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**RESULTS OF COMPARATIVE RBMK NEUTRON
COMPUTATION USING VNIIEF CODES
(CELL COMPUTATION, 3D STATICS, 3D KINETICS)**

Report on stage 4 of Task Order 007 under University of California-VNIIEF
Subcontract No 0002E0004-95

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_____1995

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_____1995

MASTER

1995

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Introduction

In conformity with the protocol of the Workshop (12/7-16/1994, Los Alamos, USA) under Contract "Assessment of RBMK reactor safety using modern Western Codes" VNIIEF performed a neutronics computation series to compare western and VNIIEF codes and assess whether VNIIEF codes are suitable for RBMK type reactor safety assessment computation. The work was carried out in close collaboration with M.I.Rozhdestvensky and L.M.Podlazov, NIKIET employees. The effort involved:

- cell computations with the WIMS, EKRAN codes (improved modification of the LOMA code) and the S-90 code (VNIIEF Monte Carlo). Cell, polycell, burnup computation;
- 3D computation of static states with the KORAT-3D and NEU codes and comparison with results of computation with the NESTLE code (USA). The computations were performed in the geometry and using the neutron constants presented by the American party;
- 3D computation of neutron kinetics with the KORAT-3D and NEU codes. These computations were performed in two formulations, both being developed in collaboration with NIKIET. Formulation of the first problem maximally possibly agrees with one of NESTLE problems and imitates gas bubble travel through a core. The second problem is a model of the RBMK as a whole with imitation of control and protection system controls (CPS) movement in a core.

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I.1. RBMK reactor cell computations

In conformity with the protocol of the Workshop under Contract " Assessment of RBMK reactor safety using modern Western Codes " (12/7-16/1994, Los Alamos, USA), Task 2, item 1 "cell computations" VNIIEF performed a RBMK cell computation series with various codes. The computations were aimed at determination of suitability of corresponding codes for computations to estimate RBMK cell parameters and comparison of computed results with those obtained with the WIMS code. The results of WIMS computations were presented by the American party and repeated by us with introduction of minor specifications.

WIMS computations were performed using the "native" library of neutron constants for WIMS. Unfortunately, we failed to perform computations using the constant library made on the basis of ENDF/B-VI (rev. 2) evaluated nuclear data due to the fact that at the latest time errors were found which had been made at preprocessing resonance region cross sections. Currently the work on a new version of the constants library for the WIMS code on the base of ENDF/B-VI (rev.2) is underway. As soon as the work is completed the computation will be repeated using neutron constants from the ENDF/B-VI (rev. 2) library.

Setting up and results of comparative computations of RBMK cell burnup computations with the codes WIMS, EKRAN (an improved modification of the LOMA code) and S-90 (Monte Carlo) are given below.

I.1. RBMK cell computations with WIMS code

The WIMS code [1] was used to compute RBMK reactor fuel cell burup up to 1800 days at a timestep of 45 days, with additional computations being made with variation in coolant density and temperature and fuel temperature at set times (0, 360, 720, 1080, 1440 and 1800 days) in order to assess density and temperature effects. At the same times two-group neutron constants averaged over the whole fuel assembly cell were computed. Results of the computations are given in Tables I.1.1 through I.1.8.

The computations performed are a repeat of those presented by the American party with minor specifications (the number of energy groups in the transport computation is increased, as well as fuel of inside and outside fuel element ring are distinguished as separate materials) which had to be introduced for better agreement with the results of burnup computations using the EKRAN code. The files of principal computation tasks are given in Appendix I.1.1.

Table I.1.1.

Values of effective multiplication factor depending on fuel
burnup, coolant density and temperature, fuel
temperature for the whole cell.

Burnup MW·day/t	Normal	$\rho_c=1\text{g/cc}$ (cdh)	$\rho_c=0.04\text{g/cc}$ (cdl)	$T_c=300\text{ K}$ (cth)	$T_f=1500\text{ K}$ (fth)
0	1.3652	1.3541	1.3687	1.3733	1.3531
3024	1.2875				
6048	1.2392	1.2146	1.2320	1.2318	1.2171
9072	1.1903				
12096	1.1414	1.1155	1.3850	1.1239	1.1200
60480	1.0924				
18144	1.0413	1.0111	1.0449	1.0224	1.0267
21168	0.9904				
24192	0.9411	0.9708	0.9540	0.9158	0.9232
27216	0.8948				
30240	0.8538	0.8207	0.8778	0.8245	0.8411

Table I.1.2.

Effective multiplication factor and two-group constants
depending on coolant density and temperature, fuel temperature
for the work cell at burnup 0 MW·day/t (0 days).

	k_{eff}	D, cm		$\Sigma_a, 10^{-3} \text{cm}^{-1}$		$\Sigma_t, 10^{-3} \text{cm}^{-1}$		$\nu\Sigma_f, 10^{-3} \text{cm}^{-1}$	
		E>E ₀	E<E ₀	E>E ₀	E<E ₀	E>E ₀	E<E ₀	E>E ₀	E<E ₀
norm	1.3652	1.116	0.834	1.094	4.458	4.955	1.144	0.680	7.006
cdh	1.3541	1.097	0.787	1.132	4.876	6.036	1.043	0.698	7.422
cdl	1.3687	1.130	0.886	1.004	3.911	3.898	1.324	0.656	6.319
cth	1.3733	1.116	0.832	1.093	4.811	4.900	1.163	0.678	7.611
fth	1.3531	1.117	0.834	1.130	4.428	4.942	1.158	0.677	6.959

Table I.1.3.

Effective multiplication factor and two-group constants
depending on coolant density and temperature, fuel temperature
for the work cell at burnup 6048 MW·day/t (360 days).

	k_{eff}	D, cm		$\Sigma_a, 10^{-3} \text{cm}^{-1}$		$\Sigma_t, 10^{-3} \text{cm}^{-1}$		$\nu\Sigma_f, 10^{-3} \text{cm}^{-1}$	
		E>E ₀	E<E ₀	E>E ₀	E<E ₀	E>E ₀	E<E ₀	E>E ₀	E<E ₀
norm	1.2392	1.116	0.834	1.137	4.684	4.882	1.181	0.601	6.774
cdh	1.2146	1.097	0.787	1.184	5.053	5.957	1.068	0.611	6.988
cdl	1.2320	1.130	0.885	1.049	4.259	3.805	1.392	0.564	6.330
cth	1.2318	1.116	0.832	1.143	4.956	4.828	1.187	0.589	7.146
fth	1.2171	1.117	0.834	1.181	4.657	4.857	1.194	0.588	6.691

Table I.1.4.

Effective multiplication factor and two-group constants
depending on coolant density and temperature, fuel temperature
for the work cell at burnup 12096 MW·day/t (720 days).

	k_{eff}	D, cm		$\Sigma_a, 10^{-3} \text{cm}^{-1}$		$\Sigma_t, 10^{-3} \text{cm}^{-1}$		$\nu\Sigma_f, 10^{-3} \text{cm}^{-1}$	
		E>E ₀	E<E ₀	E>E ₀	E<E ₀	E>E ₀	E<E ₀	E>E ₀	E<E ₀
norm	1.1414	1.116	0.834	1.182	4.561	4.832	1.162	0.519	6.189
cdh	1.1155	1.097	0.786	1.232	4.877	5.913	1.046	0.532	6.283
cdl	1.1385	1.130	0.885	1.080	4.184	3.765	1.373	0.482	5.867
cth	1.1293	1.117	0.835	1.185	4.781	4.785	1.160	0.509	6.429
fth	1.1200	1.117	0.834	1.227	4.520	4.807	1.173	0.508	6.088

Table I.1.5.

Effective multiplication factor and two-group constants
depending on coolant density and temperature, fuel temperature
for the work cell at burnup 18144 MW·day/t (1080 days).

	k_{eff}	D, cm		$\Sigma_a, 10^{-3} \text{cm}^{-1}$		$\Sigma_r, 10^{-3} \text{cm}^{-1}$		$\nu \Sigma_f, 10^{-3} \text{cm}^{-1}$	
		E>E ₀	E<E ₀	E>E ₀	E<E ₀	E>E ₀	E<E ₀	E>E ₀	E<E ₀
norm	1.0413	1.117	0.833	1.209	4.349	4.806	1.126	0.484	5.452
cdh	1.0111	1.097	0.785	1.261	4.618	5.896	1.012	0.464	5.444
cdl	1.0449	1.130	0.886	1.098	3.994	3.751	1.331	0.412	5.216
cth	1.0224	1.117	0.831	1.210	4.540	4.750	1.110	0.440	5.591
fth	1.0267	1.117	0.833	1.254	4.302	4.782	1.136	0.439	5.348

Table I.1.6.

Effective multiplication factor and two-group constants
depending on coolant density and temperature, fuel temperature
for the work cell at burnup 24192 MW·day/t (1440 days).

	k_{eff}	D, cm		$\Sigma_a, 10^{-3} \text{cm}^{-1}$		$\Sigma_r, 10^{-3} \text{cm}^{-1}$		$\nu \Sigma_f, 10^{-3} \text{cm}^{-1}$	
		E>E ₀	E<E ₀	E>E ₀	E<E ₀	E>E ₀	E<E ₀	E>E ₀	E<E ₀
norm	0.9411	1.117	0.833	1.229	4.106	4.799	1.087	3.900	4.693
cdh	0.9708	1.098	0.784	1.283	4.359	5.890	0.978	4.077	4.643
cdl	0.9540	1.131	0.886	1.112	3.786	3.746	1.286	3.548	4.568
cth	0.9158	1.117	0.830	1.229	4.282	4.752	1.078	3.835	4.759
fth	0.9232	1.117	0.833	1.276	4.064	4.775	1.097	3.828	4.610

Table I.1.7.

Effective multiplication factor and two-group constants
depending on coolant density and temperature, fuel temperature
for the work cell at burnup 30240 MW·day/t (1800 days).

	k_{eff}	D, cm		$\Sigma_a, 10^{-3} \text{cm}^{-1}$		$\Sigma_r, 10^{-3} \text{cm}^{-1}$		$\nu \Sigma_f, 10^{-3} \text{cm}^{-1}$	
		E>E ₀	E<E ₀	E>E ₀	E<E ₀	E>E ₀	E<E ₀	E>E ₀	E<E ₀
norm	0.8538	1.117	0.833	1.247	3.902	4.798	1.055	0.347	4.073
cdh	0.8207	1.098	0.783	1.302	4.163	5.884	0.953	0.368	4.026
cdl	0.8778	1.131	0.887	1.127	3.626	3.740	1.251	0.314	4.063
cth	0.8245	1.117	0.830	1.247	4.085	4.744	1.046	0.343	4.108
fth	0.8411	1.117	0.833	1.292	3.882	4.769	1.067	0.343	4.038

Table I.1.8 gives the values of effective multiplication factor for the fuel cell and polycell with a CPS rod, displacer and water column, where variant 1-the base computation, variant 2-see I.3.

Table I.1.8.

Effective multiplication factor for the fuel cell and polycells
with a CPS rod, displacer and water column.

		fuel cell	6 fuel cells + cell with CPS rod	6 fuel cells + cell with displacer	6 fuel cells + cell with water column
Variant 1	k_{eff}	1.3652	1.1358	1.3207	1.2721
Variant 2	k_{eff}	1.3391	1.1444	1.3105	1.2673

***** BASE CELL CALCULATION

CELL 7

SEQU 4

NGRO 33 2 2

NMES 29

NREG 5 2

NMAT 6 2

NROD 18 2 25 50 2 2 2

PREO

INIT

MATE 1 9.69 873.0 1 235.4 2.116 2238.4 86.034 16 11.85 3239.1 .0

MATE 2 5.997 588.0 2 91 96.36 56 2.62 52 0.66 58 0.29 55 0.07

MATE 3 0.516 557.0 3 2001 11.2 16 88.8

MATE 4 1.656 873.0 4 12 100.0

MATE 5 6.490 570.0 4 91 100.

MATE 6 9.69 873.0 1 235.4 2.116 2238.4 86.034 16 11.85 3239.1 .0

ANNU 1 0.750 2

ANNU 2 2.390 3

ANNU 3 4.000 3

ANNU 4 4.400 5

ANNU 5 14.105 4

ARRA 1 1 6 1.60 0.0

ARRA 2 1 12 3.09 0.2618

RODS 1 1 0.576 1

RODS 1 2 0.678 2

RODS 2 1 0.576 6

RODS 2 2 0.678 2

MESH 2 3 3 1 20

NPIJ 5

POWE 1 16.8 .1 1

FEWG 3 5 9 12 15 17 20 22 24 25 26 27 30 35 38 42 45 47 49 51 52 53 \$

54 55 56 57 58 59 60 61 63 66 69

SUPP 1 1 1 1 1 1 1 1 1 1 0 1 0 0

BEGI

PART 45 69

LEAK 5

THER 16

NOBU

BEGI

.

.

.

BEGI

POWE 1 16.8 0 1

MATE 1 -1 873.0 1

MATE 2 -1 588.0 2

MATE 3 1.0 557.0 3 2001 11.2 16 88.8

MATE 4 -1 873.0 4

MATE 5 -1 570.0 4

MATE 6 -1 873.0 1

BEGI

BEGI

MATE 1 -1 873.0 1

MATE 2 -1 588.0 2

MATE 3 0.04 557.0 3 2001 11.2 16 88.8

MATE 4 -1 873.0 4

MATE 5 -1 570.0 4

MATE 6 -1 873.0 1

BEGI
 BEGI
 MATE 1 -1 873.0 1
 MATE 2 -1 588.0 2
 MATE 3 0.516 300.0 3 2001 11.2 16 88.8
 MATE 4 -1 873.0 4
 MATE 5 -1 570.0 4
 MATE 6 -1 873.0 1
 BEGI
 BEGI
 MATE 1 -1 1500.0 1
 MATE 2 -1 588.0 2
 MATE 3 0.516 557.0 3 2001 11.2 16 88.8
 MATE 4 -1 873.0 4
 MATE 5 -1 570.0 4
 MATE 6 -1 1500.0 1
 BEGI
 BEGI

***** POLYCELL WITH CONTROL ROD

PRIME 0
 SAVE -1 1
 PCELL14FC+D+CR****
 SEQU 2
 PREOUT
 INITIATE

 * Channel tube and central pin
 MATER 1 -1 557 2 91 0.042338 178 7.325E-6
 *
 * Fuel channel coolant density 0.78 g/cc
 * Coolant with SS-spacers (coolant density 0.78 g/cc)
 MATER 2 -1 557 3 2001 0.051866 16 0.025933 \$
 1056 3.46069E-4 58 4.5806E-5 52 1.0072E-4 55 1.0302E-5 29 1.796E-4
 *
 * Fuel, gu=2.4%
 * Inside fuel ring
 MATER 3 9.69 1000.0 1 235.4 2.116 2238.4 86.034 16 11.85 3239.1 .0
 * Outside fuel ring
 MATER 7 9.69 1000.0 1 235.4 2.116 2238.4 86.034 16 11.85 3239.1 .0
 *
 * Fuel cladding
 MATER 4 -1 643 2 91 0.04279 178 7.292E-6
 *
 MATER 5=1
 *
 * Graphite 1.68 g/cc
 MATER 6 -1 743 4 12 0.08425 1010 1.75E-8
 *
 * Displacer
 MATER 8 -1 330 3 12 0.03795 1010 7.87E-9 27 0.0331
 MATER 9 -1 330 2 27 0.06025
 MATER 10 -1 330 3 2001 0.0669 16 0.03345
 *
 MATER 11=4
 *
 * Control rod, boron carbide 1.7 g/cc
 MATER 12 -1 550 -3 11 0.07412 12 0.01853

MATER 13 -1 558 3 2001 0.05218 16 0.02609
MATER 14 -1 558 -3 56 0.058 52 0.0163 58 0.00802
MATER 15 -1 558 -3 56 0.05557 52 0.01562 58 0.00769 11 0.0088211

*

RODSU 1 1 0.59 3
RODSU 1 2 0.68 4
RODSU 2 1 0.59 7
RODSU 2 2 0.68 11
* Fuel channel cell
CELL 1
ANNU 1 0.35 5
ANNU 2 0.75 1
ANNU 3 4.0 2
ANNU 4 4.4 1
ANNU 5 14.1047 6
ARRAY 1 (1 6 1.6 0.0)
ARRAY 2 (1 12 3.1 0.2618)
MESH 2 2 15 2 15
PCELL 1 0.85714 0.14286
* CONTROL ROD

CELL 2

CSPE 1

ANNU 1 2.35 10
ANNU 2 2.5 9
ANNU 3 3.3 12
ANNU 4 3.5 9
ANNU 5 4.1 10
ANNU 6 4.4 1
ANNU 7 14.1047 6
MESH 6 2 10 2 4 2 15
PCELL 2 1 0

*

TOLER 1.0E-6
PLOT 5.7 1.0
FEWGR 3 5 9 12 15 17 20 22 24 25 26 27 30 35 38 42 45 47 49 51 52 53 \$
54 55 56 57 58 59 60 61 63 66 69
SUPPR 0 1 1 1 1 1 1 1 1 1 1 1 0 0 1
BEGINC
BEGINC

***** POLYCELL WITH DISPLACER

PRIME 0

SAVE -1 1

PCELL14FC+D+CR****

SEQU 2

PREOUT

INITIATE

* Channel tube and central pin

MATER 1 -1 557 2 91 0.042338 178 7.325E-6

*

* Fuel channel coolant density 0.78 g/cc

* Coolant with SS-spacers (coolant density 0.78 g/cc)

MATER 2 -1 557 3 2001 0.051866 16 0.025933 \$

1056 3.46069E-4 58 4.5806E-5 52 1.0072E-4 55 1.0302E-5 29 1.796E-4

*

* Fuel, gu=2.4%

* Inside fuel ring

MATER 3 9.69 1000.0 1 235.4 2.116 2238.4 86.034 16 11.85 3239.1 .0
 * Outside fuel ring
 MATER 7 9.69 1000.0 1 235.4 2.116 2238.4 86.034 16 11.85 3239.1 .0
 *
 * Fuel cladding
 MATER 4 -1 643 2 91 0.04279 178 7.292E-6
 *
 MATER 5=1
 *
 * Graphite 1.68 g/cc
 MATER 6 -1 743 4 12 0.08425 1010 1.75E-8
 *
 * Displacer
 MATER 8 -1 330 3 12 0.03795 1010 7.87E-9 27 0.0331
 MATER 9 -1 330 2 27 0.06025
 MATER 10 -1 330 3 2001 0.0669 16 0.03345
 *
 MATER 11=4
 *
 * Control rod, boron carbide 1.7 g/cc
 MATER 12 -1 550 -3 11 0.07412 12 0.01853
 MATER 13 -1 558 3 2001 0.05218 16 0.02609
 MATER 14 -1 558 -3 56 0.058 52 0.0163 58 0.00802
 MATER 15 -1 558 -3 56 0.05557 52 0.01562 58 0.00769 11 0.0088211
 *
 RODSU 1 1 0.59 3
 RODSU 1 2 0.68 4
 RODSU 2 1 0.59 7
 RODSU 2 2 0.68 11
 * Fuel channel cell
 CELL 1
 ANNU 1 0.35 5
 ANNU 2 0.75 1
 ANNU 3 4.0 2
 ANNU 4 4.4 1
 ANNU 5 14.1047 6
 ARRAY 1 (1 6 1.6 0.0)
 ARRAY 2 (1 12 3.1 0.2618)
 MESH 2 2 15 2 15
 PCELL 1 0.85714 0.14286
 * Displacer
 CELL 2
 CSPE 1
 ANNU 1 3.45 8
 ANNU 2 3.7 9
 ANNU 3 4.1 10
 ANNU 4 4.4 1
 ANNU 5 14.1047 6
 MESH 4 2 3 2 15
 PCELL 2 1 0
 *
 TOLER 1.0E-6
 PLOT 5.7 1.0
 FEWGR 3 5 9 12 15 17 20 22 24 25 26 27 30 35 38 42 45 47 49 51 52 53 \$
 54 55 56 57 58 59 60 61 63 66 69
 SUPPR 0 1 1 1 1 1 1 1 1 1 1 0 0 1
 BEGINC
 BEGINC .

***** POLYCELL WIHT WATER COLUMN

PRIME 0

SAVE -1 1

PCELL14FC+D+CR****

SEQU 2

PREOUT

INITIATE

* Channel tube and central pin

MATER 1 -1 557 2 91 0.042338 178 7.325E-6

*

* Fuel channel coolant density 0.78 g/cc

* Coolant with SS-spacers (coolant density 0.78 g/cc)

MATER 2 -1 557 3 2001 0.051866 16 0.025933 \$

1056 3.46069E-4 58 4.5806E-5 52 1.0072E-4 55 1.0302E-5 29 1.796E-4

*

* Fuel, gu=2.4%

* Inside fuel ring

MATER 3 9.69 1000.0 1 235.4 2.116 2238.4 86.034 16 11.85 3239.1 .0

* Outside fuel ring

MATER 7 9.69 1000.0 1 235.4 2.116 2238.4 86.034 16 11.85 3239.1 .0

*

* Fuel cladding

MATER 4 -1 643 2 91 0.04279 178 7.292E-6

*

MATER 5=1

*

* Graphite 1.68 g/cc

MATER 6 -1 743 4 12 0.08425 1010 1.75E-8

*

* Displacer

MATER 8 -1 330 3 12 0.03795 1010 7.87E-9 27 0.0331

MATER 9 -1 330 2 27 0.06025

MATER 10 -1 330 3 2001 0.0669 16 0.03345

*

MATER 11=4

*

* Control rod, boron carbide 1.7 g/cc

MATER 12 -1 550 -3 11 0.07412 12 0.01853

MATER 13 -1 558 3 2001 0.05218 16 0.02609

MATER 14 -1 558 -3 56 0.058 52 0.0163 58 0.00802

MATER 15 -1 558 -3 56 0.05557 52 0.01562 58 0.00769 11 0.0088211

*

RODSU 1 1 0.59 3

RODSU 1 2 0.68 4

RODSU 2 1 0.59 7

RODSU 2 2 0.68 11

* Fuel channel cell

CELL 1

ANNU 1 0.35 5

ANNU 2 0.75 1

ANNU 3 4.0 2

ANNU 4 4.4 1

ANNU 5 14.1047 6

ARRAY 1 (1 6 1.6 0.0)

ARRAY 2 (1 12 3.1 0.2618)

MESH 2 2 15 2 15

PCELL 1 0.85714 0.14286

* Water column

CELL 2

CSPE 1

ANNU 1 4.1 10

ANNU 2 4.4 1

ANNU 3 14.1047 6

MESH 10 2 15

PCELL 2 1 0

*

TOLER 1.0E-6

I.2. Computation of neutron-physical characteristics of RBMK reactor channels with EKRAN code¹

Neutron-physical characteristics of the RBMK reactor fuel assembly with account of fuel burnup were computed with the CONCORD program complex on PC/AT personal computer. The burnup computation by the CONCORD program complex was performed by the following scheme.

At the first stage 33-group macroscopic neutron constants were computed by a given isotope composition of computational fuel assembly regions for all RBMK cell regions (for fixed values of physical characteristics of the cells: coolant density and temperature, fuel temperature, etc.). Macroscopic constants were computed with the MARX module of the CONCORD complex.

The scheme of neutron constant preprocessing in the CONCORD complex is as follows. Using the BEND program complex on the base of libraries of estimated neutron data 33-group neutron constants were preliminarily prepared for selected temperature values (0, 300, 600, 1000, 1500 K) and background cross sections (∞ , 1000, 0)² for all isotopes comprising the initial cell compositions or appearing during fuel burnup. Neutron cross sections for water and graphite were computed with account of chemical bonds (by the data of tape 320 from National Nuclear Data Center, BNL). At preparation of the 33-group constant system anisotropy of scattered neutron escape was accounted in the P_3 -approximation. The 33-group system of neutron constants contains 22 groups in the thermalization region and 11 groups in the neutron deceleration region. Using thus obtained system of 33-group macroscopic constants the MARX code computed macroscopic constants for separate regions of the RBMK reactor cell. In the CONCORD complex resonant self-shielding of cross sections under the condition of heterogeneous fuel location in the given cell was accounted in terms of I.I. Bondarenko's formalism of background cross sections. For resonant absorber (and scatterer) the background cross section is of the form

$$\sigma_0^{(\text{het})} = \sigma_0^{(\text{hom})} + A.$$

¹ The EKRAN code is a modified version of the LOMA code.

² To provide process cross-sections dependency of dilution cross-section the special interpolation formula is used.

where $\sigma_0^{(hom)}$ - background cross section per a nucleus of a selected type in homogeneous mixture of nuclei from fuel unit material compound, A - correction for heterogeneous effects. The background cross section $\sigma_0^{(hom)}$ in homogeneous mixture is found by iterations using a known scheme. For an isolated unit (Wigner-Seitz cell radius equals infinity) in the narrow resonance approximation

$$A = \frac{1}{\phi \cdot \bar{l}_u},$$

where ϕ - nuclear concentration of a separated isotope, $\bar{l}_u = \frac{4V_u}{S}$ - mean unit chord, V_u - unit volume, S - unit surface area (the unit is assumed to be solid). In the CONCORD complex mutual self-shielding of units (Wigner-Seitz cell radius equals a finite number) may be accounted in several ways. The computation of the RBMK reactor cell burnup used the Bell approximation for the "cylindrical" Wigner-Seitz cell.

In this approximation one can write for the value A :

$$A = \frac{1}{\phi \cdot \bar{l}_u} \cdot \frac{\sum_{mod}}{\sum_{mod} + \frac{S}{4V_{mod}}},$$

where $\sum_{mod}$ - total macroscopic cross section in the moderator region, V_{mod} - moderator volume.

At the second stage the multi-group 2D code EKRAN [2] computes neutron spectra in cell regions and effective neutron multiplication factor k_{eff} . For finite-difference approximation of 2D transport equation the EKRAN module (a modified version of the LOMA code) uses the DS_n - method type scheme constructed on an extended template involving grid values of the function on cell edges and vertices. The use of such a template allows to construct additional relations based on representation of the solution inside cells in the form of linear functions along some straight lines at any variant of cell side illumination which secures convergence within the order of accuracy close to the second even on quite severely deformed grids. The technique of the EKRAN code uses the following iterative methods to compute k_{eff} : the Kellogg method, the direct iterative method, the method of fission source iterations and the combined method. These iterative methods are used in combination with the condensing grid method. To accelerate convergence of simple iterations within a single group, the consistent FCA-method was developed. In a computational domain a spatial grid is constructed either of arbitrary

polygons or being matrix whose cells are quadrangles arbitrary in shape. The domain can contain several subdomains differing in isotope composition. Presence of polygonal grids allows to use hexagonal cells which is convenient when computing many reactor types. By angular variables for a grid Es_n type quadratures are used. To solve the multi-group kinetic equation, the algorithm of paralleling by groups was developed.

At the third stage the neutron spectra in RBMK reactor cell fuel region obtained at the second stage were used to numerically solve the system of neutron-nucleous kinetics equations using the KINWRK module.

In the KINWRK code it is assumed that variation in nuclide concentration results from reactions of capture (n,γ) , $(n,2n)$, fission (n,f) , α , β -decay. At neutron-nucleous reaction description group representation is used. Desired concentrations and their equations are ordered as follows: first equations of actinides are arranged in conformity with the natural scheme of their radioactive decay, then liberated fission products in accordance with their genetic bonds. The whole system of the kinetics differential equations is conventionally broken into two subsystems: equations related to variation in actinide concentrations (nuclear set of actinides) and equations related to generation and change in fission products. The above ordering of nuclei kinetics equations dictates the following order of their solution: first the system of differential equations of the actinide nuclear set is solved, then fission products. Since in nuclear reactor burnup problems equation systems for actinide nuclear sets have general-structure matrices with essentially different-scale eigenvalues characteristic of rigid differential equation systems, then to solve such systems, the KINWRK module uses the exponential method. Liberated fission products are broken into two groups: instable and stable. The equation system for nuclear sets of instable liberated fission products have triangular matrices which allows to use difference-analytical formulas for their solution. The equation systems for stable fission products have tridiagonal matrices. To solve such equation systems, the KINWRK technique uses an implicit two-layered scheme with weight in time. The system of algebraic equations which therewith arises is solved using the sweep method.

