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ABSTRACT

The program described in this report computes the reactivity changes associated with slurry settling in a one-region cylindrical slurry reactor. Nuclear-data computation has been included in the program in order to avoid tedious hand calculations and to reduce the amount of input data required. About 3000 cases may be processed per hour of machine time. Certain modifications to the conventional two-group method and techniques employed in improving the rate of convergence of certain iterative procedures are discussed in detail. Sample input sheets, output sheets and instructions for input data preparation are included.

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RAPID TRANSIT - A REACTIVITY SURVEY PROGRAM FOR THE IBM-704

C. W. Nestor, Jr.

INTRODUCTION

The Rapid-Transit program is designed to provide a means of computing estimates of the reactivity changes introduced in a small one-region cylindrical slurry reactor due to settling of the slurry. The main objectives of the design are to provide a program which requires as small an amount of input data as possible and which will give answers for a large number of cases in concise form in as short a time as possible. In order to meet these objectives certain assumptions have been made. The principal assumptions are that the two-group model (with a modification to allow for resonance fission and capture by fuel material) is an adequate one, and that the reactor, when slurry has settled, may be treated as if it were composed of two homogeneous regions.

The derivation of the additional source term in the fast group and the solutions for the initial critical fuel concentration and the effective multiplication constant are outlined below and discussed in detail in Appendix 1.

In order to minimize the amount of input data required for each case, nuclear constants are calculated for each reactor from input data provided for the moderator, fuel and temperature of interest. The expressions for these calculations and constants for a typical case are given in Appendix 2.

TWO-GROUP, TWO-REGION EQUATIONS

Initially, the reactor is treated as a bare cylinder and the critical fuel concentration calculated; for a series of cases, a settled height is read in and the effective multiplication constant calculated assuming all the fuel and fertile material initially present is uniformly distributed throughout the lower region.

To account for resonance fissions (significant in the small, heavily loaded reactors considered), the following approximate procedure was used. It was assumed that the bulk of the resonance absorption in fuel material occurred at an energy below that at which the resonance absorption in fertile material occurred. The fission source term in the fast group for resonance fissions is then¹

$$\eta_1 p_{o2}(1 - p_F) \Sigma_1 \phi_1 \quad (1)$$

(The number of neutrons removed from the fast group by slowing down is $\Sigma_1 \phi_1$; the probability of escaping capture by the fertile material and being captured by fuel material is $p_{o2}(1 - p_F)$, and the number of neutrons produced per capture in fuel material by resonance neutrons is η_1 .)

The modified two-group equations for a fuel-bearing region are then

$$\left. \begin{aligned} D_1 \nabla^2 \phi_1 - \Sigma_1 \phi_1 + \eta_2 \Sigma_{F2} \phi_2 + \eta_1 p_{o2}(1 - p_F) \Sigma_1 \phi_1 &= 0 \\ D_2 \nabla^2 \phi_2 - [\Sigma_{F2}(1 + r_F) + \Sigma_o] \phi_2 + p_{o2} p_F \Sigma_1 \phi_1 &= 0 \end{aligned} \right\} \quad (2)$$

For the bare reactor before settling occurs it is assumed that ϕ_1 and ϕ_2 also satisfy the differential equations

$$\left. \begin{aligned} \nabla^2 \phi_1 + B^2 \phi_1 &= 0 \\ \nabla^2 \phi_2 + B^2 \phi_2 &= 0 \end{aligned} \right\} \quad (3)$$

¹ Symbols are defined in Table 1.

Table 1. Notation

Σ_1	macroscopic removal cross section, cm^{-1}
D_1	fast group diffusion coefficient, cm
D_2	thermal group diffusion coefficient, cm
Σ_{F2}	macroscopic thermal absorption cross section for fuel material, cm^{-1}
Σ_0	macroscopic thermal absorption cross section for nonfuel material, cm^{-1}
τ	Fermi age for moderator, cm^2
ϕ_1	fast neutron flux, $\text{n/cm}^2 \text{ sec}$
ϕ_2	thermal neutron flux, $\text{n/cm}^2 \text{ sec}$
P_{02}	resonance escape probability for fertile material
P_F	resonance escape probability for fuel material
η_1	fission neutrons released per epithermal neutron absorbed in fuel
η_2	fission neutrons released per thermal neutron absorbed in fuel
f_p	poison fraction (thermal macroscopic absorption cross section for poison divided by thermal macroscopic absorption cross section for fuel)
ν	fission neutrons released per fission
α_1	$\frac{\nu}{\eta_1} - 1$; capture-to-fission ratio for epithermal neutrons
α_2	$\frac{\nu}{\eta_2} - 1$; capture-to-fission ratio for thermal neutrons
H	height of reactor, ft
L	height of settled region, ft
R	radius of reactor, ft
G_{02}	grams fertile material per liter
G_F	grams fuel material per liter
$C_{02} = G_{02}(0) H$	= initial fertile material "inventory," gm ft per liter

