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DRAGON

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MAFIA
A ONE-DIMENSIONAL BURN-UP CODE

by

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1. INTRODUCTION

Spectral changes due to the depletion of fissionable materials and build-up of fission products have a strong influence on the effective cross sections of all the various isotopes and on the reactivity of a long irradiated core.

Since, as far as the authors know, no one-dimensional burn-up code suitable for high temperature graphite reactors provides the possibility of treating spectrum changes with time, a programme, MAFIA, has been written which combines the General Atomic burn-up code FEVER [1] with the Dragon Project multi-group diffusion code MUPO [2].

FEVER is an up to four-group, one-dimensional burn-up programme which uses a few group cross section library. In order to follow spectral changes of the neutron flux it is necessary to modify the library for the different parts of the reactor core at each time step of the burn-up calculation. As this has to be repeated many times during the lifetime of a core, great care has been taken to speed up the spectrum evaluation.

MUPO is a programme which meets these requirements. It is a zero-dimensional 43-group diffusion theory code, and its source iteration routine is used for the spectrum calculation. It permits the introduction of energy dependent leakage. 43-group cross sections and scattering kernels are obtained from a library tape. This tape is used only once so that all spectrum calculations can be performed without any time consuming tape manipulation. To allow for spectrum changes across the core, this can be divided into a maximum of 4 regions and the MUPO spectrum calculation will be repeated for each zone at each time step.

To improve the accuracy of the spectrum calculation an energy dependent leakage, obtained by the FEVER one-dimensional diffusion calculation of the previous time step, is used in MUPO. By this procedure of coupling spectrum and burn-up calculations it is not necessary to provide a few group cross section library for the beginning of life which saves considerable time in input preparation and card manipulation. Few group cross sections for the reflector, however, have to be specified as they do not change markedly with burn-up.

2. PROGRAMME DESCRIPTION*

MAFIA is written in Fortran for a 32,000 word computer as a chain job with three links.

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*As the FEVER code has already been fully described by F. Todt [1] it is assumed that the reader is familiar with this report.

Link 1 reads all isotope compositions, geometrical and burn-up data which have been maintained similar to those of FEVER. From this data it prepares the average atomic concentration for each zone in which the core is divided for the spectrum calculation.

Link 2 consists of the modified MUPO-programme. At beginning of life it reads the resonance data and disadvantage factors for each material and core zone and prepares the 43-group cross section of all isotopes used.

The spectrum calculation follows the usual source iteration procedure as this is the fastest method to evaluate a neutron spectrum in many energy groups. The inherent weakness of this procedure lies in the fact that changing the fast neutron source is not in accordance with the physical reality. The shape of the spectrum, however, in the region above, let us say, 20 KeV into which fission neutrons are borne is of relatively small importance for the overall effective cross section in thermal reactors. Of greater importance is the influence of the energy dependent leakage. To account for this a new subroutine called PARBAL has been added to the original FEVER version, see the flow diagram of Figure 1, which calculates the total leakage by making a neutron balance over a so-called zone. A zone comprises one or more burn-up regions for which the change in the microscopic few group cross sections due to spectrum changes is considered to be small. Up to four zones can be used, this means that for every isotope up to four different sets of group cross sections are available.

Experience has shown that it is sufficient for the spectrum calculations to keep the four group buckling constant within the four groups. As the leakages are calculated for the critical system the source iteration process should give a k_{eff} which is close to one, in fact it is usually within a few thousandths of unity.

After having calculated the neutron spectrum for a zone link 2 of MAFIA evaluates the broad group microscopic cross sections for the various isotopes needed in the diffusion and burn-up calculation.

For each of the spectrum zones this procedure is repeated and after completion the control of the programme is transferred to link 3, a modification of the original FEVER programme.

Link 3 consists of the FEVER code proper without the input subroutines. After every burn-up step it calculates average atomic concentrations and few group leakages for the spectrum calculations of link 2. It also includes a reshuffling and recharging subroutine (see Appendix 2).

A flow diagram is shown in Fig. 1.

3. COMPUTING TIME

The computing time on the IBM 7090 depends on the nature of the problem attempted.

For straight burn-up, four energy groups, about 50 mesh points, and only one core zone for spectrum calculations, the running time has been from 30 to 40 s per time step, on the average of many subsequent cases.

4. OPERATING INSTRUCTIONS

Tape Assignment: to change the tape assignment according to the computer used, the first instructions of link 1 specify the tape units for reading of input and writing of output data, for the MUPO Library and for two further tape units necessary for storing intermediary results (see below).

At present the programme is intended for an IBM 7090. The three links are stored on the tape units B2, B3 and A4 respectively. The MUPO library is loaded on unit A5.

As there is not enough core space for all the data, necessary for FEVER and MUPO, part of the Common is stored on tape before passing from one link to another. This is done by the FAP subroutine READ-WRITE which is included in each link. It dumps part of the FEVER Common (link 1 and 3) on unit B5 in the present version, and part of the MUPO Common (link 2) on B6, but other tape units may be used. This subroutine assumes, however, that the following tape designation is valid:

Fortran Logical Designation	Actual Tape Unit
9	A5
10	A6
11	B5
12	B6

this can be changed easily to any other assignment.

5. DISCUSSION OF SOME RESULTS

Some calculations have been performed in order to compare the results of MAFIA with those of FEVER.

Two cases have been considered:

(a) Dragon reactor with 3 region core, 20 kg U-235 loading.

(b) An hypothetical loading of a big power reactor of the Dragon type, with the following assumptions.

Thermal Power	1000 MW
Power Density	15 MW/m^3
U-235 loading	1000 kg
$\frac{\text{Th-232}}{\text{U-235}}$ ratio	10

In both cases one gets with MAFIA a running time longer by almost 20% (Figs. 2 & 3). For the case (b) the spectrum variations are shown in Fig. 4 and the changes in thermal absorption cross section for a $\frac{1}{v}$ absorber and for $\nu\sigma_f$ of U-235 are shown in the following Table.

	Fresh Unpoisoned Reactor	After 700 Days
B-10 σ_a	1395 b	1461 b
U-235 $\nu\sigma_f$	413.7 b	438.3 b

The effect of the iteration on the buckling at beginning of life has also been investigated. The effect is quite important in the case (a) but negligible in case (b).

6. REFERENCES

[1] F. Todt. FEVER. "A One-Dimensional Few-Group Depletion Program for Reactor Analysis." GA-2749. 28th November, 1962.

[2] J. L. Schlösser. D.P. Report 172.

APPENDIX 1

NOTES ON DIFFERENCES FROM THE FEVER CODE

(a) FEVER options not available in MAFIA

(a.1) Cold shutdown k_{eff} will not be calculated by MAFIA, because no cold cross section blocks are provided.