Briefly describe some features of cell neutron-physical characteristic computation in the progress of fuel burnup in a cell. Specific power of energy release in a cell is calculated by the formula

$$P = \sum_m \sum_i \sum_k \sum_{\Delta} \sigma_{\Delta_i}^k N_i^m Q_{\Delta_i}^k \phi_k^m \rho_m,$$

where m-region number,
 i-group number,
 Δ -reaction index,
 k-isotope index,
 σ -microscopic cross section,
 ρ -density,
 N- total neutron flux,
 Q- energy release,
 ϕ -isotope concentration.

After specific power P has been calculated, ratio C is found which equals

$$C = P/P_0,$$

where P_0 - given specific power in the reactor cell. This factor is used to re-normalize the neutron flux in the cell for the given power. The re-normalized neutron flux is used in the module for nuclei kinetics calculation. Energy generation or fuel burnup depth B is found by the formula

$$B(t)=E(t)/M(t),$$

where E(t)-total energy release in the cell during time t, M(t)-fuel mass at time t. Note that fuel mass refers only to heavy nuclides. If a reactor operates at a preset power the value E is found by the formula

$$E(t)=P_0 \cdot V_c \cdot t,$$

where P_0 - given specific power, V_c - cell volume, t - time.

Description of performed computations.

At RBMK reactor channel computation 8 regions were distinguished for which various initial compositions were set, geometric sizes were accounted, and neutron spectra were computed.

Concentrations of nuclides comprising various fuel assembly regions are given in 10^{24} pieces/cc.

Central rod and fuel element shells:

$$\text{Cr}^{52} - 4.5854 \cdot 10^{-4}$$

$$\text{Mn}^{55} - 4.6021 \cdot 10^{-5}$$

$$\text{Fe}^{56} - 1.6945 \cdot 10^{-3} \quad T=588\text{K}$$

$$\text{Ni}^{58} - 1.7848 \cdot 10^{-4}$$

$$\text{Zr}^{91} - 3.8156 \cdot 10^{-2}$$

Inside and outside ring reactor fuel:

$$\text{U}^{235} - 5.2542 \cdot 10^{-4}$$

$$\text{U}^{238} - 2.1093 \cdot 10^{-2} \quad T=873\text{K}$$

$$\text{O}^{16} - 4.3239 \cdot 10^{-2}$$

Coolant:

$$\text{H}^1 - 3.4538 \cdot 10^{-2} \quad T=557\text{K}$$

$$\text{O}^{16} - 1.7254 \cdot 10^{-2}$$

Graphite:

$$\text{C}^{12} - 8.3118 \cdot 10^{-2} \quad T=873\text{K}$$

Fuel assembly shell:

$$\text{Zr}^{91} - 4.2852 \cdot 10^{-2} \quad T=588\text{K}$$

The whole fuel assembly burnup is computed up to a time of 1800 days at a timestep of 45 days. These timesteps were used to compute neutron spectra for all selected fuel assembly regions with the EKRAN code, to re-normalize the spectra for reactor specific power which was taken to be equal to $\text{UDG}=4.274\text{MW/m}^3$, to compute fuel burnup separately for inside and outside ring fuel elements and to re-compute the macroscopic constants with the MARX code. 2D computation of neutron spectra with the EKRAN code used the grid given in Fig.I.2.1.

Fig.I.2.1.

As it has been already mentioned, the computations were performed at a timestep equal to 45 days, in so doing for selected times (0 days, 180, 360, 720, 1080, 1440 and 1800 days) computations were additionally performed with variation in coolant density and fuel and coolant temperatures to estimate thermal and density effects (the results of these computations are given in Table I.2.1). These times were also used to compute two-group neutron constants averaged over the whole cell (see Appendix I.2.1).

Table I.2.1.

Computed results for critical parameter k_{eff} with variation in constants.

Days	Nominal Value	Variation I	Variation II	Variation III	Variation IV
0	1.355	1.3548	1.3459	1.3594	1.349
360	1.22229	1.2241	1.2207	1.2272	1.21695
720	1.1334	1.129138	1.135597	1.132799	1.125568
1080	1.04141	1.029907	1.05115	1.035074	1.032085
1440	0.94963	0.93255	0.97095	0.939177	0.94143
1800	0.859863	0.8478739	0.902324	0.8551394	0.862727

where "Nominal value" is computation for initial values (see above).

Variation I: coolant density $\rho=1\text{g/cc}$, other values did not change.

Variation II: coolant density $\rho=0.04\text{g/cc}$, other values did not change.

Variation III: coolant density $\rho=0.05\text{g/cc}$, coolant temperature $T=300\text{K}$, other values did not change.

Variation IV: fuel temperature $T=1500\text{K}$, other values were initial.

**Two-group macroscopic neutron constants averaged over RBMK reactor
fuel cell for various times.**

STEP NUMBER - 1 TIME (DAY) - 0

NUMBER OF REGIONS 8

NUMBER OF PROCESSES 4

NUMBER OF NEUTRON GROUPS 2

NUMBER OF HARMONICS 1

VELOCITIES (CM/INSTANT)

.722346E+02 .507383E-01

PROCESS - 5 Q P R - .0000000E+00 (S C A T T E R I N G)

CROSS SECTIONS

3.500130E-01 4.149280E-01

CALORIFIC VALUES (MEV.)

2.805310E-02 1.524290E-09

MATRIX PROCESS

9.845870E-01 1.541320E-02 4.635180E-03 9.953640E-01

HARMONIC - 1

1.002310E-01 -1.311630E-01 -7.707950E-02 -1.420590E-01

PROCESS - 16 Q P R - -.1166560E+01 (N , 2 N)

CROSS SECTIONS

9.079010E-06 0.000000E+00

CALORIFIC VALUES (MEV.)

-3.004380E+00 0.000000E+00

MATRIX PROCESS

9.999980E-01 6.671670E-12 0.000000E+00 0.000000E+00

PROCESS -102 Q P R - .3776620E-01 (C A P T U R E)

CROSS SECTIONS

7.870620E-04 1.298590E-03

CALORIFIC VALUES (MEV.)

5.217200E+00 1.511780E+01

PROCESS - 18 Q P R - .2065810E+02 (F I S S I O N)

CROSS SECTIONS

2.498050E-04 2.430840E-03

CALORIFIC VALUES (MEV.)

1.929880E+02 1.928250E+02

NUMBER OF SECONDARY NEUTRONS

2.504300E+00 2.415300E+00

MATRIX PROCESS

1.000000E+00 0.000000E+00 1.000000E+00 0.000000E+00

STEP NUMBER - 9 TIME (DAY) - 360
NUMBER OF REGIONS 8
NUMBER OF PROCESSES 4
NUMBER OF NEUTRON GROUPS 2
NUMBER OF HARMONICS 1
VELOCITIES (CM/INSTANT)
.721039E+02 .503165E-01

PROCESS - 5 Q P R - .0000000E+00 (S C A T T E R I N G)
 CROSS SECTIONS
3.499630E-01 4.146150E-01
 CALORIFIC VALUES (MEV.)
2.803260E-02 1.503610E-09
 MATRIX PROCESS
9.849640E-01 1.503580E-02 4.696460E-03 9.953030E-01
HARMONIC - 1
1.003270E-01 -1.314010E-01 -7.696020E-02 -1.430110E-01

PROCESS - 16 Q P R - -.1167240E+01 (N , 2 N)
 CROSS SECTIONS
9.039390E-06 0.000000E+00
 CALORIFIC VALUES (MEV.)
-2.999060E+00 0.000000E+00
 MATRIX PROCESS
9.999980E-01 4.894060E-12 0.000000E+00 0.000000E+00

PROCESS -102 Q P R - .3774730E-01 (C A P T U R E)
 CROSS SECTIONS
8.385170E-04 1.678760E-03
 CALORIFIC VALUES (MEV.)
5.114320E+00 1.303970E+01

PROCESS - 18 Q P R - .2066160E+02 (F I S S I O N)
 CROSS SECTIONS
2.129770E-04 2.235440E-03
 CALORIFIC VALUES (MEV.)
1.934320E+02 1.943470E+02
 NUMBER OF SECONDARY NEUTRONS
2.546280E+00 2.513930E+00
 MATRIX PROCESS
1.000000E+00 0.000000E+00 9.999990E-01 0.000000E+00

STEP NUMBER - 17 TIME (DAY) - 720
NUMBER OF REGIONS 8
NUMBER OF PROCESSES 4
NUMBER OF NEUTRON GROUPS 2
NUMBER OF HARMONICS 1
VELOCITIES (CM/INSTANT)
.720754E+02 .496722E-01

PROCESS - 5 Q P R - .0000000E+00 (S C A T T E R I N G)
 CROSS SECTIONS
3.501620E-01 4.148100E-01
 CALORIFIC VALUES (MEV.)
2.788110E-02 1.453520E-09
 MATRIX PROCESS
9.848300E-01 1.516990E-02 4.685580E-03 9.953150E-01
HARMONIC - 1
1.002380E-01 -1.333520E-01 -7.704730E-02 -1.427350E-01

PROCESS - 16 Q P R - -.1167920E+01 (N , 2 N)
 CROSS SECTIONS
8.979130E-06 0.000000E+00
 CALORIFIC VALUES (MEV.)
-2.993870E+00 0.000000E+00
 MATRIX PROCESS
9.999980E-01 3.484420E-12 0.000000E+00 0.000000E+00

PROCESS -102 Q P R - .3772910E-01 (C A P T U R E)
 CROSS SECTIONS
8.875780E-04 1.831620E-03
 CALORIFIC VALUES (MEV.)
5.028090E+00 1.332490E+01

PROCESS - 18 Q P R - .2066430E+02 (F I S S I O N)
 CROSS SECTIONS
1.807630E-04 2.003420E-03
 CALORIFIC VALUES (MEV.)
1.937940E+02 1.952500E+02
 NUMBER OF SECONDARY NEUTRONS
2.585450E+00 2.573150E+00
 MATRIX PROCESS
1.000000E+00 0.000000E+00 1.000000E+00 0.000000E+00

STEP NUMBER - 25 TIME (DAY) -1080
NUMBER OF REGIONS 8
NUMBER OF PROCESSES 4
NUMBER OF NEUTRON GROUPS 2
NUMBER OF HARMONICS 1
VELOCITIES (CM/INSTANT)
.721002E+02 .490499E-01

PROCESS - 5 Q P R - .000000E+00 (S C A T T E R I N G)
 CROSS SECTIONS
3.502470E-01 4.151190E-01
 CALORIFIC VALUES (MEV.)
2.780800E-02 1.355590E-09
 MATRIX PROCESS
9.847420E-01 1.525800E-02 4.622670E-03 9.953770E-01
HARMONIC - 1
1.002370E-01 -1.346990E-01 -7.730930E-02 -1.423560E-01 .

PROCESS - 16 Q P R - -.1168610E+01 (N , 2 N)
 CROSS SECTIONS
8.939280E-06 0.000000E+00
 CALORIFIC VALUES (MEV.)
-2.989110E+00 0.000000E+00
 MATRIX PROCESS
9.999980E-01 2.346510E-12 0.000000E+00 0.000000E+00

PROCESS -102 Q P R - .3771180E-01 (C A P T U R E)
 CROSS SECTIONS
9.231440E-04 1.946980E-03
 CALORIFIC VALUES (MEV.)
4.953610E+00 1.385350E+01

PROCESS - 18 Q P R - .2066610E+02 (F I S S I O N)
 CROSS SECTIONS
1.538600E-04 1.748850E-03
 CALORIFIC VALUES (MEV.)
1.941420E+02 1.960500E+02
 NUMBER OF SECONDARY NEUTRONS
2.626490E+00 2.626200E+00
 MATRIX PROCESS
1.000000E+00 0.000000E+00 9.999990E-01 0.000000E+00

STEP NUMBER - 33 TIME (DAY) -1440
 NUMBER OF REGIONS 8
 NUMBER OF PROCESSES 4
 NUMBER OF NEUTRON GROUPS 2
 NUMBER OF HARMONICS 1
 VELOCITIES (CM/INSTANT)
 .721019E+02 .485171E-01

PROCESS - 5 Q P R - .0000000E+00 (S C A T T E R I N G)
 CROSS SECTIONS
 3.502900E-01 4.154410E-01
 CALORIFIC VALUES (MEV.)
 2.775490E-02 1.257460E-09
 MATRIX PROCESS
 9.846790E-01 1.532120E-02 4.553490E-03 9.954460E-01 ,
 HARMONIC - 1
 1.002550E-01 -1.357200E-01 -7.758510E-02 -1.419420E-01

PROCESS - 16 Q P R - -.1169320E+01 (N , 2 N)
 CROSS SECTIONS
 8.895340E-06 0.000000E+00
 CALORIFIC VALUES (MEV.)
 -2.985070E+00 0.000000E+00
 MATRIX PROCESS
 9.999980E-01 1.466060E-12 0.000000E+00 0.000000E+00

PROCESS -102 Q P R - .3769560E-01 (C A P T U R E)
 CROSS SECTIONS
 9.507840E-04 2.041410E-03
 CALORIFIC VALUES (MEV.)
 4.889810E+00 1.448340E+01

PROCESS - 18 Q P R - .2066720E+02 (F I S S I O N)
 CROSS SECTIONS
 1.325420E-04 1.510120E-03
 CALORIFIC VALUES (MEV.)
 1.944820E+02 1.968660E+02
 NUMBER OF SECONDARY NEUTRONS
 2.668450E+00 2.680560E+00
 MATRIX PROCESS
 1.000000E+00 0.000000E+00 9.999990E-01 0.000000E+00

STEP NUMBER - 41 TIME (DAY) -1800
 NUMBER OF REGIONS 8
 NUMBER OF PROCESSES 4
 NUMBER OF NEUTRON GROUPS 2
 NUMBER OF HARMONICS 1
 VELOCITIES (CM/INSTANT)
 .721338E+02 .480984E-01

PROCESS - 5 Q P R - .0000000E+00 (S C A T T E R I N G)
 CROSS SECTIONS
 3.502330E-01 4.157000E-01
 CALORIFIC VALUES (MEV.)
 2.775850E-02 1.166860E-09
 MATRIX PROCESS
 9.846180E-01 1.538160E-02 4.488690E-03 9.955110E-01
 HARMONIC - 1
 1.003080E-01 -1.366490E-01 -7.786700E-02 -1.416430E-01

PROCESS - 16 Q P R - -.1170050E+01 (N , 2 N)
 CROSS SECTIONS
 8.859260E-06 0.000000E+00
 CALORIFIC VALUES (MEV.)
 -2.981850E+00 0.000000E+00
 MATRIX PROCESS
 9.999980E-01 8.408860E-13 0.000000E+00 0.000000E+00

PROCESS -102 Q P R - .3768060E-01 (C A P T U R E)
 CROSS SECTIONS
 9.718570E-04 2.114990E-03
 CALORIFIC VALUES (MEV.)
 4.836780E+00 1.514410E+01

PROCESS - 18 Q P R - .2066790E+02 (F I S S I O N)
 CROSS SECTIONS
 1.172130E-04 1.314820E-03
 CALORIFIC VALUES (MEV.)
 1.947850E+02 1.976700E+02
 NUMBER OF SECONDARY NEUTRONS
 2.707120E+00 2.734280E+00
 MATRIX PROCESS
 1.000000E+00 0.000000E+00 9.999990E-01 0.000000E+00

I.3. Results of RBMK cell and polycell computations with C-90 code (Monte Carlo method).

In the C-90 computations (the Monte Carlo method) [3] cell constants and a spectrum of fresh fuel cells and cells with a control rod, displacer and water were obtained.

The C-90 computations used the constant library ENDF/-BVI (rev. 2) with account of chemical bonds for graphite and hydrogen

I.3.1. Fuel cell computations.

Fuel cell computations were performed with specular reflection on external boundary. Two computations were made with variation in operating parameters.

Parameters of the fuel cell are given in Table I.3.1.

Table I.3.1.

		Variant 1		Variant 2	
	elements	concentration, 10^{24} pieces/cc	T, K	concentration, 10^{24} pieces/cc	T, K
Fuel	U^{235}	0.00052542	873	0.00052542	1000
	U^{238}	0.021093		0.021093	
	O^{16}	0.043239		0.043239	
Graphite (moderator)	C^{12}	0.0831036	873	0.0831036	743
Water (coolant)	H^1	0.034526	557	0.051866	557
	O^{16}	0.017263		0.025933	
Cladding	Zr^{91}	0.03786	588	0.03786	643
	Nb^{93}	0.0003728		0.0003728	
	Fe^{56}	0.0016896		0.0016896	
	Cr^{52}	0.0004584		0.0004584	
	Ni^{58}	0.0001806		0.0001806	
	Mn^{55}	0.00004596		0.00004596	
Central pipe	Zr^{91}	0.03786	588	0.03786	557
	Nb^{93}	0.0003728		0.0003728	
	Fe^{56}	0.0016896		0.0016896	
	Cr^{52}	0.0004584		0.0004584	
	Ni^{58}	0.0001806		0.0001806	
	Mn^{55}	0.00004596		0.00004596	
Channel shell	Zr^{91}	0.0418744	570	0.0418744	557
	Nb^{93}	0.0010506		0.0010506	

Computed results.

Variant 1.

$$k_{\text{eff}} = 1.369, \sigma = 0.45\%$$

Cell constants and spectrum.

	fraction, %	$\Sigma_{\text{scat}},$ 1/cm	$\Sigma_{\text{fis}},$ 1/cm	$\Sigma_{\text{cap}},$ 1/cm	$\nu\Sigma_{\text{fis}},$ 1/cm	$\Sigma_{n,2n},$ 1/cm
fast	50.8	0.3587	0.000262	0.000814	0.000664	0.000003
thermal	49.2	0.2566	0.002669	0.001459	0.006493	0

Scattering matrix

	thermal	fast
thermal	0.99506	0.01456
fast	0.00494	0.98544

Variant 1.

$$k_{\text{eff}} = 1.354, \sigma = 0.45\%$$

Cell constants and spectrum.

	fraction, %	$\Sigma_{\text{scat}},$ 1/cm	$\Sigma_{\text{fis}},$ 1/cm	$\Sigma_{\text{cap}},$ 1/cm	$\nu\Sigma_{\text{fis}},$ 1/cm	$\Sigma_{n,2n},$ 1/cm
fast	48.3	0.368	0.00026	0.000844	0.000662	0.000004
thermal	51.7	0.2718	0.002671	0.001564	0.006497	0

Scattering matrix

	thermal	fast
thermal	0.99557	0.01585
fast	0.00443	0.98415

I.3.2. C-90 computations of cells with control rod, displacer and water surrounded by eight fuel cells of variant 2.

C-90 computations of cells with a control rod, displacer and water surrounded by eight fuel cells were made with specular reflection on external boundaries of the fuel cells.

Parameters of materials in cell with a control rod, displacer, water taken in C-90 computations.

	elements	concentration, 10^{24} pieces/cc	T, K
masonry graphite	N ¹²	0.0831036	743
channel shell	Zr ⁹¹	0.0418744	557
	Nb ⁹³	0.0010506	
water	H ¹	0.0669111	330
	O ¹⁶	0.0334556	
aluminium	Al ²⁷	0.06022	330
boron carbide	B ¹⁰	0.013601	550
	B ¹¹	0.058364	
	C ¹²	0.017968	
graphite	C ¹²	0.0776838	330

Computed results.

cell with control rod + 8 fuel cells (variant 2):

$$k_{\text{eff}} = 1.154, \sigma = 0.48\%$$

cell with displacer + 8 fuel cells (variant 2):

$$k_{\text{eff}} = 1.344, \sigma = 0.64 \%$$

cell with water + 8 fuel cells (variant 2):

$$k_{\text{eff}} = 1.313, \sigma = 0.55\%$$

Cell constants and spectrum of cells with control rod, displacer and water.

	$\Sigma_{scat},$ 1/cm		$\Sigma_{cap},$ 1/cm		fraction, %	
	fast	thermal	fast	thermal	fast	thermal
cell with control rod	0.3795	0.2453	0.002729	0.006587	39.7	60.3
cell with displacer	0.3676	0.2486	0.0000496	0.000466	28.0	72.0
cell with water	0.3936	0.4511	0.0000688	0.001485	26.9	73.1

The results of the C-90 computations were used to study the effect of neighboring cells on the cell constants and the fuel cell spectrum.

Spectrum and cell constants of fuel cells depending on neighboring cells (fuel cell - variant 2).

neighboring cells		fuel cell	8 fuel+ 1 with control rod	8 fuel+ 1 with displacer	8 fuel+1 with water
fraction	fast	48.3	48.0	42.4	43.0
%	thermal	51.7	52.0	56.6	57.0
Σ_{scat}	fast	0.368	0.3668	0.3667	0.3666
1/cm	thermal	0.2718	0.2657	0.2629	0.2622
Σ_{fis}	fast	0.00026	0.000259	0.000249	0.000253
1/cm	thermal	0.002671	0.002366	0.002208	0.002237
Σ_{cap}	fast	0.000844	0.00078	0.000797	0.000767
1/cm	thermal	0.001564	0.00137	0.001305	0.001298
$\Sigma_{n,2n}$	fast	0.000004	0.000005	0.000003	0.000005
1/cm	thermal	0	0	0	0
$v\Sigma_{fis}$	fast	0.000662	0.00066	0.000636	0.000645
1/cm	thermal	0.006497	0.005732	0.00537	0.005443

II. Spatial dynamics and statics computation with KORAT-3D code

Introduction.

In conformity with the protocol of the Workshop under University of California - VNIIEF contract the work was performed on comparison of computed results obtained with the NESTLE [7] and KORAT-3D [5] codes in the time-independent case and problem formulation was suggested and computations with the KORAT-3D code were made for the dynamic test.

Formulation of the steady-state problem, including 3D geometry and neutron two-group constants, as well as computed results obtained with NESTLE were kindly presented by R.T.Perry from LANL.

The geometry and cell composition considered in the problem resemble a fragment of RBMK core. In the symmetry polycell composed of 3x3 channels, in the center, a CPS channel is located and along the periphery fuel channels. While in the real RBMK geometry the "symmetry cell" consists of 4x4 channels and the CPS channel is located in the corner of this configuration. The output file of the computation with the NESTLE code is given in Appendix 2. The KORAT-3D code was used to perform a time-independent computation in the same geometry and using the same neutron constants as in NESTLE. The results and detailed setting-up of the steady-state and time-dependent computations are given below.

The results and setting-up of the computations with the KORAT-3D code for the dynamic test are given in A.II.4.

II.1. Steady-state computations. Geometry and composition.

Uniform division along axis X and axis Y in a plane.

* = 1-overlay type # 1

* = 2-overlay type # 2

* = 3-overlay type # 3

* = i - number of material specifying a neutron constant set.

Uniform division along Z from 0 to 700 cm (a total of 14 layers). In the layers along Z "*" is replaced with materials, respectively,

We will call this division as a support grid and its cells as physical. At the computations the support grid was split into a finer one, we will call the cells of the latter as computational cells.

The boundary conditions were set as follows: on the side faces - reflection, at the top and bottom - outgoing fluxes ($D \frac{\partial \phi}{\partial n} = -0.4695 * \phi$).

II.2. Computations of k_{eff}

Initial computation of k_{eff} was performed not on a complete grid. A quarter of the plane (i.e. $0 < x, y < 75$) and a half of height were taken. Correspondingly, the boundary condition at the top was set as reflection.

The values k_{eff} for $\varepsilon_{Keff} = 10^{-7}$; $\varepsilon_{r.it.} = 10^{-9}$; $\varepsilon_{int.it.} = 10^{-11}$ (accuracies of reduction of iterations in k_{eff} , iterations in right - hand side, internal iterations) are given in Table II.1. In brackets the number of iterations in k_{eff} is given. At comparison of the computations for $\varepsilon_{Keff} = 10^{-6}$; $\varepsilon_{r.it.} = 10^{-6}$; $\varepsilon_{int.it.} = 10^{-8}$ (the results are given in Table II.2) with the given the values of k_{eff} coincided within four most significant digits, while the computation time reduced by a factor of 2.7 on the average. Therefore, the computations on convergence of k_{eff} at support grid splitting were made within the latter accuracies. The computed results are given in Table II.2, in brackets (number of iterations/computation time) are given.

Table II.1

number of divisions in Z	in X	3	6
7		0.98437 (117)	0.99881 (117)
14		0.98344 (112)	0.99785 (111)
28		0.98323 (110)	0.99764 (110)

Table II.2

umber of divisions in X	3	6	12	24
in Z				
7	0.984395 (81/25sec)	0.998834 (82/90sec)	1.002754 (82/386sec)	1.003781 (82/2380sec)
14	0.983469 (77/47sec)	0.997884 (77/161sec)	1.001796 (77/780sec)	1.002816 (77/4556sec)
28	0.983264 (76/97sec)	0.997674 (76/350sec)	1.001586 (76/1785sec)	1.002605 (76/9796sec)

Differences in k_{eff} on the grids (x:12 /z:7) (x:24 /z:14) are no more than $6.2 \cdot 10^{-5}$.

II.3. Energy release.

In the problem energy release by physical cells was computed for the characteristic value. Total energy release and energy release in plan were computed. Energy release for a physical cell was computed in the form

$$q_{l,m}(t) = \omega \left(\sum_{p \in (l,m)} V_p \left(\sum_i \Sigma_i^{fis} \Phi_i \right)_p + \sum_{k=1}^6 C_k(t) \lambda_k \right) / V_{l,m}$$

$$\frac{dC_k(t)}{dt} = \xi_k \sum_{p \in (l,m)} V_p \left(\sum_i \Sigma_i^{fis} \Phi_i \right)_p - C_k(t) \lambda_k \quad (1)$$

where l - the number of a layer through height;
 m - the number of a physical cell in plan;
 i - the number of an energy group;
 $q_{l,m}$ - specific power in cell (l,m) [W/cc];
 V_p - volume of a computational cell [cc];
 $V_{l,m}$ - volume of a physical cell [cc];
 Φ_i - neutron flux [10¹⁴ pieces/(m² sec)];
 Σ_i^{fis} - macroscopic cross section of fission in a computational cell [1/cm];
 ω - calorific value [J/10¹⁴ acts];
 k - the number of a precursor group in "residual" energy release;
 $C_k(t)$ - concentration of group -//;-
 λ_k - time constant for group -//- [1/sec];
 ξ_k - the share of precursors of the k -th group in residual energy release generated at a fission act.

The values of the constants ω , λ_k , ξ_k are given in Table A.II.1 (in Appendix II.1)

Total energy release is of the form:

$$Q = \sum_{l,m} q_{l,m} V_{l,m}$$

Normalized energy release for a physical cell

$$KV_{l,m} = V_{l,m} q_{l,m} N_f / Q, \quad \text{where } N_f - \text{the number of physical cells.}$$

Energy release in column m was computed as

$$KQ_m = N_{fp} \sum_l V_{l,m} q_{l,m} N_{fp} / Q, \quad \text{where } N_{fp} - \text{the number of physical cells in a}$$

overlay.

Energy release in plan by physical columns on a complete grid along Z (x:12 /z:14) is of the form :

1.0374	0.9626	1.0374
0.9626	-	0.9626
1.0374	0.9626	1.0374

Energy release through height has the following distribution :

0<z< 50	50<z<100	100<z<150	150<z<200	200<z<250	250<z<300	300<z<350
0.6168	1.3379	1.5973	1.4216	0.9059	0.6238	0.4966

These results agree with the NESTLE results (see Appendix II.2) with good accuracy.

