909
400	4.57	0.922	0.912	0.93	0.99	0.98	1.01	0.917
500	4.92	0.927	0.919	0.93	1.0	0.99	1.01	0.923
600	5.23	0.929	0.923	0.94	0.99	0.98	1.01	0.926
1000	6.20	0.940	0.935	0.95	0.99	0.98	1.01	0.937

TABLE 1 (*Continued*)

Sphere mass (g)	Sphere radius (cm)	EGS4 ϕ	MCNP ϕ	SS ϕ	EGS4/ SS	MCNP/ SS	EGS4/ MCNP	Recommended value
Energy: 4.0 MeV								
0.01	0.13	0.044	0.040	0.047	0.94	0.86	1.10	0.042
0.1	0.29	0.098	0.091	0.10	0.98	0.91	1.07	0.094
0.5	0.49	0.173	0.158	0.18	0.96	0.88	1.10	0.165
1	0.62	0.223	0.203	0.23	0.97	0.88	1.10	0.213
2	0.78	0.289	0.262	0.29	1.0	0.90	1.11	0.275
4	0.98	0.372	0.340	0.38	0.98	0.89	1.10	0.356
6	1.13	0.430	0.400	0.44	0.98	0.91	1.08	0.415
8	1.24	0.468	0.439	0.48	0.98	0.91	1.07	0.454
10	1.34	0.500	0.471	0.51	0.98	0.92	1.06	0.485
20	1.68	0.589	0.561	0.59	1.0	0.95	1.05	0.575
40	2.12	0.664	0.641	0.67	0.99	0.96	1.04	0.653
60	2.43	0.699	0.682	0.71	0.98	0.96	1.03	0.691
80	2.67	0.728	0.708	0.73	1.0	0.97	1.03	0.718
100	2.88	0.746	0.728	0.75	0.99	0.97	1.02	0.737
300	4.15	0.818	0.804	0.82	1.0	0.98	1.02	0.811
400	4.57	0.836	0.820	0.84	1.0	0.98	1.02	0.828
500	4.92	0.844	0.832	0.85	0.99	0.98	1.01	0.838
600	5.23	0.858	0.842	0.86	1.0	0.98	1.02	0.850
1000	6.20	0.874	0.864	0.88	0.99	0.98	1.01	0.869

ϕ = the fraction of energy emitted in the sphere assumed to be absorbed within the sphere.
SS = Siegel and Stabin and refers to previously reported data (*3*).

TABLE 2
Absorbed Fractions for All Energies and Smaller Spheres for Photons: Results from EGS4 and MCNP, with Comparisons with Each Other and Values from MIRD Pamphlet No. 8

Sphere mass (g)	Sphere radius (cm)	EGS4 ϕ	MCNP ϕ	MIRD8 ϕ	EGS4/ MIRD8	MCNP/ MIRD8	EGS4/ MCNP	Recommended value
Energy: 0.02 MeV								
1	0.620	0.205	0.191	1.07	0.198			
2	0.782	0.251	0.236	1.06	0.244			
4	0.985	0.304	0.287	1.06	0.295			
6	1.127	0.338	0.319	1.06	0.328			
8	1.241	0.363	0.343	1.06	0.353			
10	1.337	0.383	0.364	1.05	0.374			
20	1.684	0.450	0.426	1.06	0.438			
40	2.122	0.519	0.494	1.05	0.507			
60	2.429	0.560	0.536	1.04	0.548			
80	2.673	0.589	0.563	1.05	0.576			
100	2.879	0.610	0.586	1.04	0.598			
Energy: 0.03 MeV								
1	0.620	0.068	0.061	0.05	1.37	1.22	1.12	0.065
2	0.782	0.087	0.079	0.064	1.36	1.23	1.11	0.083
4	0.985	0.110	0.100	0.081	1.36	1.24	1.10	0.105
6	1.127	0.126	0.115	0.092	1.37	1.25	1.10	0.120
8	1.241	0.138	0.126	0.103	1.34	1.23	1.10	0.132
10	1.337	0.149	0.137	0.111	1.34	1.23	1.09	0.143
20	1.684	0.186	0.171	0.139	1.34	1.23	1.09	0.179
40	2.122	0.233	0.215	0.174	1.34	1.24	1.08	0.224
60	2.429	0.264	0.243	0.23	1.15	1.05	1.09	0.253
80	2.673	0.287	0.264	0.286	1.00	0.924	1.09	0.276
100	2.879	0.306	0.282	0.306	1.00	0.922	1.09	0.294

TABLE 2 (*Continued*)

Sphere mass (g)	Sphere radius (cm)	EGS4 ϕ	MCNP ϕ	MIRD8 ϕ	EGS4/ MIRD8	MCNP/ MIRD8	EGS4/ MCNP	Recommended value
Energy: 0.04 MeV								
1	0.620	0.032	0.029	0.023	1.40	1.26	1.11	0.031
2	0.782	0.041	0.038	0.03	1.38	1.27	1.08	0.040
4	0.985	0.053	0.048	0.038	1.40	1.27	1.10	0.051
6	1.127	0.062	0.056	0.043	1.43	1.31	1.09	0.059
8	1.241	0.068	0.062	0.049	1.40	1.27	1.10	0.065
10	1.337	0.074	0.068	0.054	1.37	1.25	1.10	0.071
20	1.684	0.095	0.087	0.07	1.36	1.24	1.10	0.091
40	2.122	0.122	0.112	0.09	1.36	1.24	1.10	0.117
60	2.429	0.142	0.129	0.121	1.18	1.07	1.10	0.136
80	2.673	0.157	0.142	0.152	1.03	0.937	1.10	0.150
100	2.879	0.171	0.154	0.165	1.03	0.931	1.11	0.162
Energy: 0.06 MeV								
1	0.620	0.015	0.014	0.011	1.38	1.29	1.08	0.015
2	0.782	0.020	0.019	0.014	1.40	1.34	1.04	0.019
4	0.985	0.025	0.024	0.019	1.34	1.26	1.07	0.025
6	1.127	0.030	0.028	0.022	1.36	1.26	1.08	0.029
8	1.241	0.033	0.031	0.024	1.39	1.28	1.09	0.032
10	1.337	0.036	0.033	0.027	1.34	1.24	1.08	0.035
20	1.684	0.047	0.043	0.035	1.34	1.23	1.09	0.045
40	2.122	0.062	0.056	0.046	1.34	1.22	1.09	0.059
60	2.429	0.072	0.065	0.064	1.13	1.02	1.11	0.069
80	2.673	0.081	0.072	0.079	1.03	0.915	1.12	0.077
100	2.879	0.089	0.078	0.087	1.02	0.902	1.13	0.084
Energy: 0.08 MeV								
1	0.620	0.012	0.012	0.009	1.39	1.33	1.05	0.012
2	0.782	0.016	0.015	0.012	1.31	1.29	1.02	0.016
4	0.985	0.021	0.020	0.016	1.29	1.24	1.04	0.020
6	1.127	0.024	0.023	0.018	1.33	1.28	1.04	0.023
8	1.241	0.027	0.025	0.02	1.33	1.27	1.04	0.026
10	1.337	0.029	0.028	0.022	1.33	1.26	1.05	0.028
20	1.684	0.038	0.035	0.029	1.30	1.22	1.06	0.037
40	2.122	0.049	0.046	0.037	1.33	1.23	1.07	0.047
60	2.429	0.057	0.053	0.05	1.14	1.06	1.08	0.055
80	2.673	0.064	0.058	0.064	0.999	0.913	1.09	0.061
100	2.879	0.070	0.063	0.07	0.997	0.906	1.10	0.067
Energy: 0.1 MeV								
1	0.620	0.012	0.012	0.009	1.36	1.30	1.04	0.012
2	0.782	0.015	0.015	0.012	1.29	1.25	1.03	0.015
4	0.985	0.020	0.019	0.015	1.33	1.28	1.04	0.020
6	1.127	0.023	0.022	0.017	1.34	1.30	1.03	0.023
8	1.241	0.026	0.025	0.02	1.28	1.23	1.05	0.025
10	1.337	0.028	0.027	0.021	1.31	1.27	1.03	0.027
20	1.684	0.036	0.034	0.027	1.32	1.26	1.05	0.035
40	2.122	0.046	0.043	0.036	1.28	1.20	1.06	0.045
60	2.429	0.054	0.050	0.048	1.12	1.05	1.07	0.052
80	2.673	0.060	0.056	0.061	0.979	0.911	1.08	0.058
100	2.879	0.065	0.060	0.067	0.974	0.898	1.08	0.063
Energy: 0.14 MeV								
1	0.620	0.013	0.013	0.01	1.28	1.26	1.01	0.013
2	0.782	0.016	0.016	0.012	1.36	1.33	1.02	0.016
4	0.985	0.021	0.020	0.016	1.30	1.27	1.03	0.021
6	1.127	0.024	0.023	0.018	1.33	1.30	1.03	0.024
8	1.241	0.027	0.026	0.02	1.33	1.29	1.03	0.026
10	1.337	0.029	0.028	0.022	1.30	1.27	1.03	0.028
20	1.684	0.036	0.035	0.028	1.30	1.25	1.04	0.036

TABLE 2 (*Continued*)

Sphere mass (g)	Sphere radius (cm)	EGS4 ϕ	MCNP ϕ	MIRD8 ϕ	EGS4/ MIRD8	MCNP/ MIRD8	EGS4/ MCNP	Recommended value
Energy: 0.14 MeV (*Continued*)								
40	2.122	0.047	0.045	0.036	1.30	1.24	1.04	0.046
60	2.429	0.054	0.052	0.048	1.12	1.08	1.04	0.053
80	2.673	0.060	0.057	0.061	0.981	0.933	1.05	0.058
100	2.879	0.065	0.062	0.066	0.984	0.933	1.05	0.063
Energy: 0.364 MeV								
1	0.620	0.015	0.015	0.011	1.35	1.32	1.02	0.015
2	0.782	0.019	0.018	0.014	1.33	1.32	1.01	0.019
4	0.985	0.024	0.023	0.018	1.32	1.29	1.02	0.023
6	1.127	0.027	0.026	0.02	1.36	1.32	1.03	0.027
8	1.241	0.030	0.029	0.023	1.29	1.27	1.02	0.029
10	1.337	0.032	0.032	0.025	1.29	1.27	1.02	0.032
20	1.684	0.041	0.040	0.031	1.31	1.29	1.02	0.040
40	2.122	0.052	0.050	0.039	1.32	1.29	1.03	0.051
60	2.429	0.059	0.058	0.053	1.11	1.09	1.02	0.058
80	2.673	0.064	0.063	0.066	0.975	0.958	1.02	0.064
100	2.879	0.070	0.068	0.072	0.973	0.947	1.03	0.069
Energy: 0.662 MeV								
1	0.620	0.014	0.014	0.011	1.25	1.23	1.01	0.014
2	0.782	0.018	0.017	0.014	1.26	1.24	1.02	0.018
4	0.985	0.023	0.022	0.018	1.26	1.23	1.02	0.022
6	1.127	0.026	0.025	0.02	1.30	1.27	1.02	0.026
8	1.241	0.029	0.028	0.023	1.24	1.22	1.02	0.028
10	1.337	0.031	0.030	0.024	1.30	1.27	1.03	0.031
20	1.684	0.039	0.038	0.031	1.27	1.24	1.02	0.039
40	2.122	0.050	0.049	0.038	1.31	1.28	1.02	0.049
60	2.429	0.056	0.056	0.052	1.09	1.07	1.01	0.056
80	2.673	0.063	0.061	0.065	0.967	0.941	1.03	0.062
100	2.879	0.067	0.066	0.07	0.962	0.940	1.02	0.067
Energy: 1.46 MeV								
1	0.620	0.009	0.009	0.01	0.915	0.878	1.04	0.009
2	0.782	0.013	0.012	0.012	1.05	0.998	1.05	0.012
4	0.985	0.017	0.016	0.016	1.05	1.02	1.04	0.017
6	1.127	0.020	0.019	0.018	1.10	1.07	1.03	0.020
8	1.241	0.022	0.021	0.02	1.11	1.07	1.03	0.022
10	1.337	0.024	0.023	0.021	1.15	1.12	1.03	0.024
20	1.684	0.032	0.030	0.027	1.17	1.12	1.05	0.031
40	2.122	0.040	0.039	0.033	1.22	1.18	1.03	0.040
60	2.429	0.046	0.045	0.045	1.02	1.01	1.01	0.046
80	2.673	0.051	0.050	0.056	0.915	0.898	1.02	0.051
100	2.879	0.055	0.054	0.061	0.904	0.893	1.01	0.055
Energy: 2.75 MeV								
1	0.620	0.005	0.004	0.008	0.584	0.534	1.09	0.004
2	0.782	0.007	0.007	0.01	0.686	0.658	1.04	0.007
4	0.985	0.010	0.010	0.013	0.775	0.738	1.05	0.010
6	1.127	0.012	0.012	0.014	0.829	0.849	0.976	0.012
8	1.241	0.014	0.014	0.016	0.900	0.854	1.05	0.014
10	1.337	0.016	0.015	0.017	0.931	0.900	1.03	0.016
20	1.684	0.021	0.021	0.022	0.960	0.950	1.01	0.021
40	2.122	0.029	0.028	0.027	1.07	1.05	1.02	0.028
60	2.429	0.034	0.033	0.035	0.966	0.950	1.02	0.034
80	2.673	0.038	0.037	0.046	0.818	0.808	1.01	0.037
100	2.879	0.041	0.041	0.05	0.817	0.810	1.01	0.041

ϕ = the fraction of energy emitted in the sphere assumed to be absorbed within the sphere.

TABLE 3

Absorbed Fractions for All Energies and Larger Spheres for Photons: Results from EGS4 and MCNP, with Comparisons with Each Other and Values from MIRD Pamphlet No. 3

Sphere mass (g)	Sphere radius (cm)	EGS4 ϕ	MCNP ϕ	MIRD3 ϕ	EGS4/ MIRD3	MCNP/ MIRD3	EGS4/ MCNP	Recommended value
Energy: 0.02 MeV								
300	4.153	0.710	0.692	0.684	1.04	1.01	1.03	0.701
400	4.571	0.733	0.716	0.712	1.03	1.01	1.02	0.725
500	4.924	0.750	0.733	0.731	1.03	1.00	1.02	0.742
600	5.232	0.763	0.748	0.745	1.02	1.00	1.02	0.756
1000	6.203	0.797	0.780	0.780	1.02	1.00	1.02	0.788
2000	7.816	0.837	0.828	0.818	1.02	1.01	1.01	0.833
3000	8.947	0.858	0.849	0.840	1.02	1.01	1.01	0.853
4000	9.847	0.870	0.861	0.856	1.02	1.01	1.01	0.865
5000	10.608	0.880	0.870	0.868	1.01	1.00	1.01	0.875
6000	11.272	0.887	0.877	0.876	1.01	1.00	1.01	0.882
Energy: 0.03 MeV								
300	4.153	0.410	0.388	0.357	1.15	1.09	1.06	0.399
400	4.571	0.441	0.419	0.388	1.14	1.08	1.05	0.430
500	4.924	0.464	0.440	0.412	1.13	1.07	1.06	0.452
600	5.232	0.483	0.458	0.431	1.12	1.06	1.05	0.470
1000	6.203	0.538	0.513	0.486	1.11	1.06	1.05	0.526
2000	7.816	0.610	0.590	0.559	1.09	1.06	1.03	0.600
3000	8.947	0.649	0.629	0.600	1.08	1.05	1.03	0.639
4000	9.847	0.677	0.659	0.629	1.08	1.05	1.03	0.668
5000	10.608	0.697	0.679	0.652	1.07	1.04	1.03	0.688
6000	11.272	0.714	0.696	0.671	1.06	1.04	1.03	0.705
Energy: 0.04 MeV								
300	4.153	0.249	0.233	0.191	1.30	1.22	1.07	0.241
400	4.571	0.273	0.260	0.212	1.29	1.22	1.05	0.266
500	4.924	0.294	0.280	0.229	1.29	1.22	1.05	0.287
600	5.232	0.310	0.297	0.244	1.27	1.22	1.05	0.304
1000	6.203	0.361	0.344	0.289	1.25	1.19	1.05	0.353
2000	7.816	0.434	0.422	0.360	1.21	1.17	1.03	0.428
3000	8.947	0.481	0.469	0.405	1.19	1.16	1.02	0.475
4000	9.847	0.514	0.504	0.438	1.17	1.15	1.02	0.509
5000	10.608	0.536	0.526	0.464	1.16	1.13	1.02	0.531
6000	11.272	0.557	0.548	0.485	1.15	1.13	1.02	0.552
Energy: 0.06 MeV								
300	4.153	0.137	0.130	0.109	1.25	1.19	1.06	0.133
400	4.571	0.154	0.145	0.121	1.27	1.20	1.06	0.149
500	4.924	0.167	0.159	0.131	1.28	1.21	1.05	0.163
600	5.232	0.180	0.169	0.140	1.28	1.21	1.06	0.175
1000	6.203	0.219	0.208	0.167	1.31	1.24	1.05	0.213
2000	7.816	0.279	0.270	0.212	1.32	1.28	1.03	0.275
3000	8.947	0.318	0.311	0.245	1.30	1.27	1.02	0.315
4000	9.847	0.351	0.340	0.271	1.29	1.26	1.03	0.346
5000	10.608	0.375	0.367	0.294	1.28	1.25	1.02	0.371
6000	11.272	0.396	0.388	0.312	1.27	1.24	1.02	0.392
Energy: 0.08 MeV								
300	4.153	0.108	0.106	0.086	1.25	1.23	1.02	0.107
400	4.571	0.123	0.118	0.096	1.28	1.23	1.04	0.120
500	4.924	0.135	0.129	0.104	1.30	1.24	1.04	0.132
600	5.232	0.144	0.139	0.111	1.29	1.25	1.03	0.141
1000	6.203	0.174	0.169	0.135	1.29	1.26	1.03	0.172
2000	7.816	0.228	0.221	0.173	1.32	1.28	1.03	0.225
3000	8.947	0.263	0.259	0.201	1.31	1.29	1.01	0.261
4000	9.847	0.291	0.285	0.222	1.31	1.28	1.02	0.288
5000	10.608	0.313	0.305	0.241	1.30	1.27	1.02	0.309
6000	11.272	0.334	0.326	0.258	1.29	1.26	1.02	0.330

TABLE 3 (*Continued*)

Sphere mass (g)	Sphere radius (cm)	EGS4 ϕ	MCNP ϕ	MIRD3 ϕ	EGS4/ MIRD3	MCNP/ MIRD3	EGS4/ MCNP	Recommended value
Energy: 0.1 MeV								
300	4.153	0.101	0.099	0.085	1.19	1.16	1.02	0.100
400	4.571	0.112	0.110	0.093	1.20	1.19	1.02	0.111
500	4.924	0.122	0.119	0.099	1.23	1.21	1.02	0.121
600	5.232	0.130	0.128	0.105	1.24	1.22	1.02	0.129
1000	6.203	0.159	0.156	0.125	1.28	1.25	1.02	0.158
2000	7.816	0.206	0.203	0.160	1.29	1.27	1.01	0.204
3000	8.947	0.239	0.238	0.188	1.27	1.26	1.01	0.238
4000	9.847	0.265	0.264	0.209	1.27	1.26	1.00	0.264
5000	10.608	0.289	0.283	0.227	1.27	1.25	1.02	0.286
6000	11.272	0.305	0.301	0.241	1.26	1.25	1.01	0.303
Energy: 0.16 MeV								
300	4.153	0.099	0.096	0.087	1.14	1.11	1.03	0.098
400	4.571	0.109	0.107	0.097	1.12	1.10	1.02	0.108
500	4.924	0.120	0.116	0.104	1.15	1.11	1.03	0.118
600	5.232	0.126	0.124	0.111	1.13	1.12	1.02	0.125
1000	6.203	0.152	0.150	0.130	1.17	1.15	1.01	0.151
2000	7.816	0.195	0.192	0.162	1.20	1.19	1.01	0.193
3000	8.947	0.223	0.223	0.186	1.20	1.20	1.00	0.223
4000	9.847	0.247	0.246	0.205	1.21	1.20	1.01	0.246
5000	10.608	0.266	0.264	0.222	1.20	1.19	1.01	0.265
6000	11.272	0.284	0.281	0.236	1.21	1.19	1.01	0.283
Energy: 0.364 MeV								
300	4.153	0.102	0.102	0.099	1.03	1.03	1.00	0.102
400	4.571	0.114	0.112	0.108	1.05	1.03	1.02	0.113
500	4.924	0.121	0.121	0.116	1.04	1.04	1.00	0.121
600	5.232	0.128	0.128	0.122	1.05	1.05	0.999	0.128
1000	6.203	0.151	0.151	0.142	1.06	1.07	0.999	0.151
2000	7.816	0.190	0.190	0.174	1.09	1.09	0.995	0.190
3000	8.947	0.218	0.218	0.197	1.10	1.11	0.999	0.218
4000	9.847	0.238	0.239	0.216	1.10	1.11	0.996	0.239
5000	10.608	0.253	0.255	0.231	1.10	1.11	0.991	0.254
6000	11.272	0.270	0.270	0.245	1.10	1.10	1.00	0.270
Energy: 0.662 MeV								
300	4.153	0.097	0.097	0.096	1.01	1.01	1.01	0.097
400	4.571	0.107	0.107	0.108	0.992	0.990	1.00	0.107
500	4.924	0.115	0.115	0.117	0.980	0.984	0.997	0.115
600	5.232	0.123	0.123	0.124	0.989	0.989	1.00	0.123
1000	6.203	0.143	0.144	0.144	0.996	1.00	0.995	0.144
2000	7.816	0.179	0.181	0.173	1.03	1.05	0.988	0.180
3000	8.947	0.204	0.206	0.195	1.05	1.05	0.991	0.205
4000	9.847	0.222	0.224	0.213	1.04	1.05	0.992	0.223
5000	10.608	0.237	0.240	0.228	1.04	1.05	0.991	0.239
6000	11.272	0.254	0.252	0.240	1.06	1.05	1.01	0.253
Energy: 1.46 MeV								
300	4.153	0.082	0.080	0.092	0.887	0.866	1.02	0.081
400	4.571	0.089	0.088	0.099	0.896	0.889	1.01	0.088
500	4.924	0.097	0.095	0.104	0.931	0.910	1.02	0.096
600	5.232	0.102	0.101	0.109	0.933	0.927	1.01	0.101
1000	6.203	0.121	0.120	0.125	0.964	0.963	1.00	0.120
2000	7.816	0.151	0.152	0.153	0.985	0.992	0.992	0.151
3000	8.947	0.172	0.173	0.174	0.986	0.995	0.990	0.172
4000	9.847	0.187	0.190	0.190	0.986	1.00	0.986	0.189
5000	10.608	0.201	0.203	0.204	0.985	0.994	0.991	0.202
6000	11.272	0.211	0.214	0.216	0.978	0.989	0.989	0.212

TABLE 3 (*Continued*)

Sphere mass (g)	Sphere radius (cm)	EGS4 ϕ	MCNP ϕ	MIRD3 ϕ	EGS4/ MIRD3	MCNP/ MIRD3	EGS4/ MCNP	Recommended value
Energy: 2.75 MeV								
300	4.153	0.063	0.064	0.077	0.815	0.826	0.986	0.063
400	4.571	0.068	0.071	0.083	0.824	0.850	0.970	0.069
500	4.924	0.075	0.077	0.089	0.844	0.866	0.975	0.076
600	5.232	0.080	0.083	0.093	0.862	0.888	0.972	0.081
1000	6.203	0.095	0.097	0.106	0.896	0.913	0.982	0.096
2000	7.816	0.122	0.122	0.127	0.964	0.962	1.00	0.122
3000	8.947	0.137	0.140	0.143	0.959	0.982	0.977	0.139
4000	9.847	0.151	0.154	0.156	0.971	0.988	0.982	0.153
5000	10.608	0.163	0.166	0.167	0.976	0.993	0.983	0.164
6000	11.272	0.172	0.175	0.177	0.974	0.986	0.988	0.173

ϕ = the fraction of energy emitted in the sphere assumed to be absorbed within the sphere.

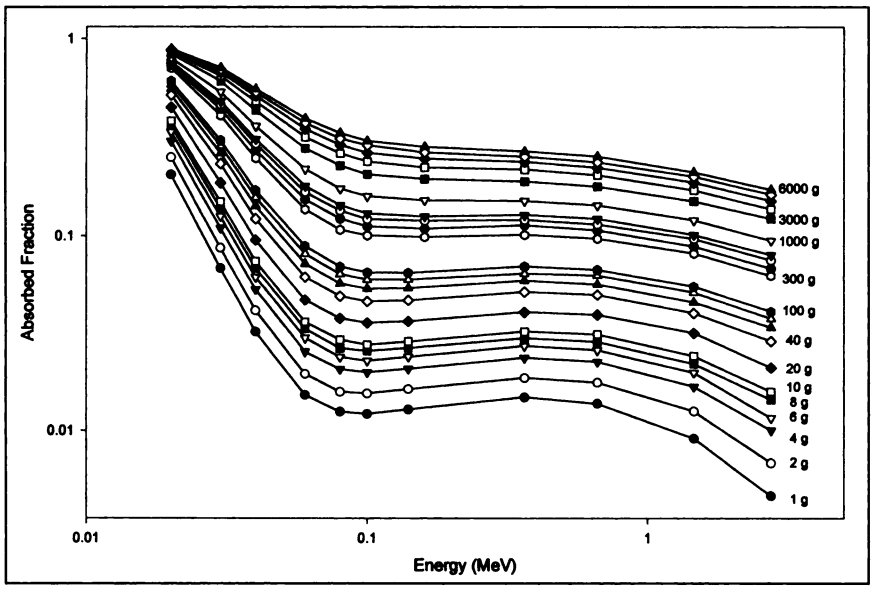

FIGURE 1. Absorbed fractions as function of energy for photons, EGS4.

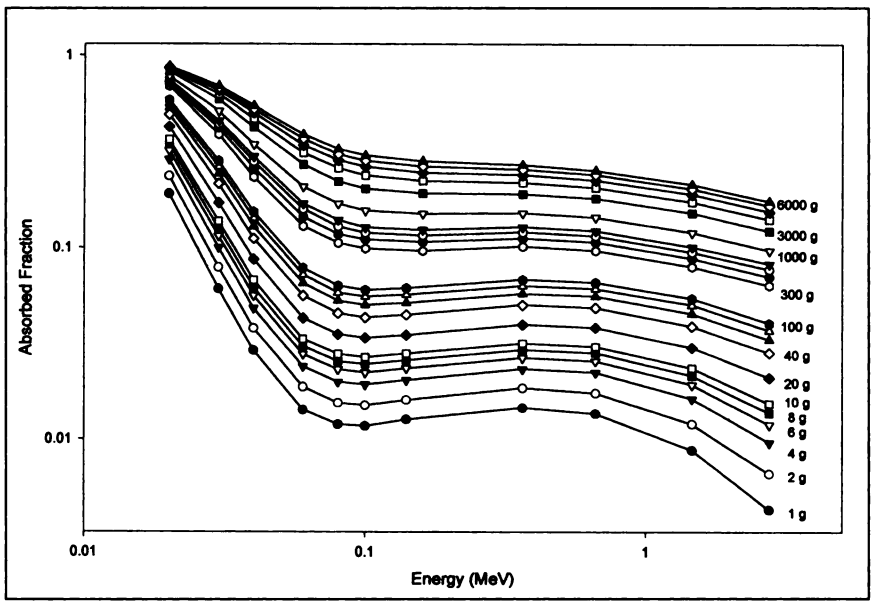

FIGURE 2. Absorbed fractions as function of energy for photons, MCNP.

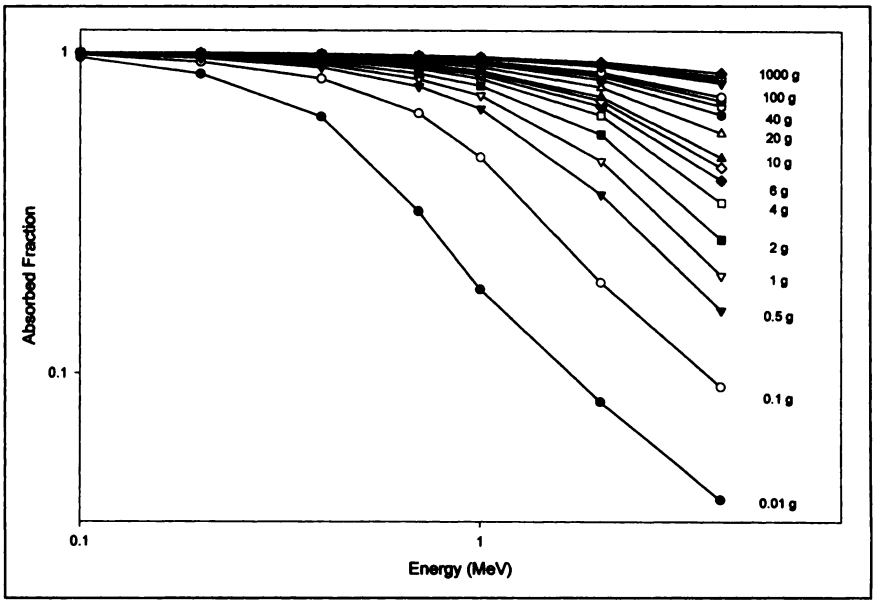

FIGURE 3. Absorbed fractions as function of energy for electrons, EGS4.

from those suggested by later authors (e.g., Cristy and Eckerman [6]), the differences are minor, and the absorbed fractions should not be much different using either composition. Values shown in the tables are typically rounded to 3 significant figures; the ratios at all times reflect the ratios between the actual values, with many significant figures.

For electrons, the codes were in very good agreement with each other (±5%) and with the published values of Siegel and Stabin (*3*), except at higher energies in the very smallest spheres, where some differences exceeded 10% on average. The EGS4 values were not much more than 5% lower than Siegel and Stabin's values in the smallest spheres at these higher energies, but the MCNP values were approximately 15% lower. EGS4 tended to suggest a higher absorbed fraction than MCNP for electrons in the smallest spheres at all energies. For photons, the codes were again in good agreement with each other but produced results that differed from the values published in *MIRD Pamphlet 8* (*1*) for some energies and sphere sizes. For most photon energies, the new values were typically 20%–40% higher than those in *MIRD 8* for most spheres. For photon energies greater than 1 MeV, however, the new values appeared to be 10%–50% lower than those in *MIRD Pamphlet 8* (*1*) for very small spheres and for spheres of 80–1000 g. The absorbed fractions from *MIRD Pamphlet 8* (*1*) have a discontinuous trend between 60 and 100 g (Fig. 6). This is not seen with the Monte Carlo code results. There appears to be some difference between the 2 codes (on the order of 6%, Table 3) for photon sources

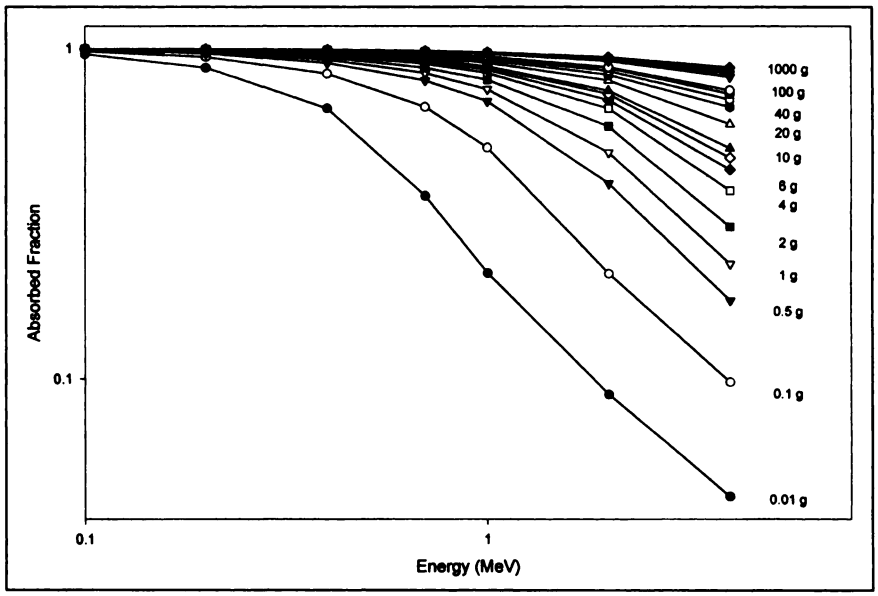

FIGURE 4. Absorbed fractions as function of energy for electrons, MCNP.

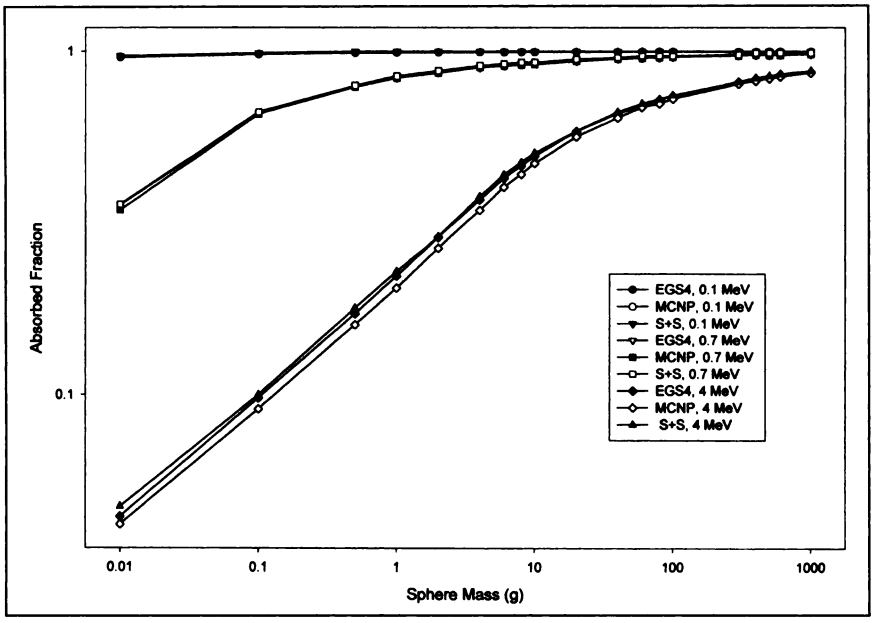

FIGURE 5. Absorbed fractions as function of mass for electrons. Comparison of results of both codes with each other and with original results of Siegel and Stabin (*3*).

in the smaller spheres between energies of 0.03 and 0.06 MeV. The reason for this difference is not obvious and may represent a real difference in the cross sections or transport methods used in these codes. Both codes are very well supported; code formalism and validation of code results is well documented (*4,5*). The cited differences between the codes (which are relatively minor given other uncertainties that will exist in any real problem in which these results are used) reflect commonly encountered differences in modeling software. The differences between the code results and those in previously published literature are most likely caused by improvements in methodology from previous decades to the present. Thus, averaged values from the 2 codes represent the best current estimates of the calculated values and should be used in place of previous values.

CONCLUSION

We present new values for electron and photon absorbed fractions in spheres of unit density, based on results from modern Monte Carlo codes. The Monte Carlo codes are well supported and have undergone extensive validation. Thus, the values given in this study should replace the previous values presented by Siegel and Stabin (*3*) for electrons and by the MIRD Committee (*1,2*) for photons. The changes for electrons are generally very minor; those for photons are more significant, especially for the smaller spheres.

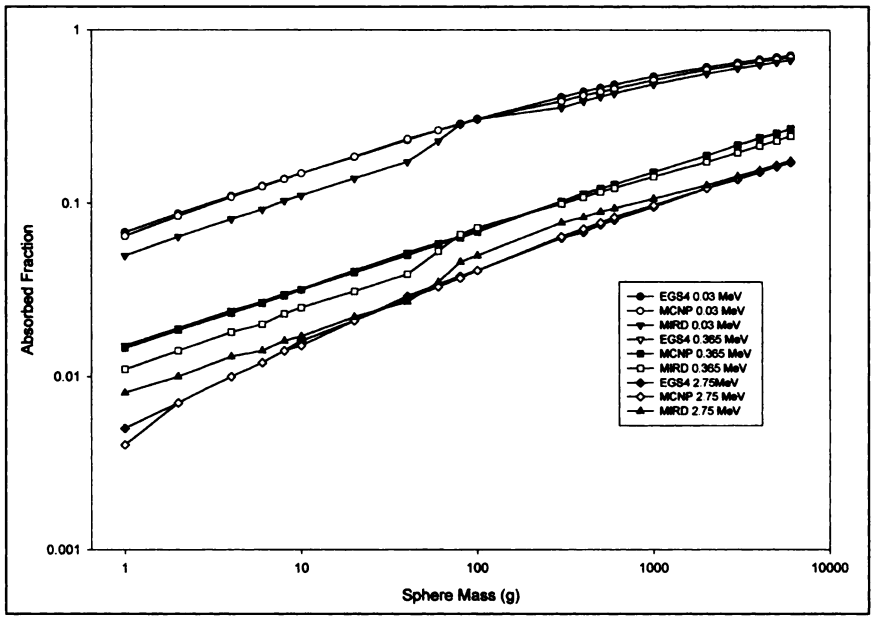

FIGURE 6. Absorbed fractions as function of mass for photons. Comparison of results of both codes with each other and with original MIRD results (*1,2*).

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