SKETCH-N: A NODAL NEUTRON DIFFUSION CODE FOR SOLVING STEADY-STATE AND KINETICS PROBLEMS

VOL. II. USER'S GUIDE

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?? SEPTEMBER 2000

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

1. Program Name and Title: SKETCH-N 1.0: A nodal code for solving neutron diffusion equations of steady-state and kinetics problems.

2. Computers for which Program is Assigned and Other Machine Versions Available: Workstations under UNIX or Windows NT.

3. Problem Solved: The SKETCH-N code solves neutron diffusion equations in x-y-z geometry for steady-state and neutron kinetics problems. The code can treat an arbitrary number of neutron energy groups and delayed neutron precursors.

4. Method of the Solution: The polynomial, semi-analytic and analytic nodal methods based on the nonlinear iteration procedure can be used for spatial discretization of diffusion equations. The time integration of the neutron kinetics problem is performed by a fully implicit scheme with an analytical treatment of the delayed neutron precursors. The steady-state eigenvalue problems are solved by inverse iterations with Wielandt shift, the Chebyshev adaptive acceleration procedure is used for the neutron kinetics problems. The block symmetric Gauss-Seidel preconditioner is applied in the both iterative methods. The flux-weighting homogenization procedure is used for partially-rodded nodes to minimize a rod cusping effect. Simple one-phase model of the thermal-hydraulics of fuel assembly is included in the code. The code also has an interface module for a coupling with transient analysis codes , such as TRAC. The interface module performs a data exchange between the codes, synchronizes a time stepping and maps the neutronics data onto thermal-hydraulics spatial mesh and vice versa. The interface module is based on the message passing library PVM (Parallel Virtual Machine).

5. Restriction on the Complexity of the Problem: The code can treat the neutron diffusion problems in Cartesian geometry. Few-group macro cross sections and their dependencies are provided by a code user. The code does not have fuel burn-up modelling capabilities. An external thermal-hydraulics code is generally required for the calculation of the "real-life" problems.

6. Typical Running Time: The running time of the full-core case C1 of the PWR NEACRP rod ejection benchmark (2 neutron energy groups, 6 groups of the delayed neutron precursors, 884x18 neutronics nodes, 910 time steps) is 68 minutes on Sun UltraSPARC I (143 MHz) with an internal thermal hydraulics model.

7. Unusual Features of the Program: Dimensions of a problem are specified as parameters in the include files, the code should be recompiled when the problem dimensions are changed. The code has PVM-based interface module developed for a coupling with transient thermal-hydraulics codes. The interface model has been used for a coupling of the SKETCH-N code with the J-TRAC (TRAC-PF1) and TRAC-BF1 codes.

8. Related and Auxiliary Programs: PVM library is used for the interface module of the code.

9. Status: The SKETCH-N code has been verified by solving the steady-state and neutron kinetics benchmark problems. The coupled J-TRAC/SKETCH-N code system has been verified against NEACRP PWR rod ejection and rod withdrawal benchmarks. NEACRP BWR cold water injection benchmark has been used for verification of the TRAC-BF1/SKETCH-N system.

10. References:

Zimin V. G. "Nodal Neutron Kinetics Models Based on Nonlinear Iteration Procedure for LWR Analysis", PhD Thesis, Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology, August 1997.

Zimin, V.G., and H. Ninokata, "Nodal Neutron Kinetics Model Based on Nonlinear Iteration Procedure for LWR Analysis," Ann. Nucl. Energy, 25, 507-528, 1998

Zimin, V.G., H. Ninokata, and L. R. Pogosbekyan "Polynomial and Semi-Analytic Nodal Methods for Nonlinear Iteration Procedure," *Proc. of the Int. Conf. on the Physics of Nuclear Science and Technology*, October 5-8, 1998, Long Island, New York, American Nuclear Society, vol. 2, pp. 994-1002, 1998

Zimin V. G., H. Asaka, Y. Anoda, and M. Enomoto, "Verification of the J-TRAC code with 3D Neutron Kinetics Model SKETCH-N for PWR Rod Ejection Analysis", *Proc. of the 9th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH 9)*, San Francisco, California, October 3-8, CD-ROM, 1999.

Asaka, H., V. G. Zimin, T. Iguchi, and Y. Anoda, "Coupling of the Thermal-Hydraulic TRAC Codes with 3D Neutron Kinetics Code SKETCH-N", *Proc. of OECD/CSNI Workshop on Advanced Thermal-Hydraulic and Neutronics Codes: Current and Future Applications*, Barcelona, Spain, 10-13 April, 2000

Zimin, V. G., H. Asaka, Y. Anoda, E. Kaloinen and R. Kyrki-Rajamaki, "Analysis of NEACRP 3D BWR Core Transient Benchmark", *Proc. of the 4th Intl. Conf. on Supercomputing in Nuclear Application SNA 2000*, September 4-7, 2000, Tokyo, Japan.

