COO--2458-18

A MULTIGROUP FORMALISM FOR EVALUATION OF CONTINUOUS SLOWING DOWN THEORY PARAMETERS

MASTER

by

Ansar Parvez and Martin Becker
Department of Nuclear Engineering
Rensselaer Polytechnic Institute
Troy, New York

950 0535

No. of pages : 11

No. of tables: 3

No. of Figs. : 3

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

* Sponsored by USERDA under Contract No.E(11-1)-2458

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

Continuous slowing down theory calculations have been found to yield significant discrepancies in the presence of strong absorption. An algorithm has been formulated for evaluating continuous slowing down theory parameters which should be applicable for cases with strong absorption. Excellent agreement with more precise calculations is obtained when the new parameters are used.

I. INTRODUCTION

The Continuous Slowing Down Theory (CSDT) provides a useful analytical model to predict the behavior of slowing down neutrons. However, two limitations are generally encountered in applying the CSDT to situations of general interest, such as the reactor assembly or an assembly consisting of a single material. These limitations arise from the inelastic slowing down of neutrons and their removal from the system due to absorption and/or leakage. In effect, both of these phenomena may cause a perturbation in the flux too large to be adequately handled by a conventional one term Taylor series expansion.[1] While a variety of efforts have been made to generalize the CSDT, a typical solution is to retain the conventional form of the Greuling-Goertzel[2] CSDT equations and incorporate inelastic scattering and/or absorption by redefining the slowing down parameters ξ and γ.

Along these lines ξ was defined[3] at RPI by employing a zero absorption reference case and choosing a ξ that forced the correct solution. The method presented only an ad-hoc definition for γ, which permitted excellent results for typical fast reactor spectra[4], but failed to make satisfactory predictions for spectra in individual materials where absorption formed a substantial part of the total cross section. Such spectra have been measured at RPI in different materials, and while the transport theory is used to provide a dependable basis for comparison between theory and experiment, the CSDT acts as an

analytical tool through which the theory experiment discrepancies can be interpreted.

Improvement was introduced later in evaluating ξ and γ by including the effect of absorption in the definition of ξ (through an iteration scheme) and by arriving at a definition of γ through separable kernels.[5] However, these ξ and γ fall short of yielding satisfactory agreement with transport calculations in the energy regions where absorption and/or leakage are comparable to the scattering. This lack of satisfactory agreement has been attributed by the authors to the reliance on the iteration scheme on an attenuation formula that is based on a weak absorption assumption, and therefore does not involve an exact reference slowing down density in the presence of absorption. A new method will be presented here to obtain the slowing down parameters ξ and γ in situations where absorption and/or leakage are high.

II. MULTIGROUP APPROACH TO DETERMINE SLOWING DOWN PARAMETER

This method combines an infinite medium multigroup (MG) solution and the Grueling Goertzel (GG) relationship. Reference group fluxes $\phi(J)$ and the slowing down densities $q(J)$ are obtained from the space independent MG solution and are compared with GG approximation to define ξ and γ.

The procedure to solve a space independent multigroup problem is very simple. Writing the steady state balance equation for the Jth group one gets

$$D(J)\nabla^2\phi(J) - \Sigma_a(J)\phi(J) + \sum_{h=1}^{h=J-1} \Sigma_{h\to g}\,\phi(h) - \sum_{h=J+1}^{N} \Sigma_{g\to h}\,\phi(g) + S(J) = 0 \quad (1)$$

where $\Sigma_{g\to h}$ is the transfer cross section from group g to group h

and other symbols have their usual meanings. There is no in-scattering to the first group and therefore the above equation reduces to

$$D(1)\nabla^2\phi(1) - \Sigma_a(1)\phi(1) \sum_{h=2}^{N} \Sigma_{1\to h}\,\phi(1) + S(1) = 0 \quad (2)$$

By approximating $D\nabla^2\phi(1)$ by $-DB^2\phi(1)$ and from a knowledge of multigroup cross sections and transfer matrices, Eq. 2 can be solved to obtain $\phi(1)$ as

$$\phi(1) = \frac{S(1)}{D(1)B^2 + \Sigma_a(1) + \sum_{k=2}^{N} \Sigma_{1\to h}} \quad (3)$$

With $\phi(1)$ known, Eq. 1 can be used to obtain $\phi(2)$ and then to obtain $\phi(3)$ when $\phi(1)$ and $\phi(2)$ are known. Continuing in this manner all the group fluxes can be ascertained.

