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TRIGLAV
A Program Package for Research Reactor Calculations

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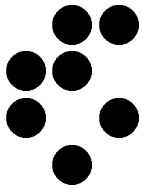

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Introduction

TRIGLAV program package is developed for reactor calculations of mixed cores in TRIGA Mark II research reactor. It can be applied for fuel element burnup calculations, for power and flux distributions calculations and for critically predictions.

Program is based on four group time independent diffusion equation in two dimensional cylindric (r, ϑ) geometry. Diffusion equation is solved using finite differences method with iteration of fission density. Material constants are assumed to be step functions of local variables r and ϑ. Neutron upscattering to higher energy groups is not neglected.

Geometry of the program is adjusted to cylindric core of the TRIGA Mark II reactor. Every fuel and non-fuel element position in the core is treated as a unit cell (see Figure 1). Group constants for all unit cells are calculated with transport program WIMS [1], which is integrated in the program package. The group constants are calculated for every unit cell in dependence of: fuel or non-fuel element geometry, material composition, actual fuel element burnup, temperature, water temperature and density, cladding temperature and of xenon concentration.

The program was originally developed for PC. VAX version is available as well. Structure of the main program is schematically presented in Figure 2. Program package is divided into several subroutines. It requires two input files `TRIGLAV.INP`, `ELEM.INP` and writes two output files `TRIGLAV.OUT` and `ELEM.OUT`. Optionally flux output data can be written on special file named `TRIGA2D.FLU`.

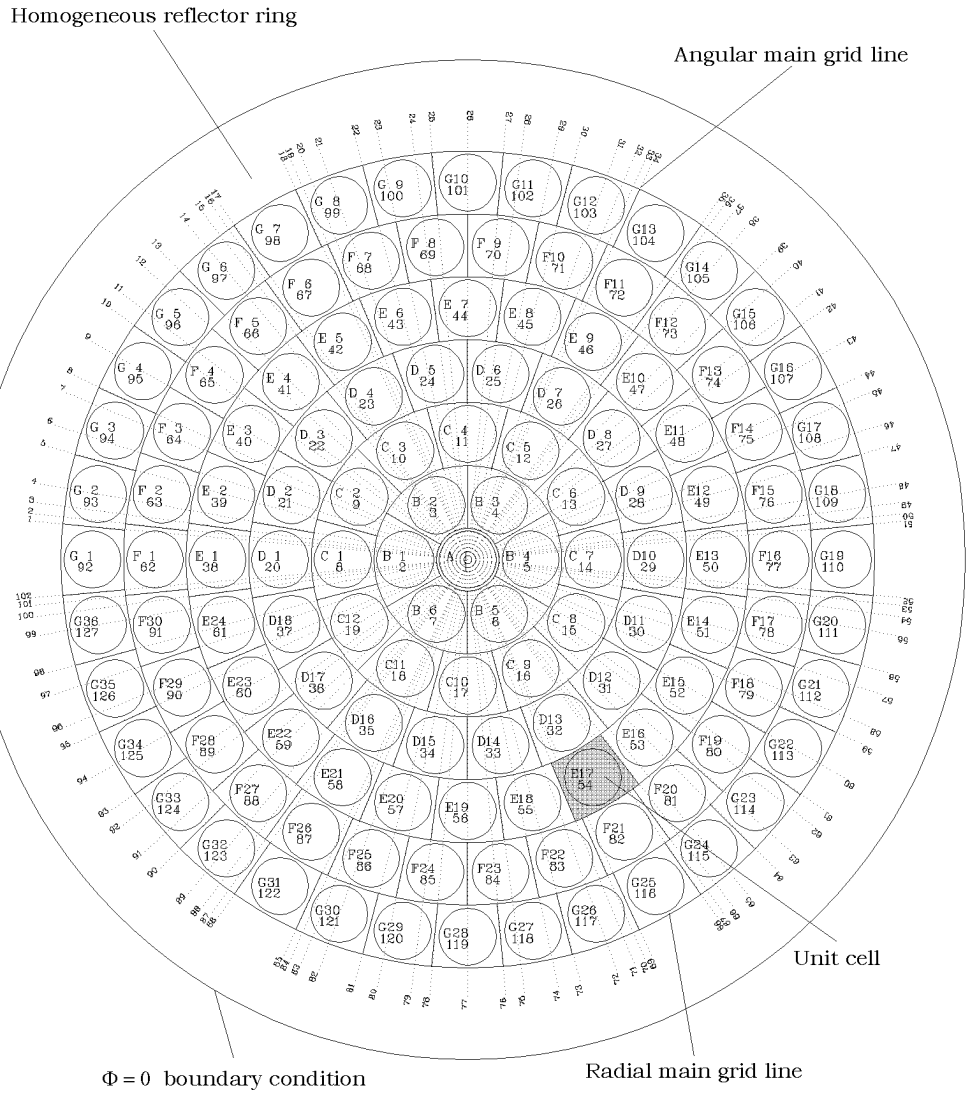

Figure 1: TRIGA Mark II reactor geometry assumed in TRIGLAV geometry model. Homogeneous unit cells are assumed. Main angular grid lines coincide with the unit cell boundaries.

Table 1: TRIGLAV program package general physical model characteristics.

geometry	two dimensional cylindric
number of energy groups in diffusion calculation	4
upscattering	not neglected
method of solution	finite differences method fission density iteration
unit cell homogenization	online with lattice cell program WIMS-D/4 in unit-cell approximation
number of energy groups in WIMS calculation	32
CPU time (Pentium PC)	$\approx 1000s$

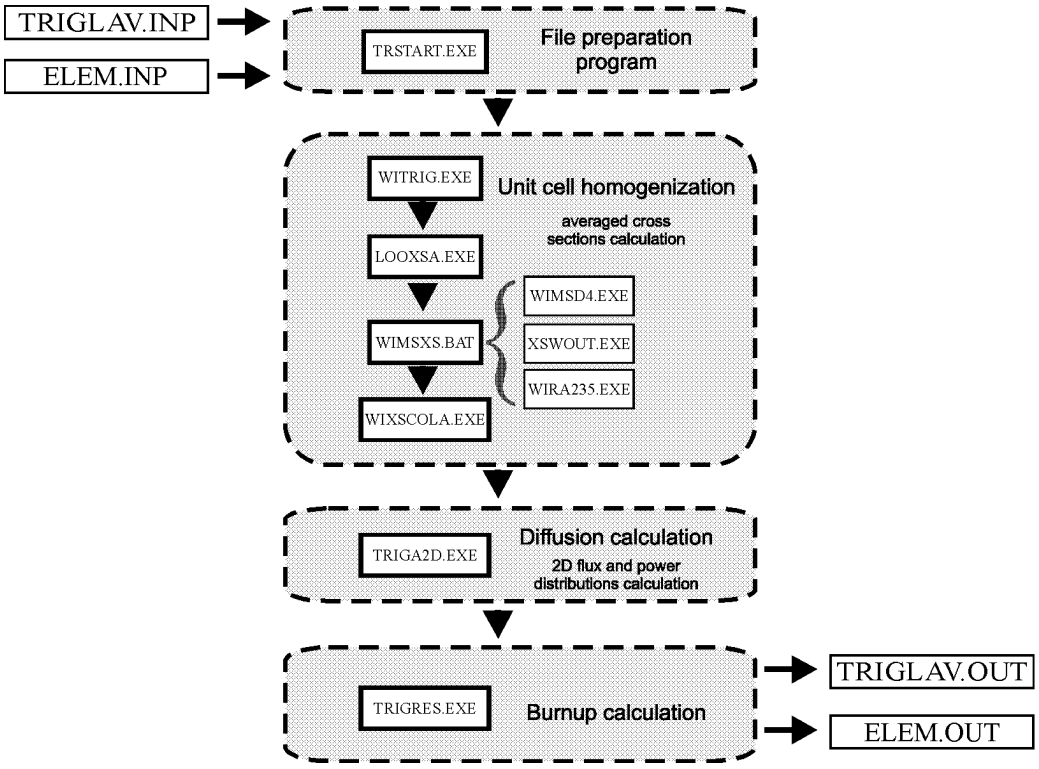

Figure 2: TRIGLAV program package schematic flow-chart.

1 General description

1.1 Diffusion approximation

The program is based on four group time independent homogeneous diffusion equation in two dimensional cylindric (r, ϑ) geometry. Equation for energy group g is written in the following form:

$$- \bigtriangledown D^g \bigtriangledown \Phi^g + \Sigma_r^g \Phi^g = (\frac{1}{k}) \chi^g F + \sum_{g'=1, g' \neq g}^{4} \Sigma^{g' \to g} \Phi^{g'}; g = 1, \ldots, 4, \qquad (1)$$

where:

Φ^g	neutron flux,
D^g	diffusion constant,
Σ_r^g	removal cross section
	$(\Sigma_r^g = \Sigma_a^g + \sum_{g'=1, g' \neq g}^{4} \Sigma^{g \to g'} + D^g B_z^2)$,
$\Sigma^{g' \to g}$	scattering cross section from group g' into group g,
χ^g	part of fission spectrum in group g
	(default TRIGLAV: $\chi_1 = 1$, $\chi_2 = \chi_3 = \chi_4 = 0$),
k	multiplication factor,
F	fission density, which is defined as:

$$F = \sum_{g=1}^{4} \nu^g \Sigma_f^g \Phi^g, \qquad (2)$$

where ν^g is number of fission neutrons in energy group g and Σ_f^g fission cross section for group g. Neutron flux $\Phi^g(r, \vartheta)$, fission density $F(r, \vartheta)$, diffusion constant $D^g(r, \vartheta)$ and all cross sections $\Sigma_r^g(r, \vartheta)$, $\Sigma^{g' \to g}(r, \vartheta)$ and $\Sigma_f^g(r, \vartheta)$ are functions of local variables r and ϑ.

All cross sections are taken as step functions of local variables r and ϑ. The points of discontinuity define the interfaces of homogeneous zones.

The $\Phi^g(r_{boundary}, \vartheta) = 0$ boundary condition is imposed for all ϑ at the outer boundary of the reactor reflector ($r_{boundary}$ is outer radius of reflector).

The diffusion equation is solved using finite differences method. The definition area which is a circle with radius $r_{boundary}$ is divided in radial direction r in J intervals and in angular direction ϑ in I mesh intervals. Intervals need not be equidistant neither in r nor in ϑ direction. For detailed description of the geometry, mathematical model and method of solution see Appendix A.

Two dimensional difference mesh is adjusted to TRIGA Mark II reactor core geometry. TRIGA Mark II reactor core is composed of 6 or 7 fuel rings and graphite or water reflector. So we have 7 (A,B,C,D,E,F fuel rings and reflector) or 8 (A,...,G fuel rings and reflector) radial zones. All fuel rings are composed of unit cells, only reflector ring is homogeneous. Central "ring" A consists of one unit cell. For this configuration we have 102 angular intervals (presented in Figure 1), coinciding with unit cell boundaries. Angular value $\vartheta = 0$ is selected at the symmetric line running trough unit cells A1, B1, C1,.... There can not be less than 102 intervals

$(\vartheta_i; i = 1, \ldots, 102)$, in angular direction because otherwise some mesh nodes would not be homogeneous. For radial dimension r we must have at least 8 intervals $(r_j; j = 1, \ldots, 7$ or $j = 1, \ldots, 8)$ depending on number of fuel rings, for the same reason. For better accuracy we can divide this minimum geometry mesh by increasing number of intervals. For more details on mesh definition see description of TRIGLAV input file in Section 3.1.

The finite difference equations are solved by fission density iterations. Each group equation is inverted by inner iterations method [3].

1.2 Unit cell homogenization

The homogenization of the material constants for each unit cell in the reactor core are made using the transport program WIMS [1]. The core may consist of fuel and non-fuel unit cells. A fuel unit cell contains fuel element and corresponding volume of surrounding water, which is equal for all unit cells in the core. In WIMS model fuel rod and surrounding water are treated explicitly in an infinite array of identical unit cells (white boundary condition is imposed on the outer boundary of the unit cell). Currently four types of fuel elements can be treated in the program (for more information see Table 2):

ST8 standard fuel element with 8.5 wt % U (20 % enrichment),

ST12 standard fuel element with 12 wt % U (20 % enrichment),

FLIP FLIP fuel element with 8.5 wt % U (70 % enrichment) and

LEU LEU fuel element with 20 wt % U (20 % enrichment).