11. Machine Requirements: A workstation under UNIX, Windows NT or Windows.

12. Program Language Used: Fortran 77

13. Operating System under which Program is Executed: UNIX, Windows NT.

14. Other Programming or Operating Information or Restrictions: The interface module requires PVM installed on a computer. The PVM is a public domain software available from NETLIB [http://www.epm.ornl.gov/pvm/pvm_home.html].

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16. Material Available:

    Source Code
    Sample LWR Benchmark Problems: Input and Output Files
    SKETCH-N Manual, vol. I. Model Description
    SKETCH-N Manual, vol. II User's Guide

17. Category: F

18. Keywords: kinetics, three-dimensional, neutron diffusion, nodal methods, nonlinear iteration procedure, reactor transient analysis.

19. Sponsor:

ACKNOWLEDGMENTS

The finite-difference code SKETCH has been developed during my doctor study and work on the advanced fast breeder reactor analysis project at the Department of Theoretical and Experimental Reactor Physics of Moscow Engineering Physics Institute (MEPhI), Moscow, Russia in 1989-1994. I'm especially grateful to Dr. Nikolay V. Schukin of MEPhI for the encouragement and interest that he has contributed over the years. The nodal code SKETCH-N for LWR analysis has been developed during my doctor course study in the Research Laboratory of Nuclear Reactors of the Tokyo Institute of Technology, Tokyo, Japan in 1994-1997. Thanks a lot to the supervisor of my doctor thesis - Prof. Hisashi Ninokata for all time, which he spent teaching me, his tolerance, kindness and hospitality. During my doctor study I had very helpful and stimulating discussions with Mr. Hideaki Ikeda and Mr. Akitoshi Hotta, both of Toden Software and Prof. Toshikazu Takeda of Osaka University. An interface module for the coupling with the transient reactor analysis codes J-TRAC and TRAC-BF1 has been developed during my stay as a postdoctoral researcher at the Thermal Hydraulics Safety Research Laboratory, Department of Reactor Safety Research, Japan Atomic Energy Research Institute (JAERI) in 1997-2000. During this time numerous code improvements have been also done. The author wants to thank Mr. Hideaki Asaka and Dr. Yoshinari Anoda, both of JAERI for the interest to my work, help in many problems and excellent working conditions.

I also wish to thank Dr. Leonid R. Pogosbekyan, VNIIAES, Moscow, Russia for his contribution to the implementation of the analytical nodal method based on matrix function theory and other helpful and stimulating discussions.

The last but not the least thanks go to my wife Olya and to all my friends for their support and encouragement.

1. INTRODUCTION

The SKETCH-N code (Zimin and Ninokata, 1998; Zimin, 2000) solves neutron diffusion equations in Cartesian geometry for steady-state and kinetics problems. The code can treat an arbitrary number of neutron energy groups and delayed neutron precursors. Polynomial, semi-analytic and analytic nodal methods based on the nonlinear iteration procedure can be used for spatial discretization of diffusion equations (Zimin et al., 1998). Time integration of the neutron kinetics equations is performed by the fully-implicit scheme with an analytical treatment of the delayed neutron precursors. Steady-state eigenvalue problems are solved by inverse iterations with a Wielandt shift accelerated by Chebyshev polynomials. An adaptive Chebyshev iterative procedure is used for neutron kinetics problems. The block symmetric Gauss-Seidel method is applied as a preconditioner in both the steady-state and transient problems. An automatic time step control based on the time step doubling technique is used in the code.

An extensive set of the steady-state and neutron kinetics LWR benchmarks has been calculated to verify the SKETCH-N code (Zimin et al., 1998; Zimin and Ninokata, 1998). The results show that the SKETCH-N code has acceptable accuracy and efficiency to be used in the LWR safety analysis and design. The code also has a simple thermal-hydraulics model, which can be used for analysis of PWR transients under single-phase flow conditions. An external thermal-hydraulics model should be used for the reactor calculations with two-phase flow. PVM based interface module has been developed to simplify the coupling with an external thermal-hydraulics code. The interface have been used for the coupling with the J-TRAC (TRAC-PF1) code (Akimoto et al., 1989) for PWR analysis and the TRAC-BF-1 code (Borkowski, 1992) for BWR applications. The J-TRAC/SKETCH-N code system has been verified against NEACRP PWR rod ejection and rod withdrawal benchmarks (Zimin et al., 1999; Asaka et al., 2000), the NEACRP BWR cold water injection benchmark has been computed by the TRAC-BF1/SKETCH-N code system (Zimin et. al., 2000).