(a.2) Punching of atom densities for restarts. This option has been considered superfluous for MAFIA. The option NTSTRT is instead used for information on recharging or reshuffling schemes.

(a.3) All core regions must have the same materials, even if with different concentrations.

(b) Differences in Input Data

A complete description of the MAFIA input data is given in Appendix 3. The main differences are:

(b.1) Library cross sections do not need to be specified for the core. They still need to be specified for the reflectors as in FEVER.

(b.2) Card 8 need not be specified any longer.

(b.3) Card 9 need not contain any cross section block specification for the core regions. Also self-shieldings do not need to be specified if they are 1.0. (Any self-shielding which is zero will automatically be changed to 1.0.)

For the reflector it is necessary to specify the cross section block numbers - which, however, start with number 101.

(b.4) The following cards will have to follow the last card of the FEVER input:

Card	Columns	
21	4	Number of zones in which the core is divided for spectrum calculations.
	7-8	Region number of the first core region.
	11-12	Region number of the last region of core zone No. 1.
	15-16	Region number of the last region of core zone No. 2.
	etc.	
22	3-4	MUPO material number of the first FEVER material in the core.

Card	Columns	
22	7-8	MUPO material number of the second FEVER material in the core.
	11-12	MUPO material number of the third FEVER material in the core.
	etc.	Going to a second card if necessary.
23		Options
	3-4	Printing option No. 1. Controls the amount of print out obtainable from link 2.
		= 0 produces least possible print out: the k_{eff} of the spectrum calculation as a check.
		= 1 additionally to the k_{eff} the user obtains also the average isotope concentration, and the group fluxes per unit lethargy for each spectrum zone.
		= 2 additionally to the previous print out the user obtains also the bucklings used for the spectrum calculation and the microscopic broad group cross sections for every isotope and spectrum zone.
	8	Controls the print out from the subroutine DPRIN of link 3 (printing of the diffusion calculation.)
		= 0 Only k_{eff}
		= 1 k_{eff} + fluxes + power distribution
		= 2 k_{eff} + fluxes + power + group cross sections.
	12	Controls the print out from the subroutine AVRAGE and PARBAL of link 3.
		= 0 No print out
		= 1 Print average region fluxes
		= 2 Average region fluxes + partial neutron balance.
	16	This option allows the use of MAFIA as well as FEVER, without recalculating the spectrum at each time step, or iterating on the buckling at beginning of life.
		= 0 (or blank) normal MAFIA run
		= -1 do not recalculate the spectrum, but use the initial cross sections for the whole life.
		= -2 as above, but do not even iterate on the bucklings at beginning of life.

Card	Columns	
24	3	Number of energy groups (Integer)
	4-6	Highest fine group number of first broad group (Integer).
	7-9	Highest fine group number of second broad group (Integer).
	etc.	———
	16-18	Number of Library Tape to be used.
25	1-5	Fuel temperature (^{o}K) (Integer).
	6-15	σ_p-value for resonance calculation of thorium (barns)
	16-25	σ_p-value for resonance calculation of U-238 (barns)
	26-30	Moderator temperature (^{o}K) (Integer).
	31-35	Total number of sets of disadvantage factors to be read (Integer).
		Card 25 has to be supplied for each zone. Only one moderator temperature will be accepted by the programme, the one specified on the first card 25.
26		Gives the disadvantage factor.
		43 numbers in fixed decimal form (12 per card), the disadvantage factor for the most thermal group has to be given first.
27	1-4	Total number of isotopes with this disadvantage factor set.
	5-8	Library Tape number of first isotope.
	9-12	of second isotope, etc.
		Cards 26 and 27 have to be repeated as often as given on Card 25 columns 31-35 for each of the spectrum zones. To simplify the input preparation the following convention holds: if the integer on Card 25 columns 31-35 (LS) is negative the same disadvantage factors are applied to the same isotopes as in the previous spectrum zone. It is not permissible to specify a negative LS after a zero LS in the previous zone.

APPENDIX 2

RECHARGING AND RESHUFFLING SUBROUTINE OF THE MAFIA CODE

The reshuffling and recharging subroutine written for the MAFIA code is kept as general as possible.

For this purpose the reactor can be divided into reshuffling areas, each of them including one or more burn-up regions. There can be up to 20 reshuffling areas and each of them can include up to 20 burn-up regions, with the limitation that the total number of burn-up regions must not exceed 20. The regions composing a reshuffling area do not need to be adjacent.

Before each reshuffle the programme calculates and prints the average atom densities for each area. Any area can be either recharged with a new composition specified in the input, or get the atom concentrations of any other area, or not be altered at all. If an area gets the atomic concentrations of another area, the two volumes must be equal.

A reshuffle can take place after any specified number of time steps or when the reactivity drops below a specified control point. There can be any number of reshuffles during the core lifetime.

MAFIA being a one-dimensional code it is not possible to treat two-dimensional variations of composition. This means that some recharging and reshuffling scheme cannot be followed with this code. For example, in radial geometry it can happen that after a recharge or reshuffle one gets azimuthal variations of composition: the same ring of fuel elements can contain elements of different composition. One cannot homogenise the ring because in that case the individual composition of the elements is lost for the following reshuffles.

The possibility of defining reshuffling areas out of non-adjacent burn-up regions can be used in these cases. In the above mentioned example it is possible to simulate azimuthal variations by radial variations. The ring can be split in several radial regions and each azimuthal zone of different fuel elements can be simulated by a reshuffling area consisting of alternative burn-up regions.

In this way, as the regions can be made very small, the result of the diffusion calculation will be almost the same as if these zones were homogenised, but the composition of each group of fuel elements is kept separate during burn-up.

This subroutine includes also the facility for iterating on the concentration of a material specified in the input, in order to adjust the reactivity to the beginning of life value. The iteration is performed in one or more reshuffling areas, as specified in the input. If the concentrations of the material used for the iteration are different in the areas specified, they are varied in such a way that their ratios remain constant.

Input preparation for the reshuffling subroutine:

In the card No. 2 of the run data the option NRSTRT (col. 28) indicates whether there are reshuffles, with or without iteration.

NRSTRT = 0 No reshuffle

1 Reshuffle but no iteration

2 Reshuffle with iteration

If NRSTRT > 0 at the end of the run data there must be the designation of the reshuffling areas.

Card	Columns	
R1	1-3	No. of reshuffling areas (NRESHZ).
R2		As many as NRESHZ - Format (21I3).
	1-3	No. of burn-up regions in this area.
	4-6	Region number of first burn-up region.
	7-9	Region number of second burn-up region.
	etc.	----------

After these cards, for each reshuffle and each area one has to specify the number of the area whose concentrations will be attributed to this area.