The neutron function by physical cells on the grid (x:12 /z:7) in layers 1,3, 7, respectively, is of the form:

layer 1

0.2745-2	0.2523-2	0.2745-2
0.1144	0.1061	0.1144
0.2523-2	0.1905-2	0.2523-2
0.1061	0.084	0.1061
0.2745-2	0.2523-2	0.2745-2
0.1144	0.1061	0.1144

layer 3

0.7647-2	0.7036-2	0.7647-2
0.3201	0.2973	0.3201
0.7036-2	0.5327-2	0.7036-2
0.2973	0.2366	0.2973
0.7647-2	0.7036-2	0.7647-2
0.3201	0.2973	0.3201

layer 7

0.2566-2	0.2367-2	0.2566-2
0.1121	0.1043	0.1121
0.2367-2	0.1811-2	0.2367-2
0.1043	0.0833	0.1043
0.2566-2	0.2367-2	0.2566-2
0.1121	0.1043	0.1121

Key:

ϕ - group 1

ϕ - group 2

II.4. Time - dependent computation

Setting up and results of test computations

During consultations with V.M.Rozhdestvensky (NIKIET) it was suggested for the dynamic test to consider getting into a core operating in the nominal mode of an air bubble, its further floating up and then filling the core with cold water. In order to simplify corresponding NESTLE computations as much as possible, geometry in the plane was preserved as described above, through height complete geometry (i.e. 14 overlays) was taken. The neutron constants, or, more precisely, the interpolation factors which will be described below, had to be modified.

The computations were performed without involvement of the thermal hydraulics computation block. The thermal-hydraulic parameters were set as input data. At the initial time the system is in the "nominal" state through the entire height of the region $\rho_{\text{cool}}=0.516(\text{g/cc})$, $T_{\text{cool}}=543(^{\circ}\text{F})$, $T_{\text{fuel}}=1112(^{\circ}\text{F})$, $T_{\text{graphite}}=1112(^{\circ}\text{F})$. As the dynamics computation begins, coolant with the parameters $\rho_{\text{cool}}=0.05(\text{g/cc})$, $T_{\text{cool}}=543(^{\circ}\text{F})$ is fed into the region. This vapor bubble begins to enter into the region at a velocity $V=2\text{ m/sec}$, the process continues during τ seconds (see Fig.II.1). At time $t=\tau$ at the entrance into core cold water with the parameters $\rho_{\text{cool}}=1(\text{g/cc})$, $T_{\text{cool}}=77(^{\circ}\text{F})$ is fed into the core and the vapor bubble continues to move upwards and gradually escapes from the core. As a result, the entire core is filled with cold water and the system becomes subcritical.

Fig II.1. H-t plot of coolant state in core.

The time - dependent computation was performed with variation in medium constants depending on coolant temperature and density (water in this case). The constants were interpolated according to the law:

$$\Sigma = \Sigma_0 + a_1 \Delta \rho + a_2 \Delta \rho^2 + a_3 \Delta T, \quad (2)$$

where Σ_0 - constants for ρ_0, T_0 ;

$$\Delta \rho = \rho - \rho_0, \Delta T = T - T_0$$

II.4.1. Checking medium constants

To check whether the interpolation factors were properly selected, k_{eff} was computed for the interpolated constants over the whole three-dimensional region. It turned out that for less dense coolant k_{eff} became lower ($k > k_1$).

1)

k			k ₁		
*	*	*	u	u	u
*	5	*	u	5	u
*	*	*	u	u	u

Though at a computation without the 5-th material in the middle this effect was not observed.

2)

k ¹			k ¹ ₁			(k ¹ < k ¹ ₁).
*	*	*	u	u	u	
*	*	*	u	u	u	
*	*	*	u	u	u	

It can be accounted for by the fact that though the ratio $\Sigma^{\text{fis}} / \Sigma^{\text{abs}}$ behaved as it had been expected at the interpolation, but neutron spectrum offset took place. For a less dense coolant the number of neutrons in the second group (principal in multiplication) decreased relative to the first. Therefore, the interpolation factor a_1 for Σ_{21}^{f} was taken to be $a_1 = a_1 / m$. The results of the k_{eff} computation on the grid (x:3 /z:7) for various m are given in Table II.3, in brackets relative deviation from results with non-interpolated constants is given. As a result, $m=3$ was taken for the time-dependent computation.

Table II.3.

m	1	2	3	4
$\Delta \rho = -0.466$ $\Delta T = 0$	0.9620 (-2%)	0.9823 (-0.2%)	0.9884 (0.4%)	0.9913 (0.7%)
$\Delta \rho = 0.484$ $\Delta T = -466$	1.0084	0.9944	0.9893	0.9868

k_{eff} for $\Delta \rho = 0.484$ (g/cc), $\Delta T = 466$ °F (see Table II.3) increases as compared to k_{eff} for non-interpolated constants. To obtain an inverse result, the values a_3 for $\sum_2^{abs}$ were assumed to be equal to the value a_3 for $\sum_2^{fis}$ for all materials.

II.4.2. Numerical simulation of variation in constants.

At the computation time constant variation in vertical was performed by three techniques. Denote by H the height of the air bubble (see Fig.II.2), $H = V \cdot t$ (for cold water $H = V \cdot (t - \tau)$), by Z_d , Z_{up} - the heights of the lower and upper bases of the layer, respectively; $h = H - Z_d$. Denote by C_o non-interpolated constants, C_i - interpolated according to law (1). In all of the three cases:

If $H > Z_{up}$, $Const = C_i$,
 If $H \leq Z_{up}$, $Const = C_o$.
 For $Z_d < H \leq Z_{up}$ in the case of

a) 'Variation by jump'

If $\bar{I} < (Z_d + Z_{up})/2$ then $Const = C_i$
 otherwise $Const = C_o$.

b) 'Smooth variation'

$$Const = (C_i \cdot h + C_o \cdot (\Delta Z - h)) / \Delta Z$$

c) 'Smooth variation with account of neutron flux'

Fig II.2.

$$Const = (C_i \cdot h \cdot f_1 + C_o \cdot (\Delta Z - h) \cdot f_2) / (h \cdot f_1 + (\Delta Z - h) \cdot f_2),$$

where f_1, f_2 - mean values of neutron numbers on the lower and upper layer bases, respectively.

$$\frac{1}{v_i} \frac{\partial \Phi_i}{\partial t} - \nabla(\kappa_i \nabla \Phi_i) + \alpha_i \Phi_i = \sum_{m=1}^{N_i} \beta_{im}^s \Phi_m + (1 - \beta) \sum_{m=1}^{N_i} \beta_{im}^f \Phi_m + Q_i \quad (3)$$

where $N_i=2$ - the number of groups ;

Q_i - the delayed neutron source ;

$\kappa_i = 1 / 3 \Sigma_i^r$; $\alpha_i = \Sigma_i^{abs} + \Sigma_{mi}^s, i \neq m$;

$\beta_{11}^f = v \beta_1^{fs}$; $\beta_{12}^f = v \beta_2^{fs}$; $\beta_{21}^f = 0$; $\beta_{22}^f = 0$;

$\beta_{im}^s = \Sigma_{im}^s, i \neq m$; $\beta_{11}^s = 0$; $\beta_{22}^s = 0$.

The values of medium constants (with $\rho_0=0.516$ (g/cc), $\Delta T_0=543$ °F of water) are given in Tables A.II.2-A.II.11 of Appendix II.1.

Equations for delayed neutron precursor kinetics are of the following form:

$$Q_1 = \sum_{k=1}^6 C_k \lambda_k \quad (4)$$

$$\frac{\partial C_k}{\partial t} = -C_k \lambda_k + \beta_k \sum_{i=1}^{N_i} v \Sigma_i^{fs} \Phi_i$$

k - the number of delayed neutron precursor group;

$C_k(t)$ - concentration of group -//-;

λ_k - time constant for group -//- [1/sec];

β_k - the share of precursors of the k-th group .

The values λ_k , β_k are given in Table A.II.12 of Appendix II.1.

II.4.3. Problems.

The problems given below differ from one another in time τ when the core begins to receive cold water, i.e. in "gas bubble" length.

Problem 1. $\tau = 1.75$

a) Computations on the grid ($x:12/z:14$) was made for three types of neutron constant interpolation through height within the computational cell (see 4.6.):

- for variation by jump, i.e. the constants are not interpolated but are taken one or another depending on position of the media interface (curve # 1 in the figure);
- for the case of linear interpolation through height depending on position of the media interface (curve # 2 in the figure);
- for the case of interpolation with account of the neutron function (curve # 2 in the figure).

The results are presented in Fig. II.3 in the form of time dependence of power released in the system for three performed computations. Considerable differences in the computed results are seen. Of course, all these differences will abruptly smooth with the number of points through height. Further computations were made using linear interpolation of neutron constants within the cell through height and interpolation with account of the neutron function and on a finer computational grid in Z.

b) The computation on the grid ($x:12/z:28$) was made both with linear interpolation and interpolation with account of the neutron function. The time dependence of power found in the computations is given in Fig.II.4, the entire earlier difference due to interpolation being annihilated. Function values at the maxima somewhat changed as compared to the computations with less number of computational points through height. As for the issue of the "two - humpness" of the time dependencies of power, we will return to it below.

Problem # 2 $\tau = 2.25$ sec.

In this computation the time when the core began to receive "cold water" was increased, i.e. the length of the gas bubble was increased by 1 meter. The computation was made on the grid ($x:12/z:28$) with interpolation using the neutron function.

The time dependence of power obtained in the computation is also given in Fig. II.4.

Problem # 3 $\tau = 3.5$ sec.

In this computation the time when the core began to receive "cold water" was more increased so that the length of the gas bubble equal the whole core height. The computation was made on the grid ($x:12/z:28$) with interpolation using the neutron function.

The time dependence of power obtained in the computation is also given in Fig. II.5. Note that the character of time dependence of power changed, namely, the curve ceased to be "two - humped".

Now a few words about the "two - humpness" of the curves in Figs. II.4 and II.5. In Fig. II.6 high dependencies of the neutron function (neutron flux) are given for different times. At $t = 0$ this is the initial time - independent distribution through height. The "two - humpness" of the curve in Fig. II.6a depends on the neutron constants of the initial state. In the central part (material # 3) the neutron constants correspond to larger fuel burnup depth. When introducing the "gas bubble" to the core we introduce positive reactivity to the system, and this is precisely the region (the region of traveling "gas bubble") where the neutron flux rapidly increases. When the "gas bubble" consists with the central (through height) region the rate of energy release growth decreases (see. fig. II.6a), and owing to the fact that "cold water" which comes in right after it and introduces negative reactivity has already filled one of the most energy releasing region on the bottom of the region the system power even drops. Then, as the "gas bubble" rises, the system power begins to grow again (this is due to higher positive reactivity of the bubble than in the center) and, as the bubble escapes from the core and the core is filled with water, the system power begins to drop since in the final state the system filled with "cold water" is subcritical.

Appendix II.1 gives the tables of time dependence of system power for the three computations with $\tau = 1.75, 2.25$ and 3.5 sec.

Setting up and results of comparative computations with the NESTLE and KORAT-3D codes are given. Neutron spatial (3D) time-independent diffusion in a core fragment close to that of the RBMK reactor was computed. Agreement between the results of the technique is good, though the KORAT-3D code requires a finer spatial grid since it does not currently use any nodal methods.

A dynamic test setting-up is suggested, in so doing the same geometry and neutron constants are used as in the static problem. The dynamic test imitates getting of a vapor (gas) bubble into the RBMK core with subsequent filling of the core with cold water. For the dynamic test results of KORAT-3D code computation series are given.

ENERGY RELEASE (grid 12 : 14)
at cold water introduction file $\tau=1.75$ (s)

Fig. II.3

ENERGY RELEASE (ghd 12.28)
at cold water introduction file τ (s)

Fig. II.4

Fig. II.5

Neutron flux in core vs height at various times T

a) T= 0 sec

b) T= 1.75 sec

c) T= 2. sec

d) T= 2.25 sec

e) T= 3. sec

f) T= 3.75 sec

Fig. II.6.

Appendix II.1.

Table A.II.1.

ω	4200					
number of precursor group	1	2	3	4	5	6
λ_k	1.772	0.5774	0.06743	0.006214	0.0004739	10^{-7}
ξ_k	0.00406	0.0112	0.02014	0.02626	0.01581	0.01663

 Σ_1^{tr}

Table A.II.2.

material	1	2	3	5
Σ_0	0.295	0.295	0.295	0.2659
a_1	0.009306	0.009264	0.009254	
a_2	0.002333	0.002334	0.002312	
a_3	$0.6494 \cdot 10^{-7}$	$0.6494 \cdot 10^{-7}$	$0.6494 \cdot 10^{-7}$	

 Σ_2^{tr}

Table A.II.3.

material	1	2	3	5
Σ_0	0.3983	0.3983	0.3984	0.4109
a_1	0.04407	0.04326	0.04368	
a_2	0.001578	0.002395	0.002474	
a_3	$-0.1991 \cdot 10^{-5}$	$-0.2121 \cdot 10^{-5}$	$-0.2316 \cdot 10^{-5}$	

 Σ_1^{abs}

Table A.II.4.

material	1	2	3	5
Σ_0	0.001132	0.001178	0.001221	0.002179
a_1	$0.1591 \cdot 10^{-3}$	$0.1708 \cdot 10^{-3}$	$0.1945 \cdot 10^{-3}$	
a_2	$-0.1525 \cdot 10^{-3}$	$-0.1654 \cdot 10^{-3}$	$-0.1842 \cdot 10^{-3}$	
a_3	$0.1169 \cdot 10^{-8}$	$0.2164 \cdot 10^{-8}$	$0.303 \cdot 10^{-8}$	

 $\Sigma_{2+1}^{\text{abs}}$

Table A.II.5.

material	1	2	3	5
Σ_0	0.004166	0.004279	0.004177	0.006797
a_1	0.001127	$0.9679 \cdot 10^{-3}$	$0.8688 \cdot 10^{-3}$	
a_2	$-0.5033 \cdot 10^{-3}$	$-0.3589 \cdot 10^{-3}$	$-0.294 \cdot 10^{-3}$	
a_3	$-0.7024 \cdot 10^{-6}$	$-0.5662 \cdot 10^{-6}$	$-0.5045 \cdot 10^{-6}$	
a_3^*	$-0.1171 \cdot 10^{-5}$	$-0.8631 \cdot 10^{-6}$	$-0.6677 \cdot 10^{-6}$	

$v\Sigma_1^{\text{fis}}$

Table A.II.6.

material	1	2	3	5
Σ_0	$0.6783 \cdot 10^{-3}$	$0.5947 \cdot 10^{-3}$	$0.5197 \cdot 10^{-3}$	0.
a_1	$0.5564 \cdot 10^{-4}$	$0.5798 \cdot 10^{-4}$	$0.5924 \cdot 10^{-4}$	
a_2	$-0.3338 \cdot 10^{-4}$	$-0.3301 \cdot 10^{-4}$	$-0.294 \cdot 10^{-4}$	
a_3	$0.2422 \cdot 10^{-8}$	$0.1602 \cdot 10^{-8}$	$0.974 \cdot 10^{-9}$	

 $v\Sigma_2^{\text{fis}}$

Table A.II.7.

material	1	2	3	5
Σ_0	0.00633	0.006143	0.005634	0.
a_1	0.001346	$0.988 \cdot 10^{-3}$	$0.7399 \cdot 10^{-3}$	
a_2	$-0.9178 \cdot 10^{-3}$	$-0.6163 \cdot 10^{-3}$	$-0.4559 \cdot 10^{-3}$	
a_3	$-0.1171 \cdot 10^{-5}$	$-0.8631 \cdot 10^{-6}$	$-0.6677 \cdot 10^{-6}$	

 v_1

Table A.II.8.

material	1	2	3	5
Σ_0	2.533	2.599	2.64	
a_1	0.0241	0.02294	0.02159	
a_2	-0.00454	-0.003869	-0.004062	
a_3	$-0.8658 \cdot 10^{-6}$	$-0.8658 \cdot 10^{-6}$	$-0.8658 \cdot 10^{-6}$	

 v_2

Table A.II.9.

material	1	2	3	5
Σ_0	2.431	2.528	2.593	
a_1	$-0.2048 \cdot 10^{-3}$	-0.02423	-0.02936	
a_2	$0.3616 \cdot 10^{-5}$	0.02276	0.02697	
a_3	$0.4329 \cdot 10^{-6}$	$0.2338 \cdot 10^{-4}$	$0.3247 \cdot 10^{-4}$	

 $\Sigma_{1 \leftarrow 2}^s$

Table A.II.10.

material	1	2	3	5
Σ_0	0.001145	0.001166	0.00115	$0.1961 \cdot 10^{-3}$
a_1	$-0.2241 \cdot 10^{-3}$	$-0.259 \cdot 10^{-3}$	$-0.2655 \cdot 10^{-3}$	
a_2	$0.9218 \cdot 10^{-4}$	$0.126 \cdot 10^{-3}$	$0.1337 \cdot 10^{-3}$	
a_3	$-0.5714 \cdot 10^{-7}$	$-0.3485 \cdot 10^{-7}$	$-0.2489 \cdot 10^{-7}$	

$\Sigma_{2 \leftarrow 1}^s$

Table A.II.11.

material	1	2	3	5
Σ_0	0.004971	0.0049	0.004853	0.003603
a_1	$2.178 \cdot 10^{-3}$	$2.188 \cdot 10^{-3}$	$2.177 \cdot 10^{-3}$	
a_1^*	$7.26 \cdot 10^{-4}$	$7.293 \cdot 10^{-4}$	$7.257 \cdot 10^{-4}$	
a_2	$0.2619 \cdot 10^{-4}$	$0.13 \cdot 10^{-4}$	$0.2839 \cdot 10^{-4}$	
a_3	$0.1089 \cdot 10^{-6}$	$0.9177 \cdot 10^{-7}$	$0.8788 \cdot 10^{-7}$	

Table A.II.12.

delayed neutrons precursors	1	2	3	4	5	6
λ_k	0.0127	0.0317	0.115	0.311	1.40	3.87
β_k	0.000246	0.001459	0.001334	0.002646	0.001055	0.000251

Group velocity $v_1 = 0.125 + 8$, $v_2 = 0.25 + 6$.

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RMBK TEST CASE -

((CONTROL OPTION EDIT))

INPUT FILES READ :

GEOMETRICAL PARAMETERS : NESTLE.GEOM
PHYSICAL PARAMETERS : NESTLE.XSECT
TRANSIENT PARAMETERS : NESTLE.KINET
SOLUTION METHOD CONTROL : NESTLE.PERFM

OUTPUT FILES WRITTEN :

HARDCOPY : NESTLE.OUTPUT

ADJOINT FLUX SOLUTION : OFF

NO DEPLETION CALCULATIONS

SEARCH OPTION : OFF

RESTART OPTION : OFF

T-H FEEDBACK OPTION : OFF

XENON - SAMARIUM FEEDBACK OPTIONS

CLEAN CORE AT STARTUP - NO XE OR SM

PROBLEM TYPE IS : EIGENVALUE PROBLEM

METHOD OF SOLUTION IS : NONLINEAR NODAL EXPANSION METHOD [NEM]

NUMBER OF NEM UPDATES PER THERMAL-HYDRAULIC UPDATE: 5

CHEBYSHEV ACCELERATION: ON

UPPER LIMIT ON CHEBYSHEV POLYNOMIAL ORDER: 5

STEADY-STATE SCALING FACTOR ACCELERATION: OFF
STEADY-STATE SPECTRAL SHIFT CORRECTION: OFF

ITERATION LIMIT AND CONVERGENCE CRITERIA

MAXIMUM NO. OF OUTER ITERATIONS : 500

MAXIMUM NO. OF THERMAL SCAT. ITERATIONS: 5
EIGENVALUE (K) CONVERGENCE CRITERIA : 0.10000E-04
OUTER L_2 CONVERGENCE CRITERIA : 0.10000E-03
OUTER L_INF CONVERGENCE CRITERIA : 0.10000E+00
INNER L_2 REL. CONVERGENCE CRITERIA : 0.50000E-02

((GEOMETRY AND COMPOSTION EDIT))

X DIRECTION FUEL BUNDLE PITCH: 9.8400(INCHES)
Y DIRECTION FUEL BUNDLE PITCH: 9.8400(INCHES)

CORE GEOMETRY AND COMPOSITION

CARTESIAN GEOMETRY

QUARTER CORE SYMMETRY

BOUNDARY CONDITIONS

INTERIOR BOUNDARIES : REFLECTIVE
TOP BOUNDARY (Z-TOP) : NON-REENTRANT
BOTTOM BOUNDARY (Z-BOTTOM) : REFLECTIVE

X-DIRECTION MESH SPACING (INCHES)

0.000 4.920 9.840 14.760 19.680 24.600 29.520 34.440 39.360 44.280
49.200 54.120 59.040

Y-DIRECTION MESH SPACING (INCHES)

0.000 4.920 9.840 14.760 19.680 24.600 29.520 34.440 39.360 44.280
49.200 54.120 59.040

Z-DIRECTION MESH SPACING (INCHES)

0.000 19.680 39.360 59.040 78.720 98.400 118.080 137.760 157.440 177.120
196.800 216.480 236.160 255.840 275.520

((BASIC FIGURE - COMPOSITION OVERLAY))

< BASIC FIGURE NUMBER = 1 >

Y\X	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	5	5	1	1	1	1	5	5	1	1
4	1	1	5	5	1	1	1	1	5	5	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	5	5	1	1	1	1	5	5	1	1
10	1	1	5	5	1	1	1	1	5	5	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1

((BASIC FIGURE - COMPOSITION OVERLAY))

< BASIC FIGURE NUMBER = 2 >

Y\X	1	2	3	4	5	6	7	8	9	10	11	12
1	2	2	2	2	2	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2	2	2	2	2	2
3	2	2	5	5	2	2	2	2	5	5	2	2
4	2	2	5	5	2	2	2	2	5	5	2	2
5	2	2	2	2	2	2	2	2	2	2	2	2
6	2	2	2	2	2	2	2	2	2	2	2	2
7	2	2	2	2	2	2	2	2	2	2	2	2
8	2	2	2	2	2	2	2	2	2	2	2	2
9	2	2	5	5	2	2	2	2	5	5	2	2
10	2	2	5	5	2	2	2	2	5	5	2	2
11	2	2	2	2	2	2	2	2	2	2	2	2
12	2	2	2	2	2	2	2	2	2	2	2	2

((BASIC FIGURE - COMPOSITION OVERLAY))

< BASIC FIGURE NUMBER = 3 >

Y\X	1	2	3	4	5	6	7	8	9	10	11	12
1	3	3	3	3	3	3	3	3	3	3	3	3
2	3	3	3	3	3	3	3	3	3	3	3	3
3	3	3	5	5	3	3	3	3	5	5	3	3
4	3	3	5	5	3	3	3	3	5	5	3	3
5	3	3	3	3	3	3	3	3	3	3	3	3
6	3	3	3	3	3	3	3	3	3	3	3	3
7	3	3	3	3	3	3	3	3	3	3	3	3
8	3	3	3	3	3	3	3	3	3	3	3	3
9	3	3	5	5	3	3	3	3	5	5	3	3
10	3	3	5	5	3	3	3	3	5	5	3	3
11	3	3	3	3	3	3	3	3	3	3	3	3
12	3	3	3	3	3	3	3	3	3	3	3	3

((BASIC FIGURE - COMPOSITION OVERLAY))

< BASIC FIGURE NUMBER = 4 >

Y\X	1	2	3	4	5	6	7	8	9	10	11	12
-----	---	---	---	---	---	---	---	---	---	----	----	----

[illegible]

((BASIC FIGURE - COMPOSITION OVERLAY))

< BASIC FIGURE NUMBER = 5 >

[illegible]

((BASIC FIGURE - COMPOSITION OVERLAY))

< BASIC FIGURE NUMBER = 6 >

[illegible]

((BASIC FIGURE - COMPOSITION OVERLAY))

< BASIC FIGURE NUMBER = 7 >

[illegible]

((BASIC FIGURE - COMPOSITION OVERLAY))

< BASIC FIGURE NUMBER = 8 >

[illegible]

((Z-DIRECTION BASIC FIGURE OVERLAY))

Z 1 2 3 4 5 6 7 8 9 10 11 12 13 14

1 2 2 2 3 3 3 3 3 3 2 2 2 1

FUEL AXIAL SUBREGIONS START AT: 1 END WITH: 14

((ROTATION ORIENTATION OF NODES FOR ADF APPLICATION))

[illegible]

((REFLECTION ORIENTATION OF NODES FOR ADF APPLICATION))

[illegible]

3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0

TOP-BOTTOM ORIENTATION OF NODES FOR ADF APPLICATION

Z 1 2 3 4 5 6 7 8 9 10 11 12 13 14

0 0 0 0 0 0 0 0 0 0 0 0 0 0

((LOCATIONS OF THE CONTROL BANKS))

Y\X	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

CONTROL BANKS OFFSET FROM BOTTOM OF FUEL WHEN FULLY INSERTED =
0.0000 [INCHES]

((RADIAL LOCATIONS OF THE EXTERNAL SOURCE))

Y\X	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0

((AXIAL LOCATIONS OF THE EXTERNAL SOURCE))

Z 1 2 3 4 5 6 7 8 9 10 11 12 13 14

0 0 0 0 0 0 0 0 0 0 0 0 0 0

((CROSS SECTION EDIT))

CORE SOLUBLE POISON CONCENTRATION VS. BURNUP

BURNUP SOLUBLE POISON (PPM)

TRANSIENT FISSION PRODUCTS DECAY CONSTANTS [1/SEC]:

IODINE	XENON	PROMETHIUM
.2875E-04	0.2092E-04	0.3556E-05

DELAYED NEUTRONS PRECURSORS DECAY CONSTANTS [1/SEC]:

PRECURSOR GROUP #	1	2	3	4	5	6
	0.1270E-01	0.3170E-01	0.1150E+00	0.3110E+00	0.1400E+01	0.3870E+01

DELAYED HEAT PRECURSORS DECAY CONSTANTS [1/SEC]:

PRECURSOR GROUP #	1	2	3	4	5	6
	0.1772E+01	0.5774E+00	0.6743E-01	0.6214E-02	0.4739E-03	0.1000E-06

DELAYED NEUTRONS FISSION SPECTRUMS

PRECURSOR GROUP #	GROUP	1	2	3	4	5	6
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

NUMBER OF COLORS: 6

MACRO CROSS-SECTION FOR COLOR 5

FUEL TYPE: NO

ROD OUT COOLANT VOLUME FRACTION : 0.05300

ROD IN COOLANT VOLUME FRACTION : 0.05300

FUEL VOLUME FRACTION : 0.00000

REF. COOLANT TEMPERATURE : 543.00 DEGREE-F

REF. EFFECTIVE FUEL TEMP. : 0.00 DEGREE-F

REF. COOLANT DENSITY : 32.184 LB/FT**3

MACRO X-SECTION ROD-OUT BASE CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	NU FISSIION	KAPPA FISSIION	NU
1	0.0	0.2659E+00	0.2179E-02	0.0000E+00	0.0000E+00	0.0000E+00
2	0.0	0.4109E+00	0.6797E-02	0.0000E+00	0.0000E+00	0.0000E+00

MACRO X-SECTION ROD-OUT LINEAR COOLANT DENSITY CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	NU FISSIION	KAPPA FISSIION	NU
1	0.0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

MACRO X-SECTION ROD-OUT QUADRATIC COOLANT DENSITY CORRECTION

ENERGY BURNUP NU KAPPA
GROUP TRANS. ABSORP. FISSION FISSION NU

1 0.0 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
2 0.0 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

MACRO X-SECTION ROD-OUT LINEAR COOLANT TEMPERATURE CORRECTION

ENERGY BURNUP NU KAPPA
GROUP TRANS. ABSORP. FISSION FISSION NU

1 0.0 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
2 0.0 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

MACRO X-SECTION ROD-OUT LINEAR SQRT(FUEL TEMPERATURE) CORRECTION

ENERGY BURNUP NU KAPPA
GROUP TRANS. ABSORP. FISSION FISSION NU

1 0.0 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00
2 0.0 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00

