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INTERNATIONAL NUCLEAR MODEL CODE COMPARISON STUDY OF

HAUSER-FESHBACH CALCULATIONS

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and

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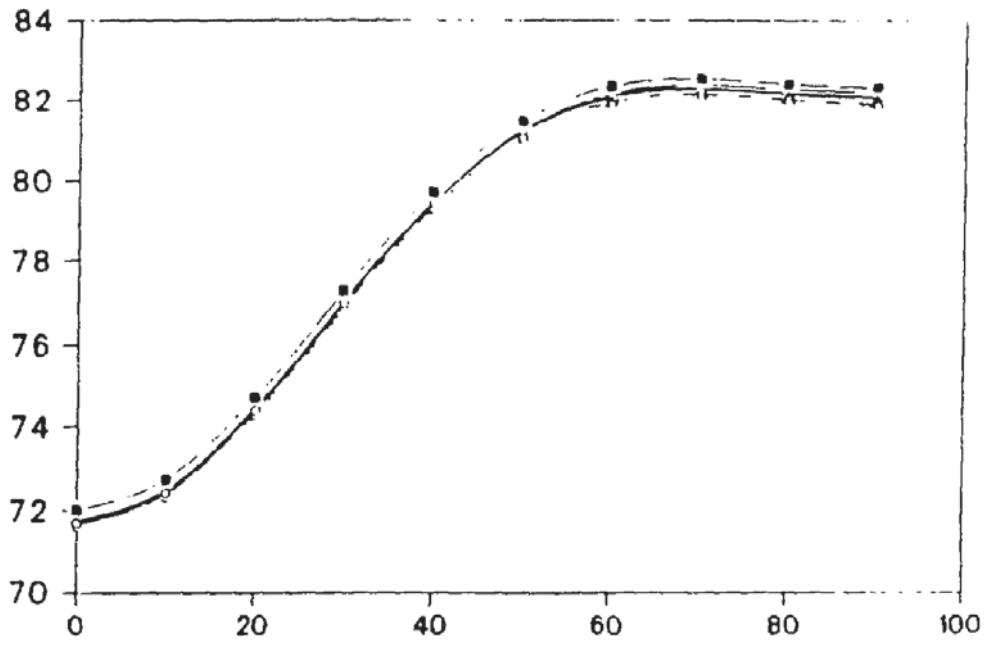

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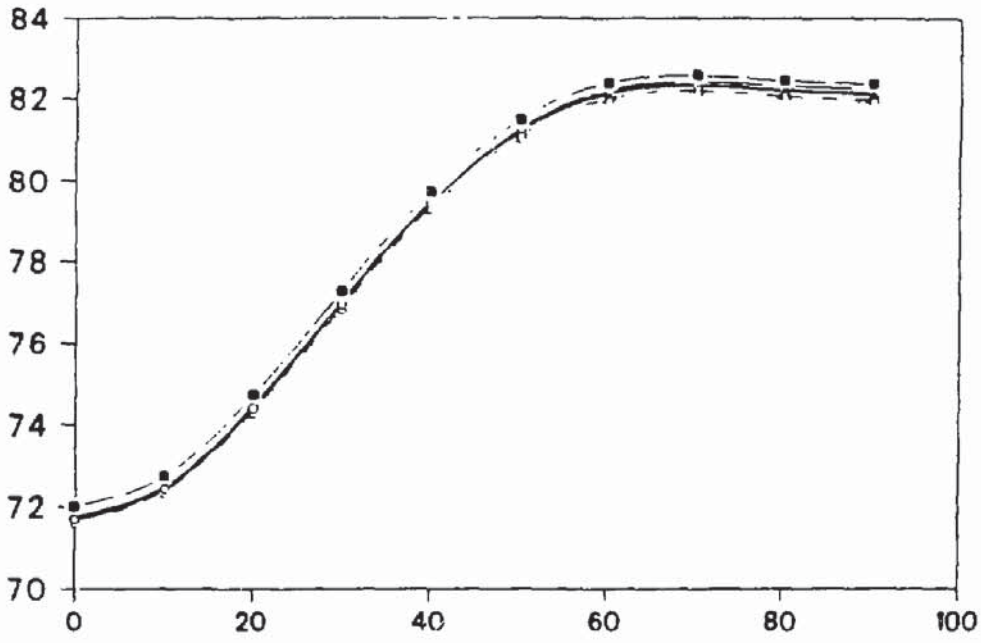

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ABSTRACT

The present comparison concerns Hauser-Feshbach calculations with and without the width fluctuation correction.

Participants were invited to calculate the elastic and inelastic scattering of neutrons from a fictitious nucleus Co60 (Z=27, N=33) at incident laboratory energies of 0.2, 0.5, 1 and 2 MeV. The optical potential was specified. The differential shape elastic, compound elastic and inelastic cross-sections were tabulated.

Among the twenty-five sets of results, twelve were sufficiently consistent with each other to be accepted as benchmark values. These fell into two sets, corresponding to calculations with and without the width fluctuation correction. The differences between the results corresponding to different forms of the width fluctuation correction were less than 2 percent.