In Chapter 2, we describe how to install the code.

In Chapter 3 the description of the SKETCH-N input and output files is given. The SKETCH-N postprocessing module, which can be used to extract the data from the SKETCH-N output binary file is also discussed.

In Chapter 4 till 6, the examples of the SKETCH-N application to the following problems:

- 2D four-group KOEBERG checker-board-loaded PWR (Muller and Weiss, 1991);
- 3D NEACRP PWR rod ejection benchmark, Case A1 (Finneman and Galati, 1992);
- 3D NEACRP BWR cold water injection benchmark, Case D1 (Finneman and Galati, 1992).

is presented.

2D PWR KOEBERG benchmark covered in Chapter 4 is the steady-state eigenvalue problem. It is a pure neutronics problem without feedbacks, which shows multigroup capabilities of the SKETCH-N code.

3D NEACRP PWR rod ejection benchmark discussed in Chapter 5 requires the both steady-state and neutron kinetics calculations with a thermal-hydraulics model. The coolant flow is under the single-phase condition and the internal thermal-hydraulics module of the SKETCH-N code is used. In the steady-state calculations, a critical boron search is performed. The transient is a super-prompt critical transient from the hot zero power conditions.

3D NEACRP cold water injection benchmark presented in Chapter 6 has been calculated by the TRAC-BF1/SKETCH-N code system. To compute this problem the TRAC-BF1 code and PVM library should be installed on the user's computer. The topics related to the installation of the TRAC-BF1 code and TRAC-BF1 input data are not covered in this user's guide. The information on these issues is available on request from Mr. Hideaki Asaka of JAERI. Contact address is

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Chapter 7 concludes this report outlining the basic features of the code and discussing the plans for the future.

The authors are very thankful for any suggestion to improve the code or this guide. Please, send your contribution by e-mail to *na.vzimin@na-net.ornl.gov* .

2. INSTALLATION

2.1 Obtaining the Source Code

The SKETCH-N source code is presently available only from the author or Mr. Asaka of JAERI. You can contact them by the following address:

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The source distribution include a compressed tar-file sketch_1x.tar.Z, x stand for the number of the newest version. The tar-file sketch_1x.tar.Z contains the source code, example and the code documentation in the PostScript format. Use the following command to extract these files

```
> uncompress sketch_1x.tar.Z

> tar –xvf sketch_1x.tar
```

2.2 Compiling and Linking the Code

There are two makefiles in the directory Source: Makefile_UNIX and Makefile_NT. In the following, we assume that you are using the UNIX workstations, the similar procedures should be done for Windows machines. To compile the code copy Makefile_UNIX into Makefile as follows

```
> cp Makefile_UNIX Makefile
```

There are three targets in Makefile:

../SKETCH is the SKETCH-N stand-alone code;
../POSTPROC is the postrprocessor for the SKETCH-N code, which is written in FORTRAN90 and requires f90 compiler;
../SKETCH_PVM is the SKETCH-N code with an interface module based on PVM. It requires the PVM library installed on the user's computer. PVM is a public domain software, which is available from NETLIB http://www.epm.ornl.gov/pvm/pvm_home.html.

To perform the SKETCH-N stand-alone calculations you need only SKETCH and POSTPROC. Build these targets as follows:

```
> make ../SKETCH
> make ../POSTPROC
```

3. STARTING THE PROGRAM

This chapter describes the code input and output data and the SKETCH-N postprocessing module.

3.1 Parameters in the include file "parameters.fh"

The include file "parameters.fh" contains the basic description of the reactor model dimensions and parameters. It is included into the file "sketch.fh" to define the array dimensions. If you change the problem you need to recompile the source code.

The variables defined in the file "parameters.fh" are separated into several groups: parameters describing the reactor geometry, parameters describing the reactor core, parameters describing the macro cross sections, parameters describing the control rods, parameters used by internal thermal-hydraulics model and parameters used for calculations with an external thermal-hydraulics model. They are defined in the Tables 3.1 till 3.6. Please, note that the variables given in the Table 3.5 are used only if the calculations are performed with the internal thermal-hydraulics model. The variables described in the Table 3.6 are used only if the external thermal-hydraulics model is used. In the case of pure neutronics calculations the values of parameters given in these tables can be set to 1.