BUCKLING**2 VALUES

GROUP #
BURNUP 1 2
0.0 0.0000E+00 0.0000E+00

MACRO ROD-OUT SCATTER BASE CORRECTION

SCATTERING KERNEL FOR SCATTERING

FROM GROUP TO GROUP
BURNUP 1 2
0.0 1 0.3603E-02
0.0 2 0.1961E-03

MACRO ROD-OUT SCATTER LINEAR COOLANT DENSITY CORRECTION

SCATTERING KERNEL FOR SCATTERING

FROM GROUP TO GROUP
BURNUP 1 2
0.0 1 0.0000E+00
0.0 2 0.0000E+00

MACRO ROD-OUT SCATTER QUADRATIC COOLANT DENSITY CORRECTION

SCATTERING KERNEL FOR SCATTERING

FROM GROUP TO GROUP
BURNUP 1 2
0.0 1 0.0000E+00
0.0 2 0.0000E+00

MACRO ROD-OUT SCATTER LINEAR COOLANT TEMPERATURE CORRECTION

SCATTERING KERNEL FOR SCATTERING

FROM GROUP TO GROUP
BURNUP 1 2
0.0 1 0.0000E+00
0.0 2 0.0000E+00

MACRO ROD-OUT SCATTER LINEAR SQRT(FUEL TEMPERATURE) CORRECTION

SCATTERING KERNEL FOR SCATTERING
FROM GROUP TO GROUP

BURNUP	1	2
0.0 1	0.0000E+00	
0.0 2	0.0000E+00	

ADF - UNRODDED

BURNUP	GROUP	N	E	S	W	UP	DOWN
0.0 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0 2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

ADF - RODDED

BURNUP	GROUP	N	E	S	W	UP	DOWN
0.0 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0 2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

NEUTRON VELOCITY [CM/SEC]

BURNUP	GROUP #	1	2
0.0	0.1250E+08	0.2500E+06	

MACRO CROSS-SECTION FOR COLOR 6

FUEL TYPE: NO

ROD OUT COOLANT VOLUME FRACTION : 0.01567

ROD IN COOLANT VOLUME FRACTION : 0.01567

FUEL VOLUME FRACTION : 0.00000

REF. COOLANT TEMPERATURE : 543.00 DEGREE-F

REF. EFFECTIVE FUEL TEMP. : 0.00 DEGREE-F

REF. COOLANT DENSITY : 32.184 LB/FT**3

MACRO X-SECTION ROD-OUT BASE CORRECTION

ENERGY	BURNUP	NU	KAPPA	NU
GROUP	TRANS.	ABSORP.	FISSION	FISSION
1	0.0 0.2769E+00	0.5265E-04	0.0000E+00	0.0000E+00
2	0.0 0.3941E+00	0.6560E-03	0.0000E+00	0.0000E+00

MACRO X-SECTION ROD-OUT LINEAR COOLANT DENSITY CORRECTION

ENERGY	BURNUP	NU	KAPPA	NU
GROUP	TRANS.	ABSORP.	FISSION	FISSION
1	0.0 0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.0 0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

MACRO X-SECTION ROD-OUT QUADRATIC COOLANT DENSITY CORRECTION

ENERGY	BURNUP	NU	KAPPA	NU
GROUP	TRANS.	ABSORP.	FISSION	FISSION
1	0.0 0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.0 0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

MACRO X-SECTION ROD-OUT LINEAR COOLANT TEMPERATURE CORRECTION

ENERGY GROUP	BURNUP TRANS.	NU ABSORP.	KAPPA FISSION	FISSION	NU
1	0.0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

MACRO X-SECTION ROD-OUT LINEAR SQRT(FUEL TEMPERATURE) CORRECTION

ENERGY GROUP	BURNUP TRANS.	NU ABSORP.	KAPPA FISSION	FISSION	NU
1	0.0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.0	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

BUCKLING**2 VALUES

GROUP #	BURNUP	1	2
	0.0	0.0000E+00	0.0000E+00

MACRO ROD-OUT SCATTER BASE CORRECTION

SCATTERING KERNEL FOR SCATTERING			
FROM GROUP		TO GROUP	
BURNUP	1	2	
0.0	1	0.4345E-02	
0.0	2	0.2524E-04	

MACRO ROD-OUT SCATTER LINEAR COOLANT DENSITY CORRECTION

SCATTERING KERNEL FOR SCATTERING			
FROM GROUP		TO GROUP	
BURNUP	1	2	
0.0	1	0.0000E+00	
0.0	2	0.0000E+00	

MACRO ROD-OUT SCATTER QUADRATIC COOLANT DENSITY CORRECTION

SCATTERING KERNEL FOR SCATTERING			
FROM GROUP		TO GROUP	
BURNUP	1	2	
0.0	1	0.0000E+00	
0.0	2	0.0000E+00	

MACRO ROD-OUT SCATTER LINEAR COOLANT TEMPERATURE CORRECTION

SCATTERING KERNEL FOR SCATTERING			
FROM GROUP		TO GROUP	
BURNUP	1	2	
0.0	1	0.0000E+00	
0.0	2	0.0000E+00	

MACRO ROD-OUT SCATTER LINEAR SQRT(FUEL TEMPERATURE) CORRECTION

SCATTERING KERNEL FOR SCATTERING			
FROM GROUP		TO GROUP	
BURNUP	1	2	
0.0	1	0.0000E+00	
0.0	2	0.0000E+00	

ADF - UNRODDED

BURNUP GROUP		N	E	S	W	UP	DOWN
0.0	1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0	2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

ADF - RODDED

BURNUP GROUP		N	E	S	W	UP	DOWN
0.0	1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0	2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

NEUTRON VELOCITY [CM/SEC]

GROUP #		
BURNUP	1	2
0.0	0.1250E+08	0.2500E+06

MACRO CROSS-SECTION FOR COLOR 1

FUEL TYPE: YES

ROD OUT COOLANT VOLUME FRACTION : 0.03600

ROD IN COOLANT VOLUME FRACTION : 0.03600

FUEL VOLUME FRACTION : 0.03000

REF. COOLANT TEMPERATURE : 543.00 DEGREE-F

REF. EFFECTIVE FUEL TEMP. : 1112.00 DEGREE-F

REF. COOLANT DENSITY : 32.184 LB/FT**3

MACRO X-SECTION ROD-OUT BASE CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	NU	KAPPA	FISSION	FISSION	NU
1	0.0	0.2950E+00	0.1132E-02	0.6783E-03	0.5314E-01	0.2553E+01		
2	0.0	0.3983E+00	0.4166E-02	0.6330E-02	0.5208E+00	0.2431E+01		

MACRO X-SECTION ROD-OUT LINEAR COOLANT DENSITY CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	NU	KAPPA	FISSION	FISSION	NU
1	0.0	0.9306E-02	0.1591E-03	0.5564E-04	0.3864E-02	0.2410E-01		
2	0.0	0.4407E-01	0.1127E-02	0.1346E-02	0.1108E+00	-.2084E-03		

MACRO X-SECTION ROD-OUT QUADRATIC COOLANT DENSITY CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	NU	KAPPA	FISSION	FISSION	NU
1	0.0	0.2333E-02	-.1525E-03	-.3338E-04	-.2557E-02	-.4540E-02		
2	0.0	0.1578E-02	-.5033E-03	-.9178E-03	-.7550E-01	0.3616E-05		

MACRO X-SECTION ROD-OUT LINEAR COOLANT TEMPERATURE CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	NU	KAPPA	FISSION	FISSION	NU
1	0.0	0.2333E-02	-.1525E-03	-.3338E-04	-.2557E-02	-.4540E-02		
2	0.0	0.1578E-02	-.5033E-03	-.9178E-03	-.7550E-01	0.3616E-05		

1	0.0	0.6494E-07	0.1169E-08	0.2422E-08	0.2078E-06	-.8658E-06
2	0.0	-.1991E-05	-.7024E-06	-.1171E-05	-.9645E-04	0.4329E-06

MACRO X-SECTION ROD-OUT LINEAR SQRT(FUEL TEMPERATURE) CORRECTION

ENERGY	BURNUP		NU	KAPPA	
GROUP	TRANS.	ABSORP.	FISSION	FISSION	NU

1	0.0	-.6593E-05	0.2460E-05	-.1791E-06	-.1509E-04	0.5128E-04
2	0.0	-.3663E-05	-.2095E-05	-.3464E-05	-.2850E-03	0.0000E+00

BUCKLING**2 VALUES

	GROUP #	
BURNUP	1	2
0.0	0.0000E+00	0.0000E+00

MACRO ROD-OUT SCATTER BASE CORRECTION

SCATTERING KERNEL FOR SCATTERING		
	FROM GROUP	TO GROUP
BURNUP	1	2
0.0	1	0.4971E-02
0.0	2	0.1145E-02

MACRO ROD-OUT SCATTER LINEAR COOLANT DENSITY CORRECTION

SCATTERING KERNEL FOR SCATTERING		
	FROM GROUP	TO GROUP
BURNUP	1	2
0.0	1	0.2178E-02
0.0	2	-.2241E-03

MACRO ROD-OUT SCATTER QUADRATIC COOLANT DENSITY CORRECTION

SCATTERING KERNEL FOR SCATTERING		
	FROM GROUP	TO GROUP
BURNUP	1	2
0.0	1	0.2619E-04
0.0	2	0.9218E-04

MACRO ROD-OUT SCATTER LINEAR COOLANT TEMPERATURE CORRECTION

SCATTERING KERNEL FOR SCATTERING		
	FROM GROUP	TO GROUP
BURNUP	1	2
0.0	1	0.1089E-06
0.0	2	-.5714E-07

MACRO ROD-OUT SCATTER LINEAR SQRT(FUEL TEMPERATURE) CORRECTION

SCATTERING KERNEL FOR SCATTERING		
	FROM GROUP	TO GROUP
BURNUP	1	2
0.0	1	-.7070E-06
0.0	2	0.1073E-05

ADF - UNRODDED

BURNUP	GROUP	N	E	S	W	UP	DOWN
0.0	1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0	2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

ADF - RODDED

BURNUP GROUP		N	E	S	W	UP	DOWN
0.0	1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0	2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

PROMPT NEUTRON FISSION SPECTRUM

GROUP #		
BURNUP	1	2
0.0	1.0000	0.0000

NEUTRON VELOCITY [CM/SEC]

GROUP #		
BURNUP	1	2
0.0	0.1250E+08	0.2500E+06

MICRO SAMARIUM AND XENON ABSORPTION CROSS-SECTIONS

TRANSIENT FISSION PRODUCTS FRACTIONAL YIELDS:

BURNUP	IODINE	XENON	PROMETHIUM
0.0	0.68600E-01	0.23000E-02	0.11300E-01

DELAYED NEUTRONS PRECURSORS FRACTION:

GROUP #							
BURNUP	1	2	3	4	5	6	
0.0	0.2460E-03	0.1459E-02	0.1334E-02	0.2646E-02	0.1055E-02	0.2510E-03	

DECAY HEAT PRECURSORS FRACTION:

GROUP #							
BURNUP	1	2	3	4	5	6	
0.0	0.4060E-02	0.1120E-01	0.2014E-01	0.2626E-01	0.1581E-01	0.1663E-01	

MACRO CROSS-SECTION FOR COLOR 2

FUEL TYPE: YES

ROD OUT COOLANT VOLUME FRACTION : 0.03600

ROD IN COOLANT VOLUME FRACTION : 0.03600

FUEL VOLUME FRACTION : 0.03000

REF. COOLANT TEMPERATURE : 543.00 DEGREE-F

REF. EFFECTIVE FUEL TEMP. : 1112.00 DEGREE-F

REF. COOLANT DENSITY : 32.184 LB/FT**3

MACRO X-SECTION ROD-OUT BASE CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	FISSION	KAPPA	FISSION	NU
1	0.0	0.2950E+00	0.1178E-02	0.5947E-03	0.4576E-01	0.2599E+01	
2	0.0	0.3983E+00	0.4279E-02	0.6143E-02	0.4859E+00	0.2528E+01	

MACRO X-SECTION ROD-OUT LINEAR COOLANT DENSITY CORRECTION

ENERGY BURNUP NU KAPPA
GROUP TRANS. ABSORP. FISSION FISSION NU

1	0.0	0.9264E-02	0.1708E-03	0.5798E-04	0.4064E-02	0.2294E-01
2	0.0	0.4326E-01	0.9679E-03	0.9880E-03	0.8253E-01	-.2423E-01

MACRO X-SECTION ROD-OUT QUADRATIC COOLANT DENSITY CORRECTION

ENERGY BURNUP NU KAPPA
GROUP TRANS. ABSORP. FISSION FISSION NU

1	0.0	0.2334E-02	-.1654E-03	-.3301E-04	-.2509E-02	-.3869E-02
2	0.0	0.2395E-02	-.3589E-03	-.6163E-03	-.5223E-01	0.2276E-01

MACRO X-SECTION ROD-OUT LINEAR COOLANT TEMPERATURE CORRECTION

ENERGY BURNUP NU KAPPA
GROUP TRANS. ABSORP. FISSION FISSION NU

1	0.0	0.6494E-07	0.2164E-08	0.1602E-08	0.1385E-06	-.8658E-06
2	0.0	-.2121E-05	-.5662E-06	-.8631E-06	-.7307E-04	0.2338E-04

MACRO X-SECTION ROD-OUT LINEAR SQRT(FUEL TEMPERATURE) CORRECTION

ENERGY BURNUP NU KAPPA
GROUP TRANS. ABSORP. FISSION FISSION NU

1	0.0	-.6593E-05	0.2566E-05	-.1589E-06	-.1319E-04	0.5495E-04
2	0.0	-.4029E-05	-.1447E-05	-.2059E-05	-.1824E-03	0.1026E-03

BUCKLING**2 VALUES

GROUP #		
BURNUP	1	2
0.0	0.0000E+00	0.0000E+00

MACRO ROD-OUT SCATTER BASE CORRECTION

SCATTERING KERNEL FOR SCATTERING

FROM GROUP TO GROUP

BURNUP	1	2
0.0	1	0.4900E-02
0.0	2	0.1166E-02

MACRO ROD-OUT SCATTER LINEAR COOLANT DENSITY CORRECTION

SCATTERING KERNEL FOR SCATTERING

FROM GROUP TO GROUP

BURNUP	1	2
0.0	1	0.2188E-02
0.0	2	-.2590E-03

MACRO ROD-OUT SCATTER QUADRATIC COOLANT DENSITY CORRECTION

SCATTERING KERNEL FOR SCATTERING

FROM GROUP TO GROUP

BURNUP	1	2
0.0	1	0.1300E-04
0.0	2	0.1260E-03

MACRO ROD-OUT SCATTER LINEAR COOLANT TEMPERATURE CORRECTION

SCATTERING KERNEL FOR SCATTERING

FROM GROUP TO GROUP

BURNUP		1	2
0.0	1		0.9177E-07
0.0	2		-.3485E-07

MACRO ROD-OUT SCATTER LINEAR SQRT(FUEL TEMPERATURE) CORRECTION

SCATTERING KERNEL FOR SCATTERING FROM GROUP TO GROUP

BURNUP		1	2
0.0	1		-.1000E-05
0.0	2		0.1136E-05

ADF - UNRODDED

BURNUP	GROUP	N	E	S	W	UP	DOWN
0.0	1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0	2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

ADF - RODDED

BURNUP	GROUP	N	E	S	W	UP	DOWN
0.0	1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0	2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

PROMPT NEUTRON FISSION SPECTRUM

	GROUP #
BURNUP	1 2
0.0	1.0000 0.0000

NEUTRON VELOCITY [CM/SEC]

	GROUP #
BURNUP	1 2
0.0	0.1250E+08 0.2500E+06

MICRO SAMARIUM AND XENON ABSORPTION CROSS-SECTIONS

TRANSIENT FISSION PRODUCTS FRACTIONAL YIELDS:

BURNUP	IODINE	XENON	PROMETHIUM
0.0	0.68600E-01	0.23000E-02	0.11300E-01

DELAYED NEUTRONS PRECURSORS FRACTION:

	GROUP #
BURNUP	1 2 3 4 5 6
0.0	0.2460E-03 0.1459E-02 0.1334E-02 0.2646E-02 0.1055E-02 0.2510E-03

DECAY HEAT PRECURSORS FRACTION:

	GROUP #
BURNUP	1 2 3 4 5 6
0.0	0.4060E-02 0.1120E-01 0.2014E-01 0.2626E-01 0.1581E-01 0.1663E-01

MACRO CROSS-SECTION FOR COLOR 3

FUEL TYPE: YES

ROD OUT COOLANT VOLUME FRACTION : 0.03600

ROD IN COOLANT VOLUME FRACTION : 0.03600

FUEL VOLUME FRACTION : 0.03000
REF. COOLANT TEMPERATURE : 543.00 DEGREE-F

REF. EFFECTIVE FUEL TEMP. : 1112.00 DEGREE-F

REF. COOLANT DENSITY : 32.184 LB/FT**3

MACRO X-SECTION ROD-OUT BASE CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	FISSION	KAPPA	FISSION	NU
1	0.0	0.2950E+00	0.1221E-02	0.5197E-03	0.3931E-01	0.2644E+01	
2	0.0	0.3984E+00	0.4177E-02	0.5634E-02	0.4346E+00	0.2593E+01	

1	0.0	0.2950E+00	0.1221E-02	0.5197E-03	0.3931E-01	0.2644E+01	
2	0.0	0.3984E+00	0.4177E-02	0.5634E-02	0.4346E+00	0.2593E+01	

MACRO X-SECTION ROD-OUT LINEAR COOLANT DENSITY CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	FISSION	KAPPA	FISSION	NU
1	0.0	0.9254E-02	0.1945E-03	0.5924E-04	0.4166E-02	0.2159E-01	
2	0.0	0.4368E-01	0.8688E-03	0.7399E-03	0.6174E-01	-.2936E-01	

1	0.0	0.9254E-02	0.1945E-03	0.5924E-04	0.4166E-02	0.2159E-01	
2	0.0	0.4368E-01	0.8688E-03	0.7399E-03	0.6174E-01	-.2936E-01	

MACRO X-SECTION ROD-OUT QUADRATIC COOLANT DENSITY CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	FISSION	KAPPA	FISSION	NU
1	0.0	0.2312E-02	-.1842E-03	-.2940E-04	-.2198E-02	-.4062E-02	
2	0.0	0.2474E-02	-.2940E-03	-.4559E-03	-.3890E-01	0.2697E-01	

1	0.0	0.2312E-02	-.1842E-03	-.2940E-04	-.2198E-02	-.4062E-02	
2	0.0	0.2474E-02	-.2940E-03	-.4559E-03	-.3890E-01	0.2697E-01	

MACRO X-SECTION ROD-OUT LINEAR COOLANT TEMPERATURE CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	FISSION	KAPPA	FISSION	NU
1	0.0	0.6494E-07	0.3030E-08	0.9740E-09	0.8658E-07	-.8658E-06	
2	0.0	-.2316E-05	-.5045E-06	-.6677E-06	-.5727E-04	0.3247E-04	

1	0.0	0.6494E-07	0.3030E-08	0.9740E-09	0.8658E-07	-.8658E-06	
2	0.0	-.2316E-05	-.5045E-06	-.6677E-06	-.5727E-04	0.3247E-04	

MACRO X-SECTION ROD-OUT LINEAR SQRT(FUEL TEMPERATURE) CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	FISSION	KAPPA	FISSION	NU
1	0.0	-.6593E-05	0.2804E-05	-.1389E-06	-.1143E-04	0.6227E-04	
2	0.0	-.4762E-05	-.1169E-05	-.1295E-05	-.1231E-03	0.1392E-03	

1	0.0	-.6593E-05	0.2804E-05	-.1389E-06	-.1143E-04	0.6227E-04	
2	0.0	-.4762E-05	-.1169E-05	-.1295E-05	-.1231E-03	0.1392E-03	

BUCKLING**2 VALUES

GROUP #	BURNUP	1	2
0.0	0.0000E+00	0.0000E+00	

MACRO ROD-OUT SCATTER BASE CORRECTION

SCATTERING KERNEL FOR SCATTERING
FROM GROUP TO GROUP

BURNUP	1	2
0.0	1	0.4853E-02
0.0	2	0.1150E-02

MACRO ROD-OUT SCATTER LINEAR COOLANT DENSITY CORRECTION

SCATTERING KERNEL FOR SCATTERING

FROM GROUP TO GROUP

BURNUP	1	2
0.0 1	0.2177E-02	
0.0 2	-0.2655E-03	

MACRO ROD-OUT SCATTER QUADRATIC COOLANT DENSITY CORRECTION

SCATTERING KERNEL FOR SCATTERING

FROM GROUP TO GROUP

BURNUP	1	2
0.0 1	0.2839E-04	
0.0 2	0.1337E-03	

MACRO ROD-OUT SCATTER LINEAR COOLANT TEMPERATURE CORRECTION

SCATTERING KERNEL FOR SCATTERING

FROM GROUP TO GROUP

BURNUP	1	2
0.0 1	0.8788E-07	
0.0 2	-0.2489E-07	

MACRO ROD-OUT SCATTER LINEAR SQRT(FUEL TEMPERATURE) CORRECTION

SCATTERING KERNEL FOR SCATTERING

FROM GROUP TO GROUP

BURNUP	1	2
0.0 1	-0.1315E-05	
0.0 2	0.1169E-05	

ADF - UNRODDED

BURNUP GROUP N E S W UP DOWN

0.0 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0 2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

ADF - RODDED

BURNUP GROUP N E S W UP DOWN

0.0 1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0 2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

PROMPT NEUTRON FISSION SPECTRUM

GROUP

BURNUP	1	2
0.0	1.0000	0.0000

NEUTRON VELOCITY [CM/SEC]

GROUP

BURNUP	1	2
0.0	0.1250E+08	0.2500E+06

MICRO SAMARIUM AND XENON ABSORPTION CROSS-SECTIONS

TRANSIENT FISSION PRODUCTS FRACTIONAL YIELDS:

BURNUP IODINE XENON PROMETHIUM

0.0	0.68600E-01	0.23000E-02	0.11300E-01
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DELAYED NEUTRONS PRECURSORS FRACTION:

	GROUP #					
BURNUP	1	2	3	4	5	6
0.0	0.2460E-03	0.1459E-02	0.1334E-02	0.2646E-02	0.1055E-02	0.2510E-03

DECAY HEAT PRECURSORS FRACTION:

	GROUP #					
BURNUP	1	2	3	4	5	6
0.0	0.4060E-02	0.1120E-01	0.2014E-01	0.2626E-01	0.1581E-01	0.1663E-01

MACRO CROSS-SECTION FOR COLOR 4

FUEL TYPE: YES

ROD OUT COOLANT VOLUME FRACTION : 0.03600

ROD IN COOLANT VOLUME FRACTION : 0.03600

FUEL VOLUME FRACTION : 0.03000

REF. COOLANT TEMPERATURE : 543.00 DEGREE-F

REF. EFFECTIVE FUEL TEMP. : 1112.00 DEGREE-F

REF. COOLANT DENSITY : 32.184 LB/FT**3

MACRO X-SECTION ROD-OUT BASE CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	NU	KAPPA	FISSION	FISSION	NU
1	0.0	0.2950E+00	0.1250E-02	0.4563E-03	0.3394E-01	0.2689E+01		
2	0.0	0.3986E+00	0.4013E-02	0.5019E-02	0.3785E+00	0.2652E+01		

MACRO X-SECTION ROD-OUT LINEAR COOLANT DENSITY CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	NU	KAPPA	FISSION	FISSION	NU
1	0.0	0.9243E-02	0.2114E-03	0.5896E-04	0.4138E-02	0.1992E-01		
2	0.0	0.4450E-01	0.7915E-03	0.5270E-03	0.4383E-01	-.2978E-01		

MACRO X-SECTION ROD-OUT QUADRATIC COOLANT DENSITY CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	NU	KAPPA	FISSION	FISSION	NU
1	0.0	0.2334E-02	-.1981E-03	-.2856E-04	-.2115E-02	-.3166E-02		
2	0.0	0.2438E-02	-.2461E-03	-.3198E-03	-.2748E-01	0.2741E-01		

MACRO X-SECTION ROD-OUT LINEAR COOLANT TEMPERATURE CORRECTION

ENERGY GROUP	BURNUP	TRANS.	ABSORP.	NU	KAPPA	FISSION	FISSION	NU
1	0.0	0.6494E-07	0.3485E-08	0.5281E-09	0.4762E-07	-.6494E-06		
2	0.0	-.2554E-05	-.4652E-06	-.4962E-06	-.4286E-04	0.3615E-04		

MACRO X-SECTION ROD-OUT LINEAR SQRT(FUEL TEMPERATURE) CORRECTION

ENERGY	BURNUP			NU	KAPPA	
GROUP	TRANS.	ABSORP.	FISSION	FISSION	NU	

1	0.0	-6593E-05	0.2959E-05	-.1103E-06	-.8938E-05	0.5861E-04
2	0.0	-.5128E-05	-.9780E-06	-.6524E-06	-.7106E-04	0.1538E-03

BUCKLING**2 VALUES

	GROUP #	
BURNUP	1	2
0.0	0.0000E+00	0.0000E+00

MACRO ROD-OUT SCATTER BASE CORRECTION

SCATTERING KERNEL FOR SCATTERING		
	FROM GROUP	TO GROUP
BURNUP	1	2
0.0	1	0.4830E-02
0.0	2	0.1123E-02

MACRO ROD-OUT SCATTER LINEAR COOLANT DENSITY CORRECTION

SCATTERING KERNEL FOR SCATTERING		
	FROM GROUP	TO GROUP
BURNUP	1	2
0.0	1	0.2168E-02
0.0	2	-.2638E-03

MACRO ROD-OUT SCATTER QUADRATIC COOLANT DENSITY CORRECTION

SCATTERING KERNEL FOR SCATTERING		
	FROM GROUP	TO GROUP
BURNUP	1	2
0.0	1	0.4133E-04
0.0	2	0.1375E-03

MACRO ROD-OUT SCATTER LINEAR COOLANT TEMPERATURE CORRECTION

SCATTERING KERNEL FOR SCATTERING		
	FROM GROUP	TO GROUP
BURNUP	1	2
0.0	1	0.8831E-07
0.0	2	-.1861E-07

MACRO ROD-OUT SCATTER LINEAR SQRT(FUEL TEMPERATURE) CORRECTION

SCATTERING KERNEL FOR SCATTERING		
	FROM GROUP	TO GROUP
BURNUP	1	2
0.0	1	-.1491E-05
0.0	2	0.1194E-05

ADF - UNRODDED

BURNUP	GROUP	N	E	S	W	UP	DOWN
0.0	1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0	2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

ADF - RODDED

BURNUP	GROUP	N	E	S	W	UP	DOWN
0.0	1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.0	2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

PROMPT NEUTRON FISSION SPECTRUM

	GROUP #	
BURNUP	1	2
0.0	1.0000	0.0000

NEUTRON VELOCITY [CM/SEC]

	GROUP #	
BURNUP	1	2
0.0	0.1250E+08	0.2500E+06

MICRO SAMARIUM AND XENON ABSORPTION CROSS-SECTIONS

TRANSIENT FISSION PRODUCTS FRACTIONAL YIELDS:

BURNUP	IODINE	XENON	PROMETHIUM
0.0	0.68600E-01	0.23000E-02	0.11300E-01

DELAYED NEUTRONS PRECURSORS FRACTION:

	GROUP #					
BURNUP	1	2	3	4	5	6
0.0	0.2460E-03	0.1459E-02	0.1334E-02	0.2646E-02	0.1055E-02	0.2510E-03

DECAY HEAT PRECURSORS FRACTION:

	GROUP #					
BURNUP	1	2	3	4	5	6
0.0	0.4060E-02	0.1120E-01	0.2014E-01	0.2626E-01	0.1581E-01	0.1663E-01

THERMAL HYDRAULIC PARAMETERS:

POLYNOMIAL ORDER & POLYNOMIAL COEFFICIENT
 FOR THE AVERAGE FUEL TEMPERATURE [F]
 VS. LINEAR POWER DENSITY [K W/FT]
 POLY-ORDER : 0 1
 COEF : 0.5575E+03 0.2016E+01