1. Introduction

Several intercomparisons [1],[2] of computer codes used to calculate nuclear cross sections show general agreement but significant differences in detail. Since these codes embody the same mathematical functions and the intercomparisons use the same input parameters one would expect, if the codes are indeed identical, that the results would be the same to a high degree of accuracy, limited only by the rounding errors of the computer used. The motivation for the present study is to remove these uncertainties by providing reliable benchmarks for such calculations.

A previous report [3] contained the results of an intercomparison of nuclear optical model codes for charged and uncharged particles. The present study is devoted to Hauser-Feshbach calculations. In section 2 the specifications of the test calculations are given, and section 3 gives and dicusses the calculated results.

2. Specification of the Calculations

The Hauser-Feshbach theory enables the cross-sections of compound nucleus reactions to discrete final states to be calculated from a knowledge of the transmission coefficients in all channels and the energies and total angular momenta of the states of the residual nuclei.

Since the purpose of this intercomparison is to compare the computer codes, we calculate only inelastic neutron scattering from a fictitious nucleus Co60 (Z=27, N=33) with states at the following energies (MeV) : 0^+, 0; 2^+, 0.1; 4^+, 0.3; 0^+, 1.0. The calculations were made at the following incident (lab) energies : 0.2, 0.5, 1, 2 MeV and the differential shape elastic, compound elastic and inelastic scattering cross-sections were tabulated at 10° intervals in the CM system.

The transmission coefficients were calculated from optical potentials specified for all channels by

$$V(r) = Uf_u(r) + iWg(r)$$

where $$f_u(r) = \left[1 + \exp\left\{ (r - r_u A^{1/3})/a_u \right\} \right]^{-1}$$

$$g(r) = -4a_w \frac{df_w(r)}{dr}$$

with U=50 MeV, W=10 MeV, $r_u=r_w=1.2$ fm; $a_u=a_w=0.6$ fm. As in the optical model intercomparison, the wave number parameter was 0.218732. For consistency reasons, integer masses were used.

Hauser-Feshbach calculations may differ in several respects, in particular concerning the method used to take account of the correlation between the incident channel and the outgoing compound elastic channel. This correlation affects the compounds elastic cross-section at low energies, and consequently the non-elastic channels open at these energies. Its magnitude can be calculated in two ways: (i) by the Moldauer width fluctuation correction (WFC) and (ii) by the HRTW formalism [5]. The Moldauer WFC requires the evaluation of an integral and the HRTW formalism in its simpler form requires an iteration calculation. Since earlier codes have the Moldauer WFC and later codes the HRTW method, calculations were made with whatever options were available. The specific WFC options used are as follows:

The Width Fluctuation Correction (WFC)

There are several ways of making the WFC:

1. Moldauer

   W as integral — Phys. Rev. $\left\{\begin{matrix}\underline{123},968(1961)\\ \underline{135},B642(1964)\end{matrix}\right\}$

2. Moldauer (M)

   $$\nu_a = 1.78+(T_a^{1.212}-0.78)e^{-0.228\sum_c T_c}$$ Nucl. Phys. A344,185(1980)

   Then $W_a = 1 + 2/\nu_a$

3. Tepel-Hofmann-Weidenmüller (THW)

   $$W_a = 1+\frac{2}{1+T_a^{1/2}}$$ Phys. Lett. 49B,1(1974)

4. Hofmann-Richert-Tepel-Weidenmüller (HRTW)

   $$W_a = 1+\frac{2}{1+T_a^{F}} +87\left[\frac{Ta-\bar{T}}{\sum_c T_c}\right]^2 \left(\frac{Ta}{\sum_c T_c}\right)^5$$

   $$\bar{T} = \sum_c T_c^{\,2}/\sum_c T_c$$ Z.Physik A297,153(1980) Ann.Phys.(NY) 90,403(1975)

   $$F = \left(\frac{4\bar{T}}{\sum_c T_c}\right)\left(1+\frac{Ta}{\sum_c T_c}\right) / \left(1+\frac{3\bar{T}}{\sum_c T_c}\right)$$

   Iterative method.

It is worth noting that the previous statistical model intercomparison exercise did not include differential cross-sections, and in some of the outgoing channels the cross-sections differed by quite large factors. It therefore remained desirable to make a precise intercomparison of statistical model codes so as to establish the correct values, and this is the principal motivation of the present study.

3. Results and Comments

Ten participants presented twenty-five solutions to this benchmark obtained with thirteen different codes (Annex). Most of the results received showed consistency within each of the two classes, (Table A) without the width fluctuation correction (WFC), (Table B) including the WFC in either the Moldauer [4] or the HRTW [5] form. The results are tabulated in this report, and we recommend them as benchmark values.

Some other calculations, however, showed marked differences from these standards, and are excluded from this report.

All the calculations summarised here have total reaction cross-sections within 1 percent of each other, indicating that the optical model calculations are consistent.