Parameter Name	Description
N_POLY	number of the bundles (assemblies) in the reactor model
NCHM	maximum number of nodes per bundle (assembly) in X-Y plane
NH	number of the nodes in radial (X-Y) plane; if the calculations are performed with 1 node per assembly NH=N_POLY
NDD	dimension of reactor model: 3D calculations NDD=3; 2D calculations NDD=2; 1D calculations NDD=3;
NXR	maximum number of bundles in X directions
NX	maximum number of nodes in X direction
NYR	maximum number of bundles in Y directions
NY	maximum number of nodes in Y direction
NZR	number of axial layers defining material composition of the bundle;
NZ	number of axial layers used for the calculations
N_BUNDLE_TYPE	number of different bundle types

Table 3.1 Parameters describing the reactor geometry.

Parameter Name	Description
NP_Reactor_Core	number of fuel bundles in the reactor core
NZR_Core	number of axial layers in the reactor core

Table 3.2 Parameters describing the reactor core geometry.

Parameter Name	Description
NG	number of neutron energy groups
MD	number of delayed neutron precursors
NNODE	number of material compositions
N_FEEDBACKS	number of feedbacks, presently 4: boron concentration, coolant density or void, Doppler fuel temperature

Table 3.3 Parameters describing the macro cross sections.

Parameter Name	Description
NN_CRod	number of control rods
NN_CRod_Type	number of control rod types
NN_CRod_Comp	number of control rod material compositions
NN_CRod_El	number of control rod elements, for example 2 for PWR: absorber and driver
NN_Crod_Bundle	number of the bundles covered by control rod: 1 in the case of PWR and 4 in the case of BWR

Table 3.4 Parameters describing the control rods.

Parameter Name	Description
NN_FRD_FUEL	number of the heat conduction nodes in the fuel
NN_FRD_CLAD	number of the heat conduction nodes in the cladding

Table 3.5 Parameters used by internal thermal-hydraulics model.

Parameter Name	Description
NN_RT_HC_TRAC	number of the heat conduction channels in the external T/H model
NN_RT_FD_TRAC	number of the fluid dynamics channels in the external T/H model
NN_Z_HC_TRAC	number of the axial layers of the heat conduction mesh in the external T/H model
NN_Z_FD_TRAC	number of the axial layers of the fluid dynamics mesh in the external T/H model

Table 3.6 Parameters used for calculations with an external thermal-hydraulics model.

3.2 Input Data in the Namelist File "SKETCH.INI"

The file "SKETCH.INI" contains several namelists defining the SKETCH input data. The namelist INI_PROBLEM defines the type of the problem and solution methods used by the code. The variables are listed in the Tables 3.7. The namelist INI_FILES defines the names of the input, output and restart files. The variables are given in the Table 3.8. The iteration convergence criteria are given in the namelist INI_CONVERGENCE. The variables are given in the Table 3.9. We recommend to use the default values.

Variable Name	Default value	Description
Problem_Type	–	type of the computed problem: "Eigenvalue" – steady-state eigenvalue calculations "BoronSearch" – steady-state critical boron search "Kinetics" – neutron kinetics calculations
TH_Model	"None"	thermal-hydraulics model used for the calculations, variants "None" – no thermal-hydraulics model; "Internal" – SKETCH internal thermal-hydraulics model "External" – external thermal-hydraulics model
Nodal_Method	"SANM"	spatial discretization method used for calculations: "PNM" – polynomial nodal method; "SANM" – semi-analytic nodal method; "ANM" – analytic nodal method, "MCFD" – finite-difference method, "PNM1" – polynomial nodal method, algorithm based on matrix functions;
Kinetics_Method	"DRT"	method of the solution of kinetics equation: "DRT" – direct method, fully-implicit scheme; "IQS" – improved quasi-static method; "PNT" –point neutron kinetics
Iter_Solver	"CSA"	linear iterative solver for neutron kinetics calculations: "CSA" – Chebyshev Semi-Analytic method; "CSI" – Chebyshev Semi-Iterative method; "CG" – Conjugate Gradient method; "BCGSTAB" – BiConjuagate Gradient Method STABilized, "TFQMR" - Transpose Free Quasi Minimal Residual Method; "FOM" – Arnoldi's Method "GMRES" – Generalized Minimal Residual Method

Table 3.7 Variables defining a type of the problem and solution methods in the namelist INI_PROBLEM.