Average non-fuel unit cell containing non-fuel element (graphite element, beryllium element, irradiation channel, control rods or just water) and surrounding water, can not be treated in the unit cell approximation. Super-cell approach is used instead. In this model non-fuel cell is surrounded by several fuel rods. Next six non-fuel elements are included in the program:

GR graphite element (C in Al tube),

BE beryllium element (Be in Al tube),

IC1 irradiation channel, void channel (empty Al tube),

IC2 irradiation channel, half void, half water (1/2 empty + 1/2 water in Al tube),

IC3 irradiation channel, filled with water (water in Al tube) and

LW water only (without tube).

Water and graphite reflector constants are calculated by the program in unit cell approximation. Notation:

W water reflector and

G graphite reflector.

The burnup increment of each element in a burnup step is calculated from flux and power distribution. Calculated burnup increments are automatically added to the burnup read from file `ELEM.INP` and are written to file `ELEM.OUT`. Burnup increment is defined as specific power per element (in [kW]) multiplied by burnup time [days]. Specific power per element is calculated from power distribution and input reactor power.

Table 2: Fuel elements considered in TRIGLAV.

	ST8	ST12	FLIP	LEU
Dimension [cm]				
Fuel length	38.1	38.1	38.1	38.1
Element diameter	3.75	3.75	3.75	3.75
Fuel diameter	3.64	3.64	3.64	3.64
Zr-rod diameter	0.635	0.635	0.635	0.635
Cladding thickness	0.05	0.05	0.05	0.05
Composition				
part of U in fuel [wt %]	8.5	12	8.5	20
$\rho_{init.}$ [gcm^{-3}]	5.8	6.1	5.9	6.4
$m_{init.}(U)$ [g]	190.2	276.6	191.8	494.9
$(wt\%^{235}U)_{init.}$ [wt %]	0.017	0.023	0.059	0.040
$e_{init.}$ [%]	19.9	19.9	70.0	19.8
$(wt\%^{166}Er)_{init.}$ [wt %]			0.005	0.001
$m(^{166}Er)_{init.}$ [g]			11.5	3.6
$(wt\%^{167}Er)_{init.}$ [wt %]			0.003	0.001
$m(^{167}Er)_{init.}$ [g]			7.9	2.5

2 Subroutines

The program package TRIGLAV is run by batch procedure named TRIGLAV (file `TRIGLAV.BAT`), which starts all subroutines and manipulates temporally files within the program package. The batch procedure TRIGLAV and input files `TRIGLAV.INP` and `ELEM.INP` must be in the same directory, all other executable subroutines may be in separate directory. After the program package execution all output files are written to the directory of the input files. The batch procedure also writes log file `TRIGLAV.LOG`. Flow-chart of TRIGLAV program package is presented in Figure 3.

2.1 Subroutine TRSTART

The subroutine TRSTART reads input file `TRIGLAV.INP` and prepares temporary input file `TRIGA2D.INP` for cross section and diffusion calculations.

2.2 Subroutine WITRIG

In subroutine WITRIG the input files for the program WIMS are prepared for each fuel and non-fuel unit cell in reactor core.

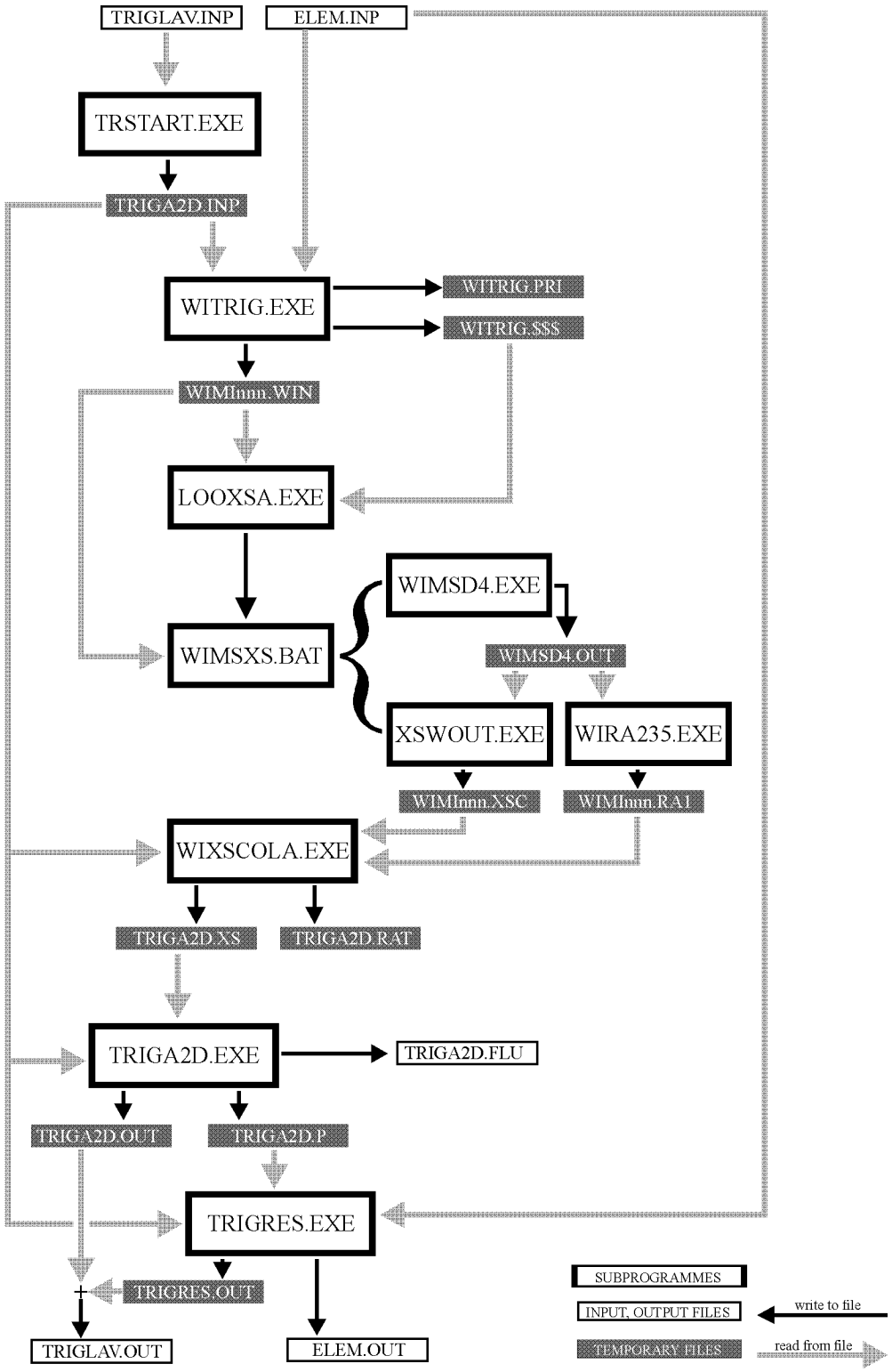

Figure 3: Flow-chart of TRIGLAV program package.

Table 3: Initial power form factors.

Fuel ring	A	B	C	D	E	F	G
α_P	1.0	0.9	0.8	0.7	0.6	0.5	0.5

Fuel element data are read from input files and material constants are calculated. Element type, mass of U ($m(U)$ in [g]), enrichment of U (e in [%]), mass of ^{166}Er and ^{167}Er ($m(Er)$ in [g]) (only for FLIP and LEU elements) and burnup of the element (BU_1 in [MWd] and BU_2 in [%]) are read from file `ELEM.INP`. Thermal power of reactor (P in [kW]), temperature of coolant (T_{water} in [K]) and xenon condition are read from `TRIGLAV.INP` file. All non-fuel element data are read from `TRIGLAV.INP` input file. Material constants are calculated according to water temperature and reactor power.

Some operation parameters used as input data for WIMS program are also calculated, such as: initial power distribution, fuel temperature (depending on fuel power), density of the fuel, weight percent of ^{235}U and weight percent of ^{166}Er and ^{167}Er. Initial guess for power distribution is calculated as follows:

$$P_{el} = \alpha_P(R)\frac{m_{el}(U)}{\overline{m}}(1 - \frac{BU_2}{100})\overline{P}, \tag{3}$$

$$\overline{m} = \frac{\sum_{el} m_{el}(U)}{N}, \tag{4}$$

$$\overline{P} = \frac{P}{N}, \tag{5}$$

where:

$\alpha_P(R)$	is power form factor of the ring R (see Table 3),
$m_{el}(U)$	is mass of ^{235}U in element,
$\overline{m}$	is average mass of ^{235}U per element in the core,
BU_2	is burnup of the element in percent of ^{235}U,
P	is thermal power of the reactor and
$\overline{P}$	is average power in the core,
N	is number of fuel elements in core.

It is important to note, that this guess is used only for temperature profile calculation needed in the cross section homogenization and for xenon concentration calculation. It is not to be mistaken for the actual power distribution which is the final result of the calculation.

The input parameters which are not the function of the operation conditions or fuel history (geometry of the elements and their material composition) are fixed in the program and are presented in Table 2. The WIMS input model, number of groups and number of the mesh points are also fixed in the program. An example for WIMS input automatically generated in the program package is presented in Figures 5, 6 and 7.

2.2.1 Fuel density and material weight-percent calculation

Actual fuel element composition may (normally only slightly) deviate from the typical values built in the code (see Table 2). This can be automatically compensated

in the code.

The density of the fuel and the weight-percent of the ^{235}U for the specific fuel element are calculated according to the input data $m(U)$ and e read from input file (`ELEM.INP` file).

$$\rho_{fuel} = \rho_{init.} \frac{m(U)}{m_{init.}(U)}, \tag{6}$$

$$wt\%^{235}U = (wt\%^{235}U)_{init.} \frac{e}{e_{init.}}. \tag{7}$$

$m_{init.}$, $\rho_{init.}$, $e_{init.}$ and $(wt\%^{235}U)_{init.}$ are typical values built in the model. FLIP and LEU fuel elements contain also burnable absorbers ^{166}Er and ^{167}Er. The weight-percent for both Er isotopes is calculated for every FLIP and LEU element:

$$wt\%Er = (wt\%Er)_{init.} \frac{m(Er)}{m(Er)_{init.}}. \tag{8}$$

This equation is used for both erbium isotopes. For typical initial fuel composition data see Table 2.

2.2.2 Temperature calculation

We assume that fuel temperature depends on power distribution. Water and cladding temperature depend only on total reactor power and are assumed constant in all unit cells regardless of their position in the core.

The following empirical relation between power of the element and its fuel temperature is assumed [2]:

$$T_{fuel,el} = T_{fuel}(P_{el}) = a_1 P_{el} + a_2 P_{el}^2 + a_3 P_{el}^3 + T_{water}, \tag{9}$$

$$a_1 = 67.18 K/kW, a_2 = -8.381 K/kW^2, a_3 = 0.3843 K/kW^3,$$

where specific element power P_{el} in [kW] is calculated in equation (3). The temperature of the fuel cladding is calculated as an average of fuel and water temperature:

$$T_{clad} = \frac{T_{fuel} + T_{water}}{2}. \tag{10}$$

Water temperature (parameter T_{water}) is read form input file `TRIGLAV.INP`. The correlation between the temperature of water and its density (at $\approx$ 2bars) is built into the program. Thermal expansion of other materials is not taken into account.