where B^2 is the geometric buckling. Upon substitution of Eqs. (3) into Eqs. (2), the following expression for the critical fuel cross section, Σ_{F2} , can be derived:

$$\Sigma_{F2} = \frac{D_2 B^2 + \Sigma_0}{\frac{\eta_2 P_{O2} P_F}{1 + B^2 \tau - \eta_1 P_{O2}(1-P_F)} - (1 + f_p)} \quad (4)$$

(It has been assumed that $\Sigma_1 = D_1/\tau$)

The solution of (4) is the critical fuel cross section for the bare reactor. Since p_F depends on the fuel cross section, it is necessary to use an iterative procedure to obtain the solution of (4). (See Appendix 1 for details.)

For the settled case Eqs. (2) apply in the lower region; in the upper region, denoted by the subscript R, the appropriate equations are:

$$\left. \begin{aligned} D_{1R} \nabla^2 \phi_{1R} - \Sigma_{1R} \phi_{1R} &= 0 \\ D_{2R} \nabla^2 \phi_{2R} - \Sigma_{2R} \phi_{2R} + P_R \Sigma_{1R} \phi_{1R} &= 0 \end{aligned} \right\} \quad (5)$$

The fission source term in the fast group equation is written as:

$$\eta_2 \Sigma_{F2} \phi_2 + \eta_1 P_{O2}(1 - P_F) \Sigma_1 \phi_1 = v_c \left[\frac{\Sigma_{F2}}{1 + \alpha_2} \phi_2 + \frac{P_{O2}(1-P_F)}{1 + \alpha_1} \Sigma_1 \phi_1 \right] \quad (6)$$

The eigenvalue v_c is related to k_{eff} , the effective multiplication constant, by

$$k_{eff} = v/v_c. \quad (7)$$

As in the conventional two-group procedure, solutions to the two-group equations are assumed to satisfy an equation of the form:

$$\nabla^2 F + \gamma^2 F = 0. \quad (8)$$

At the interface $Z = L$, the boundary conditions of continuity of fluxes and net currents are applied which results in a criticality condition - the requirement that a certain determinant vanish - for ν_c . Since upper and lower bounds can be placed on ν_c , considerable computing time is saved in bringing the critical determinant to the desired degree of convergence.

INPUT DATA REQUIRED

The input format is shown in Table 2 and a sample input sheet is shown in Table 3. A discussion of the nuclear data used in Rapid Transition is given in Appendix 2.

OPERATING INSTRUCTIONS

If a large number of cases are to be run, it is recommended that an input tape be used rather than card input. In the present form of the program the input tape is placed on logical unit 1 and the output is written on logical unit 2.

Sense switch settings: 1 up - card input
 down - tape input
 2 up - tape output only
 down - on line in addition to tape

To run with tape input, mount the input tape on logical unit 1, place the program deck in the reader, depress sense switch 1 and press the "clear" and "load cards" switches. For card input, leave sense switch 1 up and place the input data deck in the reader following the program deck.

The normal stop is at octal location 232 with 10101 in the address portion of the storage register.

OUTPUT

The output, written on logical tape unit 2, is of the form shown in Table 4. Listing instructions are 1 file, program control.