If this number is negative this means that the area is reloaded with new fuel. In this case another card will follow, and the absolute value of the number will give the number of material concentrations to be read in the following card.

If NRSTRT = 2 one has also to specify the data for the iteration.

Card	Columns	
R3	1-3	As many as NRESHZ.
		If Integer positive: it specifies the number of the reshuffle area from which the isotope concentrations are to be taken.
		If Integer negative: its absolute value gives the number of isotopes to be read in card R4.
R4		Only for loading of fuel elements.
	1-2	FEVER material number (Int)
	3-12	concentration.

Card	Columns	
R4	13-14	FEVER material number (Int)
	15-24	concentration.
	etc.	

The first card R3 and, if necessary, card R4 refer to the first reshuffle area, the second card(s) to the second reshuffle area, etc.

Card	Columns	
R5	1-3	FEVER material number of the material used for iteration.
	4-6	No. of areas on which to iterate.
	7-9	Area number of first area on which to iterate.
	10-12	Area number of second area on which to iterate.
	etc.	

MAFIA REFLECTOR AND LIBRARY DATA

Word	1	2	3	4	5	6	
Column	4	6-8	11-12	15-16	19-20	23-14	One card per library.
Format	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal	
Card A1	Number of groups $2 \leq N26 \leq 4$	Number of reflector cross section blocks (sets) in library $NLB \leq 20$	Number of special material data sets in library $NLT \leq 15$	Special data set number to be used for nonsaturating fission product (Material 13)	Special data set number to be used for Xe-135 (Material 14)	Special data set number to be used for Sm-149 (Material 15)	
Symbol	N26	NLB	NLT	M1	M2	M3	

Word	1	2	3	4			
Column	1-12	13-24	25-36	37-48			One card per library.
Format	Decimal	Decimal	Decimal	Decimal			
Card A2	Diffusion coefficient adjustment factor for Group 1	Diffusion coefficient adjustment factor for Group 2	Diffusion coefficient adjustment factor for Group 3	Diffusion coefficient adjustment factor for Group 4			Supply as many diffusion coefficient factors as groups (N26).
Symbol	BUG (1)	BUG (2)	BUG (3)	BUG (4)			

Word	1	2	3				
Column	1-12	13-24	25-36				One card per library.
Format	Decimal	Decimal	Decimal				
Card A3	Eigenvalue convergence criterion	Point convergence criterion	Control search convergence criterion				
Symbol	CONK	CONEIG	SERCON				

Word					
Column	2-40	61-72			One card for each cross section set (NLB) followed by as many card A5's as there are groups (N26).
Format	Hollerith	Decimal			
Card A4	Cross section block identification (Alpha-numeric) Only for reflector data	Density factor (dilution due to physical expansion)			
Symbol		X BUG			

Word	1	2	3	4	5	
Column	1-12	13-24	25-36	37-48	49-60	
Format	Decimal	Decimal	Decimal	Decimal	Decimal	
Card A5	$\nu\sigma_f$	σ_T	σ_A	$\sigma_{g,\ g+1}$	ν	
Symbol	FISIG(1E, 1L)	TOSIG(1E, 1L)	ABSIG(1E, 1L)	OUSIG(1E, 1L)	XNU(1E, 1L)	

One card for each group (N26).

Word	1	2	3	4	5	
Column	1-12	13-24	25-36	37-48	49-60	
Format	Decimal	Decimal	Decimal	Decimal	Decimal	
Card A6	A capture product of preceding nuclide? 0.0 - NO 1.0 - YES	Fission yield from U-233	Fission yield from U-235	Fission yield from Pu-239	Fission yield from Pu-241	
Symbol	DIRAC(K)	YIELD 1(K)	YIELD 2(K)	YIELD 3(K)	YIELD 4(K)	

One card for each special data set (NLT).

MAFIA CASE INPUT DATA

Word	
Column	2-72
Format	Hollerith
Card 1	Case Identification (Alpha-numerical)
Symbol	

One card per case.

Word	1	2	3	4	5	6
Column	3-4	8	12	16	20	24
Format	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal
Card 2	Number of regions ≤ 20	Geometry 1-slab 2-cylinder	0-Control poison search, burnup 1-Straight burnup 2-Single diffusion calculation	0-Calculation hot max. k_{eff} 1-Omit above calculation	0-Plot power and summary data 1-Omit plot	0-Calculation xenon build-up before proceeding 1-All initial atom densities given as input
Symbol	N20	N27	JSER	NSPEC	NPLOT	NXE

One card per case.

Word	7	8	9	10		
Column	28	32	36	61-72		
Format	No Decimal	No Decimal	No Decimal	Decimal		
Card 2 (cont'd)	0-No effect 1-Reshuffle without iteration 2-Reshuffle with iteration	Reflector cross section library for next case 1-Same 0-Read new library (if any)	0-No effect 1-Shutdown-Start-up 2-Xenon override calculation	Position of mesh point zero		
Symbol	NRSTRT	KSER	NSHUFL	RAD		

Word	1	2	3	4		
Column	1-12	13-24	25-36	37-48		
Format	Decimal	Decimal	Decimal	Decimal		
Card 3	Left albedo Group 1	Left albedo Group 2	Left albedo Group 3 if necessary	Left albedo Group 4 if necessary		
Symbol	ALI(1)	ALI(2)	ALI(3)	ALI(4)		

One card per case; supply as many albedo values as groups.

Word	1	2	3	4		
Column	1-12	13-24	25-36	37-48		
Format	Decimal	Decimal	Decimal	Decimal		
Card 4	Right albedo Group 1	Right albedo Group 2	Right albedo Group 3 if necessary	Right albedo Group 4 if necessary		
Symbol	AL2(1)	AL2(2)	AL2(3)	AL2(4)		

One card per case.

Word	1	2	3	4	5	6
Column	10-12	13-24	25-36	37-48	49-60	61-72
Format	No Decimal	Decimal	Decimal	Decimal	Decimal	Decimal
Card 5	Number of intervals in this region	Region outer radius	Transverse buckling Group 1	Transverse buckling Group 2	Transverse buckling Group 3 if necessary	Transverse buckling Group 4 if necessary
Symbol	NVALS(IR)	RADR(IR)	TRANS(1, IR)	TRANS(2, IR)	TRANS(3, IR)	TRANS(4, IR)

One card for each region.