2.2.3 Burnup calculation

The unit cell cross sections are calculated at given burnup with WIMS using the burnup option. Burnup of fuel element (BU_1 in [MWd]) is given on the input. It is divided into n intervals, each 1MWd in size and a reminder γ of correct size (interval $n+1$) to accommodate the prescribed burnup value BU_1:

$$BU_1 = nb + \gamma \tag{11}$$

$$\gamma = BU_1 \bmod b \tag{12}$$

$$b = 1 MWd$$

2.2.4 Xenon correction

The equilibrium concentration of ^{143}Xe is calculated for each fuel element at it's specific power using WIMS code. As the initial fuel element specific power distribution is unknown, its distribution P_{el} is given by equation (3).

2.3 Subroutine LOOXA

The subroutine LOOXA prepares the `WIMSXS.BAT` batch procedure.

2.4 Subroutine WIMSXS

Subroutine WIMSXS runs the WIMSD4 program for all unit cells with input files named `WIMInnn.WIN`. When WIMS outputs are prepared, the subroutine XSWOUT reads each WIMS output, performs the group condensation from 32 energy groups into 4 groups and writes four group material constants to `WIMInnn.XSC` files.

2.5 Subroutine WIXSCOLA

The subroutine WIXSCOLA combines all `WIMInnn.XSC` cross section files into one file and prepares the input cross section file with name `TRIGA2D.XS` which is cross section input file for subroutine TRIGA2D.

2.6 Subroutine TRIGA2D

TRIGA2D was developed as a stand-alone two-dimensional multigroup diffusion code. A detailed description of its mathematical model and method of solution is given in Appendix A. In TRIGLAV program, TRIGA2D is used as a subroutine. All input data come through `TRIGA2D.INP` file (geometry of reactor core, mesh points, number of groups, convergence criteria) and `TRIGA2D.XS` file (calculated cross sections, see subroutine WITRIG). The result of calculations of subroutine TRIGA2D are power and flux distributions (for all four groups) and criticality calculation (multiplication factor). Power distribution is written to file `TRIGA2D.P`, all other results are temporarily written to file `TRIGA2D.OUT` and are later rewritten to file `TRIGLAV.OUT`. TRIGA2D can optionally write all four flux distributions to special file `TRIGA2D.FLU`.

2.7 Subroutine TRIGRES

TRIGRES calculates the burnup increment of each element if required. Reactor power P and burnup time step Δt are taken from `TRIGA2D.INP` temporary file. Element power P_{el} values are calculated from fission density distribution $F(r, \vartheta)$ stored in `TRIGA2D.P` file. Element power is normalized as follows:

$$P_{el} = \beta_P \frac{c}{\nu} \int_{V_{el}} F(r, \vartheta) dV, \tag{13}$$

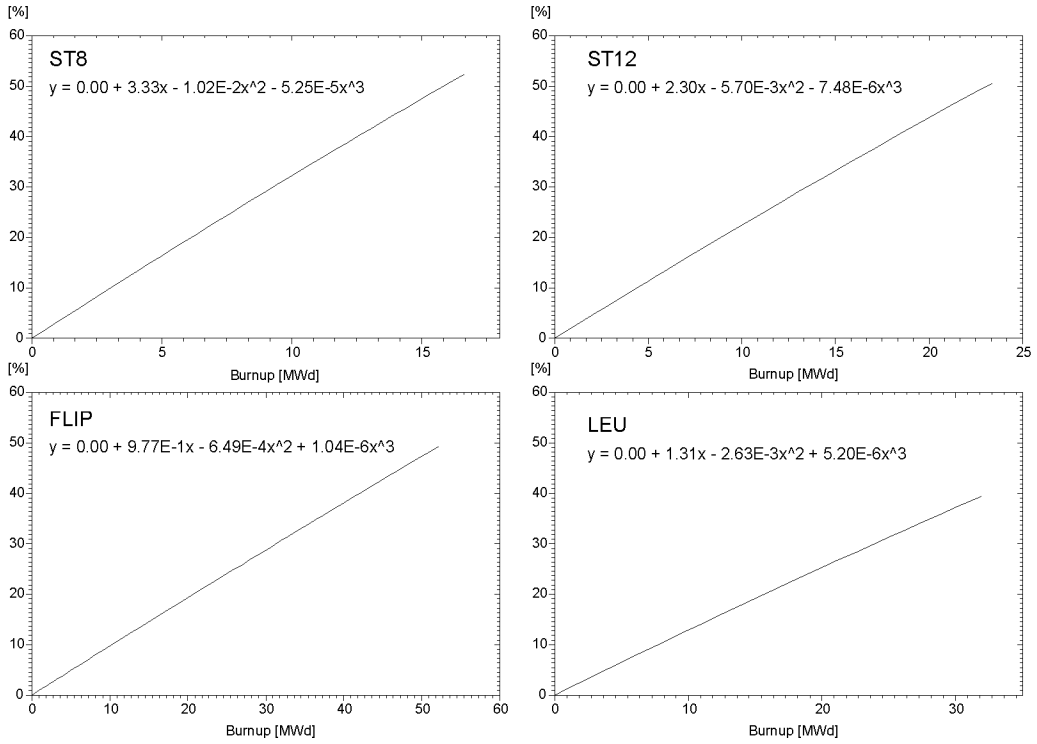

Figure 4: Relations between element burnup in [MWd] and in [%] for considered fuel elements.

where normalization factor β_P is defined as

$$\beta_P = \frac{P}{\frac{c}{\nu}\int_{V_{core}} F(r,\vartheta)dV}. \tag{14}$$

In first equation integration takes place over volume of each particular fuel element V_{el} and in last equation integration takes place over entire core volume V_{core}. Here P is thermal reactor power in [kW], $c = 3,15 \cdot 10^{-11} J$ and $\nu = 2.45$.

Burnup increments are then calculated as follows:

$$\Delta BU_{1,el} = P_{el}\Delta t. \tag{15}$$

Burnup values in percent ($BU_{2,el}$) are determined for each fuel element according to relations presented in Figure 4 which are calculated using WIMS code and built into the code.

Results of TRIGRES are burnup increments ΔBU_{el} for all fuel elements in the reactor core ($\Delta BU_{1,el}$ in [MWd] and $\Delta BU_{2,el}$ in [%]). They are automatically added to the burnup of elements in `ELEM.INP` so that `ELEM.OUT` contains updated burnup of elements in the core.

Power of elements and burnup of all elements in the core are written also to the output file `TRIGRES.OUT` and are later rewritten to final output file `TRIGLAV.OUT`.

```
* WIMS-D/4 :******************** No.,Id.=  8  7255 ST12
* RoUr    6.22438 W235    0.02332 W166    0.00000  W167   0.00000  PEl   6.06718
* TUran 496.21127 TWate 311.29999 RoWat   0.99094r MUrR 281.16000  BuMWR 0.00000
* st. 12% triga fuel.el., P=10kW/el., P(spec.)=35.971kW/kgU
* IDENT    ST12
CELL 6
SEQUENCE 1
NGROUP 32
NMESH 11 11
NREGION 5 0 5
NMATERIAL 4 1
PREOUT
INITIATE
ANNULUS 1 0.31750 4
ANNULUS 2 1.82245 1
ANNULUS 3 1.82626 0
ANNULUS 4 1.87706 2
ANNULUS 5 2.31317 3
FEWGROUP 2 4 6 11 14 21 23 25 26 27 28 29 30 32 33 35 38 $
         40 41 43 45 47 49 52 54 55 56 57 60 63 66 69
MESH 1 4 1 1 4
BUCKLING 0.0  0.00464
MATERIAL 1 6.2244 496.21  1   235.4  0.0233190  2238.4  0.0938579  91    0.8670113 $
                          5001    0.0158076  3239.1  0.0000000
MATERIAL 2 7.8890 403.76  2  1056    1.0000000
MATERIAL 3 0.9909 311.30  3  2001    0.1119000  16      0.8881000
MATERIAL 4 6.4900 496.21  2  91      1.0000000
POWERC 0 0
BEGINC
LEAKAGE 5
BUCKLING 0.0  0.00464
BEGINC
POWERC 0 0
BEGINC
BEGINC
* EOF
```

Figure 5: An example for WIMS input automatically generated in the package. Presented input is for ST12 fresh fuel element without xenon.

```
* WIMS-D/4 :******************** No.,Id.= 71  8535 ST8
* RoUr    5.80196 W235    0.01691 W166    0.00000  W167   0.00000  PEl   1.95501
* TUran 413.47626 TWate 311.29999 RoWat   0.99094r MUrR 189.89000  BuMWR 7.30100
* stand. 8% triga fuel.el., P=10kW/el. or P(spec.)=35.971kW/kgU
* IDENT    ST8
CELL 6
SEQUENCE 1
NGROUP 32
NMESH 11 11
NREGION 5 0 5
NMATERIAL 4 1
PREOUT
INITIATE
ANNULUS 1 0.31750 4
ANNULUS 2 1.82245 1
ANNULUS 3 1.82626 0
ANNULUS 4 1.87706 2
ANNULUS 5 2.31317 3
FEWGROUP 2 4 6 11 14 21 23 25 26 27 28 29 30 32 33 35 38 $
         40 41 43 45 47 49 52 54 55 56 57 60 63 66 69
MESH 1 4 1 1 4
BUCKLING 0.0  0.00464
MATERIAL 1 5.8020 413.48  1   235.4  0.0169128  2238.4  0.0680060  91    0.8986332 $
                           5001    0.0164630  3239.1  0.0000000
MATERIAL 2 7.8890 362.39  2  1056    1.0000000
MATERIAL 3 0.9909 311.30  3  2001    0.1119000  16      0.8881000
MATERIAL 4 6.4900 413.48  2  91      1.0000000
POWERC 1   52.662067 100.000000    7
BEGINC
BEGINC
POWERC 1   52.662067  30.096142    1
BEGINC
BEGINC
POWERC 1   10.295468   0.010000    2
BEGINC
LEAKAGE 5
BUCKLING 0.0  0.00464
BEGINC
* EOF
```

Figure 6: An example for WIMS input automatically generated in the package. Presented input is for ST8 fuel element (BU=7.301MWd) with xenon.

```
* WIMS-D/4 :******************** No.,Id.= 73  IC1  IC1
* RoUr    0.00000 W235    0.00000 W166    0.00000 W167    0.00000  PEl   0.00000
* TUran 311.29999 TWate 311.29999 RoWat   0.99094 rMUrR   0.00000  BuMWR 0.00000
* IC1, void channel, T(F,Zr)=470F, T(W,Al)=298F, T(Fe)=350F
* IDENT    IC1
CELL 7
SEQUENCE 1
NGROUP 32
NMESH  8 11
NREGION 4 1 8
NMATERIAL 6 1
PREOUT
INITIATE
ANNULUS 1 1.70000  0
ANNULUS 2 1.90000  5
ANNULUS 3 2.313177 3
ANNULUS 4 6.120091 6
ARRAY 1 (1 6 4.189053 0)
RODSUB 1 1 0.31750  4
RODSUB 1 2 1.82245  1
RODSUB 1 3 1.82626  0
RODSUB 1 4 1.87706  2
FEWGROUP 2 4 6 11 14 21 23 25 26 27 28 29 30 32 33 35 38 40 $
         41 43 45 47 49 52 54 55 56 57 60 63 66 69
MESH 1 1 2 4
BUCKLING 0.0  0.00464
MATERIAL 1 6.1223 470.00  1   235.4  0.0233230  2238.4  0.0938579  91    0.8670113 $
                            5001    0.0158076  3239.1  0.0000000
MATERIAL 2 7.8890 350.00  2  1056    1.0000000
MATERIAL 3 0.9909 311.30  3  2001    0.1119000  16      0.8881000
MATERIAL 4 6.4900 470.00  2  91      1.0000000
MATERIAL 5 2.7000 311.30  2  27      1.0000000
MATERIAL 6 0.9909 311.30  3  2001    0.1119000  16      0.8881000
POWERC 0 0
BEGINC
REGION 1 3
LEAKAGE 5
BUCKLING 0.0  0.00464
BEGINC
POWERC 0 0
BEGINC
BEGINC
* EOF
```

Figure 7: An example for WIMS input automatically generated in the package. Presented input is for IC1 non-fuel unit cell (void irradiation channel). Super-cell approach is used for non-fuel unit cells.