Table 2. Input Format

Input tape: sense switch 1 down (logical unit 1)

cards: sense switch 1 up

Data cards:

1	Title - printer control character plus any 71 Hollerith characters	
2	D_1 , D_2 , τ , Σ_{M2} , AD_1 , AD_2 , AF , BF , $A1$	} Format 9E8.0
(any 8 space field)
3	$A2$, $A3$, $AT1$, $AT2$, $SO2$, SML , Z , α_2 , α_R	

Case cards:

R card: R , E , e_{z1} , e_{z2} , e_R , C_{O2} , f_P , f_M , Σ_P^1 (same format as above)

Convergence card: JF , GNU , $CCDEL$, $CCKE$, $NIIT$, $NOIT$ (11, 3E8.0, 213)

L cards: L (Format F6.2)

The last L card should be followed by a blank card. Any desired identification may be placed in cols. 73-80 of any card. A series of cases (R card followed by L cards) is ended with a blank R card; the code will then read new data cards. To stop, place seven blank cards after the blank R card.

Definition of symbols:

- D_1 = fast group diffusion coefficient for pure moderator
- D_2 = slow group diffusion coefficient for pure moderator
- τ = Fermi age
- Σ_{M2} = Macroscopic absorption cross section for pure moderator

Table 2. Input Format - contd.

Definition of symbols:

$\left. \begin{matrix} AD_1 \\ AD_2 \end{matrix} \right\} =$ Coefficients in equations for diffusion coefficients in slurry

$\left. \begin{matrix} AF \\ BF \end{matrix} \right\} =$ Coefficients in equation for fuel resonance escape probability

A1, A2, A3: coefficients in equation for fertile material resonance escape probability

AT1, AT2 coefficients in equation for age in slurry

$SO_2 = \Sigma_{o2}/G_{o2}$

SMI = coefficient in equation for moderator cross section in slurry

$Z = G_F/\Sigma_{2F}$

α = capture-to-fission ratio in thermal group

α_R = capture-to-fission ratio in fast group

G_F = fuel concentration, grams/liter

G_{o2} = fertile material concentration, grams/liter

Σ_{2F} = thermal group macroscopic absorption cross section for fuel material

Σ_{o2} = thermal group macroscopic absorption cross section for fertile material

R = equivalent reactor radius, ft

H = equivalent reactor height, ft

e_{z1}, e_{z2}, e_R = extrapolation distances for bottom, top and sides, respectively

C_{o2} = product of initial fertile material concentration in grams per liter by reactor height in feet (proportional to fertile material inventory)

Table 2. Input Format - contd.

Definition of symbols:

f_p	=	poison fraction associated with fission products	
f_M	=	poison fraction associated with fuel molecule (e.g., sulfur in UO_2SO_4)	
Σ_p'	=	macroscopic absorption cross section of fuel-independent poison	
JF	=	control number, not used in present version of code (leave blank in col. 1)	
GNU	=	number of neutrons/fission	
CCDEL	=	convergence criterion for critical determinant	
CCKE	=	" " " effective multiplication factor, k_e	Any 8 space field (usually 5×10^{-6})
NIIT	=	number of inner iterations (upper limit, ≤ 100)	
NOIT	=	number of outer iterations (upper limit, ≤ 100)	
L	=	length of settled region, ft.	