Variable Name	Default value	Description
FILE_INPUT	""	name of the input file with the geometry and macro cross section data
FILE_MAP	""	name of the input file with the mapping matrices, used only if TH_Model="External"
FILE_DIST	""	name of the input file with the distributions (xenon, burnup, void history, etc.), used in the Ringhals-1 BWR calculation;
FILE_CD	""	name of the input file with macro cross section tables, used in the Ringhals-1 BWR calculation;
FILE_DMP_IN	""	Name of the input dump file for restart
FILE_DMP_OUT_ST	""	Name of the output dump file to restart the steady-state calculations
FILE_DMP_OUT_KIN	""	Name of the output dump file to restart the kinetics calculations

Table 3.8. Names of the input, output and restart files defined in the namelist INI_FILES.

Variable Name	Default value	Description
N_OUT_MAX	 1 1000	number of outer iterations for the nonlinear iteration convergence test: in the steady-state calculations; in the kinetics calculations (1 nonlinear iteration per time step);
N_OUTER	 10 1000	maximum number of the outer iterations per nonlinear iteration: in the steady-state calculations; in the kinetics calculations (1 nonlinear iteration per time step);
E_OUTER_L	1.E-5	convergence criterion for the steady-state eigenvalue
E_FLUX_L	 1.E-5 1.E-4	convergence criterion for the neutron flux: in the steady-state calculations; in the kinetics calculations;
N_INTER	2	maximum number of inner iteration per outer iteration
E_INTER	1.E-8	convergence criterion for the inner iterations (never satisfied, fixed number of inner iterations per outer iteration)
E_BORON_START	1.E-2	accuracy of the eigenvalue estimate when a critical boron search starts
E_CRITICAL	1.E-5	convergence criterion for the critical boron search

Table 3.9. Convergence criteria defined in the namelist INI_CHEBYSHEV.

The namelist INI_CHEBYSHEV defines the parameters used by the Chebyshev iterative methods. The variables are given in the Table 3.10. We recommend to use the default values. Please only note, that the convergence of the steady-state iterations can be significantly improve if you use the value of the Wieland shift DELTA_SHIFT not equal to zero. For the LWR calculations, the value DELTA_SHIFT in the interval [5,20] provide "optimal" convergence. Please, decrease the value of the Wieland shift if the iterations diverge.

Variable Name	Default Value	Description
XME_INI	0.8	estimate of the dominance ratio (steady-state calculations) or spectral radius (kinetics calculations) of the iterative matrix
XBE	0.0	estimate of the minimum eigenvalue of the iteration matrix
F_CHEB	 0.0 0.8	adaptive parameter of the Chebyshev iterative method: F_CHEB=0.0 non-adaptive, default in the steady-state Calculations; F_CHEB=0.8 – adaptive, default in the kinetics calculations
NPOLINS	5	number of the outer iteration when the Chebyshev method starts
DELTA_SHIFT	0.	inverse value of the Wieland shift in the steady-state iterations

Table 3.10. Parameters of the Chebyshev iterations defined in the namelist INI_CHEBYSHEV.

The variables related to the time step size selection during neutron kinetics calculations are given in the namelist INI_TIME_STEP. The list is presented in Table 3.11. Even the default value of the flag I_AUTO specified the user defined time step, we strongly encourage to set I_AUTO=1 and to use the automatic time step size selection. In our experience, the time step doubling techniques used in the code is reliable and gives accurate solution.

Variable Name	Default Value	Description
I_AUTO	0	flag of the automatic time step selection: I_AUTO=0 – user defined time step size; I_AUTO=1 – automatic time step selection;
NP_VIEW	1	number of the time step size intervals
TTV(NP_VIEW)	1.	real array of dimension NP_VIEW – right end points of the time step size intervals [s]; the last value TTV(NP_VIEW) is the end of the transient;
DT_INPUT (NP_VIEW)	0.01	real array of dimension NP_VIEW – time step size for the time step intervals, [s].
ST_EPS	5.E-3	accuracy criterion of the automatic time step size selection
FACMAX	2.	maximum increase of the time step size per time step
DT_STEP_MAX	1.	maximum value of the time step size, [s]
N_ZAP	1	output into the SKETCH binary output file per each N_ZAPth time step

Table 3.11. Time step size data defined in the namelist INI_TIME_STEP.

3.3 Input Data in the SKETCH-N Input File

The name of the SKETCH-N input file is defined under the variable FILE_INPUT in the namelist INI_FILES in the file "SKETCH.INI". The examples are given in the following Chapters. Here we present the list of all input data, which can be given in this file. The input file starts with 5 lines of the problem header, which is always input and is used in the SKETCH output files. The actual data starts on the line 6 and are given in the following form. First we have the identifier, which is 12 characters, actual data starts at the following line and are given in free format. Arbitrary number of the blank lines may precede or follow the data. The variable identifiers and input data are separated into several groups, related to the SKETCH modules. The first characters of the identifier name give the abbreviation of the SKETCH-N module, the other characters encode the variable name. For example, the identifier XS_BASE_DATA stands for the basic macro cross section data of the XS module, CRD_MAT_COMP is the identifier of the control rod material compositions, etc. Some input cards can be omitted, for example the delayed neutron precursors parameters are not needed if only steady-state calculations are performed. If the data are needed, but the code can not find the identifier name in the input file, the code uses the default values and gives the warning message into the output file "Error.msg". If default values are not defined or the code has an error reading the input data, the execution is stopped with an error message into the error message file "Error.msg".