Once the fluxes have been determined, the slowing down density at the bottom of group J or at the top of group J+1 is simply given by

$$q_b(J) = q_t(J+1) = \sum_{i=1}^{J} \sum_{h=J+1}^{N} \sum_{i \to h} \phi(i) \tag{4}$$

We can now compare the multigroup solutions with the GG approximation for flux in an infinite medium where

$$\phi(u) = \frac{S(u)}{\Sigma_t(u)} + \frac{q(u)}{\left[\xi(u)\Sigma(u)+\gamma(u)\Sigma_a(u)\right]} \tag{5}$$

The GG equation can be written in a multigroup form at the top and bottom of each group, such that

$$\phi(J) = \frac{S_t(J)}{\Sigma_t(J)} + \frac{q_t(J)}{\left[\xi(J)\Sigma_s(J)+\gamma(J)\Sigma_a(J)\right]_t} \tag{6}$$

and

$$\phi(J) = \frac{S_b(J)}{\Sigma_t(J)} + \frac{q_b(J)}{\left[\xi(J)\Sigma_s(J)+\gamma(J)\Sigma_a(J)\right]_b} \tag{7}$$

where $S_t(J)$ and $S_b(J)$ are the sources at the top and bottom of each group, and $q_t(J)$ and $q_b(J)$ are the slowing down densities at the same points.

For a given source distribution, the only unknown in Eqs. 6 and 7 is the GG coefficient $(\xi\Sigma_s+\gamma\Sigma_a)$ since $q_t(J)$, $q_b(J)$, and $\phi(J)$ have been determined from the multigroup treatment. The GG coefficient at the top and bottom of the group then contains ξ and γ at the top and bottom of that group.

III. USEFULNESS OF THE MULTIGROUP METHOD

The multigroup formalism to generate ξ and γ has been tested by using these parameters in the Fermi Age equation and comparing the Age-Solution with the transport solutions. Typically these spectra have been compared for uranium, iron, and sodium. Figs. 1 and 2 shows these comparisons for uranium and iron respectively. The high energy disagreement in uranium spectra are known to be caused by the limitations in the validity of age theory at these energies. Notwithstanding this discrepancy, there is a general agreement even in those energy regions where the leakage as absorption constitute a significant part of the total cross section. (i.e., the 10 keV to 50 keV energy region for uranium and the 24.3 keV minimum in iron).

Knowing a method to determine $\xi\Sigma_s + \gamma\Sigma_a$, interest is turned to separate out a ξ and γ from this expression. Obtaining ξ is useful because this single parameter reflects a complete overview of the inelastic scattering and the secondary distribution of the scattered neutrons. Likewise, γ is a quantity which can be associated with the absorption and the leakage by which a system is characterized. Thus, these two parameters provide a physical understanding of the relationship between the neutron spectra and the basic cross sections.

Limiting ourselves initially to systems having no absorption or leakage we notice that ξ can easily be retrieved from the GG coefficient since the expression $\xi\Sigma_s + \gamma\Sigma_a$ reduces to

$\xi\Sigma_s$ with ξ being the only unknown. Not surprisingly, this ξ shows agreement with that obtained according to Reference 3 for a similar situation. This comparison is made in Fig. 3. The good agreement between the two ξ's points towards the equivalence of the two methods under the conditions of no absorption.

If, however, an absorption does exist in a system, one is left with two unknowns (ξ and γ) in the GG coefficient and a second relationship may be required between ξ and γ before these can be evaluated separately. It has been shown[4] that the approximation $\gamma = \xi$ yields satisfactory results in dealing with most fast reactor compositions where a mixture of different materials is present and the macroscopic absorption cross section is negligible compared to the macroscopic scattering cross section. If use is made of this assumption, a ξ or γ can again be obtained from the GG coefficient. This also establishes the essential correspondence between the MG and Dunn's method such that one can still apply Dunn's algorithm[3] in treating the isolated resonances in a mixture of several materials.

In a system where the absorption cannot be neglected in comparison with the scattering, the approximation $\gamma=\xi$ does not provide the best results even though it is implied by conservation arguments[5]. If we postulate at this point that ξ is a parameter which represents the scattering behavior only, while γ alone takes care of the absorption, we can evaluate both ξ and γ

from the GG coefficient. The procedure is simple. First a zero absorption ξ can be obtained by setting the absorption and leakage equal to zero. This ξ is then substituted back in $\xi\Sigma_s + \gamma\Sigma_a$ calculated with $\Sigma_a \neq 0$ and a value is obtained for γ. By doing so we define a γ to give us the right results and at the same time we maintain the form of ξ obtained for a pure scattering case. This value of γ gives us insight into the sensitivity of neutron spectra to the absorption cross section.

It is also of interest to examine the sensitivity of γ to the amount of absorption present in a system. Such a study has been specifically conducted for uranium, iron, and sodium by changing the ENDF/B-IV absorption cross sections uniformly by a factor of 0.5 to 1.5. Tables I to III present these results. For the sake of reference the table also includes the ξ obtained from the GG coefficient by using $\gamma = \xi$.

For uranium, γ does not change significantly with a change in absorption for the most part but shows strong variations in the low keV range where one approaches the limiting case of elastic scattering and the absorption is high. Also noteworthy is the fact that for any given absorption rate, near and below the inelastic threshold where ξ decreases rapidly to its elastic limit, γ declines only slowly. Such a behavior for γ is consistent with that noted by Kamei[6] where the slowing down parameters are calculated by a Taylor Series expansion. A similar trend is observed for iron and sodium. In addition, over

the entire energy range very significant variations occur in γ. Rather large (numerically) values of γ for iron and sodium result from the extremely small absorption cross-section of these materials, and the fact that this cross section appears in the denominator in the evaluation of γ.

In principle, the multigroup procedure could be used to an arbitrary degree of energy detail for the purpose of generating $\xi\Sigma_s+\gamma\Sigma_a$ and the resulting ξ and γ parameters for use in space-dependent analyses. In practice, however, inelastic scattering is a process characterized by smooth variation with energy. It therefore should be appropriate to utilize ξ and γ values obtained on a multigroup basis with cross-section data of a more refined nature. Obtaining ξ and γ values based on multigroup inelastic cross-section matrices for subsequent use with more refined energy detail was found to be acceptable in earlier work[3].

IV. SUMMARY

An algorithm has been developed for evaluation of continuous slowing down theory parameters ξ and γ in the presence of strong absorption. Spectra predicted with ξ and γ so obtained are in excellent agreement with precise calculations.

REFERENCES

1. R. V. Meghreblian and D. K. Holmes, "Reactor Analysis," McGraw Hill Book Company, Inc. (1960).

2. G. Greuling and G. Goertzel, "An Approximate Method for Treating Neutron Slowing Down," Nucl. Sci. Eng., 7, 69 (1960).

3. F. E. Dunn and M. Becker, "Improvements to Neutron Slowing Down Theory for Fast Reactors," Nucl. Sci. Eng., 47, 66 (1972).

4. F. E. Dunn and M. Becker, "The Formulation and Application of Fast Reactor Flux and Importance Spectra," Nucl. Sci. Eng., 47, 83 (1972).

5. M. Becker and E. T. Burns, "The Formulation of Continuous Slowing Down Theory for General Processes in Terms of Separable Kernels," Nucl. Sci. Eng., 42, 89 (1970).

6. Takanobu Kamei, "Generalized Continuous Neutron Slowing-Down Theory," Nucl. Sci. Eng., 57, (1975).

TABLE I

SLOWING DOWN PARAMETERS FOR URANIUM FROM THE MG METHOD

Group	Top Energy	ξ with $\gamma=\xi$	ξ $\Sigma_a = 0$	γ $1.0\Sigma_a$	γ $0.5\Sigma_a$	γ $1.5\Sigma_a$
1	1.0000E 07	0.07568	0.07623	0.07206	0.07273	0.07142
2	8.8240E 06	0.26014	0.23124	0.44898	0.41968	0.48388
3	7.7880E 06	0.20623	0.19108	0.30725	0.29749	0.31858
4	6.8720E 06	0.19685	0.18511	0.30439	0.29034	0.31962
5	5.3520E 06	0.16648	0.17289	0.08638	0.07670	0.09426
6	4.7230E 06	0.17738	0.18116	0.12956	0.12329	0.13462
7	4.1680E 06	0.19233	0.10436	0.16645	0.15262	0.16951
8	3.6780E 06	0.21276	0.21399	0.19689	0.19438	0.19890
9	3.2460E 06	0.23878	0.23912	0.23445	0.23315	0.23547
10	2.8650E 06	0.28130	0.27695	0.33344	0.33606	0.33120
11	2.2310E 06	0.32298	0.31459	0.41827	0.42317	0.41412
12	1.9690E 06	0.34092	0.33327	0.43189	0.43657	0.42792
13	1.7370E 06	0.35147	0.34960	0.37785	0.37908	0.37676
14	1.5330E 06	0.33552	0.34496	0.12260	0.11068	0.13287
15	1.3530E 06	0.28982	0.30484	0.37813	0.41789	0.34363
16	1.1940E 06	0.24061	0.24949	0.20139	0.22840	0.17775
17	1.0530E 06	0.16914	0.16887	0.18376	0.18079	0.18636
18	8.2080E 06	0.13555	0.13274	0.30553	0.30752	0.30352
19	7.2430E 05	0.10279	0.09880	0.36402	0.36765	0.36053
20	6.3920E 05	0.08348	0.07923	0.38685	0.39027	0.38347
21	5.6410E 05	0.07093	0.06668	0.39380	0.39624	0.39128
22	4.9780E 05	0.06208	0.05799	0.38981	0.39108	0.38837
23	4.3930E 05	0.05576	0.05187	0.37871	0.37864	0.37850
24	3.8770E 05	0.04733	0.04334	0.38764	0.38633	0.38852
25	3.0190E 05	0.04383	0.04036	0.33518	0.33197	0.33790
26	2.6640E 05	0.04235	0.03893	0.32268	0.31861	0.32628
27	2.3510E 05	0.04101	0.03755	0.31281	0.30784	0.31732
28	2.0750E 05	0.04053	0.03701	0.30268	0.29696	0.30798
29	1.8310E 05	0.04005	0.03652	0.29886	0.29230	0.30501
30	1.6160E 05	0.03927	0.03524	0.32073	0.31324	0.32782
31	1.2580E 05	0.03632	0.03254	0.28719	0.27955	0.29470
32	1.1100E 05	0.03426	0.02885	0.31672	0.30846	0.32484
33	9.8030E 04	0.03192	0.02751	0.30564	0.29763	0.31370
34	8.6510E 04	0.02967	0.02518	0.28968	0.28286	0.29673
35	7.6350E 04	0.02804	0.02385	0.28655	0.27992	0.29346
36	6.7370E 04	0.02707	0.02106	0.29425	0.28590	0.30260
37	5.9460E 04	0.02542	0.01668	0.35943	0.35160	0.36687
38	4.6300E 04	0.02184	0.01413	0.28478	0.27111	0.29683
39	4.0860E 04	0.02116	0.01294	0.29319	0.27251	0.31016
40	3.6060E 04	0.02022	0.01184	0.28630	0.26174	0.30479
41	3.1820E 04	0.01989	0.01110	0.28553	0.25443	0.30820
42	2.8080E 04	0.01948	0.01053	0.27993	0.24391	0.30474
43	2.4780E 04	0.02077	0.00975	0.32293	0.28569	0.34368
44	1.9300E 04	0.01875	0.00950	0.25785	0.21371	0.28340
45	1.7030E 04	0.01855	0.00928	0.24822	0.20230	0.27212
46	1.5030E 04	0.01689	0.00900	0.20585	0.16994	0.22138
47	1.3260E 04	0.01400	0.00069	0.13792	0.11880	0.14556
48	1.1700E 04	0.01069	0.00844	0.06169	0.06204	0.06119

TABLE II

SLOWING DOWN PARAMETERS FOR IRON FROM THE MG METHOD

Group	Top Energy	ξ with $\gamma=\xi$	ξ $\Sigma_a=o$	γ $1.0\Sigma_a$	γ $0.5\Sigma_a$	γ $1.5\Sigma_a$
1	1.0000E 07	0.08582	0.06231	0.06668	0.06673	0.06660
2	8.8240E 06	0.13024	0.15136	0.19233	0.18876	0.19507
3	7.7880E 06	0.18349	0.16431	0.12078	0.11801	0.12366
4	6.8720E 06	0.45687	0.22244	0.18279	0.17931	0.18808
5	5.3520E 06	0.23131	0.22329	-0.16907	-0.17947	-0.16029
6	4.7230E 06	0.25326	0.22685	-0.21549	-0.21700	-0.20917
7	4.1680E 06	0.26160	0.24321	-0.25526	-0.26208	-0.24709
8	3.6780E 06	0.25396	0.24016	-0.27778	-0.29779	-0.26534
9	3.2460E 06	0.23360	0.22765	-0.34753	-0.37486	-0.33271
10	2.8650E 06	0.26688	0.19137	-0.45685	-0.48919	-0.44008
11	2.2310E 06	0.18684	0.21099	-0.70269	-0.72650	-0.68727
12	1.9690E 06	0.18306	0.19021	-0.55988	-0.55551	-0.55500
13	1.7370E 06	0.19134	0.19779	-0.50951	-0.53939	-0.49369
14	1.5330E 06	0.18784	0.19191	-0.21781	-0.21364	-0.21500
15	1.3530E 06	0.15580	0.16832	-0.01279	-0.00959	-0.01747
16	1.1940E 06	0.16352	0.17450	0.14587	0.14181	0.14874
17	1.0530E 06	0.13390	0.12315	0.43716	0.46487	0.42823
18	8.2080E 06	0.09042	0.09681	0.40401	0.40460	0.40402
19	7.2430E 05	0.06552	0.07208	0.31648	0.31609	0.31685
20	6.3920E 05	0.04913	0.05391	0.31477	0.31427	0.31537
21	5.6410E 05	0.04596	0.05077	0.41900	0.42025	0.41922
22	4.9780E 05	0.04503	0.05002	0.43697	0.43433	0.43859
23	4.3930E 05	0.04604	0.05153	0.55587	0.55587	0.55746
24	3.8770E 05	0.03396	0.03696	0.31529	0.31338	0.31670
25	3.0190E 05	0.03554	0.03894	0.26868	0.26873	0.26975
26	2.6640E 05	0.03764	0.04104	0.27542	0.27463	0.27701
27	2.3510E 05	0.03670	0.03988	0.28272	0.27854	0.28566
28	2.0750E 05	0.03425	0.03709	0.35422	0.35252	0.35685
29	1.8310E 05	0.03565	0.03830	0.21714	0.21536	0.21906
30	1.6160E 05	0.03393	0.03582	0.28080	0.27948	0.28287
31	1.2580E 05	0.03755	0.03966	0.21622	0.21355	0.21890
32	1.1100E 05	0.03726	0.03902	0.21013	0.20912	0.21233
33	9.8030E 04	0.03723	0.03884	0.22777	0.22224	0.23187
34	8.6510E 04	0.03701	0.03840	0.14757	0.14638	0.14926
35	7.6350E 04	0.03494	0.03603	0.14269	0.14085	0.14467
36	6.7370E 04	0.03673	0.03786	0.16284	0.15947	0.16581
37	5.9469E 04	0.03559	0.03650	0.25026	0.24460	0.25460
38	4.6300E 04	0.03598	0.03692	0.24503	0.23365	0.25251
39	4.0860E 04	0.03586	0.03657	0.12584	0.12272	0.12822
40	3.6060E 04	0.03603	0.03667	0.14797	0.14541	0.15065
41	3.1820E 04	0.03683	0.03742	0.26099	0.25697	0.26655
42	2.8080E 04	0.02832	0.02868	0.08151	0.08228	0.08168
43	2.4780E 04	0.04132	0.04183	0.13522	0.13458	0.13576
44	1.9300E 04	0.03635	0.03680	0.10206	0.10032	0.10391
45	1.7030E 04	0.03576	0.03610	0.14676	0.14347	0.15054
46	1.5030E 04	0.03573	0.07158	0.07158	0.07190	0.07175
47	1.3260E 04	0.03570	0.03594	0.07870	0.08349	0.07748
48	1.1700E 04	0.03584	0.03601	0.06253	0.06289	0.06241

TABLE III

SLOWING DOWN PARAMETERS FOR SODIUM FROM THE MG METHOD

Group	Top Energy	ζ $\gamma=\zeta$	ζ $\Sigma_a = 0$	γ $1.0\ \Sigma_a$	γ $0.5\ \Sigma_a$	γ $1.5\ \Sigma_a$
1	1.0000E 07	0.23166	0.27837	0.48089	0.46829	0.49400
2	7.5000E 06	0.30806	0.48667	1.58651	1.50529	1.67478
3	5.6200E 06	0.32467	0.32450	0.25342	0.23675	0.26885
4	4.2100E 06	0.31200	0.26398	-2.75576	-2.89187	-2.64183
5	3.1600E 06	0.29121	0.24422	-19.48511	-20.05288	-18.87980
6	2.3700E 06	0.25124	0.20932	-14.60101	-14.81482	-14.23621
7	1.7800E 06	0.19406	0.16277	-9.15222	-9.82649	-8.75924
8	1.3300E 06	0.17096	0.15222	-4.60107	-4.41287	-4.56640
9	1.0000E 06	0.14936	0.13206	-2.50306	-3.03605	-2.28085
10	7.5100E 05	0.14306	0.14029	-1.56889	-1.85716	-1.44215
11	5.6300E 05	0.13125	0.13168	-1.21605	-1.53384	-1.08676
12	4.2200E 05	0.11899	0.12122	-0.48297	-0.21031	-0.55327
13	3.1700E 05	0.13891	0.14231	-0.37516	-0.28526	-0.39074
14	2.3700E 05	0.13382	0.13731	-0.10693	-0.02795	-0.14266
15	1.7800E 05	0.10870	0.11389	-0.14160	-0.26127	-0.09626
16	1.3300E 05	0.09287	0.09730	0.07542	0.12844	0.06204
17	1.0000E 05	0.09249	0.09662	0.13035	0.14946	0.12529
18	7.5200E 04	0.08447	0.08731	0.09260	0.06213	0.10379
19	5.6400E 04	0.08576	0.08852	0.10662	0.08202	0.11553
20	4.2300E 04	0.08649	0.08008	0.22661	0.22838	0.22635
21	3.1700E 04	0.08585	0.08765	0.11331	0.11150	0.11398
22	2.3800E 04	0.08554	0.08657	0.22760	0.27521	0.21227
23	1.7800E 04	0.08530	0.08628	0.11650	0.07652	0.13017
24	1.3300E 04	0.08615	0.08625	0.07003	0.03755	0.08101
25	1.0000E 04	0.08717	0.08705	0.08062	0.08366	0.07964
26	7.5300E 03	0.08638	0.08610	0.07136	0.07461	0.07030
27	5.6500E 03	0.08589	0.08593	0.06976	0.04716	0.07738
28	4.2400E 03	0.08628	0.08640	0.06882	0.02652	0.08306
29	3.1800E 03	0.08664	0.08652	0.07243	0.07148	0.07275
30	2.3800E 03	0.08672	0.08664	0.16608	0.24197	0.14094
31	1.7800E 03	0.08592	0.08634	0.09321	0.05902	0.10471
32	1.3400E 03	0.08559	0.08601	0.15708	0.19289	0.14519
33	1.0000E 03	0.08552	0.08590	0.15502	0.19284	0.14252
34	7.5500E 02	0.08506	0.08606	0.27818	0.34027	0.25755
35	5.6600E 02	0.08431	0.08492	0.18190	0.25071	0.15896
36	4.2400E 02	0.08525	0.08557	0.10002	0.09386	0.10208
37	3.1800E 02	0.08509	0.08540	0.11574	0.12468	0.11276
38	2.3800E02	0.88511	0.08543	0.11851	0.12819	0.11528
39	1.7900E 02	0.08479	0.08505	0.10226	0.10240	0.10220
40	1.3900E 02	0.08549	0.08535	0.07314	0.07390	0.07288
41	1.0000E 02	0.08692	0.08651	0.06155	0.06124	0.06165
42	7.5600E 01	0.08660	0.08642	0.06743	0.06654	0.06772
43	5.6700E 01	0.08216	0.08215	0.08138	0.08276	0.08092
44	4.2500E 01	0.08409	0.08427	0.10361	0.10252	0.10397
45	3.1900E 01	0.08316	0.08354	0.15501	0.15696	0.15436
46	2.3900E 01	0.08307	0.08352	0.13631	0.13593	0.13643
47	1.7900E 01	0.08348	0.08387	0.13749	0.13901	0.13698
48	1.3400E 01	0.08553	0.08592	0.14524	0.14665	0.14478

FIGURE CAPTIONS

Fig. 1 Comparison of MG-CSDT-Age and Transport Calculations for Uranium.

Fig. 2 Comparison of MG-CSDT-Age and Transport Calculations for Iron.

Fig. 3 Convergence between the MG method and Earlier Methods (Ref. 3) in the Limiting Case of no Absorption.

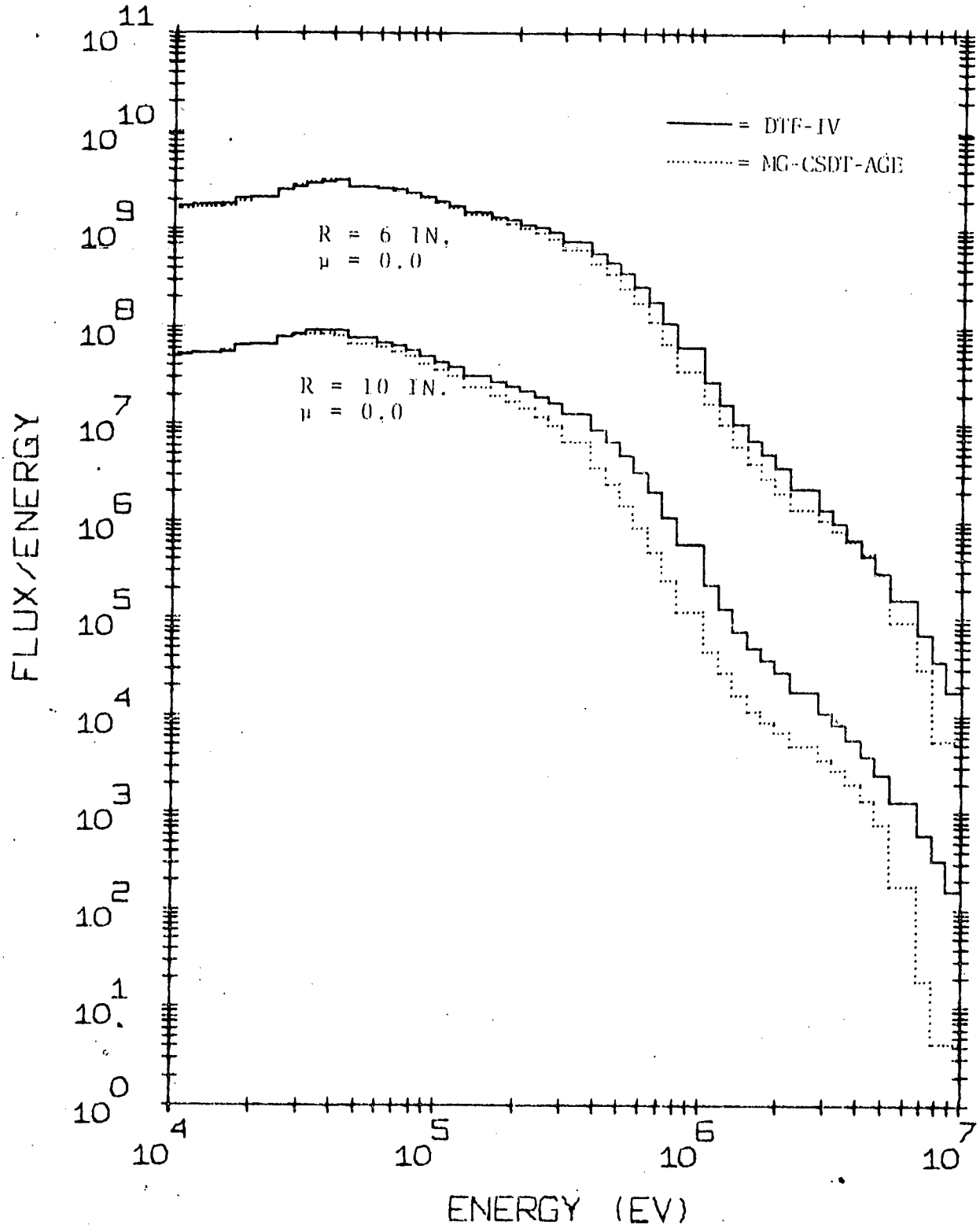
= DTF-IV
= MG-CSDT-AGE
R = 6 IN.
μ = 0.0
R = 10 IN.
μ = 0.0
FLUX/ENERGY
ENERGY (EV)
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^4
10^5
10^6
10^7