POLYNOMIAL ORDER & POLYNOMIAL COEFFICIENT
 FOR THE EFFECTIVE HEAT TRANSFER COEFF. [K W/(FT**2-F)]
 VS. FUEL TEMPERATURE [F]
 POLY-ORDER : 0 1
 COEF : 0.1262E+00 0.3684E-04

POLYNOMIAL ORDER & POLYNOMIAL COEFFICIENT
 FOR THE SURFACE FUEL TEMP. [F]
 VS. LINEAR POWER DENSITY [K W/FT]
 POLY-ORDER : 0 1
 COEF : 0.5338E+03 0.5423E-01

POLYNOMIAL ORDER & POLYNOMIAL COEFFICIENT
 FOR THE COOLANT LIQUID INTERNAL ENERGY (BTU/LBM)
 VS. COOLANT TEMPERATURE [F]
 POLY-ORDER : 0 1
 COEF : -0.1403E+03 0.1246E+01

POLYNOMIAL ORDER & POLYNOMIAL COEFFICIENT
 FOR THE COOLANT LIQUID TEMPERATURE [F]
 VS. COOLANT LIQUID INTERNAL ENERGY [BTU/LBM]
 POLY-ORDER : 0 1
 COEF : 0.1125E+03 0.8023E+00

POLYNOMIAL ORDER & POLYNOMIAL COEFFICIENT
 FOR THE COOLANT LIQUID DENSITY [LB/FT**3]
 VS. COOLANT LIQUID INTERNAL ENERGY [BTU/LBM]
 POLY-ORDER : 0 1
 COEF : 0.7486E+02 -0.5299E-01

POLYNOMIAL ORDER & POLYNOMIAL COEFFICIENT
 FOR THE FUEL SPECIFIC HEAT [BTU/LBM-F]
 VS. FUEL TEMPERATURE [F]
 POLY-ORDER : 0 1
 COEF : 0.6667E-01 0.6667E-05

FRACTION OF FISSION ENERGY DEPOSITED IN FUEL: 1.0000

NUMBER OF FUEL RODS PER FUEL BUNDLE: 18

FUEL ROD RADIUS : 0.2270 [INCHES]

FUEL DENSITY : 604.90 [LBM/FT**3]

RATIO OF DENSITY OF HM TO FUEL MATERIAL : 42.00

SYSTEM PRESSURE : 1007.00 [PSIA]

COOLANT GAS SATURATION CONDITION PROPERTIES:

SATURATION TEMPERATURE [F] : 545.40
 INTERNAL ENERGY [BTU/LBM] : 1110.10
 DENSITY [LBM/FT**3] : 0.2260E+01

COOLANT INLET TEMPERATURE : 518.00 [F]

CORE MASS VELOCITY : 0.4938E+05 [LB/HR-FT**2]

CORE POWER DENSITY : 4.32 [KW/LITER]

OTHER INPUT PARAMETERS:

FAST TO THERMAL FLUX RATIO GUESS

1 2
5.1100 1.0000

213

THE EXTERNAL SOURCE STRENGTH [# / CM**3-SEC]

GROUP 1 2
0.000000E+00 0.000000E+00

ATOMIC WEIGHT FOR THE SOLUBLE POISON: 10.81

ISOTOPIC ABUNDANCE FOR THE SOLUBLE POISON (A/O): 0.0000

REFERENCE POISON CONCENTRATION : 0.00 PPM

ATOMIC WEIGHT OF THE COOLANT : 18.02

DOPPLER EFFECTIVE FUEL TEMPERATURE WEIGHTS :

FUEL AVERAGE TEMPERATURE WEIGHT (WP) = 1.0000

FUEL TEMPERATURE RISE WEIGHT (WC) = 1.0000

=====

AVERAGE BURNUP: 0.00 MWD/MTM TIME: 0.000 HRS

KEFF = 1.0028311 PEAK(1, 1, 3) = 1.7186830

====> NO CRITICALITY OR POWER LEVEL SEARCH DONE

CORE RELATIVE POWER = 100.00 % SOLUBLE POISON CONCENTRATION (PPM) = 0.00

COOLANT INLET TEMPERATURE (F) = 518.00 COOLANT PRESSURE (PSIA) = 1007.00

COOLANT MASS FLOW RATE (LB/FT**2-HR) = 49383.00

CORE AVERAGE CHARACTERISTICS

RELATIVE POWER = 1.0000
BURNUP = 0.0000

MAXIMUM FUEL NODE CHARACTERISTICS @ NODE (X,Y,Z) EDIT

RELATIVE POWER @ (1, 1, 3) = 1.7187
BURNUP @ (0, 0, 0) = 0.0000

MAXIMUM FUEL BUNDLE CHARACTERISTICS @ BUNDLE (X,Y,Z) EDIT

RELATIVE POWER @ (1, 1, 3) = 1.6588
BURNUP @ (0, 0, 0) = 0.0000

((ASSY RADIAL RELATIVE POWER AND BURNUP EDIT))

Y\X	1	2	3	4	5	6
1	1.0375 0.0000	0.9624 0.0000	1.0375 0.0000	1.0375 0.0000	0.9624 0.0000	1.0375 0.0000
2	0.9624 0.0000	0.9624 0.0000	0.9624 0.0000	0.9624 0.0000	0.9624 0.0000	0.9624 0.0000
3	1.0375 0.0000	0.9624 0.0000	1.0375 0.0000	1.0375 0.0000	0.9624 0.0000	1.0375 0.0000
4	1.0375 0.0000	0.9624 0.0000	1.0375 0.0000	1.0375 0.0000	0.9624 0.0000	1.0375 0.0000
5	0.9624 0.0000	0.9624 0.0000	0.9624 0.0000	0.9624 0.0000	0.9624 0.0000	0.9624 0.0000
6	1.0375 0.0000	0.9624 0.0000	1.0375 0.0000	1.0375 0.0000	0.9624 0.0000	1.0375 0.0000

KEY

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*****
*                               *
* POWER                         *
* BURNUP                       *
*                               *
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((ASSY AXIAL RELATIVE POWER EDIT))

Z(IN.)	VALUE	Z(IN.)	VALUE	Z(IN.)	VALUE	Z(IN.)	VALUE	Z(IN.)	VALUE
--------	-------	--------	-------	--------	-------	--------	-------	--------	-------

9.84	0.6102	29.52	1.2937	49.20	1.5985	68.88	1.4590	88.56	0.9120
108.24	0.6270	127.92	0.4999	147.60	0.4999	167.28	0.6270	186.96	0.9120
206.64	1.4590	226.32	1.5984	246.00	1.2937	265.68	0.6102		

((ASSY AXIAL BURNUP EDIT))

Z(IN.)	VALUE	Z(IN.)	VALUE	Z(IN.)	VALUE	Z(IN.)	VALUE
--------	-------	--------	-------	--------	-------	--------	-------

9.84	0.	29.52	0.	49.20	0.	68.88	0.
108.24	0.	127.92	0.	147.60	0.	167.28	0.
206.64	0.	226.32	0.	246.00	0.	265.68	0.

((CPU TIME (SEC) EDIT))

TOTAL # OF OUTER ITERATION STEPS = 61

TOTAL # OF INNER ITERATION STEPS = 793

TOTAL CPU TIME FOR INNER STEPS ONLY = 298.19
AVERAGE NUMBER OF INNER ITTERS PER OUTER = 13.0

AV. INNER STEPS CPU TIME / OUTER STEP = 4.89

TOTAL NUMBER OF NEM UPDATES = 12

TOTAL CPU TIME IN THE NODAL ROUTINES = 68.30

TOTAL OUTER ONLY CPU TIME = 107.37

AVERAGE CPU TIME FOR OUTER ONLY = 1.76

TOTAL LOOP CPU TIME = 405.56

TOTAL CODE CPU TIME = 417.01

II.5. Test problem of 3D RBMK neutron dynamics with CPS operation imitation

This section gives setting-up and results of KORAT-3D code computation [5, 6] of one test 3D time-dependent problem which models dynamics of variation in RBMK type reactor power at some given mode of CPS rod operation. The formulation of this problem was developed in collaboration with L.N.Podlasov, a NIKIET employee.

II.5.1. Test problem formulation

Geometry of the system is presented in Fig. II.5.1. It is a 3D body constituting a parallelepiped:

$$\{ 0 \leq X \leq 1000 \text{ cm} , 0 \leq Y \leq 500 \text{ cm} , 0 \leq Z \leq 350 \text{ cm} \}.$$

Within the above region the solution of the 3D neutron diffusion equation is sought for in the two-group approximation with account of delayed neutrons:

$$\frac{1}{V_1} \frac{\partial U_1}{\partial t} - \frac{\partial}{\partial x} D_1 \frac{\partial U_1}{\partial x} - \frac{\partial}{\partial y} D_1 \frac{\partial U_1}{\partial y} - \frac{\partial}{\partial z} D_1 \frac{\partial U_1}{\partial z} + (\sigma_1^a + \sigma_1^s) U_1 = (1 - \beta) (\sigma_1^f U_1 + \sigma_2^f U_2) + \lambda * C,$$

$$\frac{1}{V_2} \frac{\partial U_2}{\partial t} - \frac{\partial}{\partial x} D_2 \frac{\partial U_2}{\partial x} - \frac{\partial}{\partial y} D_2 \frac{\partial U_2}{\partial y} - \frac{\partial}{\partial z} D_2 \frac{\partial U_2}{\partial z} + \sigma_2^a U_2 = \sigma_1^s U_1,$$

$$\frac{\partial C}{\partial t} = \beta (\sigma_1^f U_1 + \sigma_2^f U_2) - \lambda * C.$$

Initial conditions:

$$U_1(x, y, z, t) \big|_{t=0} = \frac{1}{\sigma_1^a + \sigma_1^s}, \quad U_2(x, y, z, t) \big|_{t=0} = \frac{\sigma_1^s}{\sigma_2^a * (\sigma_1^a + \sigma_1^s)},$$

$$C(x, y, z, t) \big|_{t=0} = (\sigma_1^f U_1 + \sigma_2^f U_2) \big|_{t=0} \times \beta / \lambda, \quad \beta = 0.005; \quad \lambda = 0.1.$$

On the external surface of the system being computed the reflection condition is set.

The system is split into two regions:

Region 1: $400 \leq X \leq 1000; 250 \leq Y \leq 500; 0 \leq Z \leq 350 \}$.

Region 2: the whole remaining part of the system, respectively.

At the initial time the following magnitudes of the factors are given which are the same for either region:

$$I_1 = 2 \cdot 10^7, \quad V_2 = 2.2 \cdot 10^5,$$

$$\sigma_1^a = 0.0010541, \quad \sigma_2^a = 0.00371201,$$

$$\sigma_1^f = 0.00046721, \quad \sigma_2^f = 0.004129872,$$

$$\sigma_1^s = 0.0051772,$$

$$D_1 = 1.11149, \quad D_2 = 0.771546,$$

$$V_1^f = 2.55, \quad V_2^f = 2.43.$$

The factors given in region 2 remain constant in time. In region 1 all the above cross sections and diffusion factors vary with time. Through such a variation the process is modeled which is similar to CPS rod movement in a core.

The law of variation in cross sections and diffusion factors is set as follows:

1. Span of time $0 < t^n \leq t_1$, $t_1 = 5$ sec.

Within this time interval the magnitudes of the values given at the initial time are replaced with the magnitudes:

$$D_1 = 1.11147, \quad D_2 = 0.787235,$$

$$\sigma_1^a = 0.0011659, \quad \sigma_2^a = 0.00404158,$$

$$\sigma_1^f = 0.0004673, \quad \sigma_2^f = 0.00435559,$$

$$\sigma_1^s = 0.00505223.$$

The replacement is made gradually beginning from the upper base of region 1 ($Z_k = 350$) at

velocity $V_c = \frac{Z_k}{5} = 70 \text{ cm/sec}$, by the following rule:

$$\sigma(t^n) = \frac{\Delta z_1 * \sigma(t_1) + \Delta z * \sigma(t_0)}{\Delta z_w},$$

where t^n – current time,

$$z(t^n) = Z_k - V_c * t^n,$$

$$\Delta z_w = z_{w+1} - z_w,$$

$$\Delta z = z(t^n) - z_w,$$

$$\Delta z_1 = z_{w+1} - z(t^n),$$

z_w, z_{w+1} – coordinates of the lower and upper layer base, respectively,

$z(t^n)$ – rod coordinate at current time,

$\sigma(t_0)$ – factor value at time $t=0$,

$\sigma(t_1)$ – factor value at time $t = t_1$.

2. Span of time $t_1 < t^n \leq t_2$, $t_2 = 7$ sec

Within this time interval the magnitudes of the values obtained in I.1 remain constant.

3. Span of time $t_2 < t^n \leq t_3$, $t_3 = 15$ sec.

All cross sections and diffusion factors of I.2 are replaced with the following:

$$D_1 = 1.1106, \quad D_2 = 0.789606,$$

$$\sigma_1^a = 0.00105263, \quad \sigma_2^a = 0.003709, \quad \sigma_1^f = 0.00046294, \quad \sigma_2^f = 0.004176,$$

$$\sigma_1^j = 0.00509306.$$

Like in I.1, the replacement is made gradually, beginning from the lower base of region 1 ($Z=0$) at velocity $V_c = z_k / 8 = 43.75$ cm/sec according to the rule:

$$\sigma(t^n) = \frac{\Delta z_1 * \sigma(t_2) + \Delta z * \sigma(t_3)}{\Delta z_w}, \quad z(t^n) = (t^n - t_3) * V_c.$$

4. Span of time $t_3 < t^n \leq t_4$, $t_4 = 17$ sec

Within this time interval the magnitudes of the values obtained in I.3 remain constant.

5. Span of time $t_4 < t^n \leq t_5$, $t_5 = 25$ sec

The cross sections and diffusion factors are gradually replaced with the initial. The replacement is made at velocity $V_c = 43.75$ cm/sec beginning from the lower base of region 1 according to the rule:

$$\sigma(t^n) = \frac{\Delta z_1 * \sigma(t_4) + \Delta z * \sigma(t_0)}{\Delta z_w}, \quad z(t^n) = (t^n - t_4) * V_c.$$

II.5.2. Time-independent computations

When accounting a geometry type (see Fig. II.5.1), the test problem was computed on an orthogonal regular spatial grid. In order to secure acceptable accuracy by spatial variables of a time-dependent computation, two series of time-dependent computations for k_{eff} parameter calculation were performed. Computations of one series differed from the other in spatial grids. Both of the selected grids are uniform in all the three spatial variables. The number of intervals in directions for either grid is given in Table II.5.1.

Table II.5.1

Number of grid intervals in each spatial direction.

	X	Y	Z
Grid 1	20	10	28
Grid 2	40	20	28

In grid 1 the points were distributed over the region as follows: in region 1 there were 60 2D points, 1680 3D points. In region 2 140 2D points, 3920 3D points. Altogether in the system there were 200 2D points, 5600 3D points. In grid 2 in region 1 there were 240 2D points, 6720 3D points. In region 2 there are 560 2D points, 15680 3D points. Altogether in the system in grid 2 there were 800 2D points, 22400 3D points.

The computation to seek for the k_{eff} parameter were made for four times in either series. These are the initial time and the times when the technique of computing cross sections and diffusion factors changes in the first physical region of the problem.

At k_{eff} parameter computation the iterative process was reduced with relative accuracy $\varepsilon=10^{-7}$. The values of the k_{eff} parameter found in the computations are given in Table II.5.2.

Table II.5.2.

k_{eff} parameter values on various spatial grids for selected times.

Time	0.0	7.0	15.0	25.0
k_{eff} on grid 1	0.999343	0.996451	1.003706	0.999343
k_{eff} on grid 2	0.999343	0.996467	1.003712	0.999343

As it follows from comparison, on the two selected grids the computed k_{eff} values agree within good accuracy. Therefore, grid 2 was not further refined, i.e. for the dynamic computation grid 2 was selected.

II.5.3. Time -dependent computation

In time variable the computation was performed by a completely implicit scheme. For the computation the timestep was selected rather small securing satisfaction of the condition that solution increment at one spatial grid be no higher than 3%.

Within the time interval of I.1 the timestep was $\Delta t=0.05$, within the time segment of I.2 the computation was made with $\Delta t=0.1$, within the time interval of I.3 the timestep equated 0.01. Beginning from time $t=15\text{sec}$ the computation was made with $\Delta t=0.005$. The number of the timesteps was 3380.

The computation was performed with relative accuracy in neutron flux of $\varepsilon_1=0.001$ (external iterations), $\varepsilon_2 = 10^{-7}$ (internal iterations). The number of the external iterations was no more than 7. On the average 4 iterations were performed. The results of time-dependent computation a given in Fig. II.5.2-II.5.4 and in Tables II.5.3-II.5.6.

Fig. II.5.2 gives the plots of the number of fission acts vs time over the whole system and in the physical regions normalized to the number of the neutrons in the system and in the physical regions, respectively, at the initial time.

Fig. II.5.3 gives profiles of neutron flux by groups and physical regions.

Fig. II.5.4 presents profiles of neutron flux by groups totalized over the system.

Tables II.5.3-II.5.6 reflect the cartogram of specific power for the selected times.

System geometry

Fig. II.5.1.

Analysis of obtained results confirms serviceability of the KORAT 3D technique in computation of this class of multidimensional reactor problems. It seems to be very interesting to perform a computation with the NESTLE code in this setting-up.

The number of fissions by physical regions and in the system

Fig. II.5.3.

Neutron flux by groups and physical regions (ph.r.)

Fig. II.5.4.

Neutron flux by groups by the system

Fig. II.5.5.

Table II.5.3.

Specific power by "channels" at time T=5.0

1	2	3	4	5	6
1 0.1373657056E+01	0.1371176139E+01	0.1366224769E+01	0.1358824821E+01	0.1349011467E+01	0.1336835991E+01
2 0.1372796695E+01	0.1370287425E+01	0.1365278489E+01	0.1357790043E+01	0.1347854704E+01	0.1335520423E+01
3 0.1371097822E+01	0.1368532508E+01	0.1363409752E+01	0.1355746250E+01	0.1345569447E+01	0.1332920493E+01
4 0.1368603630E+01	0.1365955914E+01	0.1360665742E+01	0.1352744571E+01	0.1342211968E+01	0.1329098597E+01
5 0.1365377635E+01	0.1362623177E+01	0.1357116036E+01	0.1348860642E+01	0.1337865903E+01	0.1324148112E+01
6 0.1361502126E+01	0.1358619294E+01	0.1352851083E+01	0.1344193165E+01	0.1332641041E+01	0.1318192669E+01
7 0.1357076061E+01	0.1354046599E+01	0.1347980054E+01	0.1338861767E+01	0.1326671291E+01	0.1311384473E+01
8 0.1352212447E+01	0.1349022075E+01	0.1342628029E+01	0.1333004039E+01	0.1320111599E+01	0.1303901234E+01
9 0.1347035225E+01	0.1343674124E+01	0.1336932538E+01	0.1326771730E+01	0.1313133700E+01	0.1295941407E+01
10 0.1341675771E+01	0.1338138902E+01	0.1331039548E+01	0.1320326176E+01	0.1305920730E+01	0.1287717689E+01
11 0.1336269149E+01	0.1332556363E+01	0.1325099061E+01	0.1313833169E+01	0.1298660988E+01	0.1279449117E+01
12 0.1330950282E+01	0.1327066199E+01	0.1319260575E+01	0.1307457606E+01	0.1291541300E+01	0.1271352458E+01
13 0.1325850234E+01	0.1321803917E+01	0.1313668692E+01	0.1301358305E+01	0.1284740596E+01	0.1263633854E+01
14 0.1321092787E+01	0.1316897226E+01	0.1308459131E+01	0.1295683383E+01	0.1278424288E+01	0.1256481649E+01
15 0.1316791449E+01	0.1312462936E+01	0.1303755371E+01	0.1290566498E+01	0.1272739905E+01	0.1250061165E+01
16 0.1313046989E+01	0.1308604443E+01	0.1299666056E+01	0.1286124123E+01	0.1267814233E+01	0.1244511724E+01
17 0.1309945541E+01	0.1305409851E+01	0.1296283164E+01	0.1282453851E+01	0.1263751899E+01	0.1239945801E+01
18 0.1307557226E+01	0.1302950669E+01	0.1293680880E+01	0.1279633595E+01	0.1260635153E+01	0.1236449840E+01
19 0.1305935237E+01	0.1301281001E+01	0.1291915014E+01	0.1277721425E+01	0.1258524442E+01	0.1234086033E+01
20 0.1305115284E+01	0.1300437086E+01	0.1291022782E+01	0.1276755782E+01	0.1257459323E+01	0.1232894373E+01
7	8	9	10	11	12
1 0.1322369495E+01	0.1305707361E+01	0.1286974263E+01	0.1266329294E+01	0.1243970558E+01	0.1220138286E+01
2 0.1320854306E+01	0.1303947326E+01	0.1284919760E+01	0.1263926996E+01	0.1241165104E+01	0.1216875188E+01
3 0.1317858257E+01	0.1300464461E+01	0.1280849893E+01	0.1259161523E+01	0.1235590044E+01	0.1210376882E+01
4 0.1313450418E+01	0.1295334276E+01	0.1274845065E+01	0.1252114603E+01	0.1227322099E+01	0.1200705483E+01
5 0.1307735169E+01	0.1288672454E+01	0.1267030823E+01	0.1242917305E+01	0.1216489079E+01	0.1187970874E+01
6 0.1300852407E+01	0.1280636750E+01	0.1257582601E+01	0.1231759185E+01	0.1203285188E+01	0.1172353036E+01
7 0.1292976700E+01	0.1271427834E+01	0.1246729744E+01	0.1218897950E+01	0.1187989926E+01	0.1154134314E+01
8 0.1284314568E+01	0.1261287670E+01	0.1234756508E+01	0.1204666037E+01	0.1170985841E+01	0.1133737968E+01
9 0.1275099259E+01	0.1250494134E+01	0.1221997433E+01	0.1189469154E+01	0.1152766072E+01	0.1111758570E+01
10 0.1265582750E+01	0.1239351096E+01	0.1208825198E+01	0.1173772146E+01	0.1133920682E+01	0.1088958544E+01
11 0.1256025375E+01	0.1228174352E+01	0.1195630941E+01	0.1158070780E+01	0.1115095556E+01	0.1066209003E+01
12 0.1246684152E+01	0.1217275068E+01	0.1182799699E+01	0.1142853490E+01	0.1096929534E+01	0.1044379753E+01
13 0.1237801358E+01	0.1206943423E+01	0.1170685757E+01	0.1128562138E+01	0.1079987872E+01	0.1024217392E+01
14 0.1229594988E+01	0.1197435273E+01	0.1159593147E+01	0.1115562056E+01	0.1064713758E+01	0.1006262177E+01
15 0.1222252268E+01	0.1188963903E+01	0.1149764930E+01	0.1104128125E+01	0.1051411061E+01	0.9908309456E+00
16 0.1215926709E+01	0.1181697489E+01	0.1141382055E+01	0.1094447454E+01	0.1040257019E+01	0.9780560265E+00
17 0.1210738376E+01	0.1175761512E+01	0.1134569903E+01	0.1086634020E+01	0.1031332962E+01	0.9679483744E+00
18 0.1206776475E+01	0.1171244404E+01	0.1129409200E+01	0.1080748578E+01	0.1024659426E+01	0.9604570852E+00
19 0.1204103116E+01	0.1168204489E+01	0.1125947945E+01	0.1076818200E+01	0.1020226551E+01	0.9555132267E+00
20 0.1202757139E+01	0.1166676500E+01	0.1124211855E+01	0.1074852046E+01	0.1018016279E+01	0.9530578265E+00
13	14	15	16	17	18
1 0.1195115338E+01	0.1169223897E+01	0.1142817492E+01	0.1116268185E+01	0.1089949799E+01	0.1064219109E+01
2 0.1191345187E+01	0.1164907579E+01	0.1137931626E+01	0.1110809625E+01	0.1083937944E+01	0.1057695187E+01
3 0.1183818989E+01	0.1156269104E+01	0.1128128970E+01	0.1099833834E+01	0.1071828670E+01	0.1044539336E+01
4 0.1172571705E+01	0.1143302462E+01	0.1113350509E+01	0.1083222202E+01	0.1053445342E+01	0.1024526952E+01
5 0.1157674371E+01	0.1126014891E+01	0.1093516355E+01	0.1060793795E+01	0.1028507779E+01	0.9972972223E+00
6 0.1139261561E+01	0.1104453270E+01	0.1068541569E+01	0.1032302343E+01	0.9966088114E+00	0.9623159225E+00
7 0.1117577516E+01	0.1078754786E+01	0.1038370711E+01	0.9974332904E+00	0.9571683589E+00	0.9188028038E+00
8 0.1093048402E+01	0.1049245487E+01	0.1003055412E+01	0.9557955146E+00	0.9093167971E+00	0.8655562887E+00
9 0.1066366487E+01	0.1016638465E+01	0.9629489314E+00	0.9068308753E+00	0.8514145614E+00	0.8002816236E+00
10 0.1038531096E+01	0.9822365256E+00	0.9195425307E+00	0.8493493383E+00	0.7775099287E+00	0.7154880278E+00
11 0.1010772249E+01	0.9478907369E+00	0.8759397156E+00	0.7890281493E+00	0.2511411635E+01	0.2245145649E+01
12 0.9843425883E+00	0.9155694362E+00	0.8357505809E+00	0.7373488157E+00	0.2280657343E+01	0.1986807897E+01
13 0.9602704294E+00	0.8867698417E+00	0.8013614349E+00	0.6974561681E+00	0.2121013017E+01	0.1814375644E+01
14 0.9392071450E+00	0.8622221703E+00	0.7732313062E+00	0.6664756131E+00	0.2002779492E+01	0.1690307346E+01
15 0.9214306798E+00	0.8420111866E+00	0.7507811472E+00	0.6425783736E+00	0.1914390082E+01	0.1599614590E+01
16 0.9069552954E+00	0.8258880704E+00	0.7332912396E+00	0.6244159541E+00	0.1848747115E+01	0.1533474755E+01
17 0.8956588317E+00	0.8135084059E+00	0.7201010012E+00	0.6109684911E+00	0.1800989807E+01	0.1486054803E+01
18 0.8873756040E+00	0.8045412527E+00	0.7106721895E+00	0.6014846383E+00	0.1767745789E+01	0.1453417862E+01
19 0.8819505042E+00	0.7987180553E+00	0.7046046919E+00	0.5954381261E+00	0.1746742801E+01	0.1432965242E+01
20 0.8792682833E+00	0.7958534594E+00	0.7016358232E+00	0.5924956129E+00	0.1736576725E+01	0.1423113906E+01

Continue of table II.5.3.