Table A: Hauser-Feshbach Calculations (without width fluctuation correction)

1. Total Reaction Cross-Section (m barn)

Code (Participant)	Energy (lab.) MeV 0.2	0.5	1.0	2.0
OPSTAT (Finlay)	3016	2272	2154	2007
HELENE* (Finlay)	3003	2260	2143	1999
POLIFEMO (Merchant)	2995	2265	2153	2000
HAUSER-5 (Hirata)	3000	2269	2156	2002

2. Total Compound Elastic Cross-Section (m barn)

Code (Participant)	Energy (lab.) MeV 0.2	0.5	1.0	2.0
OPSTAT (Finlay)	2586	1372	816.9	422.0
HELENE* (Finlay)	2625	1379	817.4	418.8
POLIFEMO (Merchant)	2605	1366	810.3	414.7
HAUSER-5 (Hirata)	2608	1367	811.0	414.8

3. Total Inelastic Cross Section (m barn)

Code (Participant)	Energy (lab.) MeV 0.2	0.5	1.0	2.0
OPSTAT (Finlay)	430	900	1337	1585
HELENE* (Finlay)	378	881	1326	1580
POLIFEMO (Merchant)	390	899	1343	1585
HAUSER-5 (Hirata)	392	902	1345	1587

* The results from WILMORE-6 (Chadwick) are omitted here as they are identical to the ones of HELENE (same subroutines).

4. Angular Distributions (m barn)

***** Compound Elastic *****

Energy = 0.2 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
FINLAY-OPSTAT-HF	223.820	222.990	220.620	217.000	212.580	207.900	203.530	199.980	197.670	196.870
FINLAY-HELENE-HF	228.470	227.570	225.010	221.090	216.290	211.200	206.430	202.550	200.020	199.150
MERCHANT-POLIFEMO-HF	226.938	226.042	223.463	219.522	214.700	209.587	204.797	200.904	198.368	197.489
HIRATA-HAUSER5-HF	227.300	226.400	223.810	219.850	215.010	209.870	205.060	201.150	198.610	197.720
Mean	226.632	225.750	223.226	219.365	214.650	209.639	204.954	201.146	198.667	197.807
Standard deviation	1.985	1.953	1.859	1.715	1.540	1.356	1.189	1.063	0.986	0.964

Energy = 0.5 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
FINLAY-OPSTAT-HF	127.800	126.840	124.150	120.150	115.480	110.780	106.630	103.430	101.440	100.760
FINLAY-HELENE-HF	128.040	127.110	124.460	120.530	115.940	111.330	107.250	104.110	102.150	101.490
MERCHANT-POLIFEMO-HF	127.287	126.331	123.629	119.633	114.970	110.297	106.175	103.009	101.036	100.369
HIRATA-HAUSER5-HF	127.470	126.510	123.800	119.790	115.110	110.420	106.290	103.110	101.130	100.460
Mean	127.649	126.698	124.010	120.026	115.380	110.707	106.586	103.415	101.439	100.770
Standard deviation	0.336	0.346	0.370	0.400	0.430	0.463	0.483	0.497	0.504	0.508

Energy = 1.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
FINLAY-OPSTAT-HF	91.840	90.170	85.540	79.040	72.030	65.730	60.910	57.750	56.070	55.560
FINLAY-HELENE-HF	91.770	90.090	85.480	78.990	72.010	65.750	60.960	57.840	56.180	55.680
MERCHANT-POLIFEMO-HF	91.636	89.929	85.225	78.622	71.520	65.166	60.323	57.181	55.519	55.014
HIRATA-HAUSER5-HF	91.760	90.050	85.330	78.710	71.590	65.230	60.370	57.220	55.560	55.050
Mean	91.752	90.060	85.394	78.841	71.790	65.469	60.641	57.498	55.832	55.326
Standard deviation	0.085	0.100	0.143	0.206	0.270	0.314	0.341	0.346	0.341	0.343

Energy = 2.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
FINLAY-OPSTAT-HF	61.800	59.810	54.400	47.060	39.550	33.310	29.030	26.640	25.590	25.320
FINLAY-HELENE-HF	61.180	59.220	53.900	46.660	39.250	33.080	28.850	26.460	25.410	25.140
MERCHANT-POLIFEMO-HF	60.812	58.847	53.518	46.279	38.884	32.741	28.526	26.161	25.119	24.848
HIRATA-HAUSER5-HF	60.840	58.870	53.540	46.290	38.890	32.750	28.530	26.170	25.120	24.850
Mean	61.158	59.187	53.840	46.572	39.144	32.970	28.734	26.358	25.310	25.040
Standard deviation	0.459	0.449	0.413	0.370	0.321	0.276	0.249	0.234	0.232	0.232

***** Inelastic to 1st *****

Energy = 0.2 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
FINLAY-OPSTAT-HF	28.951	29.192	29.886	30.945	32.238	33.609	34.891	35.932	36.610	36.845
FINLAY-HELENE-HF	25.530	25.740	26.340	27.250	28.370	29.570	30.690	31.600	32.190	32.400
MERCHANT-POLIFEMO-HF	26.345	26.559	27.175	28.118	29.273	30.501	31.653	32.592	33.204	33.416
HIRATA-HAUSER5-HF	26.450	26.670	27.280	28.230	29.390	30.630	31.780	32.730	33.340	33.560
Mean	26.819	27.040	27.670	28.636	29.818	31.078	32.254	33.214	33.836	34.055
Standard deviation	1.480	1.493	1.536	1.601	1.677	1.753	1.824	1.881	1.919	1.930