Fig. 1

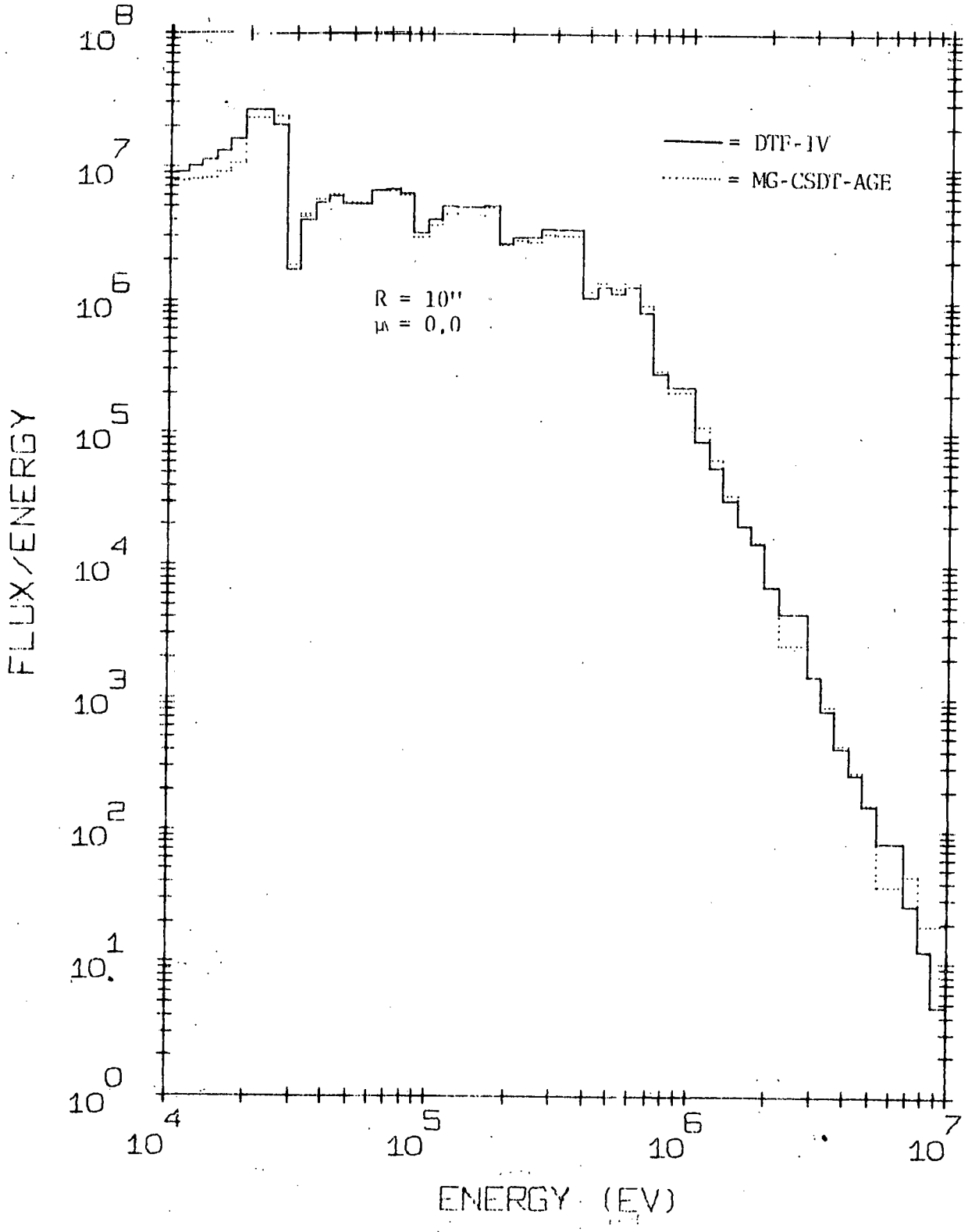
= DTF-IV
= MG-CSDF-AGE
R = 10"
μ = 0,0
FLUX/ENERGY
ENERGY (EV)
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^4
10^5
10^6
10^7