19	20	21	22	23	24
1 0.1039397634E+01	0.1015756703E+01	0.9935077921E+00	0.9727989556E+00	0.9537169775E+00	0.9362939160E+00
2 0.1032420884E+01	0.1008398271E+01	0.9858437025E+00	0.9649035908E+00	0.9456580845E+00	0.9281295631E+00
3 0.1018344028E+01	0.9935508116E+00	0.9703851499E+00	0.9489883799E+00	0.9294251757E+00	0.9116965493E+00
4 0.9969106458E+00	0.9709442483E+00	0.9468645981E+00	0.9248000557E+00	0.9047858935E+00	0.8867857326E+00
5 0.9677094722E+00	0.9401497844E+00	0.9148633632E+00	0.8919482922E+00	0.8713870517E+00	0.8530826849E+00
6 0.9301345888E+00	0.9005469964E+00	0.8737898456E+00	0.8498944305E+00	0.8287508944E+00	0.8101683849E+00
7 0.8833125454E+00	0.8512695555E+00	0.8228480657E+00	0.7979374210E+00	0.7762711845E+00	0.7575201660E+00
8 0.8259410739E+00	0.7910961172E+00	0.7609743564E+00	0.7351754564E+00	0.7131861846E+00	0.6944887876E+00
9 0.7557211929E+00	0.7180466314E+00	0.6865120331E+00	0.6602161407E+00	0.6383050085E+00	0.6200325783E+00
10 0.6662100564E+00	0.6266028656E+00	0.5946242456E+00	0.5687126549E+00	0.5476337739E+00	0.5304138504E+00
11 0.2054490669E+01	0.1908544175E+01	0.1794748661E+01	0.1705117400E+01	0.1633949631E+01	0.1577036465E+01
12 0.1784819717E+01	0.1635205281E+01	0.1521706252E+01	0.1434460023E+01	0.1366706341E+01	0.1313621147E+01
13 0.1603182839E+01	0.1448892753E+01	0.1333795245E+01	0.1246856912E+01	0.1180520773E+01	0.1129443403E+01
14 0.1473619421E+01	0.1315748322E+01	0.1198921790E+01	0.1111620817E+01	0.1045824352E+01	0.9958322254E+01
15 0.1379988306E+01	0.1219839423E+01	0.1101672283E+01	0.1013874182E+01	0.9482161582E+00	0.8987914481E+00
16 0.1312471355E+01	0.1151037135E+01	0.1031989098E+01	0.9437721184E+00	0.8780973354E+00	0.8289583738E+00
17 0.1264550419E+01	0.1102478006E+01	0.9829187096E+00	0.8944151043E+00	0.8286858556E+00	0.7796878720E+00
18 0.1231843403E+01	0.1069506686E+01	0.9496850739E+00	0.8610122010E+00	0.7952362518E+00	0.7463080115E+00
19 0.1211474609E+01	0.1049057781E+01	0.9291198947E+00	0.8403604974E+00	0.7745561435E+00	0.7256622550E+00
20 0.1201701500E+01	0.1039272142E+01	0.9192936553E+00	0.8304995903E+00	0.7646828170E+00	0.7158033927E+00
25	26	27	28	29	30
1 0.9205163353E+00	0.9063355692E+00	0.8936777329E+00	0.8824526647E+00	0.8725614033E+00	0.8639021146E+00
2 0.9122936946E+00	0.8980910900E+00	0.8854381842E+00	0.8742365971E+00	0.8643807070E+00	0.8557634813E+00
3 0.8957548856E+00	0.8815184331E+00	0.8688838264E+00	0.8577361352E+00	0.8479564985E+00	0.8394276636E+00
4 0.8707132850E+00	0.8564510964E+00	0.8438651633E+00	0.8328155885E+00	0.8231639537E+00	0.8147781780E+00
5 0.8368904759E+00	0.8226418238E+00	0.8101606357E+00	0.7992738574E+00	0.7898178240E+00	0.7816417835E+00
6 0.7939190561E+00	0.7797660668E+00	0.7674799197E+00	0.7568471803E+00	0.7476744988E+00	0.7397898607E+00
7 0.7413452699E+00	0.7274246077E+00	0.7154657579E+00	0.7052098946E+00	0.6964316780E+00	0.6889371013E+00
8 0.6786066935E+00	0.6651203791E+00	0.6536694164E+00	0.6439484921E+00	0.6357011807E+00	0.6287132826E+00
9 0.6047705433E+00	0.5919993635E+00	0.5812934824E+00	0.5723059909E+00	0.5647547130E+00	0.5584103107E+00
10 0.5162868209E+00	0.5046503256E+00	0.4950301992E+00	0.4870524206E+00	0.4804212073E+00	0.4749020136E+00
11 0.1531223718E+01	0.1494124639E+01	0.1463919523E+01	0.1439212086E+01	0.1418924853E+01	0.1402222129E+01
12 0.1271693054E+01	0.1238332359E+01	0.1211609850E+01	0.1190076469E+01	0.1172636090E+01	0.1158454406E+01
13 0.1089782932E+01	0.1058744063E+01	0.1034273526E+01	0.1014850954E+01	0.9993426848E+00	0.9868981399E+00
14 0.9575501290E+00	0.9280123654E+00	0.9050548920E+00	0.8870882145E+00	0.8729378754E+00	0.8617313480E+00
15 0.8613372704E+00	0.8327626528E+00	0.8108156525E+00	0.7938479519E+00	0.7806476288E+00	0.7703197839E+00
16 0.7919931229E+00	0.7640273503E+00	0.7427454920E+00	0.7264535978E+00	0.7139087327E+00	0.7041960872E+00
17 0.7430075117E+00	0.7154201370E+00	0.6945677485E+00	0.6787237043E+00	0.6666214782E+00	0.6573302081E+00
18 0.7097908456E+00	0.6824323072E+00	0.6618482917E+00	0.6462905423E+00	0.6344760482E+00	0.6254621727E+00
19 0.6892338296E+00	0.6620046658E+00	0.6415761813E+00	0.6261873061E+00	0.6145447856E+00	0.6056983812E+00
20 0.6794140916E+00	0.6522432518E+00	0.6318859577E+00	0.6165752489E+00	0.6050130056E+00	0.5962452864E+00
31	32	33	34	35	36
1 0.8563745769E+00	0.8498834256E+00	0.8443403946E+00	0.8396657782E+00	0.8357893190E+00	0.8326506858E+00
2 0.8482807691E+00	0.8418343218E+00	0.8363338158E+00	0.8316981210E+00	0.8278560248E+00	0.8247465795E+00
3 0.8320378293E+00	0.8256831834E+00	0.8202694702E+00	0.8157128643E+00	0.8119403683E+00	0.8088898990E+00
4 0.8075355411E+00	0.8013244133E+00	0.7960451038E+00	0.7916101305E+00	0.7879441285E+00	0.7849835540E+00
5 0.7746095816E+00	0.7686001922E+00	0.7635075563E+00	0.7592400361E+00	0.7557196823E+00	0.7528814458E+00
6 0.7330422863E+00	0.7273007227E+00	0.7224525802E+00	0.7184021751E+00	0.7150692271E+00	0.7123874942E+00
7 0.6825605043E+00	0.6771614048E+00	0.6726214777E+00	0.6688418379E+00	0.6657406830E+00	0.6632513036E+00
8 0.6228065539E+00	0.6178331618E+00	0.6136709546E+00	0.6102195193E+00	0.6073969513E+00	0.6051372467E+00
9 0.5530864324E+00	0.5486317104E+00	0.5449233392E+00	0.5418619701E+00	0.5393676815E+00	0.5373768257E+00
10 0.4703083790E+00	0.4664917772E+00	0.4633337951E+00	0.4607401149E+00	0.4586358945E+00	0.4569622346E+00
11 0.1388452846E+01	0.1377107918E+01	0.1367788309E+01	0.1360181052E+01	0.1354041231E+01	0.1349178451E+01
12 0.1146892923E+01	0.1137460770E+01	0.1129779284E+01	0.1123555879E+01	0.1118564719E+01	0.1114632408E+01
13 0.9768756092E+00	0.9687886586E+00	0.9622671903E+00	0.9570290195E+00	0.9528590665E+00	0.9495941112E+00
14 0.8528171973E+00	0.8457069318E+00	0.8400329597E+00	0.8355180736E+00	0.8319532444E+00	0.8291814553E+00
15 0.7622009345E+00	0.7557973704E+00	0.7507406106E+00	0.7467551325E+00	0.7436349517E+00	0.7412266283E+00
16 0.6966403084E+00	0.6907414083E+00	0.6861283583E+00	0.6825254478E+00	0.6797278796E+00	0.6775840836E+00
17 0.6501642981E+00	0.6446177645E+00	0.6403165465E+00	0.6369838659E+00	0.6344150776E+00	0.6324559439E+00
18 0.6185554234E+00	0.6132448953E+00	0.6091537659E+00	0.6060039832E+00	0.6035905914E+00	0.6017631095E+00
19 0.5989493156E+00	0.5937832541E+00	0.5898213359E+00	0.5867844568E+00	0.5844672678E+00	0.5827192999E+00
20 0.5895706821E+00	0.5844731094E+00	0.5805726363E+00	0.5775895768E+00	0.5753183320E+00	0.5736083928E+00

Continue of table II.5.3.

	37	38	39	40	
1	0.8301996801E+00	0.8283962737E+00	0.8272105572E+00	0.8266226566E+00	1
2	0.8223192054E+00	0.8205336512E+00	0.8193598852E+00	0.8187779719E+00	2
3	0.8065101895E+00	0.8047605967E+00	0.8036108827E+00	0.8030410142E+00	3
4	0.7826762925E+00	0.7809812486E+00	0.7798679681E+00	0.7793163302E+00	4
5	0.7506724159E+00	0.7490511367E+00	0.7479870354E+00	0.7474599800E+00	5
6	0.7103035850E+00	0.7087759670E+00	0.7077741763E+00	0.7072782284E+00	6
7	0.6613204462E+00	0.6599070003E+00	0.6589809859E+00	0.6585228161E+00	7
8	0.6033882292E+00	0.6021099360E+00	0.6012733992E+00	0.6008597734E+00	8
9	0.5358395844E+00	0.5347181055E+00	0.5339851207E+00	0.5336229679E+00	9
10	0.4556734956E+00	0.4547352849E+00	0.4541229852E+00	0.4538207243E+00	10
11	0.1345446726E+01	0.1342737010E+01	0.1340971786E+01	0.1340101322E+01	11
12	0.1111627437E+01	0.1109452471E+01	0.1108038827E+01	0.1107342677E+01	12
13	0.9471116528E+00	0.9453218382E+00	0.9441617245E+00	0.9435913629E+00	13
14	0.8270859606E+00	0.8255818303E+00	0.8246099722E+00	0.8241330710E+00	14
15	0.7394169707E+00	0.7381242118E+00	0.7372917950E+00	0.7368841647E+00	15
16	0.6759829413E+00	0.6748446378E+00	0.6741142325E+00	0.6737573129E+00	16
17	0.6310069539E+00	0.6299789495E+00	0.6293214748E+00	0.6290008335E+00	17
18	0.6004120845E+00	0.5994594753E+00	0.5988519036E+00	0.5985561006E+00	18
19	0.5814313312E+00	0.5805256358E+00	0.5799491413E+00	0.5796688138E+00	19
20	0.5723506145E+00	0.5714673985E+00	0.5709058031E+00	0.5706328971E+00	20

Table II.5.4.

Specific power by "channels" at time T=15.0

1	2	3	4	5	6
1 0.8158370447E+00	0.8166264029E+00	0.8182088995E+00	0.8205916400E+00	0.8237841369E+00	0.8277969196E+00
2 0.8161443437E+00	0.8169468810E+00	0.8185561986E+00	0.8209803280E+00	0.8242301692E+00	0.8283180891E+00
3 0.8167518883E+00	0.8175805460E+00	0.8192430351E+00	0.8217492534E+00	0.8251129064E+00	0.8293500930E+00
4 0.8176456693E+00	0.8185129039E+00	0.8202539533E+00	0.8228815436E+00	0.8264136527E+00	0.8308721060E+00
5 0.8188049263E+00	0.8197224477E+00	0.8215659579E+00	0.8243519905E+00	0.8281043091E+00	0.8328525673E+00
6 0.8202024784E+00	0.8211809726E+00	0.8231487900E+00	0.8261272471E+00	0.8301474236E+00	0.8352489735E+00
7 0.8218052032E+00	0.8228540441E+00	0.8249653677E+00	0.8281662067E+00	0.8324964429E+00	0.8380078835E+00
8 0.8235746824E+00	0.8247016466E+00	0.8269724323E+00	0.8304206293E+00	0.8350962750E+00	0.8410653270E+00
9 0.8254680251E+00	0.8266790264E+00	0.8291214299E+00	0.8328360715E+00	0.8378842636E+00	0.8443477884E+00
10 0.8274388656E+00	0.8287377311E+00	0.8313596348E+00	0.8353531392E+00	0.8407916183E+00	0.8477738646E+00
11 0.8294385147E+00	0.8308268227E+00	0.8336314923E+00	0.8379090413E+00	0.8437452812E+00	0.8512565840E+00
12 0.8314172285E+00	0.8328942247E+00	0.8358801304E+00	0.8404393745E+00	0.8466701331E+00	0.8547062444E+00
13 0.8333255447E+00	0.8348881445E+00	0.8380489671E+00	0.8428800379E+00	0.8494913822E+00	0.8580335246E+00
14 0.8351156278E+00	0.8367585047E+00	0.8400833247E+00	0.8451691503E+00	0.8521369476E+00	0.8611525684E+00
15 0.8367425662E+00	0.8384583186E+00	0.8419319680E+00	0.8472488546E+00	0.8545396618E+00	0.8639837648E+00
16 0.8386165569E+00	0.8399449490E+00	0.8435484936E+00	0.8490669112E+00	0.8566391559E+00	0.8664560276E+00
17 0.8393490227E+00	0.8411812107E+00	0.8448925216E+00	0.8505780239E+00	0.8583833580E+00	0.8685084912E+00
18 0.8402633801E+00	0.8421362869E+00	0.8459306642E+00	0.8517448766E+00	0.8597295962E+00	0.8700916448E+00
19 0.8408858707E+00	0.8427864524E+00	0.8466372711E+00	0.8525388958E+00	0.8606453524E+00	0.8711680080E+00
20 0.8412010260E+00	0.8431156035E+00	0.8469949611E+00	0.8529407706E+00	0.8611087329E+00	0.8717124776E+00
7	8	9	10	11	12
1 0.8326396649E+00	0.8383188604E+00	0.8448350487E+00	0.8521797613E+00	0.8603323407E+00	0.8692569558E+00
2 0.8332560160E+00	0.8390530278E+00	0.8457124523E+00	0.8532285647E+00	0.8615830572E+00	0.8707415875E+00
3 0.8344773493E+00	0.8405091065E+00	0.8474545350E+00	0.8553137909E+00	0.8640737808E+00	0.8737037293E+00
4 0.8362805866E+00	0.8426619628E+00	0.8500348233E+00	0.8584091245E+00	0.8677809299E+00	0.8781264161E+00
5 0.8386303535E+00	0.8454724607E+00	0.8534111708E+00	0.8624712911E+00	0.8726636768E+00	0.8839771057E+00
6 0.8414783293E+00	0.8488860843E+00	0.8575232355E+00	0.8674358298E+00	0.8786573984E+00	0.8911984422E+00
7 0.8447628033E+00	0.8528317036E+00	0.8622898967E+00	0.8732122962E+00	0.8856654354E+00	0.8996951824E+00
8 0.8484087514E+00	0.8572209898E+00	0.8676074096E+00	0.8796800705E+00	0.8935506461E+00	0.9093183805E+00
9 0.8523287373E+00	0.8619490225E+00	0.8733492568E+00	0.8866864669E+00	0.9021296520E+00	0.9198512016E+00
10 0.8564248393E+00	0.8668964926E+00	0.8793685295E+00	0.8940488901E+00	0.9111735042E+00	0.9310043577E+00
11 0.8605916171E+00	0.8719335996E+00	0.8855031660E+00	0.9015619914E+00	0.9204174610E+00	0.9424288724E+00
12 0.8647199067E+00	0.8769253242E+00	0.8915835760E+00	0.9090091900E+00	0.9295792890E+00	0.9537468912E+00
13 0.8687010384E+00	0.8817373830E+00	0.8974414223E+00	0.9161762744E+00	0.9383815968E+00	0.9645911315E+00
14 0.8724309789E+00	0.8862419996E+00	0.9029179755E+00	0.9228640208E+00	0.9465718324E+00	0.9746384134E+00
15 0.8758139451E+00	0.8903227253E+00	0.9078706928E+00	0.9288973358E+00	0.9539350808E+00	0.9836271642E+00
16 0.8787651960E+00	0.8938778625E+00	0.9121773455E+00	0.9341299462E+00	0.9602984737E+00	0.9913585036E+00
17 0.8812129134E+00	0.8968224338E+00	0.9157377790E+00	0.9384452044E+00	0.9655292685E+00	0.9976875483E+00
18 0.8830992667E+00	0.8990889490E+00	0.9184739196E+00	0.9417544306E+00	0.9695298499E+00	0.1002512219E+01
19 0.8843808694E+00	0.9006273824E+00	0.9203288136E+00	0.9439942652E+00	0.9722322813E+00	0.1005763675E+01
20 0.8850288665E+00	0.9014047712E+00	0.9212653842E+00	0.9451240863E+00	0.9735938072E+00	0.1007399504E+01
13	14	15	16	17	18
1 0.8789002202E+00	0.8891898824E+00	0.9000350218E+00	0.9113280179E+00	0.9229482743E+00	0.9347673303E+00
2 0.8806508641E+00	0.8912368439E+00	0.9024046287E+00	0.9140404790E+00	0.9260160018E+00	0.9381940860E+00
3 0.8841510805E+00	0.8953385289E+00	0.9071631314E+00	0.9194983130E+00	0.9321990484E+00	0.9451096812E+00
4 0.8893957027E+00	0.9015076228E+00	0.9143470759E+00	0.9277666640E+00	0.9415935214E+00	0.9556406667E+00
5 0.8963688470E+00	0.9097553022E+00	0.9240055183E+00	0.9389412283E+00	0.9543460706E+00	0.9699833954E+00
6 0.9050324456E+00	0.9200793589E+00	0.9361907750E+00	0.9531446802E+00	0.9706574253E+00	0.9884136758E+00
7 0.9153079333E+00	0.9324430377E+00	0.9509403219E+00	0.9705185687E+00	0.9907876446E+00	0.1011302766E+01
8 0.9270490307E+00	0.9467368652E+00	0.9682379474E+00	0.9912000079E+00	0.1015057004E+01	0.1039134777E+01
9 0.9400096810E+00	0.9627119370E+00	0.9879173579E+00	0.1015226859E+01	0.1043769284E+01	0.1072429867E+01
10 0.9538232015E+00	0.9799102187E+00	0.1009451296E+01	0.1042058714E+01	0.1076349582E+01	0.1110547637E+01
11 0.9680154714E+00	0.9976604490E+00	0.1031838363E+01	0.1070161147E+01	0.1098086850E+01	0.1122823888E+01
12 0.9820605916E+00	0.1015186093E+01	0.1053835571E+01	0.1097590716E+01	0.1189845115E+01	0.12477179319E+01
13 0.9954574639E+00	0.1031775396E+01	0.1074381393E+01	0.1122816465E+01	0.12680076514E+01	0.1398368152E+01
14 0.1007790000E+01	0.1046896891E+01	0.1092839400E+01	0.1145098097E+01	0.12545736193E+01	0.13889419136E+01
15 0.1018748020E+01	0.1060208602E+01	0.1108903975E+01	0.1164263808E+01	0.12686858131E+01	0.14051182075E+01
16 0.1028115198E+01	0.1071502388E+01	0.1122420428E+01	0.1180260845E+01	0.12803885290E+01	0.14184746211E+01
17 0.1035744869E+01	0.1080648738E+01	0.1133301854E+01	0.1193068409E+01	0.12897163951E+01	0.14290880294E+01
18 0.1041538836E+01	0.1087565652E+01	0.1141496743E+01	0.12026677580E+01	0.12966936700E+01	0.14370099900E+01
19 0.1045433168E+01	0.1092201717E+01	0.1146974298E+01	0.1209084693E+01	0.13013367517E+01	0.14422743185E+01
20 0.1047389380E+01	0.1094526746E+01	0.1149717041E+01	0.1212288432E+01	0.13036558405E+01	0.14449015990E+01

Continue of table II.5.4.

	19	20	21	22	23	24
1	0.9466547025E+00	0.9584836546E+00	0.9701361583E+00	0.9815065412E+00	0.9925036311E+00	0.1003051488E+01
2	0.9504357358E+00	0.9626067497E+00	0.9745832973E+00	0.9862558006E+00	0.9975309687E+00	0.1008332204E+01
3	0.9580730569E+00	0.9709392770E+00	0.9835726108E+00	0.9958557806E+00	0.1007691622E+01	0.1019002671E+01
4	0.9697205535E+00	0.9836577090E+00	0.9972979021E+00	0.1010512784E+01	0.1023200482E+01	0.1035283485E+01
5	0.9856181934E+00	0.1001036802E+01	0.1016059509E+01	0.1030544795E+01	0.1044387169E+01	0.1057511735E+01
6	0.1006105063E+01	0.1023463118E+01	0.1040276438E+01	0.1056391600E+01	0.1071704311E+01	0.1086147892E+01
7	0.1031639685E+01	0.1051453922E+01	0.1070501267E+01	0.1088625765E+01	0.1105735633E+01	0.1121781973E+01
8	0.1062818504E+01	0.1085666554E+01	0.1107419535E+01	0.1127945321E+01	0.1147184537E+01	0.1165119644E+01
9	0.1100267563E+01	0.1126755309E+01	0.1151686646E+01	0.1174999102E+01	0.1196692099E+01	0.1216794996E+01
10	0.1143278304E+01	0.1173924290E+01	0.1202429089E+01	0.1228848749E+01	0.1253265798E+01	0.1275769695E+01
11	0.7471399004E+00	0.7691640877E+00	0.7894409117E+00	0.8080935781E+00	0.8252326053E+00	0.8409554563E+00
12	0.7747421606E+00	0.7994638086E+00	0.8220609622E+00	0.8427320513E+00	0.8616408272E+00	0.8789234546E+00
13	0.7996805636E+00	0.8268759599E+00	0.8516345728E+00	0.8742012644E+00	0.8947791997E+00	0.9135361292E+00
14	0.8211707180E+00	0.8505218289E+00	0.8772003260E+00	0.9014696694E+00	0.9235565484E+00	0.9436511159E+00
15	0.8393198420E+00	0.8704904792E+00	0.8988170873E+00	0.9245651517E+00	0.9479724139E+00	0.9692429876E+00
16	0.8542725830E+00	0.8869343686E+00	0.9166284861E+00	0.9436158625E+00	0.9681377820E+00	0.9904060539E+00
17	0.8661343075E+00	0.8999716329E+00	0.9307531480E+00	0.9587336163E+00	0.9841542411E+00	0.1007230560E+01
18	0.8749769361E+00	0.9096857381E+00	0.9412780859E+00	0.9700031944E+00	0.9961008806E+00	0.1019788213E+01
19	0.8808480425E+00	0.9161330341E+00	0.9482634741E+00	0.9774845842E+00	0.1004034747E+01	0.1028131514E+01
20	0.8837766911E+00	0.9193483559E+00	0.9517470701E+00	0.9812159940E+00	0.1007992663E+01	0.1032294720E+01
	25	26	27	28	29	30
1	0.1013089006E+01	0.1022568735E+01	0.1031455263E+01	0.1039723408E+01	0.1047356416E+01	0.1054344279E+01
2	0.1018598795E+01	0.1028284363E+01	0.1037354925E+01	0.1045786882E+01	0.1053565067E+01	0.1060680977E+01
3	0.1029729432E+01	0.1039827997E+01	0.1049267500E+01	0.1058027669E+01	0.1066096619E+01	0.1073468930E+01
4	0.1046705224E+01	0.1057426358E+01	0.1067421290E+01	0.1076675144E+01	0.1085181210E+01	0.1092938848E+01
5	0.1069868012E+01	0.1081424324E+01	0.1092163172E+01	0.1102077554E+01	0.1111168086E+01	0.1119440756E+01
6	0.1099683084E+01	0.1112290226E+01	0.1123963485E+01	0.1134706664E+01	0.1144530109E+01	0.1153448420E+01
7	0.1136744133E+01	0.1150620042E+01	0.1163419783E+01	0.1175161239E+01	0.1185867074E+01	0.1195562577E+01
8	0.1181757812E+01	0.1197120972E+01	0.1211239725E+01	0.1224149459E+01	0.1235887777E+01	0.1246492731E+01
9	0.1235352458E+01	0.1252416791E+01	0.1268043546E+01	0.1282288854E+01	0.1295207714E+01	0.1306852863E+01
10	0.1296450462E+01	0.1315395861E+01	0.1332689911E+01	0.1348412053E+01	0.1362636647E+01	0.1375432669E+01
11	0.8553493132E+00	0.8684930094E+00	0.8804582360E+00	0.8913103217E+00	0.9011087597E+00	0.9099075832E+00
12	0.8946964427E+00	0.9090616243E+00	0.9221092033E+00	0.9339196977E+00	0.9445652352E+00	0.9541104568E+00
13	0.9306139312E+00	0.9461350806E+00	0.9602068029E+00	0.9729238072E+00	0.9843701532E+00	0.9946205712E+00
14	0.9619150627E+00	0.9784879694E+00	0.9934917165E+00	0.1007033547E+01	0.1019208238E+01	0.1030099690E+01
15	0.9885527123E+00	0.1006054395E+01	0.1021881833E+01	0.1036152803E+01	0.1048971298E+01	0.1060429215E+01
16	0.1010605864E+01	0.1028899639E+01	0.1045430363E+01	0.1060324253E+01	0.1073692869E+01	0.1085634800E+01
17	0.1028153531E+01	0.1047092188E+01	0.1064196237E+01	0.1079598314E+01	0.1093415891E+01	0.1105752870E+01
18	0.1041259486E+01	0.1060688010E+01	0.1078228105E+01	0.1094016976E+01	0.1108176407E+01	0.1120814245E+01
19	0.1049970948E+01	0.1069728878E+01	0.1087562476E+01	0.1103611862E+01	0.1118001626E+01	0.1130842211E+01
20	0.1054318983E+01	0.1074242437E+01	0.1092223611E+01	0.1108404043E+01	0.1122909697E+01	0.1135852308E+01
	31	32	33	34	35	36
1	0.1060682213E+01	0.1066369335E+01	0.1071407531E+01	0.1075800506E+01	0.1079552992E+01	0.1082670105E+01
2	0.1067131213E+01	0.1072916130E+01	0.1078038702E+01	0.1082503573E+01	0.1086316277E+01	0.1089482596E+01
3	0.1080144009E+01	0.1086124710E+01	0.1091416198E+01	0.1096025007E+01	0.1099958268E+01	0.1103223100E+01
4	0.1099951767E+01	0.1106226625E+01	0.1111771900E+01	0.1116596968E+01	0.1120711374E+01	0.1124124235E+01
5	0.1126905156E+01	0.1133573096E+01	0.1139457512E+01	0.1144571594E+01	0.1148928104E+01	0.1152538830E+01
6	0.1161478730E+01	0.1168639386E+01	0.1174948941E+01	0.1180425370E+01	0.1185085457E+01	0.1188944321E+01
7	0.1204274112E+01	0.1212027958E+01	0.1218849440E+01	0.1224762275E+01	0.1229788065E+01	0.1233945908E+01
8	0.1256001577E+01	0.1264449885E+01	0.1271870877E+01	0.1278294939E+01	0.1283749254E+01	0.1288257527E+01
9	0.1317274001E+01	0.1326517256E+01	0.1334624789E+01	0.1341634525E+01	0.1347579949E+01	0.1352489958E+01
10	0.1386863521E+01	0.1396986921E+01	0.1405854833E+01	0.1413513437E+01	0.1420003110E+01	0.1425358434E+01
11	0.9177556447E+00	0.9246968314E+00	0.9307702365E+00	0.9360102997E+00	0.9404469229E+00	0.9441055666E+00
12	0.9626131713E+00	0.9701248459E+00	0.9766909843E+00	0.9823514245E+00	0.9871405773E+00	0.9910876183E+00
13	0.1003741429E+01	0.1011791459E+01	0.1018822320E+01	0.1024879039E+01	0.1030000363E+01	0.1034219042E+01
14	0.1039782106E+01	0.1048320905E+01	0.1055773431E+01	0.1062189512E+01	0.1067611911E+01	0.1072076690E+01
15	0.1070607668E+01	0.1079578014E+01	0.1087402664E+01	0.1094135741E+01	0.1099823611E+01	0.1104505307E+01
16	0.1096237005E+01	0.1105575901E+01	0.1113718249E+01	0.1120721869E+01	0.1126636234E+01	0.1131502948E+01
17	0.1116700916E+01	0.1126340554E+01	0.1134742092E+01	0.1141966379E+01	0.1148065440E+01	0.1153082993E+01
18	0.1132025681E+01	0.1141894344E+01	0.1150493238E+01	0.1157885522E+01	0.1164125173E+01	0.1169257526E+01
19	0.1142231154E+01	0.1152254162E+01	0.1160986048E+01	0.1168491530E+01	0.1174825900E+01	0.1180035590E+01
20	0.1147330580E+01	0.1157431259E+01	0.1166230070E+01	0.1173792512E+01	0.1180174542E+01	0.1185423143E+01

Continue of table II.5.4.