3 Data files

3.1 File TRIGLAV.INP

All independent input data describing reactor operation (power, loading pattern, etc.) are entered into program TRIGLAV through `TRIGLAV.INP` file. The first part of input data are parameters for solving the diffusion equation and information, specifying the geometry and other general conditions. In second part, the information about core loading pattern of reactor core is written. All data in first part can be written in free format, while in second part core loading pattern data must be written in prescribed order and format (sample input file is in Appendix B.1). All data in `TRIGLAV.INP` file are read in lines after the characteristic keyword. All keywords begin with `$*`.

`$* TRIGLAV` This must be first card in input file, next two lines are reserved for any kind of comments and will appear also on output file.

`$* FLAGS` After this card follow print control flags for cross sections, results of inner iterations and group flux distribution printout in output file `TRIGLAV.OUT` or in special file `TRIGA2D.FLU`. 1 is entered for printout of data, 0 is entered if no printout is wanted.

- 1^{st} flag controls cross sections printout in `TRIGLAV.OUT`.
- 2^{nd} flag controls inner iterations data printout on file `TRIGLAV.OUT`.
- 3^{rd} flag controls group flux distribution printout on file `TRIGLAV.OUT`.
- 4^{th} flag controls group flux distribution printout on file `TRIGA2D.FLU`.

`$* ITERATIONS` Allowed number of inner and outer iterations for diffusion calculation is read after this card.

- number in 1^{st} line stands for allowed number of inner iterations (parameter L_{inn}).
- number in 2^{nd} line stands for allowed number of outer iterations (parameter L_{out}).

`$* CONVERGENCE` Convergence criteria for diffusion calculation.

- number in 1^{st} line stands for convergence criterion for flux distribution inner iterations (parameter ϵ_1), recommended value 0.0000001.
- 2^{nd} number stands for convergence criterion for fission density outer iterations (parameter ϵ_2), recommended value 0.001.
- 3^{rd} number stands for convergence criterion of multiplication factor outer iterations (parameter ϵ_3), recommended value 0.00001.

`$* BUCKLING` Squared axial buckling equal for all four groups in [cm^{-2}].

`$* POWER` Total thermal power of the reactor in [kW].

`$* TWATER` Temperature of water [^{o}K] (parameter T_{water}).

`$* XENON` Flag for xenon condition, if 1 is entered Xe will be in equilibrium, if 0 is entered there will be no Xe.

`$* BURNUP` Time step in [days] for burnup increment calculation (parameter Δt).

`$* RINGS` Number of fuel rings in reactor core (6 or 7) is read after this card. This number specifies geometry of TRIGA Mark II reactor core used in calculation.

- For reactors with 6 fuel rings and with graphite or water reflector (fuel rings A to F and reflector) number 6 must be entered. Then the following core geometry is assumed:
  - reactor core height (fissionable material)=38.1cm
  - ring radii: A=2.3cm, B=6.1cm, C=10.1cm, D=14.1cm, E=18.1cm, F=22.1cm
  - reactor core radius (fissionable material)=22.1 cm
  - reflector outer radius (boundary condition $\Phi = 0$)=54.5cm.
- For reactors with 7 fuel rings and with graphite or water reflector (fuel rings A to G and reflector) number 7 must be entered, Then the following core geometry is assumed:
  - reactor core height (fissionable material)=38.1cm
  - ring radii: A=2.3cm, B=6.1cm, C=10.1cm, D=14.1cm, E=18.1cm, F=22.1cm, G=26.1cm
  - reactor core radius (fissionable material)=26.1 cm
  - reflector outer radius (boundary condition $\Phi = 0$)=58.5cm.

`$* MESH` This parameter determines type of finite differences mesh used in calculation. There are six mesh densities by default.

- 1 - very coarse mesh (8/9x102), 8 or 9 (depending on the number of rings) intervals in radial direction and 102 intervals in angular direction. This is minimum number of intervals possible. (There is one radial interval per fuel ring and two in reflector.) Not recommended.
- 2 - coarse mesh (54/60x102), 54 or 60 intervals in radial direction and 102 intervals in angular direction.
- 3 - normal mesh (90/100x102), 90 or 100 intervals in radial direction and 102 intervals in angular direction. Recommended for burnup problems.
- 11 - coarse *approximately equidistant* mesh (27/29x156), 27 or 29 intervals in radial direction and 156 intervals in angular direction. Each interval in radial direction is $\approx$2cm wide and each interval in angular direction is $\approx 2.3^o$ ($\approx$0.04rad) wide.
- 12 - normal *approximately equidistant* mesh (81/87x156), 81 or 87 intervals in radial direction and 156 intervals in angular direction. Each interval in radial direction is $\approx$0.67cm wide and each interval in angular direction is $\approx 2.3^o$ ($\approx$0.04rad) wide.

- 13 - fine *approximately equidistant* mesh (90/100x156), 90 or 100 intervals in radial direction and 156 intervals in angular direction. Each interval in radial direction is ≈0.34cm wide in core and ≈1.3cm wide in reflector. Intervals in angular direction are ≈2.3^o (≈0.04rad) wide.

`$* LOADING` Core loading pattern, data in this section must be written in prescribed format (3X,6(A4,1X,A4,1X)).

Positions in core loading pattern may be occupied by fuel or non-fuel elements. In case a position is occupied by fuel element a pair of fuel element identifiers are written for each position. First identifier in the pair is the location of the element (ring+position number, e.g. B-06), the second identifier is fuel element identification number (*id*). In case a position is occupied by non-fuel element then location and characteristic name of element are written in pair. For characterizing different types of non-fuel elements we use the following characteristic names:

GR graphite element (C in Al tube),

BE beryllium element (Be in Al tube),

IC1 irradiation channel, void channel (empty Al tube),

IC2 irradiation channel, half void, half water (1/2 empty + 1/2 water in Al tube),

IC3 irradiation channel, filled with water (water in Al tube) and

LW water only (without tube).

For detailed definition of the unit cell model see Section 1. The last ring in the reactor model is always reflector. The last information in core loading pattern is type of reflector. There are two types of reflector:

W water and

G graphite.

3.2 File ELEM.INP

File `ELEM.INP` contains data of fuel elements used in calculation. All fuel elements defined by `LOADING` command must be found in this file (there can be also elements that are currently not used in reactor). If an element defined by `LOADING` command is not found in file `ELEM.INP`, then program is terminated and a message is written to file `WITRIG.PRI`.

First two lines are used for comments and will also appear on output file. Data in next lines should be written in the format (A4,1X,A4,1X,7F10.2) (nine columns) as follows:

Column	Parameter	Description
1	*id*	fuel element identification number (any combination of four alphanumeric characters)
2	*type*	element type (enter ST8, ST12, FLIP or LEU, see Table 2)
3	$m(U)$	mass of U in [g]
4	e	enrichment in [%]
5	$m(^{166}Er)$	mass of ^{166}Er in [g] (only for FLIP and LEU)
6	$m(^{167}Er)$	mass of ^{167}Er in [g] (only for FLIP and LEU)
7	BU_1	element burnup in [MWd]
8	BU_2	element burnup in [%]
9		*last burnup increment in [MWd] (this is output information)*

Identification numbers can be arbitrary (e.g. four numbers). Nevertheless we recommend to use the identification numbers of the fuel elements under which they are documented. Last burnup increment is arbitrary too, because it is an output information written in this file by TRIGRES subroutine. When preparing input you can leave last column empty. Sample input file is in Appendix B.2.

3.3 File TRIGLAV.OUT

Output file `TRIGLAV.OUT` contains all output data produced in the calculation. Sample output file is in Appendix B.3.

Output is divided in two parts. First part contains input parameters and second part the results of the calculation. All data are printed in self explanatory way.

- Printout of input parameters:
  - General input parameters:
    - file names,
    - comments and
    - print control flags.
  - Physical parameters:
    - number of groups used in calculation,
    - group energy boundaries (1^{st}=fast group,...,4^{th}=thermal group),
    - fission spectrum,
    - axial buckling in [cm$^-$2],
    - thermal power of the reactor in [kW],
    - water temperature in [^{o}K],
    - xenon condition and
    - burnup interval in [days].
  - Data related to core geometry:
    - number of fuel rings,
    - outer radius of fuel rings in [cm],
    - outer radius of reflector (water or graphite) in [cm],
    - number of unit cells per ring,
    - reflector type.

- Numerical parameters;
  - allowed number of iterations,
  - convergence criteria,
  - type of finite difference mesh used in calculation, followed by
  - number of intervals in radial and angular direction used in calculation.
- Core loading pattern.
- Cross sections for all unit cells in core are written (if print flag for cross sections is 1) as follows: element number, position, type of element, group number, diffusion constant, absorption cross section, fission yield and scattering matrix.

- After control printout all output data are printed in the following format:
  - Solutions of diffusion equation (outer, inner iterations and multiplication factor monitoring).
  - Results of outer iterations are printed in lines beginning with `OUT:`

column	description
1	`OUT:` outer iteration,
2	outer iteration number,
3	fission density normalization factor (equal to multiplication factor),
4	maximum fission density difference from previous iteration,
5	maximum relative fission density difference form previous iteration,
6	location of maximum fission density difference in radial direction (j) and
7	location of maximum fission density difference in angular direction (i).

  - If print flag for inner iterations equals 1 then inner iterations results are printed in lines beginning with `I:` (for each group in one line)

column	description
1	`I:` inner iteration,
2	number of inner iterations for group g,
3	group number g,
4	location of group flux maximum (radial)(j),
5	location of group flux maximum (angular)(i),
6	location of maximum difference of group flux (radial)(j),
7	location of maximum difference of group flux (angular)(i),
8	maximum group flux,
9	maximum difference of group flux and
10	maximum relative difference of group flux.

  - Pointwise fission density values are printed (if print flag for flux is 1). In the first block the mesh radii are printed. In the next blocks the pointwise power density values (in $[\mathrm{cm}^{-3}\mathrm{s}^{-1}]$) at the angular directions indicated on the left and at the radius indicated in the first block is printed.

- The pointwise group flux distribution is written, if print flag for flux is 1, in the same format as fission density values. In the first block the mesh radii are printed. In the next blocks the pointwise group flux values (in [[$cm^{-2}s^{-1}$]) at the angular directions indicated on the left and at the radius indicated in the first block are printed. This is repeated for each group.
- Time needed for calculation (CPU elapsed time).
- Power per element in [kW] is printed together with element number, location, characteristic name, type and power per element in [kW].
- Fuel elements of particular type (fuel and non-fuel) together with their burnup increments in [MWd].
- Fuel elements, arranged according to their identification numbers. For each fuel element power in [kW], initial burnup, burnup increment and final burnup in [MWd] are printed.
- Total core burnup increment in [MWd].
- Average fuel element burnup in [MWd] and average fuel element burnup increment in [MWd].

3.4 File ELEM.OUT

`ELEM.OUT` file contains updated burnup information for fuel elements used in the calculation (sample output file is in Appendix B.4). It contains the same type of data for each fuel element as the `ELEM.INP` file, only with updated information on burnup for used elements in last calculation. First two lines contain comments from `ELEM.INP` file. The following lines are as follows:

Column	Description
1	*fuel element identification number*
2	*element type (ST8 , ST12, FLIP or LEU)*
3	*mass of U in [g]*
4	*enrichment in [%]*
5	*mass of ^{166}Er in [g] (only for FLIP and LEU)*
6	*mass of ^{167}Er in [g] (only for FLIP and LEU)*
7	updated element burnup in [MWd]
8	updated element burnup in [%]
9	element burnup increment in [MWd]

Format used for output is (A4,1X,A4,1X,4F10.2,F10.3,F10.2,F10.3). Data in first six columns are rewritten form input file, only data in last three columns are updated. In the next burnup cycle calculations, the `ELEM.OUT` should be renamed to the `ELEM.INP` file.