Word	1	2	3	4	5	6
Column	3-4	7-8	11-12	15-16	19-20	23-24
Format	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal
Card 6	Number of power-generating regions	Region Number of 1st power-generating region	Region Number of 2nd power-generating region	Region Number of 3rd power-generating region	Region Number of 4th power-generating region	Region Number of 5th power-generating region
Symbol	N71	NBURN(1)	NBURN(2)	NBURN(3)	NBURN(4)	NBURN(5)

One or two cards per case depending on number of regions.

REGION DATA: Supply Cards 7, 8, 9, 10, 11, 12, and 13 in Sets for Each Region

Word	1	2	3	4	5	6
Column	3-4	8	12	16	19-20	23-24
Format	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal
Card 7	Total number of materials in this region	Number of special materials for this region	Number of lumped poisons for this region	Number of control poisons for this region	Number of cards 8 for this region It should be normally = 0	Number of cards 9 for this region
Symbol	NMAT(IR)	NO(IR)	NLUM(IR)	NC(IR)	NREAD 1	NREAD

One card for each region.

Word	7	8	9	10	11	12
Column	27-28	31-32	35-36	39-40	43-44	47-48
Format	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal
Card 7 (cont'd)	Number of a previous specified region having same atomic densities, self-shielding and cross section blocks	Number of a previous specified region having same special material data (Card 10)	Number of a previous specified region having same lump poison geom. data (Card 11)	Number of a previously specified region having same self-shielding coef-ficient (Card 12)	Number of a prior region having same control poison data (Card 13)	Fission product aggregate yield data identification number
Symbol	NCH1	NCH2	NCH3	NCH4	NCH5	M1

If number of cards 8 and cards 9 $\leq$ number of materials, specify $\neq$ 0 value for word 7. M1, M2, M3 omitted if correctly specified in library data (that is: region invariant).

Word	13	14				
Column	51-52	55-56				
Format	No Decimal	No Decimal				
Card 7 (cont'd)	Xe-135 yield data identification number	Sm-149 yield data identification number				
Symbol	M2	M3				

Word	1	2	3			
Column	3-4	7-8	11-12			
Format	No Decimal	No Decimal	No Decimal			
Card 8	Material Number					
Symbol	L	NHOT(L, IR)	NCOL(L, IR)			

This card is not necessary for MAFIA. If they are in the deck, they can be read and ignored by the programme. This is in order to allow the use of old FEVER inputs.

Word	1	2	3	4	5	6
Column	3-4	6-8	10-12	13-24	25-36	37-48
Format	No Decimal	No Decimal	No Decimal	Decimal	Decimal	Decimal
Card 9	Material number	Cross section block associated with this material (only for reflector)	-	Atomic density x 10^{-24}	Self-shielding factor for Group 1	Self-shielding factor for Group 2
Symbol	L	NHOT(L, IR)	NCOL(L, IR)	DEN(L, IR)	SS(1, L, IR)	SS(2, L, IR)

Supply one card for each material whose atom density $\neq$ 0.0 or self-shielding $\neq$ 1.0, or to change atomic density and self-shielding if not the same as a preceding region.
Any self-shielding = 0.0 will be changed to 1.0.

Word	7	8				
Column	49-60	61-72				
Format	Decimal	Decimal				
Card 9 (cont'd)	Self-shielding factor for Group 3	Self-shielding factor for Group 4				
Symbol	SS(3, L, IR)	SS(4, L, IR)				

Word						
Column						
Format						
Card						
Symbol						

Word						
Column						
Format						
Card						
Symbol						

SPECIAL MATERIAL DATA

Word	1	2	3	4	5	6
Column	3-4	7-8	11-12	15-16	19-20	23-24
Format						
Card 10	Special data identification number for 1st special material	Special data identification number for 2nd special material	Special data identification number for 3rd special material	Special data identification number for 4th special material	Special data identification number for 5th special material	etc.
Symbol	MX(1, IR)	MX(2, IR)	MX(3, IR)	MX(4, IR)	MX(5, IR)	etc.

One card per region only if necessary. Supply one number for each special material. Omit card if same as a preceding region (i.e., if card 7, word 8 $\neq$ 0).

LUMPED POISON DATA - Cards 11 and 12 to be Supplied in Sets for Each Lumped Poison

Word	1	2	3	4	5	6
Column	1-12	13-24	25-36	37-48	49-60	61-72
Format	Decimal	Decimal	Decimal	Decimal	Decimal	Decimal
Card 11	Number of lumped poison rods in this region	Inner diameter of lumped poison rod (cm)	Outer diameter of lumped poison rod (cm)	Height of lumped poison rod (cm)	Atomic weight of lumped poison	Density of lumped poison in the lump (g/cm^3)
Symbol	RODS(K, IR)	DILP(K, IR)	DOLP(K, IR)	HLP(K, IR)	AW(K, IR)	RHO(K, IR)

Supply one card for each lumped-poison material. Omit this data if the same as in a preceding region (i.e., if card 7, word 9 $\neq$ 0).

Word	1	2	3	4	5	6
Column	1-12	13-24	25-36	37-48	49-60	61-72
Format	Decimal	Decimal	Decimal	Decimal	Decimal	Decimal
Card 12	L.P. coefficient A_0	L.P. coefficient A_1	L.P. coefficient A_2	L.P. coefficient A_3	L.P. coefficient A_4	L.P. coefficient A_5
Symbol	A0(IE, K, IR)	A1(IE, K, IR)	A2(IE, K, IR)	A3(IE, K, IR)	A4(IE, K, IR)	A5(IE, K, IR)

Supply one card for each group (hot poison). If cold shutdown k_{eff} is computed supply two extra cards for lowest 2 groups (cold poison). Omit data if the same as in a preceding region (i.e. if card 7, word 10 $\neq$ 0).

CONTROL POISON DATA

Word	1	2				
Column	1-12	13-24				
Format	Decimal	Decimal				
Card 13	Minimum control poison atom density x 10^{-24}	Maximum control poison atom density x 10^{-24}				
Symbol	POISM(K, IR)	POISL(K, IR)				

Supply one card for each control poison material. Omit this data if the same as in a preceding region (i.e. if card 7, word 11 $\neq$ 0).