Energy = 0.5 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
FINLAY-OPSTAT-HF	63.246	63.640	64.758	66.422	68.383	70.372	72.151	73.536	74.408	74.705
FINLAY-HELENE-HF	61.880	62.260	63.340	64.960	66.880	68.830	70.600	71.980	72.860	73.150
MERCHANT-POLIFEMO-HF	63.101	63.489	64.593	66.240	68.189	70.176	71.961	73.359	74.242	74.544
HIRATA-HAUSER5-HF	63.290	63.680	64.790	66.440	68.400	70.390	72.180	73.590	74.470	74.770
Mean	62.879	63.267	64.370	66.016	67.963	69.942	71.723	73.116	73.995	74.292
Standard deviation	0.671	0.677	0.692	0.709	0.728	0.748	0.755	0.764	0.763	0.767

Energy = 1.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
FINLAY-OPSTAT-HF	86.586	87.258	89.106	91.688	94.448	96.892	98.726	99.889	100.490	100.670
FINLAY-HELENE-HF	86.410	87.080	88.910	91.470	94.210	96.640	98.480	99.650	100.260	100.440
MERCHANT-POLIFEMO-HF	87.125	87.803	89.666	92.271	95.053	97.514	99.357	100.525	101.125	101.304
HIRATA-HAUSER5-HF	87.290	87.970	89.840	92.450	95.240	97.700	99.550	100.720	101.320	101.500
Mean	86.853	87.528	89.381	91.970	94.738	97.187	99.028	100.196	100.799	100.978
Standard deviation	0.421	0.426	0.443	0.466	0.488	0.502	0.507	0.508	0.505	0.504

Energy = 2.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
FINLAY-OPSTAT-HF	72.021	72.754	74.711	77.275	79.714	81.477	82.370	82.564	82.437	82.347
FINLAY-HELENE-HF	71.690	72.430	74.390	76.970	79.440	81.240	82.170	82.400	82.300	82.220
MERCHANT-POLIFEMO-HF	71.589	72.321	74.274	76.831	79.265	81.022	81.912	82.104	81.977	81.886
HIRATA-HAUSER5-HF	71.670	72.400	74.350	76.910	79.340	81.090	81.980	82.170	82.040	81.940
Mean	71.743	72.476	74.431	76.997	79.440	81.207	82.108	82.310	82.189	82.098
Standard deviation	0.191	0.191	0.193	0.194	0.196	0.202	0.206	0.212	0.217	0.221

***** Inelastic to 2nd *****

Energy = 0.5 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
FINLAY-OPSTAT-HF	0.499	0.504	0.518	0.535	0.553	0.566	0.574	0.577	0.577	0.576
FINLAY-HELENE-HF	0.480	0.490	0.500	0.520	0.530	0.540	0.550	0.560	0.560	0.560
MERCHANT-POLIFEMO-HF	0.537	0.542	0.556	0.575	0.594	0.608	0.616	0.619	0.619	0.619
HIRATA-HAUSER5-HF	0.540	0.550	0.560	0.580	0.600	0.610	0.620	0.620	0.620	0.620
Mean	0.514	0.522	0.533	0.553	0.569	0.581	0.590	0.594	0.594	0.594
Standard deviation	0.029	0.029	0.029	0.030	0.034	0.034	0.034	0.030	0.030	0.030

Energy = 1.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
FINLAY-OPSTAT-HF	8.468	8.548	8.761	9.035	9.286	9.450	9.508	9.487	9.440	9.417
FINLAY-HELENE-HF	7.840	7.920	8.110	8.370	8.600	8.750	8.810	8.780	8.740	8.720
MERCHANT-POLIFEMO-HF	8.260	8.338	8.546	8.814	9.059	9.219	9.275	9.254	9.207	9.185
HIRATA-HAUSER5-HF	8.300	8.380	8.580	8.850	9.100	9.260	9.320	9.300	9.250	9.230
Mean	8.217	8.297	8.499	8.767	9.011	9.170	9.228	9.205	9.159	9.138
Standard deviation	0.267	0.267	0.276	0.282	0.291	0.297	0.297	0.301	0.297	0.296

Energy = 2.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
FINLAY-OPSTAT-HF	22.051	22.247	22.771	23.466	24.150	24.690	25.035	25.208	25.273	25.287
FINLAY-HELENE-HF	22.090	22.290	22.810	23.510	24.180	24.700	25.020	25.160	25.190	25.190
MERCHANT-POLIFEMO-HF	22.518	22.717	23.251	23.958	24.651	25.192	25.526	25.683	25.733	25.741
HIRATA-HAUSER5-HF	22.580	22.780	23.310	24.020	24.720	25.260	25.600	25.760	25.810	25.820
Mean	22.310	22.509	23.036	23.739	24.425	24.961	25.295	25.453	25.502	25.510
Standard deviation	0.278	0.279	0.284	0.291	0.301	0.308	0.311	0.313	0.315	0.317