3.3.1 General Reactor Model Data

The first set of the data defines the general reactor model, the identifiers start with the characters CNT (CoNTrol). Their list is given below.

CNT_RCT_TYPE
Description: Reactor type, presently only "PWR" or "BWR"
Default value: "PWR"

CNT_RCT_POWR
Description: Reactor thermal power, [MWt]
Default value: -

3.3.2 Macro Cross Section Data

The set of the data related to macro cross sections is given under identifiers, which start with XS. The input data are described below.

XS_MODL_TYPE

Description: a type of the macro cross section model, two type are available:
"POLYNOM" – polynomial representation
"TABLE" – table representation for the BWR Ringhals-1 stability benchmark

Default value: "POLYNOM"

XS_BASE_DATA

Description: Basic set of the macro cross section data, the input has different form depending on the number of neutron energy groups NG.

Default value: -

Input data format:

The input form depends on the number of neutron energy groups. In the case of two-group calculations, the input is performed as follows

```
 DO k = 1, NNODE
    read(io_unit,fmt=*, iostat=ios)
&           d(k,1),sik(k,2,1),sa(k,1),sf(k,1),sf_p(k,1),
&           d(k,2),sa(k,2),   sf(k,2),sf_p(k,2), i
 END DO
```

where

NNODE is a number of material compositions defined in the file "parameters.fh";

d(k,*) is the diffusion coefficients or neutron transport cross section of the material composition k, D *or* Σ_{tr};

sik(k,2,1) is the scattering macro cross section from group 1 into 2 of the material composition k, Σ_{s21},;

sa(k,*) is the absorption macro cross sections of the material composition k, Σ_a;

sf(k,*) is the production macro cross section of the material composition k, $\nu\Sigma_f$;

sf_p(k,*) is the fission macro cross sections of the material composition k, Σ_f;

i is the material composition number, not used in the code.

In the case of multigroup calculations NG>2, the input is performed as follows

```
 DO k = 1, NNODE
  read(io_unit,fmt=*, iostat=ios)
&           (d(k,n), sa(k,n), sf(k,n), sf_p(k,n),
&                            n = 1, NG)
      read(io_unit,fmt=*, iostat=ios)
&           ((sik(k,n,m), m = 1, NG), n = 1, NG), i
 END DO
```

The difference is that for each material composition, the scattering macro cross sections are given after all others and all elements of the scattering matrix are given in the input. Please, note that self-scattering within an energy group is not considered in the diffusion theory and the diagonal elements of the scattering matrix should be zero.

Examples:

Two-group macro cross sections of the 1st material composition of the NEACRP PWR rod ejection

benchmark are given below:

```
XS_BASE_DATA # Basic set of the macro cross section data
  0.532058E-01 0.264554E-01 0.373279E-03 0.000000E-00 0.000000E-00
  0.386406E-00 0.177215E-01 0.000000E-00 0.000000E-00            1
```

Four-group macro cross sections of the 1st material composition of the 2D PWR KOEBERG benchmark are given below:

```
XS_BASE_DATA # Basic set of the macro cross section data
    2.491869 0.003654 0.008228 0.008228
    1.045224 0.002124 0.000536 0.000536
    0.677407 0.019908 0.007058 0.007058
    0.375191 0.067990 0.083930 0.083930
      0.0      0.0      0.0      0.0
      0.063789 0.0      0.0      0.0
      0.000486 0.064381 0.0      0.001245
      0.0      0.000003 0.050849 0.0       1 Type
```

`XSP_POL_COEF`

Description: derivatives of the macro cross sections with respect to feedbacks. The following set of feedbacks is used in the code: boron concentration [ppm], coolant density [g/cm^3], coolant temperature [°C] and Doppler fuel temperature [°K]. Please, not that the units are not the SI units. The input form depends on the number of neutron energy groups.