References

[1] WIMS-D/4 - Version 100 and Cataloged Procedure, NEA Data Bank, Bat. 45, 91191 Gifsur Yvette, Cedex, France,

[2] M.Ravnik, Research Reactor Calculations, Workshop on Nuclear Reaction Data and Nuclear Reactors - Physics, Design and Safety, Miramare - Trieste, Italy, 15 April - 17 May, 1996,

[3] E.L.Wachspress, Iterative Solution of Elliptic Systems and Applications to the Neutron Diffusion Equations of Reactor Physics, Prentice-Hall, Inc., 1966,

[4] A.Peršič, M.Ravnik, S.Slavič, Two Dimensional Burn-up Calculation of TRIGA Core, 3nd Reg. Meet. Nuclear Energy in Central Europe, Portorož, Slovenia, 11 - 14 September, 1996,

[5] T.Žagar, M.Ravnik, Determination of the Burn-up of TRIGA Fuel Elements by Calculation with New TRIGLAV Program, 3nd Reg. Meet. Nuclear Energy in Central Europe, Portorož, Slovenia, 11 - 14 September, 1996,

A Mathematical model and method of solution

The four group two dimensional non-homogeneous time independent diffusion equation (1) is solved using finite differences method. The radius r is divided into J mesh points and the angle ϑ into I mesh points.

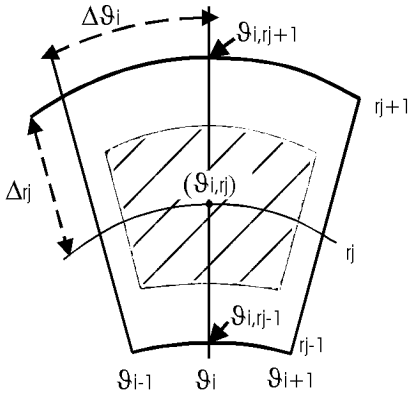

Figure 8: Difference mesh points in (r, ϑ) geometry.

Integrating the equation (1) on the area with boundary (area integrated is shown on Figure 8) $(r_{j-1/2}, r_{j+1/2})$ and $(\vartheta_{i-1/2}, \vartheta_{i+1/2})$ around the mesh point (r_j, ϑ_i) we get the following group difference equation for group g:

$$\begin{aligned} -a^g_{j,i+1/2}\Phi^g_{j,i+1} - a^g_{j,i-1/2}\Phi^g_{j,i-1} - b^g_{j+1/2,i}\Phi^g_{j+1,i} - b^g_{j-1/2,i}\Phi^g_{j-1,i} \\ +(a^g_{j,i+1/2} + a^g_{j,i-1/2} + b^g_{j+1/2,i} + b^g_{j-1/2,i} + c^g_{j,i})\Phi^g_{j,i} = f^{g,*}_{j,i} \\ g = 1, \ldots, 4, \\ j = 0, \ldots, J, \\ i = 0, \ldots, I, \end{aligned} \tag{16}$$

where:

$$a^g_{j,i+\frac{1}{2}} = \frac{r_{j+1/2}}{r_{j+1} - r_j}\left(D^g_{j+1/2,i+1/2}(\vartheta_{i+1/2} - \vartheta_i) + D^g_{j-1/2,i+1/2}(\vartheta_i - \vartheta_{i-1/2})\right), \tag{17}$$

$$a^g_{j,i-\frac{1}{2}} = \frac{r_{j-1/2}}{r_j - r_{j-1}}\left(D^g_{j-1/2,i-1/2}(\vartheta_i - \vartheta_{i-1/2}) + D^g_{j+1/2,i-1/2}(\vartheta_{i+1/2} - \vartheta_i)\right), \tag{18}$$

$$b^g_{j+\frac{1}{2},i} = \frac{1}{r_j(\vartheta_{i+1} - \vartheta_i)}\left(D^g_{j+1/2,i+1/2}(r_{j+1/2} - r_j) + D^g_{j+1/2,i-1/2}(r_j - r_{j-1/2})\right), \tag{19}$$

$$b^g_{j-\frac{1}{2},i} = \frac{1}{r_j(\vartheta_i - \vartheta_{i-1})}\left(D^g_{j-1/2,i+1/2}(r_{j+1/2} - r_j) + D^g_{j-1/2,i-1/2}(r_j - r_{j-1/2})\right), \tag{20}$$

$$\begin{aligned} c^g_{j,i} = \Sigma^g_{r,j+1/2,i+1/2}\frac{r^2_{j+1/2} - r^2_j}{2}(\vartheta_{i+1/2} - \vartheta_i) + \\ \Sigma^g_{r,j+1/2,i-1/2}\frac{r^2_j - r^2_{j-1/2}}{2}(\vartheta_{i+1/2} - \vartheta_i) + \end{aligned} \tag{21}$$

$$\Sigma^g_{r,j-1/2,i+1/2}\frac{r^2_{j+1/2}-r^2_j}{2}(\vartheta_i-\vartheta_{i-1/2})+$$
$$\Sigma^g_{r,j-1/2,i-1/2}\frac{r^2_j-r^2_{j-1/2}}{2}(\vartheta_i-\vartheta_{i-1/2}).$$

The non-homogeneous term $f^{g,*}_{j,i}$ in the equations (16) includes scattering terms and fission density F:

$$f^{g,*}_{j,i}=\chi_g F_{j,i}S_{j,i}+ \tag{22}$$
$$\left[\sum_{g'=1,g'\neq g}^{4}\Sigma^{g'\to g}_{j+1/2,i+1/2}\frac{r^2_{j+1/2}-r^2_j}{2}(\vartheta_{i+1/2}-\vartheta_i)+\right.$$
$$\sum_{g'=1,g'\neq g}^{4}\Sigma^{g'\to g}_{j+1/2,i-1/2}\frac{r^2_j-r^2_{j-1/2}}{2}(\vartheta_{i+1/2}-\vartheta_i)+$$
$$\sum_{g'=1,g'\neq g}^{4}\Sigma^{g'\to g}_{j-1/2,i+1/2}\frac{r^2_{j+1/2}-r^2_j}{2}(\vartheta_i-\vartheta_{i-1/2})+$$
$$\left.\sum_{g'=1,g'\neq g}^{4}\Sigma^{g'\to g}_{j-1/2,i-1/2}\frac{r^2_j-r^2_{j-1/2}}{2}(\vartheta_i-\vartheta_{i-1/2})\right]\Phi^{g'}_{j,i}.$$

$$F_{j,i}=\frac{1}{S_{j,i}}\left[\sum_{g=1}^{4}\nu_g\Sigma^g_{f,j+1/2,i+1/2}\frac{r^2_{j+1/2}-r^2_j}{2}(\vartheta_{i+1/2}-\vartheta_i)+\right. \tag{23}$$
$$\sum_{g=1}^{4}\nu_g\Sigma^g_{f,j-1/2,i+1/2}\frac{r^2_{j+1/2}-r^2_j}{2}(\vartheta_i-\vartheta_{i-1/2})+$$
$$\sum_{g=1}^{4}\nu_g\Sigma^g_{f,j+1/2,i-1/2}\frac{r^2_j-r^2_{j-1/2}}{2}(\vartheta_{i+1/2}-\vartheta_i)+$$
$$\left.\sum_{g=1}^{4}\nu_g\Sigma^g_{f,j-1/2,i-1/2}\frac{r^2_j-r^2_{j-1/2}}{2}(\vartheta_i-\vartheta_{i-1/2})\right]\Phi^g_{j,i},$$

$S_{j,i}$ is the integrated mesh node area:

$$S_{j,i}=\frac{r^2_{j+1/2}-r^2_{j-1/2}}{2}(\vartheta_{i+1/2}-\vartheta_{i-1/2}). \tag{24}$$

The boundary conditions are:

$$\Phi_{J,i}=0, i=0,\ldots,I, \tag{25}$$
$$\Phi^g_{j,0}=\Phi^g_{j,I}, j=0,\ldots,J. \tag{26}$$

Equation belonging to flux $\Phi^g_0(j=0)$ calculated in mesh point $(r=0,\vartheta=0)$ is written separately. The diffusion equation is integrated on area shown in Figure 9:

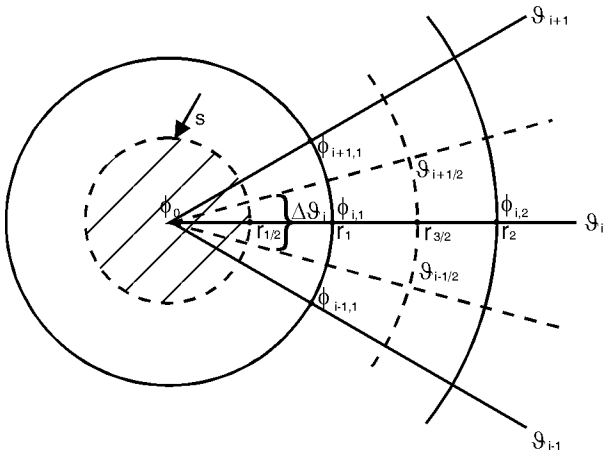

Figure 9: The volume belonging to central mesh point.

$$\oint_{\vec{s}_0} \vec{J}\vec{ds} + \int_{S_0} \Sigma_r \Phi dS = \int_{S_0} f dS \tag{27}$$

where the following relations are considered:

$$J = -D_0 \frac{\Phi_{1,i} - \Phi_0}{r_1} \tag{28}$$

$$ds = \frac{r_1 \sum_{i=0}^{I} \Delta\vartheta_i}{2} \tag{29}$$

$$\int_{S_0} \Sigma_{r,0} \Phi dS = \Sigma_r^0 \Phi_0 S_0 \tag{30}$$

$$\int_{S_0} f dS = \pi f_0 (\frac{r_1}{2})^2 = f_0 S_0 \tag{31}$$

$$S_0 = \pi (\frac{r_1}{2})^2 \tag{32}$$

If we use this relations (equations 28 to 32) in the equation (27), then the flux in the central point has the following form:

$$\Phi_0^g = \frac{f_0^g S_0 + \frac{D_0^g}{2} \sum_{i=0}^{I} \Phi_{1,i}^g \Delta\vartheta_j}{\pi D_0^g + \Sigma_{r,0}^g S_0}. \tag{33}$$

The system of equations (16) is solved iteratively. The system of equations is written in the matrix form suitable for numerical calculation:

$$-A_{j+1/2}^g \underline{\Phi}_{j+1}^g - A_{j-1/2}^g \underline{\Phi}_{j-1}^g + B_j^g \underline{\Phi}_j^g = \underline{f}_j^{g,*}. \tag{34}$$

The matrix B_j^g of group g has the dimension I x I. It has three diagonal form with

two additional nondiagonal elements:

$$B_j^g = \begin{bmatrix} e_{j,0}^g & -b_{j,1/2}^g & 0 & 0 & 0 & 0 & .. & -b_{j,I-1/2}^g \\ -b_{j,1/2}^g & e_{j,1}^g & -b_{j,3/2}^g & 0 & 0 & 0 & .. & 0 \\ 0 & -b_{j,3/2}^g & e_{j,2}^g & -b_{j,5/2}^g & 0 & 0 & .. & 0 \\ 0 & 0 & x & x & x & 0 & .. & 0 \\ 0 & 0 & 0 & x & x & x & .. & 0 \\ 0 & 0 & 0 & 0 & x & x & .. & 0 \\ .. & .. & .. & .. & .. & .. & .. & .. \\ -b_{j,1/2}^g & 0 & 0 & 0 & 0 & 0 & .. & e_{j,I}^g \end{bmatrix} \tag{35}$$

where

$$e_{j,i}^g = a_{j,i+1/2}^g + a_{j,i-1/2}^g + b_{j+1/2,i}^g + b_{j-1/2,i}^g + c_{j,i}^g, \tag{36}$$

$$e_{j,0}^g = e_{j,I}^g. \tag{37}$$

The diagonal matrix $A^g_{\substack{+\\ j-1/2}}$ with dimension I x I contains the coefficients, which are connected with the values of flux calculated in the mesh points with radius r_{j+1} (matrix $A_{j+1/2}^g$) and with radius r_{j-1} (matrix $A_{j-1/2}^g$).