***** Inelastic to 3rd *****

Energy = 2.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
FINLAY-OPSTAT-HF	33.420	32.584	30.293	27.120	23.777	20.877	18.763	17.473	16.839	16.657
FINLAY-HELENE-HF	33.080	32.260	30.010	26.890	23.600	20.740	18.650	17.360	16.730	16.550
MERCHANT-POLIFEMO-HF	33.628	32.776	30.444	27.213	23.812	20.864	18.717	17.410	16.768	16.584
HIRATA-HAUSER5-HF	33.660	32.810	30.470	27.240	23.830	20.880	18.730	17.420	16.780	16.600
Mean	33.447	32.608	30.304	27.116	23.755	20.840	18.715	17.416	16.779	16.598
Standard deviation	0.267	0.252	0.211	0.159	0.106	0.067	0.048	0.046	0.045	0.045

Table B: Hauser-Feshbach Calculations
(including width fluctuation correction)

1. Total Reaction Cross Section (m barn)

Code (Participant)	Energy (lab.) MeV 0.2	0.5	1.0	2.0
WILMORE-6 (HRTW) (Chadwick)	3004	2260	2143	1999
OPSTAT (M) (Finlay)	3016	2272	2154	2007
POLIFEMO (M) (Merchant)	2995	2265	2153	2000
COMNUC (M) (Young)	2990	2270	2153	1994
MAURINA (M) (Uhl)	3000	2269	2157	2002
COMNUC (M) (Gardner)	2990	2269	2153	1994
HELGA (THW) (Weil)	3014	2262	2152	1997
HELGA (HRTW) (Weil)	3014	2262	2152	1997

2. Total Compound Elastic Cross-Section (m barn)

Code (Participant)	Energy (lab.) MeV 0.2	0.5	1.0	2.0
WILMORE-6 (HRTW) (Chadwick)	2743	1635	1162	699
OPSTAT (M) (Finlay)	2726	1630	1160	718
POLIFEMO (M) (Merchant)	2728	1619	1146	722
COMNUC (M) (Young)	2715	1601	1128	689
MAURINA (M) (Uhl)	2734	1621	1149	703
COMNUC (M) (Gardner)	2715	1600	1128	690
HELGA (THW) (Weil)	2733	1596	1121	689
HELGA (HRTW) (Weil)	2745	1633	1150	694

3. Total Inelastic Cross-Section (m barn)

Code (Participant)	Energy (lab.) MeV 0.2	0.5	1.0	2.0
WILMORE-6 (HRTW) (Chadwick)	261	625	981	1300
OPSTAT (M) (Finlay)	290	642	994	1287
POLIFEMO (M) (Merchant)	267	646	1007	1278
COMNUC (M) (Young)	275	669	1025	1304
MAURINA (M) (Uhl)	266	648	1008	1299
COMNUC (M) (Gardner)	275	669	1025	1304
HELGA (THW) (Weil)	281	666	1031	1308
HELGA (HRTW) (Weil)	269	629	1002	1303

4. Angular Distributions (m barn)

***** Compound Elastic *****

Energy = 0.2 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
CHADWICK-WILMORE6-HRTW	245.280	244.020	240.400	234.910	228.260	221.280	214.830	209.630	206.280	205.120
FINLAY-OPSTAT-M	243.780	242.510	238.850	233.330	226.690	219.780	213.440	208.380	205.120	204.000
MERCHANT-POLIFEMO-M	244.934	243.612	239.835	234.129	227.260	220.109	213.537	208.286	204.910	203.747
YOUNG-COMNUC-M	243.500	242.200	238.500	232.900	226.100	219.000	212.500	207.300	203.900	202.800
UHL-MAURINA-M	246.000	244.000	240.000	235.000	228.000	221.000	214.000	209.000	205.000	204.000
GARDNER-COMNUC-M	243.547	242.247	238.529	232.903	226.117	219.037	212.515	207.292	203.928	202.768
WEIL-HELGA-THW	243.000	242.000	238.000	233.000	227.000	220.000	214.000	209.000	206.000	205.000
WEIL-HELGA-HRTW	245.000	244.000	240.000	235.000	228.000	221.000	215.000	210.000	207.000	206.000
Mean	244.380	243.074	239.264	233.896	227.178	220.151	213.728	208.611	205.267	204.179
Standard deviation	1.060	0.912	0.894	0.973	0.852	0.882	0.932	0.992	1.099	1.135

Energy = 0.5 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
CHADWICK-WILMORE6-HRTW	167.120	165.020	159.140	150.690	141.220	132.230	124.790	119.460	116.330	115.310
FINLAY-OPSTAT-M	166.290	164.240	158.490	150.190	140.850	131.920	124.470	119.080	115.890	114.850
MERCHANT-POLIFEMO-M	165.645	163.558	157.733	149.340	139.920	130.956	123.527	118.184	115.040	114.012
YOUNG-COMNUC-M	162.900	160.900	155.300	147.200	138.200	129.500	122.300	117.100	114.000	113.000
UHL-MAURINA-M	166.000	164.000	158.000	149.000	140.000	131.000	124.000	118.000	115.000	114.000
GARDNER-COMNUC-M	162.846	160.848	155.268	147.214	138.151	129.495	122.289	117.078	113.998	112.998
WEIL-HELGA-THW	162.000	160.000	155.000	147.000	138.000	129.000	122.000	117.000	114.000	113.000
WEIL-HELGA-HRTW	168.000	166.000	160.000	151.000	141.000	132.000	124.000	119.000	116.000	115.000
Mean	165.100	163.071	157.366	148.954	139.668	130.763	123.422	118.113	115.032	114.021
Standard deviation	2.221	2.202	1.933	1.639	1.362	1.278	1.083	0.992	0.968	0.959