Default value: 0.0

Input data format:

In the case of two-group calculations, the input is performed as follows

```
 DO k = 1, NNODE
    DO i = 1, N_FEEDBACK
&                    d_fb(i,1,k),sik_fb(i,2,1,k),sa_fb(i,1,k),
&                                sf_fb(i,1,k),sf_p_fb(i,1,k),
&                    d_fb(i,2,k),sa_fb(i,2,k),sf_fb(i,2,k),
&                                sf_p_fb(i,2,k), fdback00(i,k)
    END DO
 END DO
```

where

`NNODE` is a number of material compositions defined in the file "parameters.fh";

`N_FEEDBACK` is a number of feedbacks defined in the file "parameters.fh", `N_FEEDBACK=4`;

`d_fb(i,*,k)` is the derivative of the transport macro cross section Σ_{tr} with respect to *i*-th feedback for material composition k;

`sik_fb(i,2,1,k)` is the derivative of the scattering macro cross section Σ_{s21} with respect to *i*-th feedback for material composition k;

`sa_fb(i,*,k)` is the derivative of the absorption macro cross section Σ_a with respect to *i*-th feedback for material composition k;

`sf_fb(i,*,k)` is the derivative of the production macro cross section $\nu\Sigma_f$ with respect to *i*-th feedback for material composition k;

`sf_p_fb(i,*,k)` is the derivative of the fission macro cross section Σ_f with respect to *i*-th feedback for material composition k;

`fdback00(i,k)` is the reference value of *i*-th feedback for material composition k.

In the case of multigroup calculations NG>2, the input is performed as follows

```
 DO k = 1, NNODE
    DO i = 1, N_FEEDBACK
         read(io_unit, fmt=*, iostat=ios)
&            (d_fb(k,n,i),sa_fb(k,n,i),sf_fb(k,n,i),
&              sf_p_fb(k,n,i), n = 1, NG)
         read(io_unit,*) ((sik_fb(k,n,m,i),m=1,NG) ,n=1,NG),
&                          fdback00(i,k)
    END DO
 END DO
```

The difference is that for each material composition and each feedback, the derivatives of the scattering macro cross sections are given after all others and all elements of the derivatives of the scattering matrix are given in the input.

Examples:

Two-group derivatives of the macro cross sections of the 1st material composition of the NEACRP PWR rod ejection benchmark are given as:

```
XSP_POL_COEF # Macro cross section derivatives
 0.611833E-07 0.791457E-09 0.187731E-06 0.000000E-00 0.000000E-00
 0.517535E-05 0.102635E-04 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.745756E-01 0.371310E-01 0.207688E-03 0.000000E-00 0.000000E-00
 0.533634E-00 0.758421E-02 0.000000E-00 0.000000E-00       0.7125
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       891.45 1
```

XS_DIFF_FLAG

Description: Integer flag of the diffusion coefficient in the basic set of the macro cross section data. If XS_DIFF_FLAG==1, the diffusion coefficient is given in the basic macro cross section set, otherwise it is the transport macro cross section.

Default value: 1

XS_FEED_INIT

Description: Initial values of the feedbacks used in the first thermal-hydraulics iteration, real array of dimension N_FEEDBACK=4

Default value: 1.0

XS_CROD_COEF

Description: Differential macro cross sections for the control rod material compositions; the input form is the same as described above for the basic macro cross sections under identifier XS_BASE_DATA.

Default value: 0.0

XS_CROD_CUSP

Description: Homogenization method of the macro cross sections for the partially rodded nodes. Two choices:

"FLUX-WEIGHTING" - flux-weighting homogenization

"VOLUME-WEIGHTING" - volume-weighting homogenization

Default value: "FLUX-WEIGHTING"

XS_NEUT_SPEC
Description: Prompt neutron spectrum, real array of dimension NG
Default value: –

XS_POWR_CONV
Description: Energy release per fission [Ws/fission], real array of dimension NG
Default value: –

XS_POWR_COOL
Description: Part of the energy directly deposited into the coolant
Default value: 0.0

XS_NEUT_VELC
Description: Prompt neutron velocity [cm/s] , real array of dimension NG
Default value: –

XS_PREC_ALFA
Description: Decay constants of the delayed neutron precursors [1/s], real array of dimension MD
Default value: –

XS_PREC_BETA
Description: Fraction of the delayed yields, the input can be absolute or relative values.
Default value: –
Input data format: Either relative or absolute values can be given. First you input the integer flag i_beta. If i_beta==0 the code expects absolute values of the delayed neutron fractions. If i_beta==1 the code first reads the total fraction of the delayed neutrons and then the relative fractions for each delayed neutron groups.
Examples:
The input of the relative fractions of the delayed neutron precursors for the NEACRP PWR rod ejection benchmark is given as:

```
XS_PREC_BETA
  1 # Relative beta
  0.0076 # Total yield
  0.034 0.200 0.183 0.404 0.145 0.034 # Relative fractions (MD)
```

The input of the absolute fractions of the delayed neutron precursors for the NEACRP BWR cold water injection benchmark is given as:

```
XS_PREC_BETA
  0 # Absolute beta
  0.00026 0.00152 0.00139 0.00307 0.00110 0.00026 # bet(MD)
```

3.3.3 Geometry Description

The set of the data related to the reactor geometry model is given under identifiers, which start with GMT. The list of the identifier and the data descriptions are given as follows.