BURN-UP DATA: Supply Cards 14 and 15 only for Burn-up Cases

Word	1	2	3	4	5	6	
Column	1-12	13-24	25-36	37-48	49-60	61-72	One card per case.
Format	Decimal	Decimal	Decimal	Decimal	Decimal	Decimal	
Card 14	Large burn-up time step (days)	Thermal power of the reactor (watts)	Core height (cm)	Control point or shutdown k_{eff}	Fissions per watt-sec	Xenon removal constant (1/sec)	
Symbol	DELDAY	POWER	HCORE	ZKFIND	FIWATT	RPXE	

Word	1	2					
Column	1-4	5-8					One card per case.
Format	No Decimal	No Decimal					
Card 15	Termination time step number ≤ 24	Number of small time steps per large time step					
Symbol	JNSTOP	JNUM					

CONTROL SEARCH DATA: Supply Cards 16, 17 and 18 only for Control Search Cases

Word	1	2	3	4	5	6
Column	1-4	5-8	11-12	14-16	19-20	23-24
Format	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal
Card 16	Maximum control poison adjustments for a single region during one search	Maximum total control poison adjustments	Number of control regions adjusted simultaneously	Total number of control region adjustments in following list	Control region number (to be adjusted 1st)	Control region number (to be adjusted 2nd)
Symbol	JSMAX	JSSMAX	LSIM	KSS	NPOIS(IRR)	NPOIS(IRR)

Use additional cards if necessary.

Word	7					
Column	27-28					
Format	No Decimal					
Card 16 (cont'd)	Control region number (to be adjusted 3rd)	Supply as many control region numbers as required to complete the list				
Symbol	NPOIS(IRR)					

Use additional cards if necessary.

Word	1	2	3	4	5	6
Column	1-12	13-24	25-36	37-48	49-60	61-72
Format	Decimal	Decimal	Decimal	Decimal	Decimal	Decimal
Card 17	Minimum poison insertion fraction (corr. to 1st region in above list)	Minimum poison insertion fraction (corr. to 2nd region in above list)	Minimum poison insertion fraction (corr. to 3rd region in above list)	Minimum poison insertion fraction (corr. to 4th region in above list)	Minimum poison insertion fraction (corr. to 5th region in above list)	Minimum poison insertion fraction (corr. to 6th region in above list)
Symbol	PINMIN(IRR)	PINMIN(IRR)	PINMIN(IRR)	PINMIN(IRR)	PINMIN(IRR)	PINMIN(KSS)

Use additional cards if necessary.

Word	1	2	3	4	5	6
Column	1-12	13-24	25-36	37-48	49-60	61-72
Format	Decimal	Decimal	Decimal	Decimal	Decimal	Decimal
Card 18	Maximum poison insertion fraction (corr. to 1st region in above list)	Maximum poison insertion fraction (corr. to 2nd region in above list)	Maximum poison insertion fraction (corr. to 3rd region in above list)	Maximum poison insertion fraction (corr. to 4th region in above list)	Maximum poison insertion fraction (corr. to 5th region in above list)	Maximum poison insertion fraction (corr. to 6th region in above list)
Symbol	PINMAX(IRR)	PINMAX(IRR)	PINMAX(IRR)	PINMAX(IRR)	PINMAX(IRR)	PINMAX(KSS)

Use additional cards if necessary.

SHUTDOWN-START-UP CARD: This card may be repeated as often as desired

Word	1	2	3	4	5	
Column	1-12	13-24	25-36	39-40	44	
Format	Decimal	Decimal	Decimal	Decimal	Decimal	
Card 19	Shutdown time (hours)	New operating power (watts)	Large burnup time step (days)	Maximum number of large time steps	0-Last card for this case 1-Another card 19 for succeeding shutdown-start-up follows	
Symbol	X DOWN	POWER	DELDAY	JNSTOP	NSHUFL	

Supply this card only for shutdown-start-up case: NSHUFL = 1 (card 2, word 9).

XENON OVERRIDE CARD

Word	1	2	3	4		
Column	1-12	15-16	17-20	23-24		
Format	Decimal	No Decimal	No Decimal	No Decimal		
Card 20	Time interval of override calculation (hours)	Number of times for k_{eff} calculation during override time interval	First time step for Xe override calculation	Frequency of override calculation (number of large burn-up time steps)		
Symbol	X DOWN	JINT	NDOW	NXXX		

Supply this card only for xenon override case: NSHUFL = 2 (card 2, word 9).

Word	1	2	3	4	5	6
Column	4	7-8	11-12	15-16	19-20	23-24
Format	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal
Card 21	Number of zones in which the core is divided for spectrum calculations	Region number of first core region	Region number of last region of the first core zone	Region number of last region of the second core zone (if any)	Region number of last region of the third core zone (if any)	Region number of last region of the fourth core zone (if any)
Symbol	KZONE	IRZ(1)	IRZ(2)	IRZ(3)	IRZ(4)	IRZ(5)

One card per case.

Word	1	2	3	4	5	6
Column	3-4	7-8	11-12	15-16	19-20	23-24
Format	No Decimal	No Decimal	No Decimal	No Decimal		
Card 22	MUPO library Number of first FEVER material in the core	MUPO libary Number of second FEVER material in the core	MUPO library Number of third FEVER material in the core	MUPO library Number of fourth FEVER material in the core	MUPO library Number of fifth FEVER material in the core	MUPO library Number of sixth FEVER material in the core
Symbol	IMAT(1)	IMAT(2)	IMAT(3)	IMAT(4)	IMAT(5)	IMAT(6)

Use additional card if necessary.

Word	7	8	9	10	11	12
Column	27-28	31-32				
Format	No Decimal	No Decimal				
Card 22 (Cont'd)	MUPO library Number of seventh FEVER material in the core	etc.				
Symbol	IMAT(7)	IMAT(8)				

Use additional card if necessary.

Word	1	2	3	4		
Column	4	8	12	16		
Format	No Decimal	No Decimal	No Decimal	No Decimal		
Card 23	Printout from spectrum calculation = 0 only k_{eff} = 1 as 0 + concentration and fluxes = 2 as 1 + cross sections	Printout from diffusion calculation = 0 only k_{eff} = 1 as 0 + flux + power = 2 as 1 + cross sections	Printout of average fluxes and partial balance = 0 no printout = 1 average region fluxes = 2 as 1 + partial balance	Normally = 0 if = -1 run as FEVER, if = -2 run as FEVER and do not iterate on bucklings		
Symbol	IPRIN(1)	IPRIN(2)	IPRIN(3)	IPRIN(4)		

Printing options one per case. See Appendix 1.

Word	1	2	3	4	5	6	
Column	1-3	4-6	7-9	10-12	13-15	16-18	
Format	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal	
Card 24	Total number of energy groups	Highest fine group number of first broad group	Highest fine group number of second broad group	Highest fine group number of third broad group	Highest fine group number of fourth broad group	Library tape number	Group partition and MUPO library designation.
Symbol	KPAR	IPAR(2)	IPAR(3)	IPAR(4)	IPAR(5)	K	

Word	1	2	3	4	5		
Column	1-5	6-15	16-25	26-30	31-35		
Format	No Decimal	Decimal	Decimal	No Decimal	No Decimal		
Card 25	Fuel temperature (^{o}K)	σ_p-value of Th-232	σ_p-value of U-238	Moderator temperature (^{o}K)	Total number of sets of disadvantage factors		As many cards 25 as core zones (KZONE).
Symbol	JTEMP(L)	SA(1, L)	SA(2, L)	IRES	LS(L)		

Word	1	2	3	4	5	6	
Column	1-6	7-12	13-18	19-24	25-30	31-36	
Format	Decimal	Decimal	Decimal	Decimal	Decimal	Decimal	
Card 26	Disadvantage factor for group 1	Disadvantage factor for group 2	etc.				43 fine group disadvantage factors thermal groups first (four cards 26).
Symbol	SA(1, L)	(SA(2, L)					

Word	7	8	9	10	11	12	
Column	37-42	43-48	49-54	55-60	61-66	67-72	
Format	Decimal	Decimal	Decimal	Decimal	Decimal	Decimal	
Card 26 (Cont'd)							
Symbol							

Word	1	2	3	4		
Column	1-4	5-8	9-12	13-16		
Format	No Decimal	No Decimal	No Decimal	No Decimal		
Card 27	Total number of materials with these factors	MUPO number of first material	MUPO number of second material	etc.		
Symbol	IR	IEZ(1)	IEZ(2)			

Cards 26, 27 have to be repeated as given in card 25 word 5 for each zone.

Word						
Column						
Format						
Card						
Symbol						

Word						
Column						
Format						
Card						
Symbol						

Word						
Column						
Format						
Card						
Symbol						

RESHUFFLING OR RECHARGING DATA

Word	1						
Column	1-3						Only if card 2 word 7 is 1 or 2.
Format	No Decimal						
Card R1	Number of reshuffling areas						
Symbol	NRESHZ						

Word	1	2	3	4	5	6	
Column	1-3	4-6	7-9	10-12			One for each reshuffling area.
Format	No Decimal	No Decimal	No Decimal	No Decimal			
Card R2	Number of burn-up regions in this area	Region number of first burn-up region	Region number of second burn-up region	Region number of third burn-up region	etc.		
Symbol	NCX	LRZN(IR, 1)	LRZN(IR, 2)	LRZN(IR, 3)			

Word	1						
Column	1-3						Cards R3 will appear for each reshuffle. A blank card R3 means that the case is completed and no reshuffle follows.
Format	No Decimal						
Card 1R3	Number of the area whose atom densities will be attributed to area 1						
Symbol	NRX						

Word	1						
Column	1-3						
Format	No Decimal						
Card 2R3	Number of the area whose atom densities will be attributed to area 2						
Symbol	NRX						

Word	1					
Column	1-3					
Format	No Decimal					
Card 3R3	Number of the area whose atom densities will be attributed to area 3					
Symbol	NRX					

Word	1					
Column	1-3					
Format	No Decimal					
Card R3	As many cards R3 as reshuffling areas.					
Symbol	NRX					

If in any card R3 NRX < 0, the area is recharged. The new concentrations will be read in the card R4 which must immediately follow.

Word	1	2	3	4	5	6
Column	1-2	3-12	13-14	15-24	25-26	27-36
Format	No Decimal	Decimal	No Decimal	Decimal	No Decimal	Decimal
Card R4	Material (FEVER material number)	Concentration	Material	Concentration	Material	Concentration
Symbol	NPX(1)	CPX(1)	NPX(2)	CPX(2)	NPX(3)	CPX(3)

If in any card R3 NRX < 0 a card R4 follows, with as many concentrations as |NRX|. The other concentrations are supposed to be 0.0.

Word	7	8				
Column	37-38	39-48				
Format	No Decimal	Decimal				
Card R4 (Cont'd)	Material	Concentration	etc.			
Symbol	NPX(4)	CPX(4)				

Use additional cards if necessary.

Word	1	2	3	4	5	6	
Column	1-3	4-6	7-9	10-12	13-15		
Format	No Decimal	No Decimal	No Decimal	No Decimal	No Decimal		
Card #5	NEVER material number of the material used for iteration	Number of areas in which to iterate	Area number of first iteration area	Area number of second iteration area	Area number of third iteration area	etc.	Only if card 2 word 7 is = 2. It will be repeated at each reshuffle.
Symbol	MATIT	JARIT	NCOL(2, 1)	NCOL(2, 2)	NCOL(2, 3)		

Word							
Column							
Format							
Card							
Symbol							

Word							
Column							
Format							
Card							
Symbol							

Word							
Column							
Format							
Card							
Symbol							

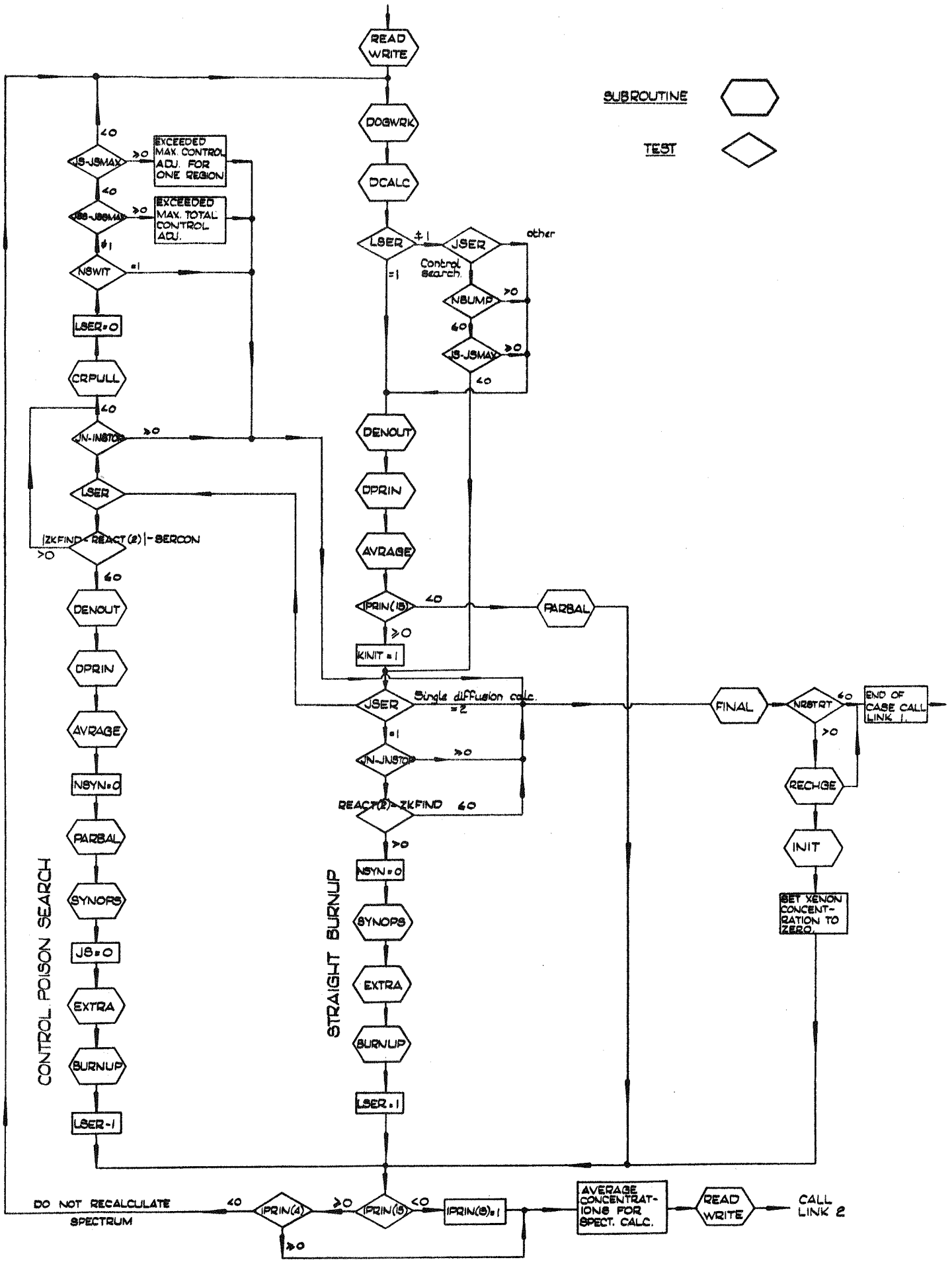

FIG. 1 MAFIA LINK 3
SIMPLIFIED FLOW DIAGRAM.

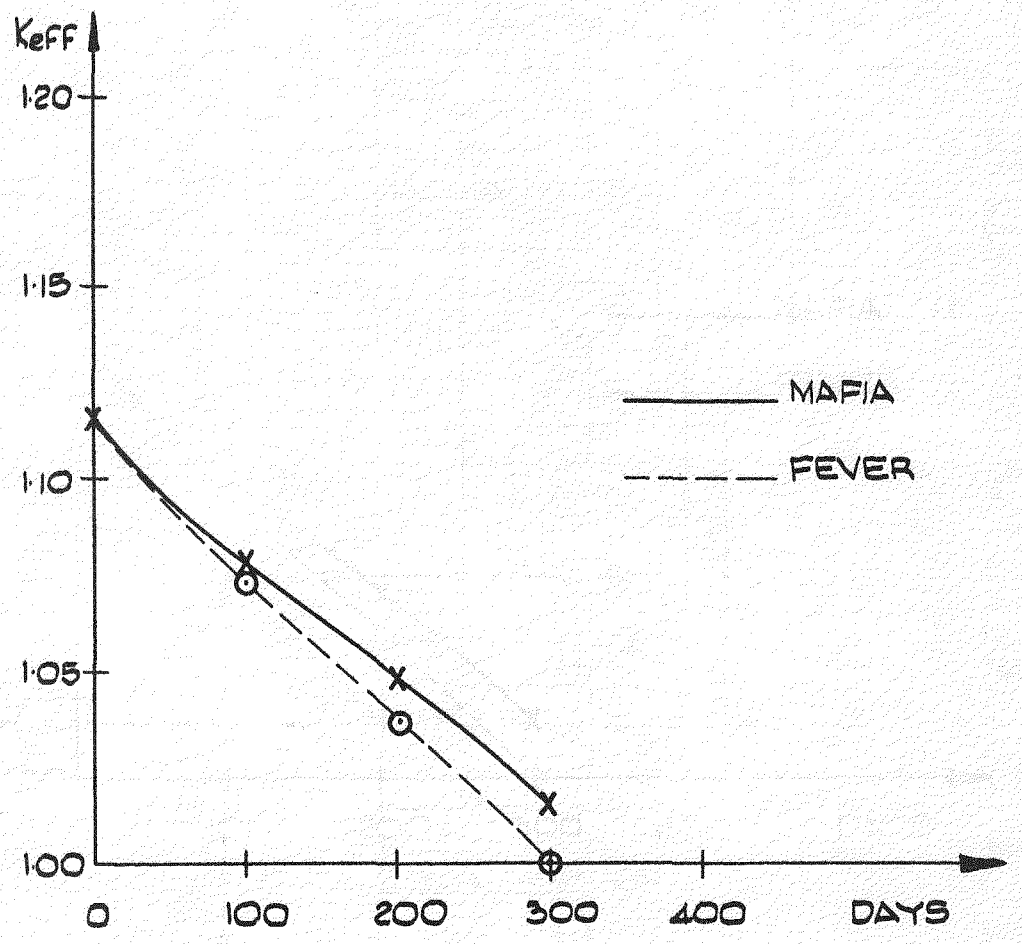

FIG. 2 DRAGON 20Kg U235 – 3 REGION CORE.

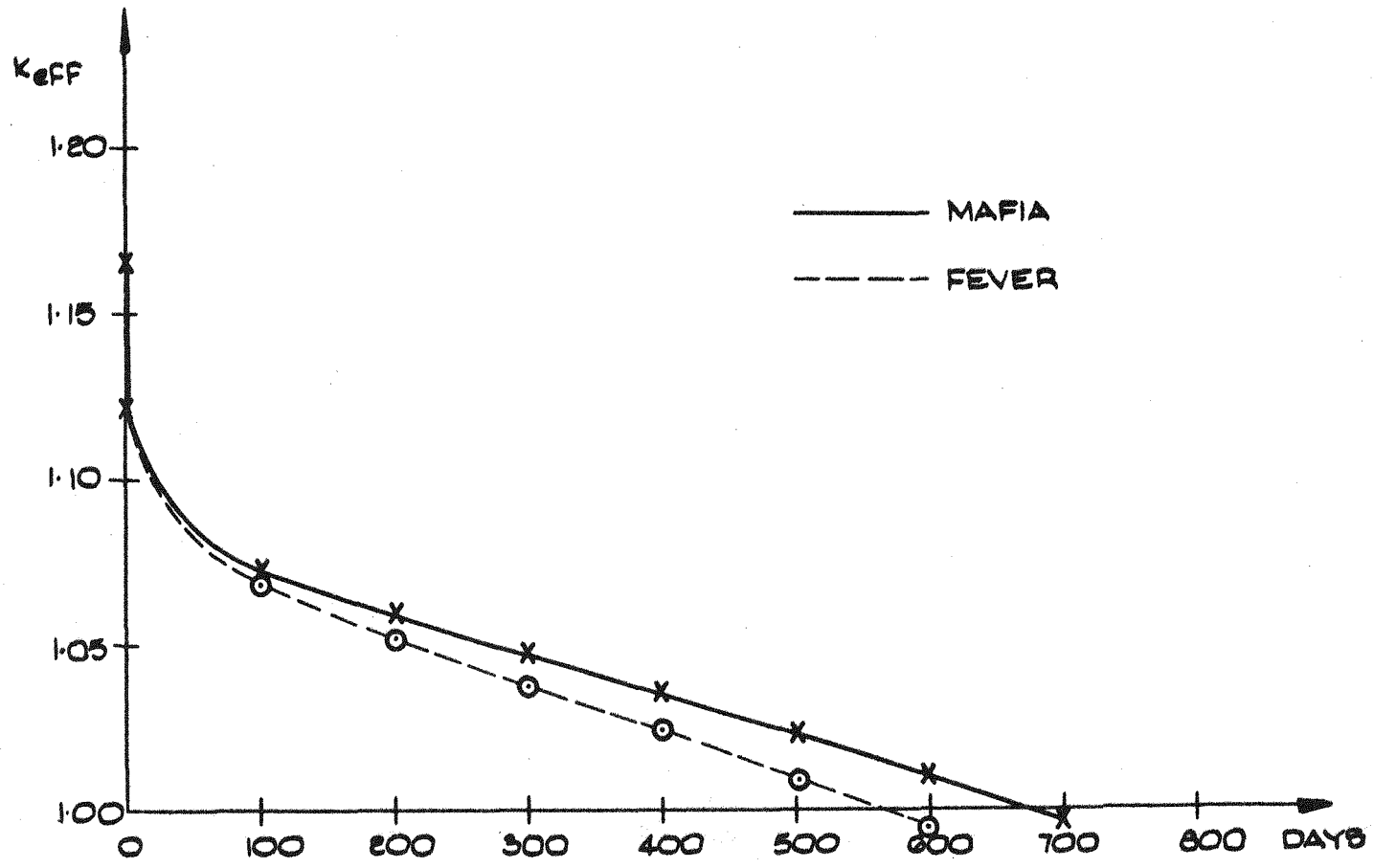

FIG. 3 BURN-UP FOR A 1000 MW. REACTOR AS CALCULATED BY MAFIA AND FEVER.

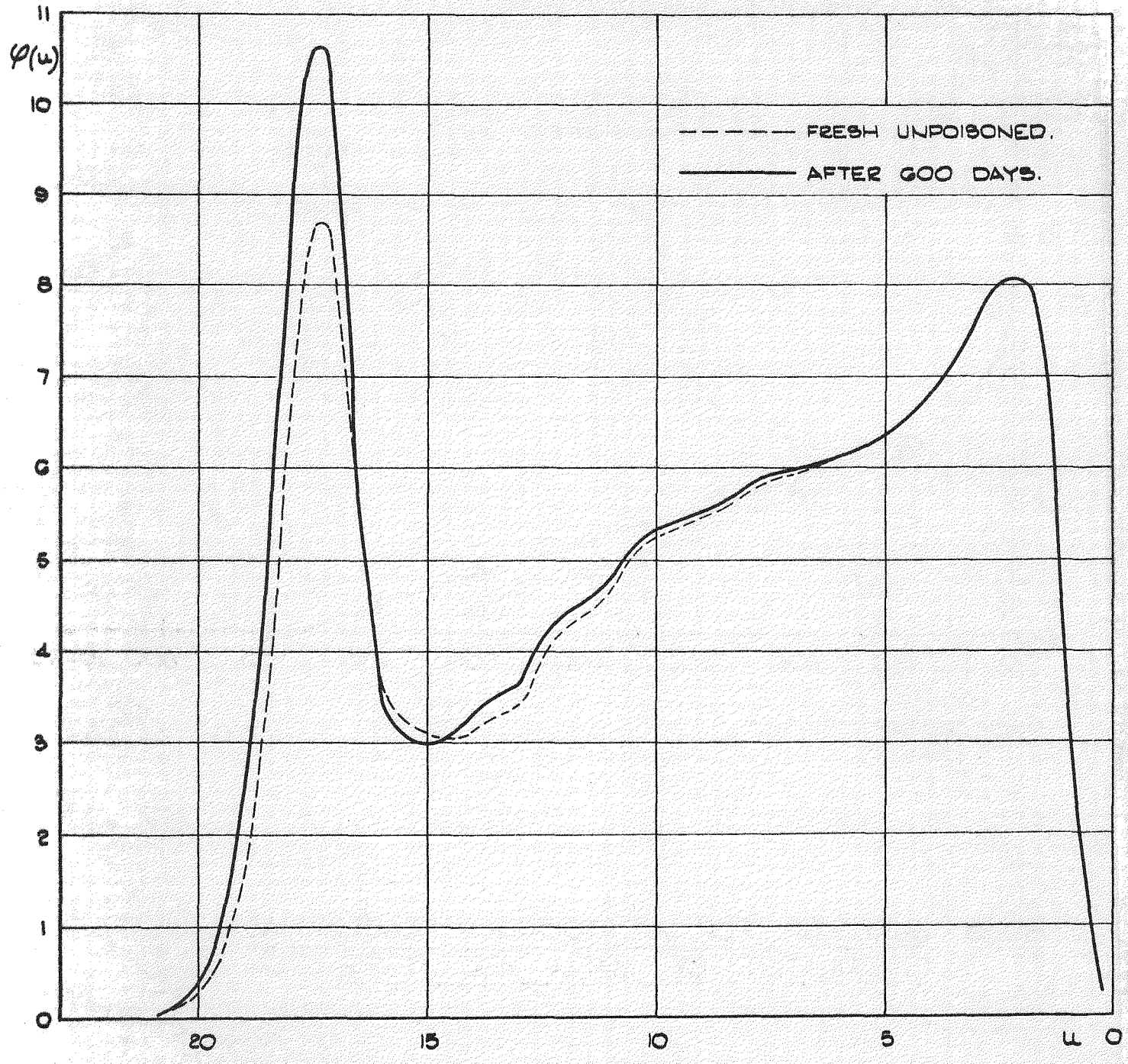

FIG. 4 NEUTRON SPECTRUM AT BEGINNING & END OF LIFE

1000 Mw. 15 Mw/m³ 1000 kg U235 N = 10