650 DATA SHEET

Table III
Typical Input Sheet

C. W. Rector

WRITTEN BY

DATE

Job Title Rapid Transit

REQUEST 1556

1-8	9-16	17-24	25-32	33-40	41-48	49-56	57-64	65-72	73-80
1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100
101	102	103	104	105	106	107	108	109	110
111	112	113	114	115	116	117	118	119	120
121	122	123	124	125	126	127	128	129	130
131	132	133	134	135	136	137	138	139	140
141	142	143	144	145	146	147	148	149	150
151	152	153	154	155	156	157	158	159	160
161	162	163	164	165	166	167	168	169	170
171	172	173	174	175	176	177	178	179	180
181	182	183	184	185	186	187	188	189	190
191	192	193	194	195	196	197	198	199	200
201	202	203	204	205	206	207	208	209	210
211	212	213	214	215	216	217	218	219	220
221	222	223	224	225	226	227	228	229	230
231	232	233	234	235	236	237	238	239	240
241	242	243	244	245	246	247	248	249	250
251	252	253	254	255	256	257	258	259	260
261	262	263	264	265	266	267	268	269	270
271	272	273	274	275	276	277	278	279	280
281	282	283	284	285	286	287	288	289	290
291	292	293	294	295	296	297	298	299	300
301	302	303	304	305	306	307	308	309	310
311	312	313	314	315	316	317	318	319	320
321	322	323	324	325	326	327	328	329	330
331	332	333	334	335	336	337	338	339	340
341	342	343	344	345	346	347	348	349	350
351	352	353	354	355	356	357	358	359	360
361	362	363	364	365	366	367	368	369	370
371	372	373	374	375	376	377	378	379	380
381	382	383	384	385	386	387	388	389	390
391	392	393	394	395	396	397	398	399	400
401	402	403	404	405	406	407	408	409	410
411	412	413	414	415	416	417	418	419	420
421	422	423	424	425	426	427	428	429	430
431	432	433	434	435	436	437	438	439	440
441	442	443	444	445	446	447	448	449	450
451	452	453	454	455	456	457	458	459	460
461	462	463	464	465	466	467	468	469	470
471	472	473	474	475	476	477	478	479	480
481	482	483	484	485	486	487	488	489	490
491	492	493	494	495	496	497	498	499	500
501	502	503	504	505	506	507	508	509	510
511	512	513	514	515	516	517	518	519	520
521	522	523	524	525	526	527	528	529	530
531	532	533	534	535	536	537	538	539	540
541	542	543	544	545	546	547	548	549	550
551	552	553	554	555	556	557	558	559	560
561	562	563	564	565	566	567	568	569	570
571	572	573	574	575	576	577	578	579	580
581	582	583	584	585	586	587	588	589	590
591	592	593	594	595	596	597	598	599	600
601	602	603	604	605	606	607	608	609	610
611	612	613	614	615	616	617	618	619	620
621	622	623	624	625	626	627	628	629	630
631	632	633	634	635	636	637	638	639	640
641	642	643	644	645	646	647	648	649	650
651	652	653	654	655	656	657	658	659	660
661	662	663	664	665	666	667	668	669	670
671	672	673	674	675	676	677	678	679	680
681	682	683	684	685	686	687	688	689	690
691	692	693	694	695	696	697	698	699	700
701	702	703	704	705	706	707	708	709	710
711	712	713	714	715	716	717	718	719	720
721	722	723	724	725	726	727	728	729	730
731	732	733	734	735	736	737	738	739	740
741	742	743	744	745	746	747	748	749	750
751	752	753	754	755	756	757	758	759	760
761	762	763	764	765	766	767	768	769	770
771	772	773	774	775	776	777	778	779	780
781	782	783	784	785	786	787	788	789	790
791	792	793	794	795	796	797	798	799	800
801	802	803	804	805	806	807	808	809	810
811	812	813	814	815	816	817	818	819	820
821	822	823	824	825	826	827	828	829	830
831	832	833	834	835	836	837	838	839	840
841	842	843	844	845	846	847	848	849	850
851	852	853	854	855	856	857	858	859	860
861	862	863	864	865	866	867	868	869	870
871	872	873	874	875	876	877	878	879	880
881	882	883	884	885	886	887	888	889	890
891	892	893	894	895	896	897	898	899	900
901	902	903	904	905	906	907	908	909	910
911	912	913	914	915	916	917	918	919	920
921	922	923	924	925	926	927	928	929	930
931	932	933	934	935	936	937	938	939	940
941	942	943	944	945	946	947	948	949	950
951	952	953	954	955	956	957	958	959	960
961	962	963	964	965	966	967	968	969	970
971	972	973	974	975	976	977	978	979	980
981	982	983	984	985	986	987	988	989	990
991	992	993	994	995	996	997	998	999	1000

Table 4. Output Format

Title - Small H ₂ O Slurry Reactors 200 Deg. C U ²³⁵			
R (reactor radius in ft)	H(reactor height in ft)	CO2 (initial fertile material inventory)	
L (height of settled region in ft)	G02 (Fertile mat'l concentration, g/liter)	GF (Fuel material concentration, g/liter)	KE (Effective mult. constant)
R	H	CO2	
1.12	2.24	448.	
L	G02	GF	KE
2.24	200.	21.356	1.0000
1.79	250.	26.725	1.0399
1.49	301.	32.106	1.0569
1.28	350.	37.374	1.0593
1.12	400.	42.713	1.0520