GMT_NUM_BNDL
Description: the numbering of the reactor bundles (assemblies), integer array of dimension (NXR,NYR)
Default value: –
Example: Reactor model of the NEACRP PWR rod ejection benchmark is described as follows:

```
GMT_NUM_BNDL # Numbering of the reactor assemblies (bundles)
  1  2  3  4  5  6  7  8  9
  10 11 12 13 14 15 16 17 18
  19 20 21 22 23 24 25 26 27
  28 29 30 31 32 33 34 35  0
  36 37 38 39 40 41 42 43  0
  44 45 46 47 48 49 50  0  0
  51 52 53 54 55 56  0  0  0
  57 58 59 60 61  0  0  0  0
  62 63 64  0  0  0  0  0  0
```

GMT_MSH_XDIR

Description: Number of points per interval and spatial mesh intervals in x-direction [cm], integer and real arrays of dimension (NXR)

Default value: –

Example: spatial mesh in x-direction for the NEACRP PWR rod ejection benchmark is defined as:

```
GMT_MSH_XDIR # Spatial mesh in x-direction

  1 10.803 2 21.606 2 21.606 2 21.606 2 21.606 2 21.606
  2 21.606 2 21.606 2 21.606 # npx(NXR),hx(NXR)
```

where two mesh points are defined per interval 21.606 cm.

GMT_MSH_YDIR

Description: Number of points per interval and spatial mesh intervals in y-direction [cm], integer and real arrays of dimension (NYR)

Default value: –

GMT_MSH_ZDIR

Description: Number of points per interval and spatial mesh intervals in z-direction [cm], integer and real arrays of dimension (NZR)

Default value: –

GMT_COR_LOAD

Description: specification of the reactor loading by the material composition, first input is an integer array of dimension (N_POLY) describing reactor loading by bundle types, then for each bundle type we define the axial material composition.

Default value: –

Input data format: First input of the core loading by the bundle types as follows.

```
READ(io_unit,  fmt=*, iostat=ios)
 &    (Core_Load(np), np = 1, N_POLY),
```

where

N_POLY is a number of the bundles (assemblies) in the reactor model.

Core_Load(np) is a bundle type

Then, we input axial material composition for each bundle type as

```
 DO i = 1, N_Bundle_Type
    READ(io_unit,  fmt=*, iostat=ios)
&                        (Bundle_Compos(n, i), n = 1, NZR)
```

```
END DO
```

where

`N_Bundle_Type` is a number of the bundle types in the reactor model;

`NZR` is a number of axial layers in the reactor model;

`Bundle_Compos(n, i)` is the material composition for each bundle type `i` and axial layer `n`;

Example:

Material compositions for NEACRP PWR rod ejection benchmark are defined as follows:

```
GMT_COR_LOAD # Core loading by the material compositions
  1  2  1  2  1  3  1  4  5
  2  1  6  1  6  1  7  4  5
  1  6  1  6  1  6  4  8  5
  2  1  6  1  6  9  4  5
  1  6  1  6  1  4  8  5
  3  1  6  9  4  8  5
  1  7  4  4  8  5
  4  4  8  5  5
  5  5  5  # core loading by the bundle types, Core_Load(N_POLY)

 1  4  15*4   1 # Material composition of the 1st bundle type
 1  5  15*9   1 # Material composition of the 2nd bundle type, etc.
 1  5  15*7   1 # nb =   3
 1  6  15*6   1 # nb =   4
 2  2  15*2   2 # nb =   5
 1  5  15*8   1 # nb =   6
 1  6  15*11  1 # nb =   7
 3  3  15*3   3 # nb =   8
 1  6  15*10  1 # nb =   9
```

`GMT_BND_COND`

Description: Boundary conditions (BC)

Default value: –

Input data format: At first, we input the integer flag `i_dr` of the boundary conditions for the East, West, North and South boundaries. If `i_dr==1` we define the logarithmic derivative of the neutron flux as a boundary condition constant, if `i_dr==0` the extrapolated distance should be given as a boundary constant. