The TDA and TIMEX Codes for Time-Dependent Neutronics and Photonics Analysis of ICF Reactors

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1. Introduction

In an inertial confinement fusion (ICF) reactor, the DT fuel in the target is heated and compressed by laser, electron, or ion beams to very high densities before it ignites. The spectrum of emerging neutrons softens considerably and neutron multiplication occurs due to neutron interactions with the dense target materials. This affects the performance of the blanket, first wall, reflector, and shield. Neutron-fuel interactions result also in gamma production which contributes to nuclear heating in the blanket. Therefore, detailed neutronics and photonics calculations must be performed for the target and coupled to the blanket calculations. During the fuel burn, the outer regions of the target begin to expand from the fully compressed state at ignition. As the burn front propagates, the peak of the spatial distribution of the neutron source moves toward the outer edge of the fuel, while behind the burn front regions of reduced ion density are created due to fuel consumption. Furthermore, the DT reactions produce alpha particles leading to a time dependent helium buildup. An accurate determination of the spectrum of emitted neutrons and gammas must account for the continuous change of density, configuration, and composition of the source region during the target burn. Elaborate coupled neutronics-photonics and hydrodynamics calculations need to be performed.[1,2] A code capable of performing time-dependent neutron and gamma transport calculations is required to perform the neutronics and photonics part of the calculations.

In an inertial confinement fusion reactor, the neutron source for the blanket calculations has a pulsed nature because of the very short burn time (~ 10-100 ps) over which neutrons are emitted from the target. Furthermore, the neutron pulse does not reach the first surface of the blanket until ~ 100

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ns after the burn and the neutron slowing down time in the blanket is much greater than the duration of the neutron source. Although steady state codes can be used to determine the average time integrated radiation damage rates and other important reactor parameters, time-dependent codes must be used to determine the instantaneous damage rate. This is important for the analysis of the first wall and structure lifetime.[3] Therefore, time-dependent neutron and gamma transport codes are required to perform target and blanket neutronics and photonics calculations for ICF reactor designs.

Two time-dependent codes, TDA[4] and TIMEX[5], have been implemented at the University of Wisconsin. Several modifications have been made to these codes to facilitate their use for design studies of ICF reactors. A brief description of the methods of solution and the important properties of the codes are given in this report. For a detailed description of the methods of solution used, one should refer to the original manuals. The modifications made to the codes are described and the complete operating instructions for the University of Wisconsin versions of the codes are given. Recommendations regarding the preference of each of the codes to the other for particular neutronics and photonics calculations in inertial confinement fusion reactor design are given.

2. The TDA Code

Time-dependent ANISN (TDA), is based on the steady-state discrete ordinates code ANISN.[6] The TDA code solves the time-dependent, one-dimensional multigroup transport equation in plane, cylindrical, and spherical geometries. Delayed neutrons are not considered. Both forward and adjoint problems are solved with vacuum, reflective, periodic, and white albedo boundary conditions. Both space and time variables are finite differenced and the angular

dependence is treated using the method of discrete ordinates. For stability and generality, weighted difference equations[7] are used to relate the cell centered flux to the fluxes at the edges of the time, space, and angle cell. This leads to three free parameters which are chosen to assure positive fluxes when the source and all previously calculated fluxes are positive. This is a generalization of the ordinary diamond difference scheme. Large time steps used in connection with the weighted difference equations have been found to yield highly inaccurate results. Large time steps can be used only if the flux varies smoothly with time and exponential difference equations are used for the time dependence. The method of solution involves performing inner iterations while outer iterations are required only if the problem includes fission reactions.

The source options used in the code include an isotropic distributed source to be used in the first time interval only, or a first collision source with a number of source spectra emitted at different time steps at the origin. The analytic first collision source option is most useful in time-dependent blanket calculations, where account must be taken for time of flight spreading.

The code reads the cross sections in ANISN format from cards, ANISN binary library tape, or a group independent tape. We note that the manual of the code distributed by RSIC[6] states that one can read the cross sections from cards or ANISN binary library tape only and the parameter ID2 must be set to zero. We found out that the code can read a group independent tape by simply setting ID2=1. Using a group independent tape results in significant reduction of the required core storage. Furthermore, the manual states that the parameter IDAT1 must be set equal to zero. We found that if the user sets

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IDAT1=1, all cross sections and sources will not be stored in the core and further reduction of the storage requirement is obtained.

Several modifications were made to the original code by F. Beranek and further modifications were introduced recently. Since a TDA run involving a large number of time steps is very expensive, a restart capability has been added which allows the user to check the results and continue the run if the calculations are progressing satisfactorily. One can stop and restart a run any number of times. The problem can be restarted from the time step immediately following the step at which the previous run was interrupted. All files accompanying a run should be saved if the user intends to restart the calculations.

TDA was originally written to solve the discrete ordinates equation with the same quadrature order for all groups. Fusion reactor neutronics calculations involve a wider range of neutron energies. While an accurate calculation for the high energy groups requires a high quadrature order, this order is usually unnecessarily high for low energy groups. The U.W. version of TDA includes the option of using group dependent quadrature orders. This results in significant reduction in computing time.

Accurate determination of the spectrum of neutrons emitted from the target of an inertial confinement fusion reactor must account for the spatial and temporal density and source variations occurring during the fuel burn. The TDA code has been modified to accept new material densities and neutron sources in all spatial intervals at any desired number of time steps.

The original version of TDA required the user to input the activity cross sections separately. Since most cross section tapes include the activity cross sections, TDA has been modified to compute the activities with the user

specifying the materials and positions for which the activities are required. Mixing of materials in an activity cross section table is also allowed. The activities calculated are the total reaction rates per unit volume at all fine mesh intervals regardless of whether the material in question exists at the interval or not. The calculated activities are printed at all time steps.

Several other options have been added to TDA to reduce the computing time. One of these modifications is the input of a flag to indicate whether there is a fissionable material in the problem. This eliminates the lengthy calculation of the fission source when the problem does not include fission. Another modification is related to the first collided source option. The lowest energy group which contains source neutrons and the time step at which the pulse has passed through the system are input. A complete description of input to the U.W. version of TDA is given in Appendix I. Familiarity with ANISN input is assumed. The files that must be assigned to the run are also given. Some limitations are explained to help the user make changes appropriate to the problem to be solved.

3. The TIMEX Code

The TIMEX code is based on the steady-state discrete ordinates code ONETRAN.[8] TIMEX solves the time-dependent one-dimensional multigroup transport equation with delayed neutrons in plane, cylindrical, spherical, and two-angle plane geometries. Both forward and adjoint problems are solved with vacuum, reflective, periodic, white, albedo, and inhomogeneous source boundary conditions. The discrete ordinates approximation for the angular variable is used with the diamond difference approximation for the angular extrapolation in curved geometries. A linear discontinuous finite element representation

for the angular flux in each spatial mesh cell, which is very accurate and stable particularly for optically thick mesh cells, is used.[9]

The time variable is differenced by an explicit technique that is unconditionally stable so that arbitrarily large time steps can be used. The explicit time differencing scheme used in TIMEX considers the loss mechanism to be proportional to the flux at the new time and the source mechanism to the fluxes at the old time. This results in the elimination of the need for iterations and the method is exceptionally fast in terms of computing time per time step. A within-group fine-mesh rebalance acceleration method[10] is available in which rebalance factors are calculated to enforce particle balance on each fine-mesh interval for each energy group. An outer rebalance option is also available and can be used when the problem includes fissionable materials and/or upscattering. Another acceleration method utilized to improve the accuracy of the time differencing scheme is the exponential extrapolation method[11] which is useful in situations where the time variation of the flux is smooth and nearly exponential. A negative flux fixup algorithm is performed when the total source (including scattering and fission) in the mesh cell is positive. In this case the negative flux is set equal to zero and the flux at the other edge of the cell is recalculated. For problems in which the group speeds differ greatly in magnitude, TIMEX permits the use of group-dependent time steps.

A first collision source option is provided in TIMEX. This option is restricted to the treatment of instantaneous sources located at the origin of the coordinate system. This is useful only for treating pulses with zero time duration and cannot be used in inertial confinement fusion reactor blanket

calculations where the time of flight spread effectively increases the pulse width.

Other source options available in TIMEX include an anisotropic distributed source and anisotropic boundary sources at the system boundaries. These sources can extend over any number of time steps. The initial conditions for a TIMEX problem can be specified by giving the complete angular flux and initial precursor concentrations on the fine mesh.

The core can be dumped onto an external file so that the problem may be restarted at a selected time step. The user may request a periodic dump at certain time intervals. A time limit dump is taken after a user input-specified time limit. The TIMEX problem may be restarted at any of the time steps for which a dump was taken. Only one file needs to be saved for a restarted run.

At selected times, the user can load new system properties including cross sections, sources, coarse mesh boundaries, fission fractions, velocities, mixing table densities, density factors, albedos, and delayed neutron parameters. The ability of the code to treat systems with properties that vary with time besides the short computing time required per time step make the code an attractive candidate for the elaborate coupled neutronics-photonics and hydrodynamics calculations for ICF targets.

The original version of TIMEX accepts cross sections either from a standard interface file, or cards. The cross section read from cards can be either in FIDO format, or the standard LASL format. The anisotropic scattering blocks must not contain the $(2n + 1)$ factor as in the ANISN binary library tape. This factor can be easily removed via the mixing table. When a system with a large number of elements is considered the cross sections can

exceed the maximum core storage capacity. We modified the code to add the option of reading cross sections from a group independent tape. One can use the code TAPEMAKER[12] to read ANISN binary library tape and perform the cross section mixing creating a group independent tape including the macroscopic cross sections for the mixtures only. The group independent tape can then be read by TIMEX. This modification reduces the storage required considerably.

It was stated in the manual for TIMEX that if (n,2n) reactions are included in the scattering matrices, the total (n,2n) reaction cross section must be entered in position IHT-4. However, this cross section is used only to check whether the effective absorption cross section is equal to the absorption cross section and is not used in the transport calculations. In fusion reactors, (n,3n) reactions can take place also and the effective absorption cross section will not be equal to the absorption cross section even if corrections due to (n,2n) reactions are made. Therefore, this cross section check is bypassed in the U.W. version of TIMEX and position IHT-4 in the cross section table is utilized for other activity cross sections.

In the original version of TIMEX, all activity reaction rates, for which cross sections are given in the cross section table, are calculated for all mixture materials. The code is modified to calculate and print only the desired activity reaction rates defined by their positions in the cross section table. The activities calculated are the total reaction rates per energy group in the user's specified edit zones. The code has the option of printing the activities and flux at specified time steps only. A detailed description of the input for the U.W. version of TIMEX is given in Appendix II. The files which must be assigned to a TIMEX run are also given. Some

limitations are explained to help the user make changes appropriate to the problem to be solved.

4. Summary and Conclusions

The multigroup discrete ordinates time-dependent codes TDA and TIMEX have been modified to facilitate their use in neutronics and photonics analysis of inertial confinement fusion reactors. A comparison between the codes regarding the methods of solution and the options available has been performed. The TIMEX code has been found to run much faster than the TDA code because no iteration is performed.

Because of its ability to treat systems with various time varying properties and because of its very short computing time, the TIMEX code is recommended for the elaborate and generally expensive coupled neutronics-photonics and hydrodynamics calculations for ICF targets. On the other hand, the TDA code is recommended for performing time-dependent blanket calculations because of its ability to account for the time of flight spread of neutrons in the different energy groups as they travel from the target to the blanket.

Although negative flux fixup routines are available in both codes, these algorithms are bypassed if the total source (including scattering and fission) for the space-angle-time-energy cell is negative. Unfortunately, negative sources can be obtained when materials with highly anisotropic scattering, such as ^{12}C, are present with large densities, the problem of negative flux can be eliminated by using a higher order of Legendre polynomial expansion to represent the scattering cross section. The expensive Monte Carlo codes[13] can also be used to eliminate the problem of negative fluxes.

Acknowledgment

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Appendix I. Operating Instructions of the U.W. Version of the TDA Code

A. Description of Input

I. Part I

Card 1: Format (10I6)

1. IFRED   0 — run is new and starting at the first time step.

           1 — restarted run starting at the time step immediately following the step at which the previous run was interrupted. If the run is terminated for any reason other than the restart flag the run cannot be restarted from the point of interruption.

2. ITIMS   Time step number at which the run is interrupted. If the restart option is not used set ITIMS = number of time intervals.

3. ITHRU   The time step at which the pulse has passed through the system if the first collision source option is used (IFG>0).

4. ILOW   Lowest energy group for source if the first collision source option is used (IFG>0).

5. IFISS   0 — no fission problem.

           1 — fission problem.

6. IGROUP(2) S_8 calculations for groups $1 \leqslant g < \text{IGROUP}(2)$.

7. IGROUP(3) S_6 calculations for groups $\text{IGROUP}(2) \leqslant g < \text{IGROUP}(3)$.

8. IGROUP(4) S_4 calculations for groups $\text{IGROUP}(3) \leqslant g < \text{IGROUP}(4)$.

9. IGROUP(5) S_2 calculations for groups $\text{IGROUP}(4) \leqslant g < \text{IGROUP}(5)$.

           If $\text{IGROUP}(N) = \text{IGROUP}(N+1)$, the quadrature order associated with those limits is not used.

10. MMPHOT   Photon groups $\text{IGROUP}(5) \leqslant g \leqslant \text{IGM}$ are treated with quadrature order MMPHOT-1.

Card 2: Format (3I6)

1. ITDFF   0 — no effect.

           1 — the code accepts time dependent sources and densities.

2. IMARK   The first time step at which new number densities and sources are input. If new values are input at later times,

flags indicating at which time steps the new data are added are given in Part IV of the input.

3. ITQ   0 - no effect.

1 - group dependent quadrature used. If ITQ=1 the 6* and 7* arrays can be filled with zeros.

II. Part II

All numerical data for this part of the input is written in the FIDO format used in ANISN. The free form FIDO format can be used in this version. Since familiarity with ANISN is assumed, the following data description is brief except for those parameters or arrays which are now concerned with time dependence. As in ANISN, the quantity in brackets is the array dimension and the expression in braces is the condition requiring entry of an array or set of arrays. If no condition is specified, entry of the array or set is required. A T follows each set which is entered.

A. Title Card - Format (12A4)

B. Parameters

15$ integer parameters [36]

1. ID   problem identification number

2. ITH   -   0 - forward solution

1 - adjoint solution

3. ISCT   maximum order of Legendre polynomial approximation to scattering cross sections

4. ISN   angular quadrature order

5. IGE   1 - slab

2 - cylinder

3 - sphere

6. IBL   left boundary condition

0 - vacuum

1 - reflection

2 - periodic

3 - white/albedo

7. IBR   right boundary condition, same options as IBL

8. IZM   number of zones

9.	IM	number of mesh intervals
10.	IEVT	0
11.	IGM	number of energy groups ($\leq$ 46)
12.	IHT	position of σ_{total} in cross-section table
13.	IHS	position of σ_{gg} in cross-section table
14.	IHM	length of cross-section table
15.	MS	length of cross-section mixing table
16.	MCR	number of cross-section sets to be read from cards
17.	MTP	number of cross-section sets to be read from tape
18.	MT	total number of cross-section sets ($\leq$ 120)
19.	IDFM	0 - no effect
		1 - enter density factors (21*)
20.	IPVT	0
21.	IQM	0 - no effect
		1 - enter distributed source to be used in first time interval, only
22.	IPM	0 - no effect
		IM - enter complete centered angular flux distribution at T=0, (IM, MM, IGM)
23.	IPP	0
24.	IIM	inner iteration maximum per group per outer iteration
25.	ID1	0 - no effect
		1 - print scalar flux
		2 - print uncollided flux if IFG > 0
		3 - both 1 and 2
26.	ID2	0 - cross-sections from cards or ANISN binary library tape
		1 - use group independent cross section tape
		2 - use cross-sections and source from previous problem
27.	ID3	number of time intervals
28.	ID4	number of activities
29.	ICM	outer iteration maximum
30.	IDAT1	0 - all data in core
		1 - cross-sections and sources stored on tape
		2 - flux and current stored on tape also

31.	IDAT2	0
32.	IFG	0 – no effect
		N – enter N source spectra (23*) for first-collision source calculation
33.	IFLU	no. of time steps for first-collision source
34.	IFN	1 – enter flux guess (3*)
		2 – use flux from previous case
35.	IPRT	0 – no effect
		1 – do not print cross sections
36.	IXTR	0 – no effect
		1 – write angular flux tape for each time interval

16* floating point parameters [14]

1.	EV	0.0
2.	EVM	0.0
3.	EPS	accuracy desired
4.	BF	buckling factor, normally 1.420892
5.	DY	cylinder or plane height for buckling correction
6.	DZ	plane depth for buckling correction
7.	DFM1	transverse dimension for void streaming correction
8.	XNF	normalization factor. For IFG=1, XNF is the actual total number of particles input at t=0. For IFG>1, normalization is based on the ratio of source at time n to that at time 0, scaled to XNF particles/sec. If IQM=1, the source is normalized to XNF particles/sec. If XNF=0, no normalization is made.
9.	PV	0.0
10.	RYF	0.5
11.	XLAL	point flux convergence criterion
12.	XLAH	0.0
13.	EQL	0.0
14.	XNPM	0.0

T

C. Cross-Sections

13$ cross-section library ID numbers [MTP] {MTP>0 and ID2=0}

14* MCR cross-section sets [IHM*IGM*MCR] {MCR>0}

T

D. Distributed Source-Centered Flux Distribution {IFG=0}

17* distributed source [IM*IGM] {IQM=1}

18* centered angular flux distribution [IM*MM*IGM] {IPM=IM}

T

E. Flux Guess {IFN=1}

3* flux guess [IM*IGM] {IFN=1}

T

F. Remainder of Data

1* fission spectrum [IGM]

4* radii [IM+1]

5* velocities [IGM]

6* angular quadrature weights [MM]

7* angular quadrature cosines [MM]

8$ zone numbers [IM]

9$ material numbers [IZM]

10$ mixture numbers [MS]

11$ component numbers [MS]

12* number densities [MS]

19$ order of Legendre polynomial approximation to scattering cross section
[IZM]

20* activity cross sections [IGM*ID4] {ID4>0}

21* density factors [IM] {IDFM=1}

22* time interval boundaries [ID3+1]

23* IFG source spectra; source emission occurs at corresponding times
specified by 24* array; the first spectrum is normalized to XNF
particles/sec (if XNF>0) and the other spectra are scaled to maintain the

same relative values. If IFG=1, the source is a pulse at t=0 normalized to XNF particles [IGM*IFG] {IFG>0}.

24* source emission time interval boundaries for first-collision source spectra [IFLU+1] {IFG>0}

25* right boundary albedo [IGM] {IBR=3}

26* left boundary albedo [IGM] {IBL=3}

27* source spectrum no. by time step [IFLU]

T

III. Part III

This part is input if ID4>0. In this case the 20* array must still be defined and can be filled with zeros.

Card 1: Format (I6)

    ID4F   number of lines of activity data that follow (< 30)

Cards 2 Through ID4F+1 (I=1, ID4F): Format (2I6, F12.8, I6)

    MAT(I)   material number of elements for which activity cross-section is needed

    IPOS(I)   cross section position for activity

    DENS(I)   the number density of MAT(I) if MAT(I) corresponds to one of the input elements. If MAT(I) corresponds to one of the mixtures, DENS(I) is the density factor

    MIX(I)   If MAT(I) is the first material in a mixture, the following MIX(I)-1 materials are mixed with it to form one macroscopic activity cross section.

IV. Part IV

This part is input if ITDFF>0 and more than one set of new densities and sources are to be read. This part consists of N-1 cards where N is the number of new data input. Each card has the variable ISTEP with the format (I6). ISTEP is the number of time steps until the next new data set is input.

B. Files Assigned to the Run

Files 2 and 3 are used to store cross sections and sources when IDAT1≠0. Files 8 and 9 are used to store flux and current when IDAT1=2. The input cross-section file must be assigned to the logical unit number 4. The calcu-

lated fluxes are written after every time interval on file 15. If activities are to be retained, file 18 must be assigned and the activities are written on it.

If time dependent sources and densities are used (ITDFF=1) new number densities and sources are read from the unformatted file 16. This file must contain a list of new densities and sources arranged according to arrays 12* and 17* (or 18*). If new values are to be inserted for more than one time step, the values for later time steps are placed directly behind the previous data.

If the restart option is used, file 10 must be assigned. It receives a dump of all information to restart the problem. All files must be saved if the user plans to restart the run. In this case file 15 must be copied to another file before restarting since the fluxes will be overwritten by the new values.

C. Other Operating Information

The limitations on IGM and MT in 15$ array of part II of the input are determined by the dimensions of the array TOTCR in subroutine GUTS. The dimension can be changed to allow for larger number of groups and elements. The limitation on ID4F on card 1 of part III is determined by the dimensions of MAT, IPOS, DENS and MIX in subroutine S807. For larger numbers of activities these dimensions are to be increased.

Appendix II. Operating Instructions for the U.W. Version of the TIMEX Code

A. Data Input Rules

Except for the control parameters, cross sections, and edit parameters, all floating-point numbers and integers are read into TIMEX in special formats by the LOAD subroutine. These formats are [6(I1,I2,E9.4)] for reading floating-point numbers and [6(I1,I2,I9)] for integers. In each word of both of these formats, the first integer field, I1, designates the options listed below. The second integer field, I2, controls the execution of the option, and the remainder of the field, I9 or E9.4, is for the input data. All data blocks read with these formats must be ended with a 3 in the I1 field after the last word of the block. The available options are given below.

Value of I1	Nature of Option
0 or blank	No action.
1	Repeat data word in 9 field number of times indicated in I2 field.
2	Place number of linear interpolants indicated in I2 field between data word in 9 field and data word in next 9 field. Not allowed for integers.
3	Terminate reading of data block. A 3 must follow last data word of all blocks.
4	Fill remainder of block with data word in 9 field. This operation must be followed by a terminate (3).
5	Repeat data word in 9 field 10 times the value of the I2 fields.
9	Skip to the next data card.

B. Description of Input

On the following pages the input data for TIMEX are listed in exactly the order in which they are entered on the code. The data are divided into five categories: (1) job title cards, (2) control integers on cards 1 through 4 and control floating-point numbers on cards 5 and 6, (3) problem-dependent data on subsequent cards, (4) edit input, and (5) time-zone control input.

1. Job Title Cards

The user begins by indicating on a card in a I6 format the number of title or job description cards he wants to use. He then enters the descriptive material on these cards which are read with a 18A4 format.

2. Input of Control Numbers

On cards 1 through 4, the user enters the following control integers which are read in a 12I6 format and on cards 5 and 6 the following control floating-point numbers in a 6E12.4 format:

Number of Word on Card	Name of Variable	Comments
CONTROL INTEGERS	(12I6)---CARD 1	
1	ITH	0/1 (direct/adjoint) type of calculation performed.
2	ISCT	0/N (isotropic/N^{th} order anisotropic) order of scattering calculation. NM spherical harmonic flux components are computed.
3	ISN	S_N angular quadrature order. Must be an even number.
4	IGM	Number of energy groups.
5	IM	Number of coarse-mesh intervals.
6	IBL	0/1/2/3/4 (vacuum/reflective/periodic/white/albedo) left boundary condition.
7	IBR	0/1/2/3/4 right boundary condition.
8	IGD	Number of delayed neutron groups.
9	ISTART	0/1/2/$\pm$3/4/5/6 angular flux initial condition.

ISTART	Option
0	Zero initial flux, no input required.
1	Cell-centered isotropic angular flux on the fine mesh: F(IT). One distribution is entered from cards for each of IGM energy groups.

| | | | 2 | Complete angular flux on the fine mesh: F(2,IT). One distribution is entered from cards for each of MM angles. A set of MM distributions is entered for each of IGM energy groups. |

		2	Complete angular flux on the fine mesh: F(2,IT). One distribution is entered from cards for each of MM angles. A set of MM distributions is entered for each of IGM energy groups.
		±3	A problem restart dump is read from unit NDMP1.
		4	The initial angular flux is read from standard interface file RAFLUX or AAFLUX mounted on unit IAFLUX.
		5	Energy spectrum for the first collision source: UFS(IGM). The first collision source is computed. The initial angular flux is assumed zero throughout the system.
		6	The initial angular flux is read from the special NTIMEX file created by the ONETRAN code.
10	IQOPT		0/±1/±2/±3/±4/5 inhomogeneous source input option.

IQOPT	Option
0	Zero distributed source (no input).
±1	Energy spectrum for the distributed source: EQ(IGM). One spectrum for each NMQ components.
±2	Flat distributed source on the fine mesh: Q(IT). One distribution for each group and each NMQ components.
±3	Linear distributed source on the fine mesh: Q(2,IT). The first subscript is the left edge and the right edge sources, respectively. One distribution for each group and for each NMQ components.

	±4	A single energy spectrum for the distributed source: EQ(IGM), followed by a single linear distributed source on the fine mesh: Q(2,IT). The distributed source is formed by the product of the energy spectrum and the fine-mesh spatial distribution. One spectrum and one spatial distribution for each NMQ componens.
	5	Input of both distributed and boundary sources from standard interface file FIXSRC mounted on unit IFIXSR.
11	IGEOM	1/2/3/4 (plane/cylindrical/spherical/two-angle plane) geometry option.
12	IQUAD	1/2/±3 (built-in P_n/built-in DP_n/+: card input, −: interface file) source of S_N quadrature constants w and μ.

CONTROL INTEGERS   (12I6)--CARD 2

1	MT	Total number of materials (cross-section blocks including anisotropic cross sections) in the problem.
2	MTP	Number of input material sets from interface file ISOTXS. CAUTION: Each material set from this field yields ISCT+1 materials. See LMTP below.
3	MCR	Number of input materials from the code-dependent input file. If MCR is negative, each MCR material is read as a single block on the FIDO format, terminated by the FIDO terminator: T.
4	MS	Number of mixture instructions.
5	IHT	Row of total cross section in the cross-section format.

6	IHS	Row of within-group scattering cross section in the cross-section format. For problems with upscattering (IHS>IHT+1), IHS must be flagged negative if σ^{up} is present in the cross-section table, and to be removed. Not applicable for FIDO format input.
7	IHM	Total number of rows in the cross-section format.
8	IDEN	0/1 (no/yes) space-dependent density factors.
9	IQAN	0/N (isotropic/N^{th}-order anisotropic) order of source anisotropy. NMQ spherical harmonic source components are required input. CAUTION: ISCT>IQAN is required.
10	IQL	0/1 (no/yes) left boundary source.
11	IQR	0/1 (no/yes) right boundary source.
12	IACC	0/1/2 (no/within-group/within-group plus outer) rebalance option.

CONTROL INTEGERS   (I6,1X,5I1,I6,6I1,4I6)-----------------------------CARD 3

1	IFISS	1/2/3/4 (fission spectrum/zone-dependent fission spectrum/fission matrix/zone-dependent fission matrix) type of fission fractions.
2	KP1	0/1 (no/yes) delayed neutron precursor print trigger.
	KP2	0/1 (no/yes) zone edit option print triggers.
	KP3	0/1 (no/yes) angular flux print trigger.
	KP4	0/1 (no/yes) exponential extrapolation factor print trigger.
	KP5	0/1 (no/yes) flux components print trigger.
3	IPLOT	0/1/2/3/4 (no/semi-log/linear/semi-log movie/linear movie) scalar flux plotting option.
4	I1	0/1 (no/yes) initial flux print suppression trigger.

	I2	0/1/2 (all/isotropic/none) time zone flux print trigger.
	I3	0/1/2 (all/mixed/none) cross-section print trigger.
	I4	0/1 (no/yes) time zone fission print trigger.
	I5	0/1/2/3 (all/unnormalized/normalized/none) source print trigger.
	I6	0/1 (no/yes) fine-mesh geometry table print suppression trigger.
5	ITLIM	0/N (none/N second) time limit.
6	IFO	0/1 (no/yes) interface file output trigger.
7	IPCOPT	0/1/2 (zero/equilibrium/card input) initial precursor concentration option.
8	IANISN	0/1 (no/yes) group independent tape read (used only if MCR < 0).

CONTROL INTEGERS   (12I6)--CARD 4

1	ITXS	0/1 (no/yes) load new cross-section blocks at each time zone.
2	ITQ	0/1 (no/yes) load new inhomogeneous sources at each time zone.
3	ITB	0/1 (no/yes) load new coarse-mesh boundaries at each time zone.
4	ITIDXS	0/1 (no/yes) load new cross-section identification array at each time zone.
5	ITFISS	0/1 (no/yes) load new fission fractions at each time zone.
6	ITVEL	0/1 (no/yes) load new group speeds at each time zone.
7	ITMIX	0/1 (no/yes) load new mixture tables at each time zone.
8	ITDEN	0/1 (no/yes) load new fine-mesh density factors at each time zone.

9	ITLBDO	0/1 (no/yes) load new left boundary group-albedos at each time zone.
10	ITRBDO	0/1 (no/yes) load new right boundary group-albedos at each time zone.
11	ITDELY	0/1 (no/yes) load new delayed neutron parameters at each time zone.

CONTROL FLOATING POINT DATA   (6E12.6)---------------------------------CARD 5

1	NORM	Normalization factor. If NORM$\neq$0, the total number of source particles (if inhomogeneous sources are present) or the total number of prompt fission particles (if inhomogeneous sources are <u>not</u> present) are normalized to this number. No normalizations are performed if NORM=0.0.
2	BHGT	Buckling height (in cm if cross sections are in cm^{-1}). If BHGT is flagged negative, the transport cross section in position IHT-3 is used for calculation of the buckling absorption.
3	BWTH	Buckling width (plane geometry only).

MOVIE CONTROL DATA (I6,2E12.6)---CARD 6

Enter only for movie plots (IPLOT>2). (Not implemented in the U.W. version.)

1	NSPMP	Number of time steps per movie plot.
2	FMIN	Minimum value of scalar flux over complete time range.
3	FMAx	Maximum value of scalar flux over complete time range.

3. Problem-Dependent Data

In the input data listed below, all the items are dimensionless except for the source, flux, velocities, mesh specifications, cross sections, bucklings, and mixture densities.

With the exception of the cross sections from the code-dependent input file, all the following data are loaded by the LASL block loader using the special formats described in part A of this Appendix. We denote these formats by S(I) for integers and S(E) for floating point numbers.

Block Name and Dimension	Format	Number of Entries	Comments
IHR(IM)	S(I)	IM	Number of fine mesh intervals in each coarse mesh.
WGT(MM)	S(E)	MM	S_N quadrature weights. <u>Enter only if IQUAD=+3.</u>
U(MM)	S(E)	MM	S_N quadrature μ cosines. <u>Enter only if IQUAD=+3.</u>
C(IHM,IGM,MIN)	--	--	Cross-section blocks. MIN=MCR+MTP*(ISCT+1). Four options are available for reading cross sectons. The LASL input format may not be mixed with the FIDO format. 1. <u>LASL Input.</u> If MCR>0, MCR blocks of IHM*IGM numbers are read in a 6E12.5 format. Each block is preceded by the identification card read in a 18A4 format. 2. <u>FIDO Input.</u> If MCR<0, |MCR| blocks of data are created from FIDO input. The 14* card must <u>not</u> preceed the FIDO input data. 3. <u>Interface File ISOTXS.</u> When MTP≠0, MTP material sets are read from standard interface file ISOTXS. On this file each material set consists of ISCT+1 cross-section blocks for the isotropic and ISCT anisotropic cross sections. The first

(isotropic) component of the first material is stored in cross-section block MCR+1, the first component of the second material is stored in cross-section block MCR+ISCT+2, etc. Should the ISOTXS file not contain ISCT anisotropic components, zeroes are supplied for the components not present. If the ISOTXS file contains more components than needed, only the first ISCT+1 components are read. The maximum number of up-scatter groups and downscatter groups (MAXUP, MAXDN) in the ISOTXS file must be consistent with the choice of IHT, IHS, and IHM. If they are not consistent, this will be flagged as an error.

4. Group Independent File. When IANISN=1, |MCR| blocks of data are read in FIDO format from a group independent file.

LMTP(MTP)	S(I)	MTP	Position numbers of material sets to be read from ISOTXS. Do not enter unless MTP>0. The material sets are loaded into the C block in the order they appear on the ISOTXS file, and not in the order they appear in the LMTP array.
Initial angular flux AF(2,IT)	S(E)	--	Number of entries depends on option.

ISTART	Number of entries
0	None.
1	IT, one distribution for each group.

	2	MM sets of 2*IT, MM sets for each group.	
	±3	Problem restart dump from unit NDMP1.	
	4	Angular flux from standard interface file on unit IAFLUX.	
	5	IGM	
	6	ONETRAN angular flux file on unit NTIMEX.	

Initial precursor concentrations PC(2,IT)   S(E)   2*IT

Initial precursor concentrations. IGD blocks of length 2*IT. <u>Enter only if IPCOPT=2.</u>

Input sources   S(E)   --

Number of entries depends on option. The sources are loaded as: (a) distributed source (if any) for each group; for each anisotropic component; (b) left boundary source (if any) and right boundary source (if any); for each group. For IQOPT flagged negative, an energy spectrum is input for each (assumed isotropic) boundary source. For IQOPT positive or zero, the complete angular distribution of the boundary sources is input, a distribution for each group.

Q(NMQ,2,IT)

QL(MM/2)

QR(MM/2)

IQOPT	Number of entries for distributed source
0	None.
±1	IGM; one for each NMQ components.
±2	IT; one for each group; for each NMQ components.

		±3	2*IT; one for each group; for each NMQ components.
		±4	IGM and 2*IT; both for each NMQ components.
RAD(IM+1)	S(E)	IM+1	Coarse-mesh radii.
IDC(IM)	S(I)	IM	Cross-section material identification numbers. These numbers assign a cross-section block to each coarse-mesh interval. These numbers must be flagged negative for an anisotropic source to be calculated in that coarse-mesh interval.
CHI(IGM,IM)	S(E)	--	Prompt fission fractions. Fraction of fission yield emerging in each group. May be either a spectrum (χ_g) or a matrix $(\chi_{g' \to g})$ and may be coarse-mesh zone-dependent.

IFISS	Number of entries
1	IGM; single fission spectrum.
2	IGM*IM; IM sets of spectra loaded as a single block.
3	IGM sets of length IGM; single fission matrix, loaded by rows in blocks of IGM length.
4	IGM sets of length IGM*IM; IM sets of matrices, loaded by rows in blocks of IGM*IM length.

VEL(IGM)	S(E)	IGM	Group speeds.
MIXNUM(MS)	S(I)	MS	Numbers of identifying cross-section block being mixed. Do not enter if MS=0.

MIXCOM(MS)	S(I)	MS	Numbers controlling cross-section mixture process. <u>Do not enter if MS=0.</u>
MIXDEN(MS)	S(E)	MS	Mixture densities. <u>Do not enter if MS=0.</u>
DEN(IT)	S(E)	IT	Fine-mesh density factors. <u>Enter only if IDEN=1.</u>
LB(IGM)	S(E)	IGM	Left boundary group-albedos. <u>Enter only if IBL=4.</u>
RB(IGM)	S(E)	IGM	Right boundary group-albedos. <u>Enter only if IBR=4.</u>
LAM(KM,IGD)	S(E)	KM*IGD	Delayed neutron decay constants. <u>Enter only if IGD>0.</u> KM=1 for IFISS=1 or 3. KM=IM (coarse-mesh-dependent) for IFISS=2 or 4.
BETA(KM,IGD)	S(E)	KM*IGD	Delayed neutron fractions. <u>Enter only if IGD>0.</u>
PS(KM,IGD,IGM)	S(E)	KM*IGD*IGM	Delayed neutron spectrum. <u>Enter only if IGD>0.</u>

4. Zone-Edit Input

The zone-edit input, <u>entered only if KP2=1,</u> consists of control integers entered on cards indicated by EDIT1, 2, and 3; and the remaining edit input entered in the special format discussed above.

The zone-edit control integers and the zone-edit arrays are read for all NZEDS edits with the initial problem and written onto a scratch file (NEDIT) for use during edits as required.

EDIT CONTROL INTEGERS   (I6)--EDIT 1

1	NZEDS	Number of zone edits.

ZONE EDIT CONTROL INTEGERS   (12I6)--EDIT 2

1	NZ	Total number of zones.

2	NCA	Number of constituent activities calculated.
3	NMA	Number of microscopic activities calculated.
4	NORMZ	Zone identification number for normalization of power density. If NORMZ=0, whole-system normalization is performed.
5	NACT	Number of activity cross sections to be used in the zone edit ($<$ 12).

ZONE EDIT CONTROL INTEGERS   (12I6)--EDIT 3

1→NACT	IPOS(J), J=1, NACT	Positions of activity cross sections used.

ZONE EDIT ARRAYS THROUGH LOAD--

IDCA(NCA)	S(I)	NCA	Cross-section material identification numbers for constituent activities. Enter only if NCA$>$0.
IDMA(NMA)	S(I)	NMA	Cross-section material identification numbers for microscopic activities. Enter only if NMA$>$0.
NEDZ(IT)	S(I)	IT	Zone identification numbers. These numbers assign a zone number to each fine-mesh interval.

5. Time-Zone Control Input

The time-zone control input consists of the time-zone control parameters entered on TZCARD1 and an optional array through the LASL LOAD routine. As many time-zone control variables cards as desired may be read in each time zone.

Setting the variable NTS=-1 indicates the beginning of a new time zone. The program then returns to processing the input of the new problem-dependent arrays. Only those arrays specified by the triggers ITXS through ITDELY of CARD 4 are required to be input, in the same order as they appear in Sec. B.3. Once the new arrays have been read, the time-zone control parameters for the new time zone are read and the time-integration resumed.

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Setting the variable NTS=0 indicates the termination of the problem. The program then begins processing the input of a new problem, starting with the job title card. As many problems as desired may be stacked on the input file. Execution of TIMEX is normally terminated with a detection of an end-of-file on the input stream.

TIME-ZONE CONTROL VARIABLES		(5I6,1X,5I1,E12.6)----------------------TZCARD 1
1	NTS	Number of time steps. For NTS=0, the problem is terminated. For NTS=-1, all other variables on TZCARD 1 are ignored and the new problem-dependent data of Sec. B.3. are entered as specified by the triggers on CARD 4 of Sec. B.2.
2	NSPP	Number of time steps per printout.
3	NSPD	Number of time steps per restart dump. NSPD=0 specifies no restart dump.
4	IFREQ	0/1 (no/yes) frequency extrapolation.
5	INDTS	0/1 (no/yes) group-dependent time step sizes.
6	KP1	0/1 (no/yes) delayed neutron precursor print trigger.
	KP2	0/1 (no/yes) zone-edit print trigger.
	KP3	0/1 (no/yes) angular flux print trigger.
	KP4	0/1 (no/yes) exponential extrapolation factor print trigger.
	KP5	0/1 (no/yes) flux components print trigger.
7	DELTAT	Time step size.

TIME ZONE ARRAY THROUGH LOAD---

IGTSF(IGM)	S(I)	IGM	Time step scale factors. Enter only if INDTS>0.

C. Files Assigned to the Run

If the restart option is used, file 21 must be assigned and saved. It receives a dump of all information at the time steps specified for core dump. In a restarted run this file must be assigned to the run.

The scratch files 18, 13, and 4 must be assigned to the run. If the cross sections are not read in FIDO format, file 4 needs not to be assigned.

If cross sections are to be read in a group independent form, the cross section file must be assigned to the logical unit number 9.

D. Other Operating Information

The limitation on NACT on card EDIT 2 is determined by the dimensions of IPOS in common SAWAN. The dimension can be changed if a larger number of activities needs to be calculated. The movie and plotting options have not yet been implemented in the U.W. vesion of TIMEX.