Energy = 1.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
CHADWICK-WILMORE6-HRTW	144.530	141.140	131.830	118.880	105.160	93.170	84.340	78.880	76.160	75.370
FINLAY-OPSTAT-M	144.720	141.310	131.940	118.900	105.090	93.010	84.100	78.570	75.810	75.000
MERCHANT-POLIFEMO-M	143.448	140.035	130.673	117.658	103.880	91.846	82.991	77.519	74.789	73.996
YOUNG-COMNUC-M	140.400	137.100	128.000	115.400	102.100	90.440	81.840	76.510	73.840	73.060
UHL-MAURINA-M	144.000	141.000	131.000	118.000	104.000	92.100	83.200	77.700	75.000	74.200
GARDNER-COMNUC-M	140.374	137.077	128.029	115.445	102.108	90.443	81.840	76.509	73.839	73.061
WEIL-HELGA-THW	141.000	137.000	128.000	115.100	101.500	89.700	81.100	75.900	73.300	72.600
WEIL-HELGA-HRTW	144.000	141.000	131.000	118.200	104.200	92.000	83.200	77.700	75.100	74.300
Mean	142.809	139.458	130.059	117.198	103.505	91.589	82.826	77.411	74.730	73.948
Standard deviation	1.885	2.022	1.749	1.617	1.418	1.266	1.143	1.041	1.004	0.979

Energy = 2.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
CHADWICK-WILMORE6-HRTW	106.210	102.550	92.660	79.350	65.900	54.900	47.480	43.400	41.640	41.190
FINLAY-OPSTAT-M	109.700	105.880	95.590	81.730	67.760	56.370	48.710	44.520	42.730	42.280
MERCHANT-POLIFEMO-M	111.336	107.402	96.791	82.533	68.198	56.544	48.763	44.554	42.786	42.347
YOUNG-COMNUC-M	104.900	101.300	91.500	78.310	65.020	54.160	46.840	42.810	41.060	40.610
UHL-MAURINA-M	107.000	104.000	93.600	80.000	66.300	55.200	47.700	43.600	41.800	41.400
GARDNER-COMNUC-M	104.990	101.354	91.542	78.345	65.048	54.184	46.862	42.823	41.078	40.627
WEIL-HELGA-THW	105.500	101.800	91.800	78.500	65.000	54.000	46.700	42.700	40.900	40.500
WEIL-HELGA-HRTW	106.100	102.400	92.400	79.000	65.500	54.500	47.100	43.000	41.300	40.800
Mean	106.967	103.336	93.235	79.721	66.091	54.982	47.519	43.426	41.662	41.219
Standard deviation	2.337	2.248	1.974	1.606	1.258	0.995	0.823	0.751	0.741	0.741

***** Inelastic to 1st *****

Energy = 0.2 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
CHADWICK-WILMORE6-HRTW	18.050	18.170	18.520	19.060	19.720	20.420	21.070	21.610	21.950	22.070
FINLAY-OPSTAT-M	19.185	19.335	19.764	20.415	21.202	22.025	22.785	23.396	23.790	23.926
MERCHANT-POLIFEMO-M	18.386	18.517	18.890	19.459	20.153	20.886	21.568	22.121	22.480	22.604
YOUNG-COMNUC-M	18.960	19.100	19.480	20.080	20.800	21.560	22.280	22.860	23.230	23.360
UHL-MAURINA-M	18.400	18.500	18.900	19.400	20.100	20.800	21.500	22.100	22.400	22.600
GARDNER-COMNUC-M	18.960	19.095	19.483	20.076	20.799	21.563	22.277	22.855	23.231	23.361
WEIL-HELGA-THW	19.000	19.100	19.500	20.100	20.800	21.500	22.200	22.800	23.100	23.300
WEIL-HELGA-HRTW	17.900	18.000	18.300	18.800	19.400	20.100	20.700	21.200	21.600	21.700
Mean	18.605	18.727	19.105	19.674	20.372	21.107	21.798	22.368	22.723	22.865
Standard deviation	0.484	0.495	0.528	0.576	0.624	0.659	0.705	0.736	0.739	0.750