	37	38	39	40	
1	0.1085156827E+01	0.1087017599E+01	0.1088256008E+01	0.1088874566E+01	1
2	0.1092008053E+01	0.1093897512E+01	0.1095154876E+01	0.1095782860E+01	2
3	0.1105826110E+01	0.1107773009E+01	0.1109068323E+01	0.1109715181E+01	3
4	0.1126843785E+01	0.1128877003E+01	0.1130229351E+01	0.1130904573E+01	4
5	0.1155414166E+01	0.1157562781E+01	0.1158991381E+01	0.1159704526E+01	5
6	0.1192015051E+01	0.1194308418E+01	0.1195832672E+01	0.1196593393E+01	6
7	0.1237252105E+01	0.1239719935E+01	0.1241359491E+01	0.1242177562E+01	7
8	0.1291839777E+01	0.1294512177E+01	0.1296286949E+01	0.1297172282E+01	8
9	0.1356388759E+01	0.1359295791E+01	0.1361225674E+01	0.1362188171E+01	9
10	0.1429608196E+01	0.1432775405E+01	0.1434877306E+01	0.1435925385E+01	10
11	0.9470073303E+00	0.9491690166E+00	0.9506031838E+00	0.9513181828E+00	11
12	0.9942166426E+00	0.9965467857E+00	0.9980923205E+00	0.9988627242E+00	12
13	0.1037562052E+01	0.1040050772E+01	0.1041701124E+01	0.1042523668E+01	13
14	0.1075613497E+01	0.1078245792E+01	0.1079991025E+01	0.1080860761E+01	14
15	0.1108212878E+01	0.1110971652E+01	0.1112800454E+01	0.1113711750E+01	15
16	0.1135356132E+01	0.1138222738E+01	0.1140122777E+01	0.1141069498E+01	16
17	0.1157054871E+01	0.1160009358E+01	0.1161967448E+01	0.1162943035E+01	17
18	0.1173319726E+01	0.1176341081E+01	0.1178343337E+01	0.1179340885E+01	18
19	0.1184158631E+01	0.1187225024E+01	0.1189257027E+01	0.1190269365E+01	19
20	0.1189576794E+01	0.1192665845E+01	0.1194712813E+01	0.1195732591E+01	20

Table II.5.5.

Specific power by "channels" at time T=17.0

	1	2	3	4	5	6
1	0.6329843806E+00	0.6348948669E+00	0.6387157431E+00	0.6444462258E+00	0.6520836598E+00	0.6616217364E+00
2	0.6335637635E+00	0.6354939698E+00	0.6393548599E+00	0.6451467978E+00	0.6528688407E+00	0.6625169378E+00
3	0.6347089134E+00	0.6366781807E+00	0.6406183475E+00	0.6465320866E+00	0.6544219144E+00	0.6642883595E+00
4	0.6363928374E+00	0.6384197414E+00	0.6424769238E+00	0.6485705523E+00	0.6567084012E+00	0.6668980112E+00
5	0.6385756562E+00	0.6406776056E+00	0.6448872128E+00	0.6512153422E+00	0.6596768755E+00	0.6702889148E+00
6	0.6412053591E+00	0.6433981818E+00	0.6477924525E+00	0.6544049258E+00	0.6632594523E+00	0.6743853180E+00
7	0.6442188433E+00	0.6465163682E+00	0.6511235127E+00	0.6580640617E+00	0.6673726373E+00	0.6790932993E+00
8	0.6475432548E+00	0.6499569060E+00	0.6548002659E+00	0.6621051756E+00	0.6719186697E+00	0.6843019810E+00
9	0.6510976253E+00	0.6536360514E+00	0.6587333270E+00	0.6664301913E+00	0.6767874517E+00	0.6898855299E+00
10	0.6547947885E+00	0.6574635540E+00	0.6628261567E+00	0.6709328261E+00	0.6818591053E+00	0.6957060452E+00
11	0.6585435345E+00	0.6613448987E+00	0.6669774854E+00	0.6755013048E+00	0.6870071102E+00	0.7016172958E+00
12	0.6622509385E+00	0.6651837420E+00	0.6710839750E+00	0.6800213899E+00	0.6921018895E+00	0.7074691197E+00
13	0.6658247854E+00	0.6688844546E+00	0.6750430114E+00	0.6843795847E+00	0.6970146336E+00	0.7131121718E+00
14	0.6691759975E+00	0.6723546681E+00	0.6787555011E+00	0.6884663367E+00	0.7016211196E+00	0.7184026471E+00
15	0.6722209784E+00	0.6755077272E+00	0.6821285492E+00	0.6921790807E+00	0.7058052907E+00	0.7232066268E+00
16	0.6748837880E+00	0.6782649552E+00	0.6850779106E+00	0.6954249813E+00	0.7094624121E+00	0.7274037876E+00
17	0.6770980832E+00	0.6805576629E+00	0.6875301367E+00	0.6981232850E+00	0.7125016931E+00	0.7308903463E+00
18	0.6788087755E+00	0.6823288527E+00	0.6894243681E+00	0.7002072368E+00	0.7148483440E+00	0.7335812372E+00
19	0.6799733697E+00	0.6835345847E+00	0.6907137502E+00	0.7016255534E+00	0.7164450908E+00	0.7354116082E+00
20	0.6805629739E+00	0.6841450000E+00	0.6913664771E+00	0.7023434823E+00	0.7172532191E+00	0.7363377760E+00
	7	8	9	10	11	12
1	0.6730481237E+00	0.6863415417E+00	0.7014683620E+00	0.7183788845E+00	0.7370035429E+00	0.7572494164E+00
2	0.6740815100E+00	0.6875444273E+00	0.7028754332E+00	0.7200281384E+00	0.7389358151E+00	0.7595073703E+00
3	0.6761274654E+00	0.6899275976E+00	0.7056655485E+00	0.7233019938E+00	0.7427764639E+00	0.7640021898E+00
4	0.6791441241E+00	0.6934453043E+00	0.7097896529E+00	0.7281495412E+00	0.7484753869E+00	0.7706887124E+00
5	0.6830682172E+00	0.6980277016E+00	0.7151718171E+00	0.7344905239E+00	0.7559516392E+00	0.7794914652E+00
6	0.6878148098E+00	0.7035797838E+00	0.7217069060E+00	0.7422111008E+00	0.7650865819E+00	0.7902947417E+00
7	0.6932774342E+00	0.7099806673E+00	0.7292583849E+00	0.7511592134E+00	0.7757154374E+00	0.8029287811E+00
8	0.6993289814E+00	0.7170837985E+00	0.7376571824E+00	0.7611409077E+00	0.7876189795E+00	0.8171534232E+00
9	0.7058236810E+00	0.7247186849E+00	0.7467026712E+00	0.7719194909E+00	0.8005185643E+00	0.8326440938E+00
10	0.7126003802E+00	0.7326945892E+00	0.7561666827E+00	0.7832194383E+00	0.8140785730E+00	0.8489887831E+00
11	0.7194871175E+00	0.7408062713E+00	0.7658008872E+00	0.7947360583E+00	0.8279191395E+00	0.8657042458E+00
12	0.7263067207E+00	0.7488413843E+00	0.7753469743E+00	0.8061501666E+00	0.8416384559E+00	0.8822720872E+00
13	0.7328829334E+00	0.7565887083E+00	0.7845482229E+00	0.8171452009E+00	0.8548396965E+00	0.8981845161E+00
14	0.7390464706E+00	0.7638462045E+00	0.7931606463E+00	0.8274233388E+00	0.8671555483E+00	0.9129839834E+00
15	0.7446404475E+00	0.7704279779E+00	0.8009621443E+00	0.8367177880E+00	0.8782649207E+00	0.9262856097E+00
16	0.7495248052E+00	0.7761695925E+00	0.8077588373E+00	0.8448000585E+00	0.8879003569E+00	0.9377816567E+00
17	0.7535795931E+00	0.7809316178E+00	0.8133885994E+00	0.8514827316E+00	0.8958482107E+00	0.9472348918E+00
18	0.7567071781E+00	0.7846016485E+00	0.8177224128E+00	0.8566192059E+00	0.9019450186E+00	0.9544685630E+00
19	0.7588335836E+00	0.7870952162E+00	0.8206643720E+00	0.8601019962E+00	0.9060728984E+00	0.9593574625E+00
20	0.7599092171E+00	0.7883560497E+00	0.8221510986E+00	0.8618607660E+00	0.9081555633E+00	0.9618214617E+00
	13	14	15	16	17	18
1	0.7789975349E+00	0.8021015268E+00	0.8263881115E+00	0.8516597452E+00	0.8776993971E+00	0.9042770409E+00
2	0.7816240391E+00	0.8051374662E+00	0.8298698459E+00	0.8556165950E+00	0.8821516205E+00	0.9092347063E+00
3	0.7868614467E+00	0.8112023073E+00	0.8368378744E+00	0.8635488970E+00	0.8910900861E+00	0.9191995360E+00
4	0.7946751479E+00	0.8202786440E+00	0.8472987120E+00	0.8754925616E+00	0.9045831324E+00	0.9342723023E+00
5	0.8050041394E+00	0.8323312677E+00	0.8612549062E+00	0.8914978610E+00	0.9227341668E+00	0.9546091446E+00
6	0.8177484306E+00	0.8472937435E+00	0.8786939244E+00	0.9116238388E+00	0.9456831801E+00	0.9804292756E+00
7	0.8327492893E+00	0.8650450923E+00	0.8995673509E+00	0.9359272538E+00	0.9736090543E+00	0.1012028160E+01
8	0.8497604473E+00	0.8853688033E+00	0.9237482041E+00	0.9644349721E+00	0.1006726118E+01	0.1049790573E+01
9	0.8684149248E+00	0.9078825517E+00	0.9509289963E+00	0.9970424879E+00	0.1045199596E+01	0.1094103586E+01
10	0.8882047956E+00	0.9319663473E+00	0.9803996885E+00	0.1033026921E+01	0.1088264501E+01	0.1144106192E+01
11	0.9084981636E+00	0.9567616171E+00	0.1010932495E+01	0.1070564230E+01	0.5854614616E+00	0.6180997058E+00
12	0.9286021310E+00	0.9812900262E+00	0.1041033050E+01	0.1107364719E+01	0.6081853972E+00	0.6444795377E+00
13	0.9478486619E+00	0.1004638865E+01	0.1069393343E+01	0.1141606192E+01	0.6291559355E+00	0.6687130487E+00
14	0.9656634583E+00	0.1026089597E+01	0.1095157042E+01	0.1172299419E+01	0.6477378601E+00	0.6900364314E+00
15	0.9815930270E+00	0.1045134285E+01	0.1117828743E+01	0.1199057950E+01	0.6638102267E+00	0.7083837800E+00
16	0.9952960866E+00	0.1061422230E+01	0.1137092854E+01	0.1221649551E+01	0.6773075411E+00	0.7237343678E+00
17	0.1006520999E+01	0.1074705613E+01	0.1152729771E+01	0.1239906355E+01	0.6881751189E+00	0.7360616057E+00
18	0.1015085280E+01	0.1084807674E+01	0.1164582695E+01	0.1253703162E+01	0.6963672740E+00	0.7453370275E+00
19	0.1020861684E+01	0.1091606361E+01	0.1172542344E+01	0.1262949806E+01	0.7018487048E+00	0.7515357625E+00
20	0.1023769492E+01	0.1095024444E+01	0.1176539131E+01	0.1267587608E+01	0.7045954619E+00	0.7546398169E+00

Continue of table II.5.5.

19	20	21	22	23	24
1 0.9311571043E+00	0.9581059544E+00	0.9848985516E+00	0.1011323657E+01	0.1037187324E+01	0.1062314728E+01
2 0.9366200566E+00	0.9640648020E+00	0.9913363688E+00	0.1018217994E+01	0.1044512149E+01	0.1070042063E+01
3 0.9476097895E+00	0.9760586602E+00	0.1004298149E+01	0.1032100515E+01	0.1059261409E+01	0.1085600601E+01
4 0.9642567524E+00	0.9942430876E+00	0.1023959364E+01	0.1053161751E+01	0.1081636718E+01	0.1109200075E+01
5 0.9867642705E+00	0.1018860036E+01	0.1050591454E+01	0.1081694649E+01	0.1111946417E+01	0.1141159934E+01
6 0.1015419724E+01	0.1050249577E+01	0.1084572200E+01	0.1118102953E+01	0.1150612134E+01	0.1181914531E+01
7 0.1050612159E+01	0.1088866126E+01	0.1126397959E+01	0.1162909495E+01	0.1198174173E+01	0.1232016593E+01
8 0.1092846235E+01	0.1135282961E+01	0.1176677831E+01	0.1216743304E+01	0.1255274169E+01	0.1292117058E+01
9 0.1142620105E+01	0.1190031947E+01	0.1235950056E+01	0.1280141061E+01	0.1322445866E+01	0.1362747364E+01
10 0.1198979807E+01	0.1252046923E+01	0.1303045308E+01	0.1351842831E+01	0.1398349590E+01	0.1442496916E+01
11 0.6499408554E+00	0.6804362592E+00	0.7095374972E+00	0.7372395020E+00	0.7635367164E+00	0.7884213926E+00
12 0.6797110242E+00	0.7132256393E+00	0.7450390976E+00	0.7751997563E+00	0.8037389316E+00	0.8306748120E+00
13 0.7070050422E+00	0.7433060208E+00	0.7776501849E+00	0.8101169462E+00	0.8407639535E+00	0.8696300747E+00
14 0.7309618456E+00	0.7697136488E+00	0.8063140510E+00	0.8408520455E+00	0.8733995290E+00	0.9040092432E+00
15 0.7515233277E+00	0.7923666316E+00	0.8309157237E+00	0.8672567352E+00	0.9014664755E+00	0.9336053597E+00
16 0.7686907823E+00	0.8112662535E+00	0.8514434436E+00	0.8893011542E+00	0.9249157558E+00	0.9583508870E+00
17 0.7824550666E+00	0.8264085291E+00	0.8678887776E+00	0.9069667843E+00	0.9437162441E+00	0.9782014205E+00
18 0.7927996729E+00	0.8377821082E+00	0.8802393225E+00	0.9202357070E+00	0.9578418978E+00	0.9931216096E+00
19 0.7997074453E+00	0.8453737623E+00	0.8884819654E+00	0.9290918396E+00	0.9672715792E+00	0.1003084101E+01
20 0.8031649586E+00	0.8491726020E+00	0.8926061783E+00	0.9335231225E+00	0.9719903056E+00	0.1008070126E+01
25	26	27	28	29	30
1 0.1086550609E+01	0.1109758696E+01	0.1131820482E+01	0.1152633658E+01	0.1172110411E+01	0.1190175752E+01
2 0.1094651745E+01	0.1118205022E+01	0.1140583980E+01	0.1161687161E+01	0.1181427705E+01	0.1199731577E+01
3 0.1110961066E+01	0.1135207158E+01	0.1158222395E+01	0.1179907189E+01	0.1200176689E+01	0.1218958828E+01
4 0.1135694343E+01	0.1160985517E+01	0.1184959864E+01	0.1210752099E+01	0.1228587310E+01	0.1248089848E+01
5 0.1169179284E+01	0.1195874229E+01	0.1221135753E+01	0.1244872401E+01	0.1267007330E+01	0.1287475935E+01
6 0.1211859783E+01	0.1240324781E+01	0.1267207938E+01	0.1292424898E+01	0.1315905295E+01	0.1337590267E+01
7 0.1264298185E+01	0.1294907548E+01	0.1323753890E+01	0.1350762448E+01	0.1375871211E+01	0.1399028504E+01
8 0.1327153252E+01	0.1360288460E+01	0.1391446378E+01	0.1420564441E+01	0.1447590876E+01	0.1472482593E+01
9 0.1400955224E+01	0.1436997619E+01	0.1470816246E+01	0.1502363127E+01	0.1531598414E+01	0.1558488834E+01
10 0.1484229819E+01	0.1523503173E+01	0.1560279415E+01	0.1594527006E+01	0.1626219335E+01	0.1655333896E+01
11 0.8118849421E+00	0.8339188287E+00	0.8545150159E+00	0.8736661653E+00	0.8913657042E+00	0.9076078256E+00
12 0.8560177924E+00	0.8797737185E+00	0.9019457458E+00	0.9225354236E+00	0.9415433436E+00	0.9589695345E+00
13 0.8967419006E+00	0.9221181080E+00	0.9457721500E+00	0.9677139333E+00	0.9879508919E+00	0.1006488692E+01
14 0.9327200126E+00	0.9595609509E+00	0.9845543106E+00	0.1007717387E+01	0.1029063811E+01	0.1048604442E+01
15 0.9637204061E+00	0.9918485063E+00	0.1018018925E+01	0.1042255116E+01	0.1064576034E+01	0.1084997103E+01
16 0.9896584164E+00	0.1018880575E+01	0.1046051864E+01	0.1071200587E+01	0.1094350046E+01	0.1115519480E+01
17 0.1010476680E+01	0.1040587643E+01	0.1068572482E+01	0.1094463106E+01	0.1118286177E+01	0.1140063954E+01
18 0.1026130280E+01	0.1056915515E+01	0.1085517892E+01	0.1111971824E+01	0.1136306389E+01	0.1158546078E+01
19 0.1036585188E+01	0.1067823497E+01	0.1096841028E+01	0.1123673754E+01	0.1148352306E+01	0.1170902634E+01
20 0.1041818434E+01	0.1073284329E+01	0.1102510464E+01	0.1129533559E+01	0.1154385000E+01	0.1177091459E+01
31	32	33	34	35	36
1 0.1206765944E+01	0.1221827079E+01	0.1235313826E+01	0.1247188346E+01	0.1257419367E+01	0.1265981411E+01
2 0.1216535934E+01	0.1231787682E+01	0.1245442207E+01	0.1257462285E+01	0.1267817166E+01	0.1276481803E+01
3 0.1236192596E+01	0.1251826540E+01	0.1265817485E+01	0.1278129445E+01	0.1288732711E+01	0.1297603096E+01
4 0.1265970421E+01	0.1282180082E+01	0.1296677830E+01	0.1309429535E+01	0.1320407047E+01	0.1329587462E+01
5 0.1306223917E+01	0.1323205727E+01	0.1338383284E+01	0.1351724929E+01	0.1363204576E+01	0.1372801014E+01
6 0.1357430522E+01	0.1375384813E+01	0.1391418713E+01	0.1405503638E+01	0.1417616053E+01	0.1427736830E+01
7 0.1420191165E+01	0.1439323133E+01	0.1456394346E+01	0.1471379858E+01	0.1484259138E+01	0.1495015503E+01
8 0.1495203621E+01	0.1515723909E+01	0.1534018400E+01	0.1550066299E+01	0.1563850480E+01	0.1575357026E+01
9 0.1583006524E+01	0.1605128148E+01	0.1624834202E+01	0.1642108466E+01	0.1656937563E+01	0.1669310606E+01
10 0.1681851654E+01	0.1705756535E+01	0.1727035017E+01	0.1745675797E+01	0.1761669512E+01	0.1776008514E+01
11 0.9223874537E+00	0.9357001936E+00	0.9475422754E+00	0.9579104988E+00	0.9668021807E+00	0.9742151088E+00
12 0.9748137081E+00	0.9890754112E+00	0.1001754122E+01	0.1012849311E+01	0.1022360474E+01	0.1030287162E+01
13 0.1023331709E+01	0.1038483351E+01	0.1051946294E+01	0.1063722643E+01	0.1073814055E+01	0.1082221825E+01
14 0.1066348004E+01	0.1082301541E+01	0.1096470758E+01	0.1108860269E+01	0.1119473792E+01	0.1128314294E+01
15 0.1103530924E+01	0.1120187823E+01	0.1134976255E+01	0.1147903132E+01	0.1158974065E+01	0.1168193559E+01
16 0.1134724794E+01	0.1151979138E+01	0.1167293362E+01	0.1180676384E+01	0.1192135479E+01	0.1201676511E+01
17 0.1159815005E+01	0.1177554786E+01	0.1193296119E+01	0.1207049585E+01	0.1218823845E+01	0.1228625897E+01
18 0.1178711452E+01	0.1196819716E+01	0.1212885199E+01	0.1226919761E+01	0.1238933131E+01	0.1248933185E+01
19 0.1191346626E+01	0.1209702658E+01	0.1225986074E+01	0.1240209600E+01	0.1252383692E+01	0.1262516823E+01
20 0.1197675483E+01	0.1216156035E+01	0.1232548970E+01	0.1246867451E+01	0.1259122301E+01	0.1269322295E+01

Continue of table II.5.5.

	37	38	39	40	
1	0.1272854155E+01	0.1278021927E+01	0.1281473308E+01	0.1283200839E+01	1
2	0.1283436223E+01	0.1288665023E+01	0.1292156980E+01	0.1293904768E+01	2
3	0.1304721319E+01	0.1310072516E+01	0.1313645856E+01	0.1315434272E+01	3
4	0.1336952528E+01	0.1342488181E+01	0.1346184175E+01	0.1348033823E+01	4
5	0.1380497350E+01	0.1386280569E+01	0.1390141189E+01	0.1392073027E+01	5
6	0.1435850741E+01	0.1441946055E+01	0.1446014231E+01	0.1448049695E+01	6
7	0.1503635672E+01	0.1510109416E+01	0.1514429286E+01	0.1516590421E+01	7
8	0.1584574852E+01	0.1591495418E+01	0.1596112504E+01	0.1598422049E+01	8
9	0.1679218912E+01	0.1686655788E+01	0.1691616355E+01	0.1694097424E+01	9
10	0.1785686690E+01	0.1793699315E+01	0.1799042939E+01	0.1801715308E+01	10
11	0.9801475005E+00	0.9845979712E+00	0.9875655053E+00	0.9890494370E+00	11
12	0.1036628986E+01	0.1041385633E+01	0.1044556863E+01	0.1046142518E+01	12
13	0.1088946949E+01	0.1093990177E+01	0.1097352044E+01	0.1099032893E+01	13
14	0.1135384099E+01	0.1140684979E+01	0.1144218211E+01	0.1145984623E+01	14
15	0.1175565166E+01	0.1181091603E+01	0.1184774833E+01	0.1186616133E+01	15
16	0.1209304116E+01	0.1215021846E+01	0.1218832274E+01	0.1220737075E+01	16
17	0.1236461283E+01	0.1242334256E+01	0.1246247902E+01	0.1248204230E+01	17
18	0.1256926168E+01	0.1262916879E+01	0.1266908801E+01	0.1268904202E+01	18
19	0.1270615719E+01	0.1276685549E+01	0.1280730069E+01	0.1282751725E+01	19
20	0.1277474403E+01	0.1283583982E+01	0.1287654926E+01	0.1289689772E+01	20

Table II.5.6.

Specific power by "channels" at time T=25.0

1	2	3	4	5	6
1 0.8701658347E+00	0.8710482280E+00	0.8728090168E+00	0.8754401440E+00	0.8789293737E+00	0.8832601208E+00
2 0.8703354057E+00	0.8712211463E+00	0.8729886618E+00	0.8756299574E+00	0.8791328865E+00	0.8834809743E+00
3 0.8706704584E+00	0.8715628196E+00	0.8733436406E+00	0.8760050518E+00	0.8795350859E+00	0.8839174901E+00
4 0.8711629045E+00	0.8720650123E+00	0.8738654232E+00	0.8765564560E+00	0.8801264139E+00	0.8845593806E+00
5 0.8718008361E+00	0.8727155976E+00	0.8745414444E+00	0.8772709469E+00	0.8808927706E+00	0.8853914527E+00
6 0.8725687944E+00	0.8734988282E+00	0.8753553793E+00	0.8781313313E+00	0.8818158025E+00	0.8863939018E+00
7 0.8734481208E+00	0.8743956918E+00	0.8762875064E+00	0.8791168196E+00	0.8828732895E+00	0.8875427099E+00
8 0.8744173893E+00	0.8753843494E+00	0.8773151575E+00	0.8802034923E+00	0.8840396302E+00	0.8888101549E+00
9 0.8754529100E+00	0.8764406467E+00	0.8784132450E+00	0.8813648508E+00	0.8852864245E+00	0.8901654284E+00
10 0.8765292961E+00	0.8775386914E+00	0.8795548595E+00	0.8825724456E+00	0.8865831422E+00	0.8915753565E+00
11 0.8776200804E+00	0.8786514819E+00	0.8807119239E+00	0.8837965683E+00	0.8878978675E+00	0.8930052103E+00
12 0.8786983673E+00	0.8797515737E+00	0.8818558876E+00	0.8850069900E+00	0.8891980964E+00	0.8944195832E+00
13 0.8797375033E+00	0.8808117642E+00	0.8829584427E+00	0.8861737243E+00	0.8904515670E+00	0.8957833071E+00
14 0.8807117470E+00	0.8818057794E+00	0.8839922413E+00	0.8872677935E+00	0.8916270920E+00	0.8970623741E+00
15 0.8815969212E+00	0.8827089400E+00	0.8849315930E+00	0.8882619729E+00	0.8926953684E+00	0.8982248317E+00
16 0.8823710270E+00	0.8834987899E+00	0.8857531216E+00	0.8891314908E+00	0.8936297366E+00	0.8992416175E+00
17 0.8830148043E+00	0.8841556691E+00	0.8864363624E+00	0.8898546639E+00	0.8944068667E+00	0.9000873104E+00
18 0.8835122221E+00	0.8846632145E+00	0.8869642844E+00	0.8904134501E+00	0.8950073529E+00	0.9007407764E+00
19 0.8838508865E+00	0.8850087760E+00	0.8873237225E+00	0.8907939058E+00	0.8954162025E+00	0.9011856959E+00
20 0.8840223561E+00	0.8851837383E+00	0.8875057114E+00	0.8909865371E+00	0.8956232104E+00	0.9014109653E+00
7	8	9	10	11	12
1 0.8884112397E+00	0.8943567861E+00	0.9010657733E+00	0.9085019444E+00	0.9166235913E+00	0.9253834516E+00
2 0.8886531977E+00	0.8946237368E+00	0.9013617155E+00	0.9088309565E+00	0.9169897788E+00	0.9257908715E+00
3 0.8891314900E+00	0.8951515190E+00	0.9019469308E+00	0.9094817179E+00	0.9177142671E+00	0.9265971862E+00
4 0.8898349617E+00	0.8959279827E+00	0.9028081599E+00	0.9104397668E+00	0.9187813255E+00	0.9277853611E+00
5 0.8907471162E+00	0.8969351279E+00	0.9039257183E+00	0.9116835803E+00	0.9201674771E+00	0.9293298969E+00
6 0.8918464096E+00	0.8981493934E+00	0.9052737670E+00	0.9131848113E+00	0.9218416810E+00	0.9311969339E+00
7 0.8931066589E+00	0.8995420668E+00	0.9068207121E+00	0.9149086572E+00	0.9237656418E+00	0.9333444672E+00
8 0.8944975726E+00	0.9010798329E+00	0.9085297606E+00	0.9168144035E+00	0.9258943093E+00	0.9357227532E+00
9 0.8959854094E+00	0.9027254742E+00	0.9103596582E+00	0.9188561873E+00	0.9281766405E+00	0.9382750198E+00
10 0.8975337606E+00	0.9044387240E+00	0.9122656206E+00	0.9209840096E+00	0.9305566858E+00	0.9409585996E+00
11 0.8991044436E+00	0.9061772606E+00	0.9142004502E+00	0.9231449969E+00	0.9329750221E+00	0.9436465571E+00
12 0.9006584794E+00	0.9078978129E+00	0.9161158011E+00	0.9252848696E+00	0.9353704829E+00	0.9463297641E+00
13 0.9021571214E+00	0.9095573314E+00	0.9179635332E+00	0.9273495334E+00	0.9376820632E+00	0.9489192365E+00
14 0.9035628913E+00	0.9111141695E+00	0.9196970788E+00	0.9292866832E+00	0.9398508351E+00	0.9513484652E+00
15 0.9048405817E+00	0.9125292218E+00	0.9212727488E+00	0.9310473180E+00	0.9418217188E+00	0.9535555025E+00
16 0.9059581868E+00	0.9137669700E+00	0.9226509166E+00	0.9325870845E+00	0.9435450075E+00	0.9554846761E+00
17 0.9068877312E+00	0.9147964035E+00	0.9237970408E+00	0.9338674106E+00	0.9449776076E+00	0.9570879137E+00
18 0.9076059761E+00	0.9155917924E+00	0.9246825097E+00	0.9348564158E+00	0.9460840023E+00	0.9583257316E+00
19 0.9080949905E+00	0.9161333050E+00	0.9252853019E+00	0.9355296095E+00	0.9468369710E+00	0.9591679504E+00
20 0.9083425818E+00	0.9164074674E+00	0.9255904733E+00	0.9358703954E+00	0.9472180986E+00	0.9595941921E+00
13	14	15	16	17	18
1 0.9347287170E+00	0.9446011848E+00	0.9549375757E+00	0.9656700302E+00	0.9767267760E+00	0.9880329437E+00
2 0.9351812803E+00	0.9451025411E+00	0.9554909890E+00	0.9662782582E+00	0.9773919681E+00	0.9887565691E+00
3 0.9360772441E+00	0.9460954656E+00	0.9565874201E+00	0.9674837266E+00	0.9787107769E+00	0.9901916463E+00
4 0.9373982668E+00	0.9475603325E+00	0.9582059942E+00	0.9692643418E+00	0.9806598988E+00	0.9923136393E+00
5 0.9391168089E+00	0.9494675888E+00	0.9603151960E+00	0.9715866723E+00	0.9832039976E+00	0.9950852667E+00
6 0.9411961396E+00	0.9517776503E+00	0.9628726509E+00	0.9744056158E+00	0.9862952558E+00	0.9984559292E+00
7 0.9435904202E+00	0.9544408257E+00	0.9658248802E+00	0.9776639868E+00	0.9898727916E+00	0.1002360940E+01
8 0.9462449537E+00	0.9573973512E+00	0.9691070934E+00	0.9812920709E+00	0.9938619744E+00	0.1006720565E+01
9 0.9490967547E+00	0.9605776863E+00	0.9726431357E+00	0.9852072531E+00	0.9981737434E+00	0.1011438965E+01
10 0.9520756564E+00	0.9639034197E+00	0.9763458033E+00	0.9893138598E+00	0.1002704309E+01	0.1016403266E+01
11 0.9551061400E+00	0.9672892457E+00	0.9801186240E+00	0.9935028805E+00	0.8563668934E+00	0.8683929793E+00
12 0.9581098800E+00	0.9706461714E+00	0.9838600718E+00	0.9976570175E+00	0.8602669463E+00	0.8726698674E+00
13 0.9610087049E+00	0.9738854560E+00	0.9874692303E+00	0.1001661570E+01	0.8640234522E+00	0.8767871196E+00
14 0.9637275025E+00	0.9769223402E+00	0.9908507881E+00	0.1005410611E+01	0.8675374173E+00	0.8806360060E+00
15 0.9661966814E+00	0.9796789034E+00	0.9939180605E+00	0.1008808500E+01	0.8707197473E+00	0.8841193426E+00
16 0.9683540470E+00	0.9820859888E+00	0.9965946399E+00	0.1011771402E+01	0.8734927142E+00	0.8871527510E+00
17 0.9701461569E+00	0.9840844845E+00	0.9988155438E+00	0.1014228325E+01	0.8757907485E+00	0.8896653107E+00
18 0.9715292860E+00	0.9856262180E+00	0.1000528010E+01	0.1016121816E+01	0.8775609355E+00	0.8915999417E+00
19 0.9724701094E+00	0.9866745799E+00	0.1001692047E+01	0.1017408428E+01	0.8787633443E+00	0.8929136529E+00
20 0.9729461704E+00	0.9872049478E+00	0.1002280805E+01	0.1018059038E+01	0.8793712465E+00	0.8935777048E+00

19	20	21	22	23	24
1 0.9995114879E+00	0.1011084163E+01	0.1022672500E+01	0.1034198732E+01	0.1045586635E+01	0.1056762258E+01
2 0.1000294303E+01	0.1011926220E+01	0.1023573189E+01	0.1035156850E+01	0.1046600469E+01	0.1057829672E+01
3 0.1001847137E+01	0.1013596880E+01	0.1025360416E+01	0.1037058204E+01	0.1048612498E+01	0.1059948091E+01
4 0.1004144168E+01	0.1016068959E+01	0.1028005560E+01	0.1039872665E+01	0.1051591038E+01	0.1063084256E+01
5 0.1007146079E+01	0.1019300991E+01	0.1031464879E+01	0.1043554120E+01	0.1055487543E+01	0.1067187163E+01
6 0.1010799352E+01	0.1023236362E+01	0.1035678504E+01	0.1048039322E+01	0.1060235327E+01	0.1072186692E+01
7 0.1015035284E+01	0.1027802113E+01	0.1040569021E+01	0.1053246285E+01	0.1065747800E+01	0.1077991693E+01
8 0.1019768720E+01	0.1032907352E+01	0.1046039598E+01	0.1059072168E+01	0.1071916158E+01	0.1084487534E+01
9 0.1024896510E+01	0.1038441259E+01	0.1051971642E+01	0.1065390674E+01	0.1078606579E+01	0.1091533128E+01
10 0.1030295770E+01	0.1044270849E+01	0.1058222242E+01	0.1072049261E+01	0.1085657267E+01	0.1098957853E+01
11 0.8805836370E+00	0.8928398663E+00	0.9050673600E+00	0.9171773926E+00	0.9290870964E+00	0.9407194913E+00
12 0.8852380057E+00	0.8978671727E+00	0.9104590026E+00	0.9229216238E+00	0.9351697686E+00	0.9471246563E+00
13 0.8897176676E+00	0.9027053873E+00	0.9156477619E+00	0.9284497589E+00	0.9410237217E+00	0.9532890895E+00
14 0.8939035469E+00	0.9072252245E+00	0.9204944924E+00	0.9336132304E+00	0.9464914471E+00	0.9590468455E+00
15 0.8976900457E+00	0.9113125552E+00	0.9248766599E+00	0.9382813620E+00	0.9514344709E+00	0.9642520461E+00
16 0.9009859314E+00	0.9148691670E+00	0.9286890801E+00	0.9423421319E+00	0.9557341597E+00	0.9687797349E+00
17 0.9037147896E+00	0.9178130452E+00	0.9318441073E+00	0.9457023228E+00	0.9592918634E+00	0.9725260308E+00
18 0.9058152741E+00	0.9200784939E+00	0.9342716581E+00	0.9482874844E+00	0.9620288476E+00	0.9754080504E+00
19 0.9072412638E+00	0.9216162020E+00	0.9359191965E+00	0.9500418610E+00	0.9638861832E+00	0.9773637782E+00
20 0.9079619642E+00	0.9223932803E+00	0.9367517152E+00	0.9509283248E+00	0.9648246472E+00	0.9783519472E+00
25	26	27	28	29	30
1 0.1067654531E+01	0.1078195756E+01	0.1088321979E+01	0.1097973273E+01	0.1107093931E+01	0.1115632587E+01
2 0.1068773051E+01	0.1079362643E+01	0.1089534298E+01	0.1099227946E+01	0.1108387779E+01	0.1116962367E+01
3 0.1070992911E+01	0.1081678480E+01	0.1091940264E+01	0.1101717917E+01	0.1110955438E+01	0.1119601274E+01
4 0.1074279280E+01	0.1085106895E+01	0.1095502017E+01	0.1105403904E+01	0.1114756288E+01	0.1123507442E+01
5 0.1078578723E+01	0.1089592077E+01	0.1100161457E+01	0.1110225634E+01	0.1119728010E+01	0.1128616653E+01
6 0.1083817734E+01	0.1095057238E+01	0.1105838650E+01	0.1116100193E+01	0.1125784903E+01	0.1134840624E+01
7 0.1089900722E+01	0.1101402504E+01	0.1112429647E+01	0.1122919791E+01	0.1132815592E+01	0.1142064667E+01
8 0.1096707419E+01	0.1108502228E+01	0.1119803709E+01	0.1130548914E+01	0.1140680126E+01	0.1150144749E+01
9 0.1104089797E+01	0.1116201799E+01	0.1127800034E+01	0.1138820984E+01	0.1149206579E+01	0.1158904035E+01
10 0.1111868873E+01	0.1124314366E+01	0.1136224413E+01	0.1147534956E+01	0.1158187601E+01	0.1168129403E+01
11 0.9520033942E+00	0.9628732588E+00	0.9732689769E+00	0.9831356598E+00	0.9924234116E+00	0.1001087106E+01
12 0.9587137815E+00	0.9698706559E+00	0.9805345284E+00	0.9906500995E+00	0.1000167240E+01	0.1009040724E+01
13 0.9651720581E+00	0.9766052197E+00	0.9875272002E+00	0.9978823056E+00	0.1007620187E+01	0.1016695525E+01
14 0.9712043583E+00	0.9828956864E+00	0.9940588535E+00	0.1004637786E+01	0.1014581924E+01	0.1023845861E+01
15 0.9766578226E+00	0.9885826556E+00	0.9999639974E+00	0.1010745414E+01	0.1020876144E+01	0.1030310698E+01
16 0.9814015019E+00	0.9935295431E+00	0.1005100787E+01	0.1016058469E+01	0.1026351638E+01	0.1035934727E+01
17 0.9853265315E+00	0.9976227795E+00	0.1009351249E+01	0.1020454883E+01	0.1030882570E+01	0.1040588665E+01
18 0.9883460562E+00	0.1000771746E+01	0.1012621230E+01	0.1023837218E+01	0.1034368463E+01	0.1044169260E+01
19 0.9903950946E+00	0.1002908643E+01	0.1014840278E+01	0.1026132545E+01	0.1036734103E+01	0.1046599203E+01
20 0.9914304100E+00	0.1003988356E+01	0.1015961509E+01	0.1027292330E+01	0.1037929427E+01	0.1047827029E+01
31	32	33	34	35	36
1 0.1123542285E+01	0.1130780509E+01	0.1137309171E+01	0.1143094591E+01	0.1148107448E+01	0.1152322735E+01
2 0.1124904717E+01	0.1132172294E+01	0.1138727006E+01	0.1144535177E+01	0.1149567497E+01	0.1153798974E+01
3 0.1127608361E+01	0.1134934128E+01	0.1141540478E+01	0.1147393745E+01	0.1152464644E+01	0.1156728210E+01
4 0.1131610203E+01	0.1139021959E+01	0.1145704607E+01	0.1151624502E+01	0.1156752394E+01	0.1161063363E+01
5 0.1136844287E+01	0.1144368252E+01	0.1151150447E+01	0.1157157264E+01	0.1162359502E+01	0.1166732304E+01
6 0.1143219960E+01	0.1150880215E+01	0.1157783301E+01	0.1163895659E+01	0.1169188161E+01	0.1173636026E+01
7 0.1150619514E+01	0.1158437407E+01	0.1165480295E+01	0.1171714686E+01	0.1177111544E+01	0.1181646183E+01
8 0.1158895189E+01	0.1166888717E+01	0.1174087335E+01	0.1180457642E+01	0.1185970712E+01	0.1190601977E+01
9 0.1167865690E+01	0.1176048835E+01	0.1183415546E+01	0.1189932539E+01	0.1195571014E+01	0.1200306537E+01
10 0.1177312657E+01	0.1185694695E+01	0.1193237696E+01	0.1199908502E+01	0.1205678463E+01	0.1210523291E+01
11 0.1009086171E+01	0.1016384386E+01	0.1022949693E+01	0.1028754029E+01	0.1033773170E+01	0.1037986602E+01
12 0.1017229975E+01	0.1024698833E+01	0.1031415347E+01	0.1037351584E+01	0.1042483458E+01	0.1046790591E+01
13 0.1025067747E+01	0.1032700759E+01	0.1039562716E+01	0.1045625814E+01	0.1050866107E+01	0.1055263350E+01
14 0.1032389027E+01	0.1040175392E+01	0.1047173213E+01	0.1053354810E+01	0.1058696369E+01	0.1063177773E+01
15 0.1039008503E+01	0.1046933589E+01	0.1054054306E+01	0.1060343086E+01	0.1065776236E+01	0.1070333760E+01
16 0.1044767159E+01	0.1052813009E+01	0.1060040711E+01	0.1066422796E+01	0.1071935675E+01	0.1076559456E+01
17 0.1049532587E+01	0.1057678448E+01	0.1064994748E+01	0.1071454100E+01	0.1077033003E+01	0.1081711651E+01
18 0.1053199019E+01	0.1061421880E+01	0.1068806392E+01	0.1075325231E+01	0.1080954965E+01	0.1085675854E+01
19 0.1055687246E+01	0.1063962392E+01	0.1071393221E+01	0.1077952454E+01	0.1083616703E+01	0.1088366274E+01
20 0.1056944534E+01	0.1065246107E+01	0.1072700349E+01	0.1079279999E+01	0.1084961694E+01	0.1089725762E+01

Continue of table II.5.6.

	37	38	39	40	
1	0.1155719709E+01	0.1158281841E+01	0.1159996776E+01	0.1160856295E+01	1
2	0.1157208878E+01	0.1159780696E+01	0.1161502080E+01	0.1162364822E+01	2
3	0.1160163743E+01	0.1162754755E+01	0.1164488923E+01	0.1165358052E+01	3
4	0.1164536754E+01	0.1167156120E+01	0.1168909170E+01	0.1169787734E+01	4
5	0.1170255073E+01	0.1172911418E+01	0.1174689095E+01	0.1175579965E+01	5
6	0.1177218737E+01	0.1179919971E+01	0.1181727541E+01	0.1182633347E+01	6
7	0.1185298182E+01	0.1188051303E+01	0.1189893423E+01	0.1190816493E+01	7
8	0.1194331124E+01	0.1197142014E+01	0.1199022602E+01	0.1199964891E+01	8
9	0.1204118922E+01	0.1206992137E+01	0.1208914225E+01	0.1209877249E+01	9
10	0.1214422937E+01	0.1217361486E+01	0.1219327076E+01	0.1220311835E+01	10
11	0.1041377403E+01	0.1043932150E+01	0.1045640842E+01	0.1046496842E+01	11
12	0.1050256188E+01	0.1052866932E+01	0.1054612905E+01	0.1055487532E+01	12
13	0.1058800872E+01	0.1061465461E+01	0.1063247285E+01	0.1064139821E+01	13
14	0.1066782469E+01	0.1069497347E+01	0.1071312650E+01	0.1072221912E+01	14
15	0.1073999208E+01	0.1076759565E+01	0.1078605146E+01	0.1079529535E+01	15
16	0.1080277787E+01	0.1083077729E+01	0.1084949664E+01	0.1085887219E+01	16
17	0.1085473771E+01	0.1088306492E+01	0.1090200250E+01	0.1091148707E+01	17
18	0.1089471686E+01	0.1092329643E+01	0.1094240200E+01	0.1095197050E+01	18
19	0.1092184995E+01	0.1095060087E+01	0.1096982052E+01	0.1097944600E+01	19
20	0.1093556055E+01	0.1096439807E+01	0.1098367537E+01	0.1099332966E+01	20

III. Comparison of some methods for solving a conditionally-critical problem with the New code.

A.S.Sukhikh.

Using solution of the problem formulated in the previous report section as an example, various methods for computing the principal eigenvalue and corresponding eigenvector of the generalized eigenvalue problem are compared. The comparison results are treated in this report section.

The following methods for solving the conditionally-critical problem are compared:

- 1) the method of inverse iteration with various fixed values of the shear parameter (the method of source iteration and the Wilandt method with and without Chebyshev acceleration) [8,9].
- 2) the method of inverse iteration with specification of the shear parameter value using the Rayleigh relation [8,9], and
- 3) the method of 'Rayleigh' iteration [10].

The first group represents methods conventionally used in reactor computations. The method of item 2 implies ability to solve high-dimensional systems of linear equations with nonsymmetrical, ill-conditioned and indefinite matrices.

The method of Rayleigh iteration is similar to the method of inverse iteration with specification of the shear parameter value by the Rayleigh formula. The difference is that approximate left and right eigenvectors are computed as a result of solution of two eigenvalue problems rather than that of two linear equation systems.

For simultaneous solution of linear equation systems with direct and conjugate matrices in the method of inverse iteration and for solution of eigenvalue problems in the method of Rayleigh iteration the Lanczos method in combination with the Galerkin method [11,8] was used. For matrix re-conditioning incomplete *LU*-decomposition with controllable accuracy [12] was used.

Preliminarily briefly dwell on comparison of test problem solution results obtained with the Neu code with those found with the NESTLE code. Currently in the Neu code the finite-difference scheme accurate within the second order in space is implemented, and to achieve high accuracy in this problem, a relatively high number of computational points is needed. Table III.1 gives the results of computations using computational grids of different refinement of regions homogeneous in their physical parameters (region dimensions : $DDX \times DDY \times DDZ = 4.92 \times 4.92 \times 19.68$ inch, refinement

degree: : NMULTZ=NMULTXY=1, 2, 4 и 8). In addition, the expected limit result (NMULTZ=NMULTXY= ∞),) which, apparently, will be reached by the Neu code at NMULTS=NMULTXY-32 and the result obtained with the NESTLE nodal code are given.

Accuracy of conditionally-critical problem solution (write the problem in the form

$$L\varphi = \frac{1}{K} \cdot Q\varphi, \quad (1)$$

$$\varphi > 0, K > 0, \quad (2)$$

where operator L describes neutron diffusion, absorption and scattering, operator Q describes generation of secondary neutrons, φ - neutron flux density, K - effective factor of neutron multiplication) was controlled by verification whether the following conditions for residue of equation (1) is satisfied:

$$\sum_j \left| \left(l_{ij} - \frac{1}{\tilde{K}} \cdot q_{ij} \right) \cdot \tilde{\varphi}_j \right| \leq t \cdot \left| \left(l_{ii} - \frac{1}{\tilde{K}} \cdot q_{ii} \right) \cdot \tilde{\varphi}_i \right|, \forall i, t = 10^{-5}, \quad (3)$$

where indices i and j are common for spatial computational points and energy neutron groups, l_{ij} and q_{ij} - elements of matrices L and Q, the parameter t sets required accuracy for the approximare solution $(\tilde{K}, \tilde{\varphi})$. Nequality (3) determines required degree of neutron disbalance at each spatial point and in each energy group relative to total neutron flux from it. At 32-bit computations maximum achievable accuracy corresponds to the value of the accuracy parameter $t \approx 10^{-7}$.

Table III.1.
Results of the test problem solution with Neu and NESTLE codes.

NMULTZ	NMULT XY	K Eff	$\Delta(K \text{ Eff})$	The number of external and the total number of internal iterations
1	1	1.01447		3 9
2	2	1.00596	0.00851	2 18
4	4	1.00363	0.00233=0.00851/3.7	2 33
8	8	1.00304	0.00059=0.00233/3.9	1 39
∞	∞	1.00283		
NESTLE		1.00283		

Various methods of conditionally-critical problem solution were compared on a problem with a grid refinement degree of NMULTS=NMULTXY=4. Since 1/32

fraction of a polycell was computed, then such a refinement degree corresponds to problem dimensionality equal to 8064 ($=2$ neutron groups $\times 12 \times 12$ computational points along axes X and $Y \times 28$ computational points along axis Z). It took from several minutes to several tens of minutes to solve these problems on PC/AT 386/387 33 MHz (while it took about half an hour to solve the fourth problem from Table 1-64512 unknowns).

The obtained value of the neutron multiplication factor (1.00363) was used to renormalize matrix Q so that the new problem have the principal eigenvalue equal to unity, $K = K_1 = 1$. All other results are given for the modified problem with the renormalized matrix Q . In particular, the value of the second eigenvalue equal to $K_2 = 0.935310$ was obtained for it.

For the initial vectors a vector with identical elements $\varphi_0 = \varphi_0^+ = \sigma \equiv (1, 1, \dots)^*$ was selected where φ_0^+ - initial approximation for the conjugate problem and various values of the initial value of the shear parameter k_0 .

The values of Chebyshev method parameters were computed in advance. One more preliminary remark pertains to the effect of LU -decomposition accuracy on problem solution time. Table III.2 gives the number of external and the total number of internal iterations and the time of problem solution with the method of Rayleigh iteration.

Table III.2

Dependence of problem solution time on LU -decomposition accuracy.

t_f	The number of external and the total number of internal iterations	Time of solution (sec.) i386/387/33	Time fraction used for LU -decomposition %	Time fraction used for iterations %
1	Convergence is not reached			
0.1	2 75	252	2	95
0.05	2 58	205	4	93
0.02	2 40	170	6	89
0.01	2 39	176	6	89
0.005	2 33	160	11	84
0.002	2 25	181	25	70
0.001	2 23	254	43	53

The number of iterations decreases with increase in decomposition accuracy, but the time of one iteration and the time of LU -decomposition grow, therefore the total time is minimum. The value of the parameter t_f limits the values of the error matrix

elements. Since at the first stage the number of error matrix filling elements grows with decrease in the value of the parameter t_f , then it is not improbable that the norm of the matrix can also grow. Then the number of iterations can even increase with decrease in the parameter t_f . At decomposition of the matrix on its portrait ($t_f=1$) convergence was not reached in the Lanczos method.

The table of problem solution time dependence on LU -decomposition accuracy for the method of inverse iteration with shear parameter specification by the Rayleigh formula shows up practically like Table III.2, in particular, the solution time minimum is also reached at $t_f = 0.005$, but convergence was not yet reached at $t_f = 0.1$. The use of more accurate LU -decomposition increases stability of computations with the Lanczos method.

Further computations were performed at $t_f = 0.005$.

The results of testing the methods for solution of the conditionally-critical problem (1)-(2) are given in Table III.3. In all the computations the error of the effective multiplication factor value was no more than $0.5 \cdot 10^{-5}$.

Table III.3.
The number of external and the total number of internal iterations.

k_0	1. Inverse iteration (Wilandt method)	2. Inverse iteration (Wilandt method)	3. Inverse iteration (accelerated Chebyshev)	4. Inverse iteration (accelerated Rayleigh)	5. Rayleigh iteration
10	61 120	50 265	14 83	3 43	4 33
2	40 77	29 188	-	3 36	4 38
1.3	26 58	14 132	8 89	3 34	3 35
1.1	25 69	7 97	5 84	3 38	3 34
1.03	14 51	4 75	3 62	3 40	2 32
1.01	13 48	2 45	2 45	3 45	2 34
1.003	12 54	2 46	2 46	2 38	2 38
1	1 23	1 23		1 23	1 23
0.997	37 91	2 46	2 43	2 38	2 23
0.99	17 60	3 66	3 68	2 32	2 34
0.96	→0.93531	→0.93531	5 115	3 40	2 31
0.935				3 36	2 28
0.9				3 32	3 34
0.7				3 34	3 32

Internal iteration convergence was controlled with two parameters : the ratio of residual norm to solution norm and the ratio of residual norm to right-hand side norm. The iteration stopped when one of these two ratios reached a preset value. In methods using shear parameter specification by the Rayleigh formula (two last columns of

Table III.3) the internal iterations, as a rule, stopped by the second parameter and sometimes, at the last external iteration, by the first. In the Chebyshev method (the third column of Table III.3) the second criterion was switched off, that is the residual norm-solution norm ratio was only controlled, since insufficient accuracy of equation solution led to divergence of the method. Computations using the method of inverse iteration without acceleration were performed in both the versions. In the case of higher accuracy of linear equation system solution at internal iterations (the second column of Table III.3) more regular convergence is observed, however, at high values of the shear parameter high accuracy appears to be excess.

On the whole it is seen from Table III.3 that for this problem the methods using shear parameter specification using the Rayleigh relation are more preferable as compared to conventional methods, particularly if solution of both direct and conjugate problems is needed. Conventional methods do not require solution of the conjugate problem, so for them the cost of one internal iteration can be twice as low, though it is hard to obtain an iterative procedure with the only matrix-by-vector multiplication at an iteration which would be of the same efficiency as the Lanczos method.

One more note regarding the method of Rayleigh iteration. The use of the Lanczos method to solve eigenvalue problems requires to memorize all the Lanczos vectors (since they are needed only at final solution assembly, their storage in the secondary memory is permitted; in the main memory four vectors have to be stored), while in the method of inverse iteration solution of linear equation systems requires to store only ten vectors (all the ten in the main memory).

The only qualitative advantage of the Rayleigh iteration method over the methods of inverse iteration, namely , a wider domain of convergence in the shear parameter, did not manifest in this example. Methods with a fixed shear parameter value converge to the principal eigenvalue only if $k_0 > K_2$, while the method of inverse iteration with specification of the shear parameter value by the Rayleigh formula can have unconnected domain of convergence depending on initial vectors (for the RBMK reactors there are examples where the domain of convergence is concentrated only nearby the principal eigenvalue at initial vectors $\varphi_0 = \varphi_0^+ = \sigma \equiv (1, 1, \dots)^*$). The closer are the initial vectors to the problem solution, the wider is the domain of convergence.

The domain of convergence of Rayleigh iteration is only restricted with existence of regular LU -decomposition at shear parameter values from this domain (if LU -decomposition is not used the method is not efficient).

In this problem one can demonstrate unconnectivity of the inverse iteration method domain of connectivity if internal iterations are not stopped by the second criterion, that is if the linear equation systems are solved more accurately, then at the start from the value $k_0 = 0.935$ which is in immediate proximity to the second eigenvalue $K_2 = 0.935310$ convergence just to the value K_2 is observed. At the start from the value lying in the middle between the second and third eigenvalues, nevertheless, convergence to the principal eigenvalue is also observed.

One of the performed computations failed: Lanczos iterations did not converge at one of external iterations. Unfortunately such things sometimes happen in practice at the start of the Lanczos method from residual vectors. Currently the author of this section is working on mastering more reliable methods.

It should be noted that this example being relatively complex in terms of approximation accuracy and, hence, problem dimensionality is fairly simple in terms of iteration convergence owing to the fact that the first and second eigenvalues are a substantial distance off each other ($K_2/K_1 = 0.935$). More complex problems, with values $K_2/K_1 \geq 0.99$, are also characteristic of the RBMK reactors.

Conclusion

The report presents the results of comparative neutron computations of the RBMK reactor with VNIIEF codes and gives comparison with computed results obtained with some western codes.

The results of RBMK cell and polycell computations with WIMS, EKRAN and S-90 codes are given. Results of computations with WIMS and EKRAN codes do not always agree with one another, in some cases reactivity factors are of different signs. Apparently, it is due to the fact that in the EKRAN code in the resonant region the grid of constants in background cross sections (see I.2) is insufficiently fine (some time ago it was sparse owing to insufficient amount of computer memory). Currently the work is commenced to update the cross sections library for the EKRAN code using a finer grid in background cross sections for principal isotopes.

Comparative computations of RBMK cell burnup were performed using the WIMS and EKRAN codes. Good agreement of computed results is seen for computations in terms of cell k_{eff} . Cell isotope composition during burnup was also compared (these results are not reported owing to vast amount of the material); the comparison showed good agreement between the techniques.

The report gives comparative results of 3D RBMK static computation with the NESTLE, KORAT-3D and NEU codes. Good agreement among the results is seen, though it should be noted that in the codes KORAT-3D and NEU the agreeing results are reached on a finer grid than in the NESTLE code.

The report also gives results of 3D kinetics computation for two test problems with the KORAT-3D code. It would be interesting to perform comparative computation with the NESTLE code.

To conclude with, we would like to note that the problem of making full-value computation of 3D kinetics for RBMK operational and emergency modes remains currently unsolved and calls for further efforts both regarding improvement of the codes and modification of the program complexes comprising thermal hydraulics and neutron kinetics and regarding development and improvement of the cell neutron data base for RBMK core with parameters covering both operational and emergency modes.

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