APPENDIX 1: DERIVATION OF CRITICALITY CONDITIONS AND SOLUTIONS

1. Bare Reactor

The two-group equations are of the form

$$\left. \begin{aligned} - \left[D_1 B^2 + \Sigma_1' \right] \phi_1 + \eta_2 \Sigma_{F2} \phi_2 &= 0 \\ - \left[D_2 B^2 + \Sigma_0 + \Sigma_{F2}(1 + r_F) \right] \phi_2 + p \Sigma_1 \phi_1 &= 0 \end{aligned} \right\} \quad (A1.1)$$

$$\text{with } \Sigma_1' = \Sigma_1 \left[1 - p_{o2}(1 - p_F) \eta_1 \right],$$

$$p = p_{o2} p_F.$$

From the first equation

$$\phi_1 = \frac{\eta_2 \Sigma_{F2}}{D_1 B^2 + \Sigma_1'} \phi_2.$$

Substitution into the second equation and solution for Σ_{F2} yields

$$\Sigma_{F2} = \frac{D_2 B^2 + \Sigma_0}{\frac{\eta_2 p_{o2} p_F}{1 + B^2 \tau - \eta_1 p_{o2}(1 - p_F)} - (1 + r_F)} \quad (A1.2)$$

In order to solve Eq. (A1.2), an iterative procedure must be employed.

The equation is of the form

$$x = f(x).$$

One possible procedure is to put

$$x_{i+1} = f(x_i).$$

This procedure, however, is not convergent in regions where the slope of $f(x)$ is larger than 1 in absolute magnitude, and is slowly convergent otherwise if

$f(x)$ has negative slope. A sequence of values computed from this procedure is shown in Table A1, and a geometrical interpretation is shown in Fig. A1.

An alternative method is the so-called "Aitken delta-squared process," which amounts to the replacement of $f(x)$ by a linear function between two successive iterates (Cf. Fig. A2). The "next guess" x_{i+1} is given by

$$x_{i+1} = \frac{\left[f(x_{i-1}) \right]^2 - f(x_i) f(x_{i-2})}{2f(x_{i-1}) - f(x_i) - f(x_{i-2})} \quad (\text{A1.3})$$

Caution must be exercised in the application of this procedure because the expression for x_{i+1} becomes indeterminate as the values $f(x_i)$, $f(x_{i-1})$ and $f(x_{i-2})$ approach equality.

In the "Rapid Transit" program the "delta-squared" process is applied after every three iterations with the scheme

$$x_{i+1} = f(x_i),$$

provided the differences between successive iterates are larger in absolute magnitude than 10^{-3} . If the iterates are closer but not yet converged to the desired level, the sequence is examined to determine whether it is oscillatory or not. If it is, the "next guess" is

$$x_{i+1} = \frac{1}{2} \left\{ \frac{x_i + x_{i-1}}{2} + \frac{x_{i-1} + x_{i-2}}{2} \right\}; \quad (\text{A1.4})$$

if not, the scheme

$$x_{i+1} = f(x_i)$$

is continued. Sequences obtained from this procedure are shown in Table A2.

If the error at each iteration is plotted on semi-logarithmic paper, a reasonably straight line results, as illustrated in Fig. A3. An estimate may

be made of the number of iterations necessary to bring the error below the desired level; for this case this estimate is 78 iterations for a relative error of 5×10^{-5} . This level of convergence is obtained in about 10 iterations if the Aitken process is applied after the third and sixth iterations.

Table A1. Sequence of Values Obtained from $x_{i+1} = f(x_i)$

1	$x_i (\times 100)$
1	2.3637
2	0.5107
3	1.8768
4	0.81521
5	1.6112
6	0.99660
7	1.4612
8	1.1040
9	1.3753
10	1.1673
11	1.3256
12	1.2044
13	1.2968
14	1.2261
15	1.2801
16	1.2388
17	1.2703
18	1.2463
19	1.2646
20	1.2506

Table A2. Sequence of Values Obtained from Use of
"Delta-Squared" Process at Every Third Step

	$x_i (\times 100)$	δ^2 value
1	2.36374	
2	0.51070	
3	1.87682	1.29708
4	1.22594	←
5	1.28021	
6	1.23873	1.25670
7	1.25663	←
8	1.25668	
9	1.25665	Converged to relative error of 5×10^{-5} .