$$A^g_{\substack{+\\ j-1/2}} = \begin{bmatrix} -a^g_{\substack{+\\ j-1/2,0}} & 0 & 0 & 0 & 0 & .. & 0 \\ 0 & -a^g_{\substack{+\\ j-1/2,1}} & 0 & 0 & 0 & .. & 0 \\ 0 & 0 & -a^g_{\substack{+\\ j-1/2,2}} & 0 & 0 & .. & 0 \\ 0 & 0 & 0 & x & 0 & .. & 0 \\ 0 & 0 & 0 & 0 & x & .. & 0 \\ .. & .. & .. & .. & .. & .. & .. \\ 0 & 0 & 0 & 0 & 0 & .. & -a^g_{\substack{+\\ j-1/2,I}} \end{bmatrix}. \tag{38}$$

$$a_{j,0}^g = a_{j,I}^g. \tag{39}$$

The solution of the system calculated in the mesh points with radius r_j and with angular components ϑ_i, (i = 0,...,I) represents the vector Φ_j^g with dimension I

$$\underline{\Phi}_j^g = \begin{bmatrix} \Phi_{j,0}^g \\ \Phi_{j,1}^g \\ \Phi_{j,2}^g \\ .. \\ .. \\ \Phi_{j,I}^g \end{bmatrix}. \tag{40}$$

The coefficients of vector $f_j^{*,g}$ represent the source term calculated in the mesh points with radius r_j. The value of fission density is calculated in the iteration procedure in the outer iteration. The scattering terms are calculated in the current inner

iteration.

$$\underline{f}_j^{*,g} = \begin{bmatrix} f_{j,0}^{*,g} \\ f_{j,1}^{*,g} \\ f_{j,2}^{*,g} \\ .. \\ .. \\ f_{j,I}^{*,g} \end{bmatrix}. \tag{41}$$

The four group diffusion system in difference approximation is solved using the method of fission density iteration. Each group equation is solved by Gauss-Seidel's method. The procedure is as follows:

- At the beginning of calculations in the cycle of inner iterations the flux $\Phi_{1,i}$ $(i = 0, \ldots, I)$ is calculated:

$$\underline{\Phi}_1^{(l)} = B_1^{-1}(\underline{f}_1^{*,(l)} + A_{3/2}\underline{\Phi}_2^{(l-1)} + A_{1/2}\underline{\Phi}_0^{(l)}) \tag{42}$$

  or in general for flux at the r_j:

$$\underline{\Phi}_j^{(l)} = B_j^{-1}(\underline{f}_j^{*,(l)} + A_{j+1/2}\underline{\Phi}_{j+1}^{(l-1)} + A_{j-1/2}\underline{\Phi}_{j-1}^{(l)}) \tag{43}$$

  The flux $\underline{\Phi}_{j+1}$ is calculated in previous $(l-1)$ inner iteration and $\underline{\Phi}_{j-1}$ is calculated in the current (l) iteration.

- In the next steps the flux in mesh points with radius $r_2, r_3, ...r_j$ $(j = 0, \ldots, J)$ is calculated. When the flux of l^{th} iteration in all mesh points is known, the prescribed convergence criterion for flux is checked:

$$max_{j,i} \mid \Phi_{j,i}^{(l)} - \Phi_{j,i}^{(l-1)} \mid \leq \epsilon_1 \tag{44}$$

  We also check if the prescribed number of inner iteration is not exceeded $(l+1 \geq L_{max})$.

- If the prescribed convergence criterion is not fulfilled, the calculation of flux is continued. The next $(l+1)$ iteration is calculated in the direction of falling radius.

When the cycle of inner iterations is finished, the new approximation value for fission density is determined in the cycle of outer iteration. The multiplication factor is also calculated in the cycle of outer iteration.

The maximal difference between the point values of $F^{(l)}$ and $F^{(l-1)}$ is calculated for all mesh points and checked if the difference is sufficient for convergence criterion:

$$max_{j,i} \frac{\mid F_{j,i}^{(l)} - F_{j,i}^{(l-1)} \mid}{\mid F_{j,i}^{(l)} \mid} \leq \epsilon_2. \tag{45}$$

The convergence criterion for multiplication factor is also checked:

$$\mid k^{(l)} - k^{(l-1)} \mid \leq \epsilon_3, \tag{46}$$

where ϵ_1, ϵ_2 and ϵ_3 are prescribed values for convergence criteria and L_{inn} allowed maximum number of inner iterations.

B Sample input and output files

B.1 TRIGLAV.INP

An example of main input file for typical 250kW TRIGA Mark II reactor.

```
$* TRIGLAV
Test core No:139 (B2=0.0048, P=250kW, Tw=311.3K, Xe=1,t=47.87d, R=6)
First two rows are free for comments!
$* FLAGS        ! print control flags:
   0            ! (0-no, 1-yes) cross sections printout in TRIGLAV.OUT
   0            ! (0-no, 1-yes) inner iterations data printout in TRIGLAV.OUT
   0            ! (0-no, 1-yes) flux data printout in TRIGLAV.OUT
   0            ! (0-no, 1-yes) flux data printout in plot file TRIGLAV.FLU
$* ITERATIONS   ! maximum allowed number of:
   900          ! inner iterations
   900          ! outer iterations
$* CONVERGENCE  ! convergence criteria for:
   0.0000001    ! inner iterations
   0.001        ! outer iterations
   0.00001      ! multiplication factor
$* BUCKLING     ! squared axial buckling for all four groups
   0.0048       ! [cm-2]
$* POWER        ! thermal reactor power
   250.0        ! [kW]
$* TWATER       ! water temperature
   311.3        ! [K]
$* XENON        ! xenon correction flag
   1            ! (0-Xe free, 1-Xe in equilibrium)
$* BURNUP       ! burnup interval in days
   47.87        ! [days]
$* RINGS        ! number of rings in reactor
   6            ! (6-rings A-F, 7-rings A-G)
$* MESH         ! finite difference mesh type
   3            ! (select 1, 2, 3, 11, 12, or 13)
$* LOADING      ! core loading pattern
   A-01 IC2
   B-01 6094 B-02 8536 B-03 6189 B-04 6100 B-05 8537 B-06 6181
   C-01 7255 C-02 7212 C-03 7213 C-04 IC1  C-05 7214 C-06 7249
   C-07 7282 C-08 6754 C-09 7257 C-10 7178 C-11 7219 C-12 7220
   D-01 7177 D-02 6175 D-03 7256 D-04 7223 D-05 7247 D-06 7268
   D-07 7228 D-08 7229 D-09 6179 D-10 7179 D-11 6172 D-12 7233
   D-13 7270 D-14 7236 D-15 7225 D-16 7265 D-17 7245 D-18 6161
   E-01 6190 E-02 6080 E-03 6193 E-04 6089 E-05 6163 E-06 6180
   E-07 6090 E-08 6092 E-09 6174 E-10 7848 E-11 6187 E-12 8528
   E-13 6083 E-14 6169 E-15 6102 E-16 6167 E-17 6097 E-18 6099
   E-19 6171 E-20 8533 E-21 6185 E-22 6170 E-23 6191 E-24 6101
   F-01 GR   F-02 GR   F-03 GR   F-04 GR   F-05 GR   F-06 GR
   F-07 6107 F-08 6110 F-09 6642 F-10 8535 F-11 6077 F-12 IC1
   F-13 BE   F-14 6166 F-15 IC2  F-16 7847 F-17 GR   F-18 6084
   F-19 IC2  F-20 6165 F-21 GR   F-22 GR   F-23 6196 F-24 IC2
   F-25 6088 F-26 IC2  F-27 GR   F-28 GR   F-29 GR   F-30 GR
      R G
```

B.2 ELEM.INP

An example of fuel element input file for typical 250kW TRIGA Mark II reactor.

```
Fuel elements for core No:139
 id  type     mU[g]      e[%]     Er166[g]  Er167[g]  BU[MWd]    BU[%]  BUi[MWd]
6077 ST8      192.00     19.99      0.00      0.00     5.495     17.97
6080 ST8      192.00     19.99      0.00      0.00     7.406     24.07
6083 ST8      192.00     19.99      0.00      0.00     6.335     20.66
6084 ST8      192.00     19.99      0.00      0.00     5.459     17.86
6088 ST8      192.00     19.99      0.00      0.00     5.864     19.16
```

6089	ST8	193.00	19.99	0.00	0.00	5.985	19.54
6090	ST8	192.00	19.99	0.00	0.00	5.531	18.09
6092	ST8	192.00	19.99	0.00	0.00	8.354	27.06
6094	ST8	193.00	19.99	0.00	0.00	8.326	26.97
6097	ST8	192.00	19.99	0.00	0.00	6.877	22.39
6099	ST8	192.00	19.99	0.00	0.00	6.664	21.71
6100	ST8	193.00	19.99	0.00	0.00	5.717	18.69
6101	ST8	192.00	19.99	0.00	0.00	5.635	18.42
6102	ST8	192.00	19.99	0.00	0.00	6.053	19.76
6107	ST8	192.00	19.99	0.00	0.00	5.898	19.27
6110	ST8	193.00	19.99	0.00	0.00	7.930	25.73
6161	ST8	192.00	19.99	0.00	0.00	7.884	25.58
6163	ST8	192.00	19.99	0.00	0.00	6.713	21.87
6165	ST8	192.00	19.99	0.00	0.00	5.929	19.36
6166	ST8	192.00	19.99	0.00	0.00	6.013	19.63
6167	ST8	192.00	19.99	0.00	0.00	5.939	19.40
6169	ST8	192.00	19.99	0.00	0.00	5.990	19.56
6170	ST8	193.00	19.99	0.00	0.00	6.106	19.93
6171	ST8	192.00	19.99	0.00	0.00	6.057	19.77
6172	ST8	192.00	19.99	0.00	0.00	5.977	19.52
6174	ST8	192.00	19.99	0.00	0.00	8.482	27.46
6175	ST8	192.00	19.99	0.00	0.00	8.357	27.07
6179	ST8	193.00	19.99	0.00	0.00	7.508	24.39
6180	ST8	193.00	19.99	0.00	0.00	7.475	24.29
6181	ST8	193.00	19.99	0.00	0.00	7.801	25.32
6185	ST8	192.00	19.99	0.00	0.00	8.345	27.03
6187	ST8	192.00	19.99	0.00	0.00	7.928	25.72
6189	ST8	192.00	19.99	0.00	0.00	7.954	25.80
6190	ST8	193.00	19.99	0.00	0.00	7.044	22.92
6191	ST8	192.00	19.99	0.00	0.00	5.309	17.38
6193	ST8	192.00	19.99	0.00	0.00	6.051	19.75
6196	ST8	193.00	19.99	0.00	0.00	7.299	23.73
6642	ST8	193.00	19.99	0.00	0.00	5.469	17.89
6754	ST12	273.17	19.90	0.00	0.00	0.230	0.53
7177	ST12	232.92	19.90	0.00	0.00	0.148	0.34
7178	ST12	235.62	19.90	0.00	0.00	0.204	0.47
7179	ST12	238.45	19.90	0.00	0.00	0.172	0.40
7212	ST12	277.68	19.90	0.00	0.00	0.200	0.46
7213	ST12	277.97	19.90	0.00	0.00	0.201	0.47
7214	ST12	277.44	19.90	0.00	0.00	0.205	0.47
7219	ST12	278.74	19.90	0.00	0.00	0.226	0.52
7220	ST12	278.45	19.90	0.00	0.00	0.217	0.50
7223	ST12	277.97	19.90	0.00	0.00	0.156	0.36
7225	ST12	277.32	19.90	0.00	0.00	0.197	0.46
7228	ST12	277.97	19.90	0.00	0.00	0.161	0.37
7229	ST12	277.25	19.90	0.00	0.00	0.171	0.40
7233	ST12	278.45	19.90	0.00	0.00	0.204	0.47
7236	ST12	278.45	19.90	0.00	0.00	0.203	0.47
7245	ST12	277.04	19.90	0.00	0.00	0.182	0.42
7247	ST12	279.59	19.90	0.00	0.00	0.163	0.38
7249	ST12	281.06	19.90	0.00	0.00	0.214	0.50
7255	ST12	281.16	19.90	0.00	0.00	0.209	0.48
7256	ST12	280.11	19.90	0.00	0.00	0.161	0.37
7257	ST12	280.78	19.90	0.00	0.00	0.237	0.55
7265	ST12	277.20	19.90	0.00	0.00	0.189	0.44
7268	ST12	279.24	19.90	0.00	0.00	0.165	0.38
7270	ST12	276.38	19.90	0.00	0.00	0.203	0.47
7282	ST12	277.39	19.90	0.00	0.00	0.223	0.52
7847	ST8	189.00	20.11	0.00	0.00	5.478	17.92
7848	ST8	188.00	19.68	0.00	0.00	5.320	17.41
8528	ST8	191.75	19.92	0.00	0.00	7.570	24.59
8533	ST8	188.17	19.92	0.00	0.00	7.484	24.32
8535	ST8	189.89	19.92	0.00	0.00	7.301	23.74
8536	ST8	188.03	19.92	0.00	0.00	7.659	24.87
8537	ST8	190.87	19.92	0.00	0.00	7.676	24.92