Fig. 2

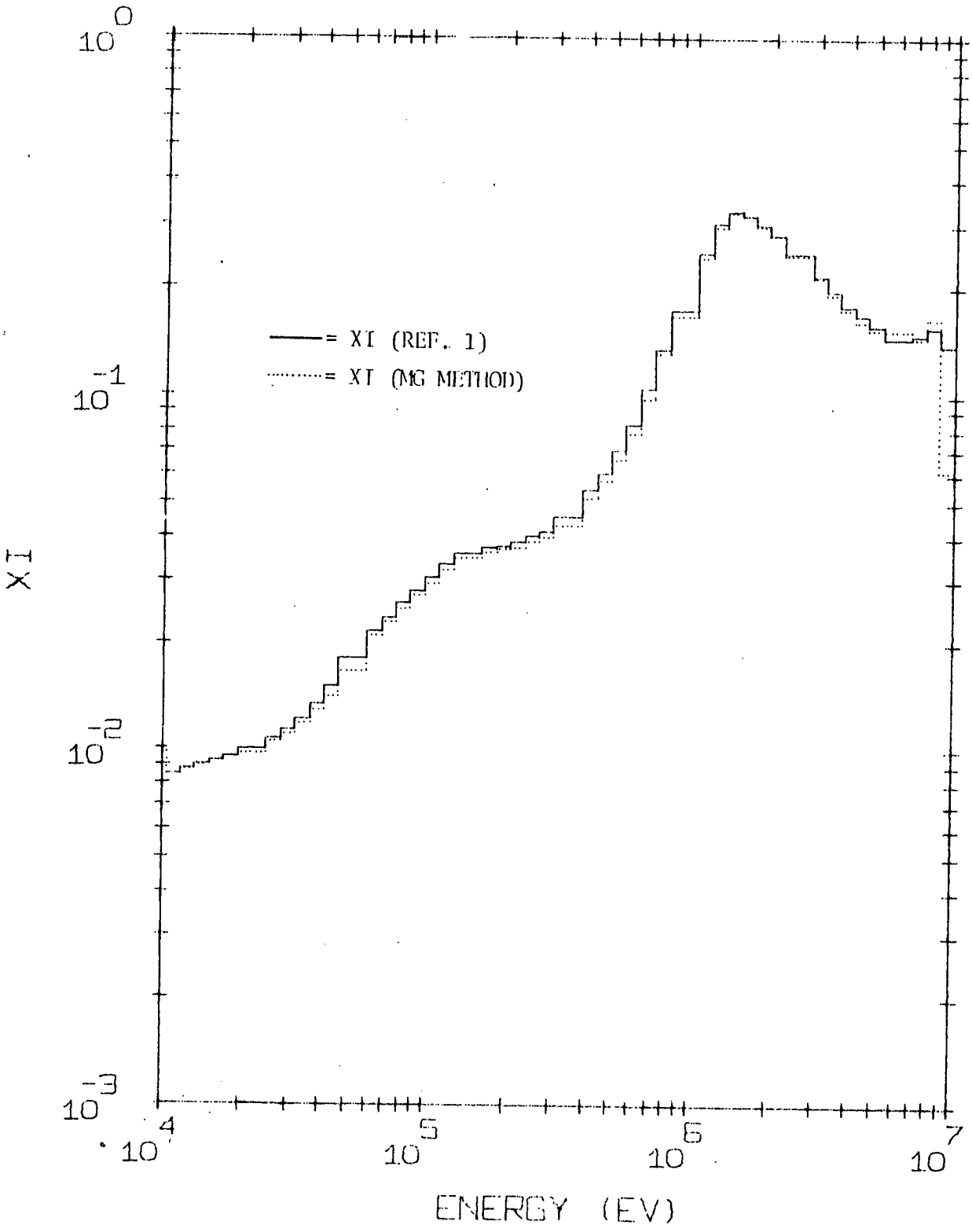
10^0
10^-1
10^-2
10^-3
XI
= XI (REF. 1)
= XI (MG METHOD)
10^4
10^5
10^6
10^7
ENERGY (EV)

Fig. 3