FIGURE A 3. SEMI-LOG PLOT OF ERROR FOR CASE IN TABLE A1.

Fig. A1 - Geometrical Visualization of $x_{i+1} = f(x_i)$
for a Convergent Case

Fig. A2. Aitken Delta-Squared Process Applied to "Divergent" Case

Note that the $x_{i+1} = f(x_i)$ scheme yields a strongly divergent sequence.

APPENDIX 2: NUCLEAR CONSTANTS

Two-group nuclear constants have been prepared for mixtures of light and heavy water and for light water-heavy water-thorium oxide slurries; temperatures considered were 20°C, 100°C and 200°C; mole-fraction of D₂O was assumed to be 0, 0.25, 0.50, 0.75 and 1.0; thorium concentration was varied from 0 to 1200 g/liter. These constants are calculated on the basis of the following correlations:

$$1. \text{ Diffusion coefficients, } D_i(G) = \frac{D_i(0)}{1 + A_i G} \left. \begin{array}{l} i = 1 \text{ for fast group} \\ i = 2 \text{ for slow group} \end{array} \right\}$$

$$2. \text{ Fertile material absorption cross section, } \Sigma_{02}(G) = S_{02} G$$

$$3. \text{ Effective moderator absorption cross section,}$$

$$\Sigma_M(G) = \Sigma_M(0) [1 - S_M G]$$

$$4. \text{ Fermi age, } \tau_M(G) = \tau_M(0) [1 + a_1 G + A_2 G^2]$$

$$5. \text{ Resonance escape probabilities:}$$

$$\text{Fertile material, } p_{02} = (1 + c_1 G)/(1 + c_2 G + c_3 G^2)$$

$$\text{Fuel material, } p_F = \exp \left[-A_F G_F / (1 - B_M G) \right]$$

where

$$a_1, a_2, A_F, A_i, B_M$$

$$c_1, c_2, c_3, S_M, S_{02} \text{ are dimensional constants given in Table A2.1}$$

$$D_i(0) = \text{diffusion coefficient for } i\text{th group, based on zero thorium concentration.}$$

G = concentration of fertile material, g/liter

G_F = concentration of fuel material, g/liter

$\Sigma_M(0)$ = macroscopic absorption cross section of pure moderator

$\tau_M(0)$ = Fermi age of pure moderator

Constants for the first three correlations are derivable from the densities and cross sections of the materials involved; constants for the last two were obtained from data from other calculations.

Table A2.1 lists the parameter values to be used in the above correlations for several temperatures.

Table A2.1. Typical Nuclear Constants for $\text{ThO}_2\text{-U}^{235}\text{-H}_2\text{O}$ Slurries

Temperature, °C	20	100	200
Thoria-water slurry			
$D_1(0)$, cm	0.586	0.609	0.673
$D_2(0)$, cm	0.160	0.177	0.218
$\Sigma_M(0)$, cm^{-1}	0.0196	0.0167	0.0133
$\tau_M(0)$, cm^2	33.0	35.6	43.6
S_M , liter/g	1.17×10^{-4}	1.17×10^{-4}	1.17×10^{-4}
S_{O_2} , liter/g-cm	1.74×10^{-5}	1.55×10^{-5}	1.37×10^{-5}
A_1 , liter/g	-2.71×10^{-5}	-2.35×10^{-5}	-1.45×10^{-5}
A_2 , liter/g	-8.38×10^{-5}	-7.60×10^{-5}	-7.92×10^{-5}
a_1 , liter/g	0	4.21×10^{-6}	0
a_2 , liter/g	9.09×10^{-7}	2.39×10^{-7}	6.88×10^{-7}
c_1 , liter/g	0	0	0
c_2 , liter/g	1.16×10^{-4}	1.30×10^{-4}	1.46×10^{-4}
c_3 , liter/g	-2.67×10^{-8}	-3.67×10^{-8}	-4.51×10^{-8}
U^{235} fuel			
A_F , liter/g	-6.05×10^{-4}	-6.28×10^{-4}	-6.95×10^{-4}
B_M , liter/g	1.15×10^{-4}	1.15×10^{-4}	1.15×10^{-4}
Z ,* g-cm/liter	655	757	869

* Conversion factor to convert fuel-macroscopic absorption cross section (cm^{-1}) to fuel concentration (g/liter)

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