B.3 TRIGLAV.OUT

An example of output information for typical 250kW TRIGA Mark II reactor calculation.

```
 ------------------------------------------------------------------------------
 I               Program TRIGLAV,   At-PC-execution:  xx-xxx-xx  xx:xx:xx    I
 ------------------------------------------------------------------------------

 File names               :
 --------------------------
 Cross sections input file:TRIGA2D.XS
 Triga2D input file       :TRIGA2D.INP
 Triga2D output file      :TRIGA2D.OUT
 Output power file        :TRIGA2D.P
 Flux output file         :TRIGA2D.FLU

 Comments:
 ---------
Test core No:139 (B2=0.0048, P=250kW, Tw=311.3K, Xe=1,t=47.87d, R=6)
First two rows are free for comments!

 Print control flags:
 --------------------
 Cross sections     :  0
 Inner iterations   :  0
 Flux               :  0
 Flux output file   :  0

 Physical model            :
 ---------------------------
 No. of groups             :  4
 1st group boundaries[MeV] :     10.00000000      0.00911800
 2nd group boundaries[eV]  :   9118.00000000      4.00000000
 3rd group boundaries[eV]  :      4.00000000      0.62500000
 4th group boundaries[eV]  :      0.62500000      0.00000000
 Chi(ig),ig=1,4            :  1.0000  0.0000  0.0000  0.0000
 Buckling(ig),ig=1,4       :  0.0048  0.0048  0.0048  0.0048
 Thermal power[kW]         :250.0000
 Water temperature[K]      :311.3000
 Xenon correction          :  1
 Burnup time[days]         : 47.8700

 Core geometry parameters  :
 ---------------------------
 No. of fuel rings         :  6
 Fuel ring outer radius[cm]:  2.0270  6.0175  9.9595 13.9270 17.9020 22.0600
 Reflector outer radius[cm]: 54.5000
 No. of unit cells/ring    :  1  6 12 18 24 30
 Reflector type            :G

 Numerical parameters      :
 ---------------------------
 Inner iterations limit    :900
 Outer iterations limit    :900
 Inner iter. con. criterion:   0.100000E-06
 Outer iter. con. criterion:   0.100000E-02
 K-eff conver. criterion   :   0.100000E-04

 Mesh type                 :  3

 Radial mesh points
 No. of points/ring        : 10 10 10 10 10 10
 No. of points/reflector   : 30
 Sum. of radial mesh points: 90

 Angular mesh points
```

```
No. of basic points       :102
Mesh densification factor :  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
for each basic angular    :  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
mesh point                :  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
                             1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
                             1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
                             1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
Sum. of angular points    :102
```

Loading pattern:

```
 1 A-01 IC2
 2 B-01 6094  3 B-02 8536  4 B-03 6189  5 B-04 6100  6 B-05 8537  7 B-06 6181
 8 C-01 7255  9 C-02 7212 10 C-03 7213 11 C-04 IC1  12 C-05 7214 13 C-06 7249
14 C-07 7282 15 C-08 6754 16 C-09 7257 17 C-10 7178 18 C-11 7219 19 C-12 7220
20 D-01 7177 21 D-02 6175 22 D-03 7256 23 D-04 7223 24 D-05 7247 25 D-06 7268
26 D-07 7228 27 D-08 7229 28 D-09 6179 29 D-10 7179 30 D-11 6172 31 D-12 7233
32 D-13 7270 33 D-14 7236 34 D-15 7225 35 D-16 7265 36 D-17 7245 37 D-18 6161
38 E-01 6190 39 E-02 6080 40 E-03 6193 41 E-04 6089 42 E-05 6163 43 E-06 6180
44 E-07 6090 45 E-08 6092 46 E-09 6174 47 E-10 7848 48 E-11 6187 49 E-12 8528
50 E-13 6083 51 E-14 6169 52 E-15 6102 53 E-16 6167 54 E-17 6097 55 E-18 6099
56 E-19 6171 57 E-20 8533 58 E-21 6185 59 E-22 6170 60 E-23 6191 61 E-24 6101
62 F-01 GR   63 F-02 GR   64 F-03 GR   65 F-04 GR   66 F-05 GR   67 F-06 GR
68 F-07 6107 69 F-08 6110 70 F-09 6642 71 F-10 8535 72 F-11 6077 73 F-12 IC1
74 F-13 BE   75 F-14 6166 76 F-15 IC2  77 F-16 7847 78 F-17 GR   79 F-18 6084
80 F-19 IC2  81 F-20 6165 82 F-21 GR   83 F-22 GR   84 F-23 6196 85 F-24 IC2
86 F-25 6088 87 F-26 IC2  88 F-27 GR   89 F-28 GR   90 F-29 GR   91 F-30 GR
92    R G
```

Results of direct diffusion equation:

Outer iterations:

OUT:	no.	k	max.F dif.	rel.max.F dif.	loc.of max.dif.	
OUT:	1	0.0000540	0.0327435	1.0000000	26	2
OUT:	2	0.9325488	688.2034300	0.9999530	21	31
OUT:	3	0.9747917	102.6434940	0.1531170	11	59
OUT:	4	0.9867924	43.1834717	0.0605197	11	59
OUT:	5	0.9918061	20.0569458	0.0273404	11	59
OUT:	6	0.9940394	9.5270386	0.0115418	21	65
OUT:	7	0.9950610	4.8729248	0.0058688	21	65
OUT:	8	0.9955383	2.6137085	0.0031380	21	68
OUT:	9	0.9957675	1.5017700	0.0018004	21	70
OUT:	10	0.9958784	0.9354858	0.0015802	39	26
OUT:	11	0.9959312	0.6947632	0.0011749	39	26
OUT:	12	0.9959607	0.5179443	0.0008767	39	26

```
Multiplication factor: 0.9959607
---------------------- =========
Excess reactivity    :    -405.6
---------------------- =========

CPU - elapsed time:     849.32 sec
-------------------
```

Power per element:

No.	Pos.	Ident.	Type	Power[kW]	No.	Pos.	Ident.	Type	Power[kW]
1	A-01	IC2	IC2	0.000	2	B-01	6094	ST8	4.486
3	B-02	8536	ST8	4.439	4	B-03	6189	ST8	4.563
5	B-04	6100	ST8	4.893	6	B-05	8537	ST8	4.649
7	B-06	6181	ST8	4.646	8	C-01	7255	ST12	5.349
9	C-02	7212	ST12	5.290	10	C-03	7213	ST12	5.456
11	C-04	IC1	IC1	0.000	12	C-05	7214	ST12	5.569
13	C-06	7249	ST12	5.604	14	C-07	7282	ST12	5.617
15	C-08	6754	ST12	5.623	16	C-09	7257	ST12	5.703
17	C-10	7178	ST12	4.902	18	C-11	7219	ST12	5.494

19	C-12 7220	ST12	5.411	20	D-01 7177	ST12	3.850
21	D-02 6175	ST8	2.887	22	D-03 7256	ST12	4.432
23	D-04 7223	ST12	4.457	24	D-05 7247	ST12	4.766
25	D-06 7268	ST12	4.818	26	D-07 7228	ST12	4.621
27	D-08 7229	ST12	4.684	28	D-09 6179	ST8	3.248
29	D-10 7179	ST12	4.331	30	D-11 6172	ST8	3.407
31	D-12 7233	ST12	4.879	32	D-13 7270	ST12	4.752
33	D-14 7236	ST12	4.754	34	D-15 7225	ST12	4.669
35	D-16 7265	ST12	4.541	36	D-17 7245	ST12	4.484
37	D-18 6161	ST8	2.951	38	E-01 6190	ST8	2.405
39	E-02 6080	ST8	2.410	40	E-03 6193	ST8	2.500
41	E-04 6089	ST8	2.537	42	E-05 6163	ST8	2.540
43	E-06 6180	ST8	2.554	44	E-07 6090	ST8	2.722
45	E-08 6092	ST8	2.550	46	E-09 6174	ST8	2.483
47	E-10 7848	ST8	2.597	48	E-11 6187	ST8	2.619
49	E-12 8528	ST8	2.727	50	E-13 6083	ST8	2.732
51	E-14 6169	ST8	2.784	52	E-15 6102	ST8	2.848
53	E-16 6167	ST8	2.804	54	E-17 6097	ST8	2.716
55	E-18 6099	ST8	2.710	56	E-19 6171	ST8	2.768
57	E-20 8533	ST8	2.562	58	E-21 6185	ST8	2.545
59	E-22 6170	ST8	2.593	60	E-23 6191	ST8	2.567
61	E-24 6101	ST8	2.520	62	F-01 GR	GR	0.000
63	F-02 GR	GR	0.000	64	F-03 GR	GR	0.000
65	F-04 GR	GR	0.000	66	F-05 GR	GR	0.000
67	F-06 GR	GR	0.000	68	F-07 6107	ST8	1.992
69	F-08 6110	ST8	1.871	70	F-09 6642	ST8	2.004
71	F-10 8535	ST8	1.881	72	F-11 6077	ST8	2.023
73	F-12 IC1	IC1	0.000	74	F-13 BE	BE	0.000
75	F-14 6166	ST8	2.192	76	F-15 IC2	IC2	0.000
77	F-16 7847	ST8	2.188	78	F-17 GR	GR	0.000
79	F-18 6084	ST8	2.233	80	F-19 IC2	IC2	0.000
81	F-20 6165	ST8	2.232	82	F-21 GR	GR	0.000
83	F-22 GR	GR	0.000	84	F-23 6196	ST8	2.149
85	F-24 IC2	IC2	0.000	86	F-25 6088	ST8	2.218
87	F-26 IC2	IC2	0.000	88	F-27 GR	GR	0.000
89	F-28 GR	GR	0.000	90	F-29 GR	GR	0.000
91	F-30 GR	GR	0.000	92	R G	G	0.000

No. of elements of particular type in core:

Type	No.	Bu.increm.[MWd]	Sum.
IC2	5	0.000000E+00	5
ST8	45	0.133977E+00	50
ST12	25	0.237542E+00	75
IC1	2	0.000000E+00	77
GR	13	0.000000E+00	90
BE	1	0.000000E+00	91
G	1	0.000000E+00	92

Burnup of elements [MWd] :

No.	Pos.	Ident.	Type	Power	Burnup +	Bu.increm. =	Burnup
1	F-11	6077	ST8	2.023	5.495	0.097	5.592
2	E-02	6080	ST8	2.410	7.406	0.115	7.521
3	E-13	6083	ST8	2.732	6.335	0.131	6.466
4	F-18	6084	ST8	2.233	5.459	0.107	5.566
5	F-25	6088	ST8	2.218	5.864	0.106	5.970
6	E-04	6089	ST8	2.537	5.985	0.121	6.106
7	E-07	6090	ST8	2.722	5.531	0.130	5.661
8	E-08	6092	ST8	2.550	8.354	0.122	8.476
9	B-01	6094	ST8	4.486	8.326	0.215	8.541
10	E-17	6097	ST8	2.716	6.877	0.130	7.007
11	E-18	6099	ST8	2.710	6.664	0.130	6.794
12	B-04	6100	ST8	4.893	5.717	0.234	5.951
13	E-24	6101	ST8	2.520	5.635	0.121	5.756
14	E-15	6102	ST8	2.848	6.053	0.136	6.189
15	F-07	6107	ST8	1.992	5.898	0.095	5.993