Energy = 0.5 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
CHADWICK-WILMORE6-HRTW	43.590	43.890	44.700	45.900	47.260	48.600	49.740	50.590	51.100	51.270
FINLAY-OPSTAT-M	45.614	45.919	46.775	48.017	49.428	50.792	51.946	52.794	53.303	53.472
MERCHANT-POLIFEMO-M	45.069	45.364	46.195	47.407	48.795	50.150	51.310	52.175	52.700	52.875
YOUNG-COMNUC-M	46.680	46.990	47.860	49.130	50.590	52.020	53.260	54.180	54.740	54.930
UHL-MAURINA-M	45.200	45.500	46.400	47.600	49.000	50.300	51.500	52.400	52.900	53.000
GARDNER-COMNUC-M	46.645	46.954	47.824	49.096	50.556	51.990	53.224	54.149	54.714	54.902
WEIL-HELGA-THW	46.500	46.800	47.700	48.900	50.400	51.700	52.900	53.800	54.300	54.500
WEIL-HELGA-HRTW	43.900	44.200	45.000	46.200	47.600	49.000	50.100	50.900	51.400	51.600
Mean	45.400	45.702	46.557	47.781	49.204	50.569	51.748	52.624	53.145	53.319
Standard deviation	1.202	1.206	1.236	1.257	1.298	1.312	1.354	1.390	1.407	1.413

Energy = 1.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
CHADWICK-WILMORE6-HRTW	61.790	62.330	63.780	65.790	67.890	69.670	70.930	71.660	71.990	72.090
FINLAY-OPSTAT-M	63.352	63.899	65.393	67.448	69.584	71.394	72.660	73.382	73.703	73.787
MERCHANT-POLIFEMO-M	63.300	63.844	65.330	67.375	69.503	71.307	72.572	73.295	73.617	73.702
YOUNG-COMNUC-M	64.610	65.160	66.680	68.770	70.970	72.840	74.180	74.960	75.330	75.430
UHL-MAURINA-M	63.300	63.900	65.400	67.400	69.500	71.300	72.600	73.300	73.700	73.700
GARDNER-COMNUC-M	64.609	65.163	66.681	68.776	70.969	72.845	74.181	74.965	75.329	75.428
WEIL-HELGA-THW	64.600	65.200	66.800	68.900	71.100	73.000	74.300	75.000	75.400	75.500
WEIL-HELGA-HRTW	62.300	62.900	64.400	65.500	68.700	70.500	71.800	72.500	72.800	72.900
Mean	63.483	64.050	65.558	67.495	69.777	71.607	72.903	73.633	73.984	74.067
Standard deviation	1.078	1.080	1.113	1.318	1.165	1.207	1.230	1.246	1.270	1.275

Energy = 2.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
CHADWICK-WILMORE6-HRTW	58.330	58.940	60.560	62.670	64.640	65.990	66.610	66.640	66.440	66.340
FINLAY-OPSTAT-M	58.596	59.210	60.837	62.934	64.869	66.180	66.735	66.718	66.485	66.365
MERCHANT-POLIFEMO-M	57.063	57.653	59.218	61.236	63.101	64.371	64.916	64.911	64.696	64.583
YOUNG-COMNUC-M	58.490	59.090	60.700	62.790	64.720	66.040	66.630	66.650	66.440	66.330
UHL-MAURINA-M	58.000	58.600	60.200	62.200	64.200	65.500	66.000	66.000	65.800	65.700
GARDNER-COMNUC-M	58.489	59.096	60.708	62.791	64.725	66.055	66.643	66.663	66.459	66.349
WEIL-HELGA-THW	58.300	59.000	60.600	62.800	64.700	66.100	66.700	66.700	66.500	66.400
WEIL-HELGA-HRTW	58.100	58.700	60.400	62.400	64.500	65.800	66.400	66.400	66.200	66.100
Mean	58.171	58.786	60.403	62.478	64.432	65.754	66.329	66.335	66.128	66.021
Standard deviation	0.491	0.502	0.518	0.557	0.574	0.599	0.619	0.624	0.625	0.626

***** Inelastic to 2nd *****

Energy = 0.5 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
CHADWICK-WILMORE6-HRTW	0.700	0.707	0.726	0.750	0.774	0.791	0.799	0.801	0.799	0.798
FINLAY-OPSTAT-M	0.713	0.720	0.739	0.764	0.788	0.805	0.813	0.815	0.813	0.812
MERCHANT-POLIFEMO-M	0.769	0.777	0.797	0.824	0.849	0.868	0.877	0.878	0.876	0.875
YOUNG-COMNUC-M	0.730	0.738	0.757	0.782	0.807	0.824	0.833	0.835	0.834	0.833
UHL-MAURINA-M	0.785	0.793	0.814	0.841	0.867	0.885	0.895	0.896	0.894	0.893
GARDNER-COMNUC-M	0.731	0.738	0.758	0.783	0.807	0.825	0.834	0.836	0.835	0.834
WEIL-HELGA-THW	0.727	0.734	0.753	0.779	0.803	0.820	0.829	0.830	0.828	0.827
WEIL-HELGA-HRTW	0.758	0.766	0.786	0.812	0.837	0.855	0.863	0.864	0.862	0.861
Mean	0.739	0.747	0.766	0.792	0.816	0.834	0.843	0.844	0.843	0.842
Standard deviation	0.029	0.029	0.030	0.031	0.032	0.032	0.033	0.032	0.032	0.032

Energy = 1.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
CHADWICK-WILMORE6-HRTW	7.610	7.690	7.880	8.130	8.350	8.500	8.550	8.530	8.490	8.470
FINLAY-OPSTAT-M	8.377	8.456	8.666	8.936	9.184	9.347	9.406	9.387	9.342	9.320
MERCHANT-POLIFEMO-M	8.020	8.096	8.297	8.556	8.793	8.949	9.005	8.986	8.942	8.921
YOUNG-COMNUC-M	7.891	7.965	8.163	8.418	8.652	8.806	8.862	8.845	8.803	8.782
UHL-MAURINA-M	8.050	8.120	8.320	8.580	8.820	8.980	9.040	9.020	8.980	8.950
GARDNER-COMNUC-M	7.891	7.965	8.163	8.418	8.652	8.806	8.862	8.844	8.802	8.782
WEIL-HELGA-THW	8.180	8.250	8.460	8.730	8.970	9.120	9.180	9.150	9.100	9.080
WEIL-HELGA-HRTW	8.150	8.230	8.440	8.700	8.840	9.090	9.150	9.120	9.070	9.050
Mean	8.021	8.097	8.299	8.559	8.783	8.950	9.007	8.985	8.941	8.920
Standard deviation	0.230	0.230	0.237	0.244	0.246	0.254	0.257	0.255	0.252	0.252

Energy = 2.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
CHADWICK-WILMORE6-HRTW	19.510	19.680	20.150	20.780	21.390	21.880	22.200	22.360	22.420	22.440
FINLAY-OPSTAT-M	19.684	19.861	20.335	20.968	21.600	22.117	22.475	22.685	22.788	22.818
MERCHANT-POLIFEMO-M	19.375	19.548	20.013	20.632	21.248	21.745	22.080	22.268	22.353	22.376
YOUNG-COMNUC-M	19.650	19.830	20.300	20.930	21.550	22.050	22.390	22.580	22.660	22.680
UHL-MAURINA-M	19.800	20.000	20.500	21.100	21.700	22.200	22.600	22.800	22.900	22.900
GARDNER-COMNUC-M	19.641	19.817	20.289	20.917	21.541	22.044	22.379	22.565	22.647	22.668
WEIL-HELGA-THW	19.800	20.000	20.400	21.100	21.700	22.200	22.500	22.700	22.800	22.800
WEIL-HELGA-HRTW	19.800	20.000	20.400	21.100	21.700	22.200	22.500	22.700	22.800	22.800
Mean	19.658	19.842	20.298	20.941	21.554	22.055	22.391	22.582	22.671	22.685
Standard deviation	0.153	0.164	0.154	0.169	0.163	0.166	0.172	0.183	0.194	0.188

***** Inelastic to 3rd *****

Energy = 2.0 MeV

Participants	ANGLE (Deg) 0	10	20	30	40	50	60	70	80	90
CHADWICK-WILMORE6-HRTW	27.290	26.550	24.550	21.780	18.890	16.460	14.620	13.560	13.060	12.920
FINLAY-OPSTAT-M	27.714	26.957	24.890	22.042	19.069	16.528	14.715	13.643	13.138	12.998
MERCHANT-POLIFEMO-M	27.438	26.689	24.641	21.819	18.874	16.355	14.556	13.490	12.986	12.846
YOUNG-COMNUC-M	27.490	26.750	24.730	21.940	19.030	16.520	14.720	13.640	13.120	12.970
UHL-MAURINA-M	27.700	26.900	24.800	22.000	19.000	16.400	14.600	13.500	13.000	12.900
GARDNER-COMNUC-M	27.494	26.756	24.735	21.947	19.028	16.520	14.717	13.637	13.119	12.974
WEIL-HELGA-THW	27.800	27.000	24.900	22.000	19.100	16.600	14.700	13.700	13.200	13.000
WEIL-HELGA-HRTW	27.600	26.800	24.800	21.900	19.000	16.400	14.600	13.500	13.000	12.900
Mean	27.566	26.800	24.756	21.929	18.999	16.473	14.654	13.584	13.078	12.939
Standard deviation	0.169	0.148	0.119	0.091	0.080	0.083	0.066	0.081	0.078	0.055

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ANNEX

Statistical Model Participants and Contributions

Participant	Computer Code	Comments
Avrigeanu, Rumania	STAPRE	M-no ang. dist.
Chadwick, UK	WILMORE6	HF, M, HRTW
Gardner, USA	COMNUC	M
Finlay, USA	OPSTAT	HF, M, THW, HRTW
Finlay, USA	HELENE	HF, M
Hirata, Brazil	HAUSER5	HF, HRTW
Merchant, Brazil	POLIFEMO	HF, M
Sheldon, USA	CINDY	HF, M
Sheldon, USA	JACQUI	HF, M-no ang. dist.
Sheldon, USA	NANCY	HRTW
Uhl, Austria	MAURINA	M
Weil, USA	HELGA	THW, HRTW
Weil, USA	HFCODE	THW-no ang. dist.
Young, USA	COMNUC	M

HF: Hauser-Feshbach calculations without WFC

M: Moldauer WFC

THW: Tepel-Hofmann-Weidenmüller WFC

HRTW: Hofmann-Richert-Tepel-Weidenmüller WFC