16	F-08	6110	ST8	1.871	7.930	0.090	8.020
17	D-18	6161	ST8	2.951	7.884	0.141	8.025
18	E-05	6163	ST8	2.540	6.713	0.122	6.835
19	F-20	6165	ST8	2.232	5.929	0.107	6.036
20	F-14	6166	ST8	2.192	6.013	0.105	6.118
21	E-16	6167	ST8	2.804	5.939	0.134	6.073
22	E-14	6169	ST8	2.784	5.990	0.133	6.123
23	E-22	6170	ST8	2.593	6.106	0.124	6.230
24	E-19	6171	ST8	2.768	6.057	0.133	6.190
25	D-11	6172	ST8	3.407	5.977	0.163	6.140
26	E-09	6174	ST8	2.483	8.482	0.119	8.601
27	D-02	6175	ST8	2.887	8.357	0.138	8.495
28	D-09	6179	ST8	3.248	7.508	0.155	7.663
29	E-06	6180	ST8	2.554	7.475	0.122	7.597
30	B-06	6181	ST8	4.646	7.801	0.222	8.023
31	E-21	6185	ST8	2.545	8.345	0.122	8.467
32	E-11	6187	ST8	2.619	7.928	0.125	8.053
33	B-03	6189	ST8	4.563	7.954	0.218	8.172
34	E-01	6190	ST8	2.405	7.044	0.115	7.159
35	E-23	6191	ST8	2.567	5.309	0.123	5.432
36	E-03	6193	ST8	2.500	6.051	0.120	6.171
37	F-23	6196	ST8	2.149	7.299	0.103	7.402
38	F-09	6642	ST8	2.004	5.469	0.096	5.565
39	C-08	6754	ST12	5.623	0.230	0.269	0.499
40	D-01	7177	ST12	3.850	0.148	0.184	0.332
41	C-10	7178	ST12	4.902	0.204	0.235	0.439
42	D-10	7179	ST12	4.331	0.172	0.207	0.379
43	C-02	7212	ST12	5.290	0.200	0.253	0.453
44	C-03	7213	ST12	5.456	0.201	0.261	0.462
45	C-05	7214	ST12	5.569	0.205	0.267	0.472
46	C-11	7219	ST12	5.494	0.226	0.263	0.489
47	C-12	7220	ST12	5.411	0.217	0.259	0.476
48	D-04	7223	ST12	4.457	0.156	0.213	0.369
49	D-15	7225	ST12	4.669	0.197	0.224	0.421
50	D-07	7228	ST12	4.621	0.161	0.221	0.382
51	D-08	7229	ST12	4.684	0.171	0.224	0.395
52	D-12	7233	ST12	4.879	0.204	0.234	0.438
53	D-14	7236	ST12	4.754	0.203	0.228	0.431
54	D-17	7245	ST12	4.484	0.182	0.215	0.397
55	D-05	7247	ST12	4.766	0.163	0.228	0.391
56	C-06	7249	ST12	5.604	0.214	0.268	0.482
57	C-01	7255	ST12	5.349	0.209	0.256	0.465
58	D-03	7256	ST12	4.432	0.161	0.212	0.373
59	C-09	7257	ST12	5.703	0.237	0.273	0.510
60	D-16	7265	ST12	4.541	0.189	0.217	0.406
61	D-06	7268	ST12	4.818	0.165	0.231	0.396
62	D-13	7270	ST12	4.752	0.203	0.227	0.430
63	C-07	7282	ST12	5.617	0.223	0.269	0.492
64	F-16	7847	ST8	2.188	5.478	0.105	5.583
65	E-10	7848	ST8	2.597	5.320	0.124	5.444
66	E-12	8528	ST8	2.727	7.570	0.131	7.701
67	E-20	8533	ST8	2.562	7.484	0.123	7.607
68	F-10	8535	ST8	1.881	7.301	0.090	7.391
69	B-02	8536	ST8	4.439	7.659	0.212	7.871
70	B-05	8537	ST8	4.649	7.676	0.223	7.899

Core burnup increment [MWd] = 11.9675

Average fuel element burnup [MWd] = 4.57794

Average fuel element burnup increment [MWd]= 0.170965

B.4 ELEM.OUT

An example of updated fuel elements burnup data.

Fuel elements for core No:139

id	type	mU[g]	e[%]	Er166[g]	Er167[g]	BU[MWd]	BU[%]	BUi[MWd]
6077	ST8	192.00	19.99	0.00	0.00	5.592	18.28	0.097
6080	ST8	192.00	19.99	0.00	0.00	7.521	24.43	0.115
6083	ST8	192.00	19.99	0.00	0.00	6.466	21.08	0.131
6084	ST8	192.00	19.99	0.00	0.00	5.566	18.20	0.107
6088	ST8	192.00	19.99	0.00	0.00	5.970	19.50	0.106
6089	ST8	193.00	19.99	0.00	0.00	6.106	19.93	0.121
6090	ST8	192.00	19.99	0.00	0.00	5.661	18.51	0.130
6092	ST8	192.00	19.99	0.00	0.00	8.476	27.45	0.122
6094	ST8	193.00	19.99	0.00	0.00	8.541	27.65	0.215
6097	ST8	192.00	19.99	0.00	0.00	7.007	22.80	0.130
6099	ST8	192.00	19.99	0.00	0.00	6.794	22.12	0.130
6100	ST8	193.00	19.99	0.00	0.00	5.951	19.44	0.234
6101	ST8	192.00	19.99	0.00	0.00	5.756	18.81	0.121
6102	ST8	192.00	19.99	0.00	0.00	6.189	20.20	0.136
6107	ST8	192.00	19.99	0.00	0.00	5.993	19.57	0.095
6110	ST8	193.00	19.99	0.00	0.00	8.020	26.01	0.090
6161	ST8	192.00	19.99	0.00	0.00	8.025	26.03	0.141
6163	ST8	192.00	19.99	0.00	0.00	6.835	22.25	0.122
6165	ST8	192.00	19.99	0.00	0.00	6.036	19.71	0.107
6166	ST8	192.00	19.99	0.00	0.00	6.118	19.97	0.105
6167	ST8	192.00	19.99	0.00	0.00	6.073	19.83	0.134
6169	ST8	192.00	19.99	0.00	0.00	6.123	19.99	0.133
6170	ST8	193.00	19.99	0.00	0.00	6.230	20.33	0.124
6171	ST8	192.00	19.99	0.00	0.00	6.190	20.20	0.133
6172	ST8	192.00	19.99	0.00	0.00	6.140	20.04	0.163
6174	ST8	192.00	19.99	0.00	0.00	8.601	27.84	0.119
6175	ST8	192.00	19.99	0.00	0.00	8.495	27.51	0.138
6179	ST8	193.00	19.99	0.00	0.00	7.663	24.88	0.155
6180	ST8	193.00	19.99	0.00	0.00	7.597	24.67	0.122
6181	ST8	193.00	19.99	0.00	0.00	8.023	26.02	0.222
6185	ST8	192.00	19.99	0.00	0.00	8.467	27.42	0.122
6187	ST8	192.00	19.99	0.00	0.00	8.053	26.11	0.125
6189	ST8	192.00	19.99	0.00	0.00	8.172	26.49	0.218
6190	ST8	193.00	19.99	0.00	0.00	7.159	23.29	0.115
6191	ST8	192.00	19.99	0.00	0.00	5.432	17.77	0.123
6193	ST8	192.00	19.99	0.00	0.00	6.171	20.14	0.120
6196	ST8	193.00	19.99	0.00	0.00	7.402	24.06	0.103
6642	ST8	193.00	19.99	0.00	0.00	5.565	18.20	0.096
6754	ST12	273.17	19.90	0.00	0.00	0.499	1.15	0.269
7177	ST12	232.92	19.90	0.00	0.00	0.332	0.77	0.184
7178	ST12	235.62	19.90	0.00	0.00	0.439	1.01	0.235
7179	ST12	238.45	19.90	0.00	0.00	0.379	0.88	0.207
7212	ST12	277.68	19.90	0.00	0.00	0.453	1.05	0.253
7213	ST12	277.97	19.90	0.00	0.00	0.462	1.07	0.261
7214	ST12	277.44	19.90	0.00	0.00	0.472	1.09	0.267
7219	ST12	278.74	19.90	0.00	0.00	0.489	1.13	0.263
7220	ST12	278.45	19.90	0.00	0.00	0.476	1.10	0.259
7223	ST12	277.97	19.90	0.00	0.00	0.369	0.85	0.213
7225	ST12	277.32	19.90	0.00	0.00	0.421	0.97	0.224
7228	ST12	277.97	19.90	0.00	0.00	0.382	0.88	0.221
7229	ST12	277.25	19.90	0.00	0.00	0.395	0.91	0.224
7233	ST12	278.45	19.90	0.00	0.00	0.438	1.01	0.234
7236	ST12	278.45	19.90	0.00	0.00	0.431	0.99	0.228
7245	ST12	277.04	19.90	0.00	0.00	0.397	0.92	0.215
7247	ST12	279.59	19.90	0.00	0.00	0.391	0.90	0.228
7249	ST12	281.06	19.90	0.00	0.00	0.482	1.11	0.268
7255	ST12	281.16	19.90	0.00	0.00	0.465	1.07	0.256
7256	ST12	280.11	19.90	0.00	0.00	0.373	0.86	0.212
7257	ST12	280.78	19.90	0.00	0.00	0.510	1.18	0.273
7265	ST12	277.20	19.90	0.00	0.00	0.406	0.94	0.217
7268	ST12	279.24	19.90	0.00	0.00	0.396	0.91	0.231

7270	ST12	276.38	19.90	0.00	0.00	0.430	0.99	0.227
7282	ST12	277.39	19.90	0.00	0.00	0.492	1.13	0.269
7847	ST8	189.00	20.11	0.00	0.00	5.583	18.25	0.105
7848	ST8	188.00	19.68	0.00	0.00	5.444	17.81	0.124
8528	ST8	191.75	19.92	0.00	0.00	7.701	25.00	0.131
8533	ST8	188.17	19.92	0.00	0.00	7.607	24.70	0.123
8535	ST8	189.89	19.92	0.00	0.00	7.391	24.02	0.090
8536	ST8	188.03	19.92	0.00	0.00	7.871	25.54	0.212
8537	ST8	190.87	19.92	0.00	0.00	7.899	25.63	0.223

C Accessory programs

C.1 Manual for program TRGRAPH

```
 Program reads flux data from TRIGA2D output in (r,theta) format
and rewrites data in (x,y,z) format.
 This format is suitable for WinSurfer program, used for graphical
presentation of results.
 Control data are printed in first line of output file. All other
data in file are written in three columns. x and y locations [cm]
are written in first two columns. Flux [cm-2s-1] or fission density
[cm-3s-1] is written in third column.
 Program reads input parameters from input file TRGRAPH.INP or from
keyboard. When program finds input file, then it reads input param-
eters from file, otherwise it asks user to type in parameters.
 Input keywords in input file may be:
 '$* FLUX FILE'- input flux (TRIGA2D) file name
 '$* DATA FILE'- output data (x,y,z) file name
 '$* GROUP NUMBER'- group to proces (0 stands for fission density)
 'CIRCLE'- optional parameter, followed by radius in [cm] in next
           line. If this parameter is present, then program will
           cut data in circle with selected radius.
 'SQUARE'- optional parameter, followed by dimension/2 in [cm] in
           next line. If this parameter is present, then program
           will cut data in square with selected dimension.
 'NORMALIZE'- optional parameter. If this keyword is present, all
              data will be normailzed to maximum value.
 Parameters are read line by line, each data in its own line.
```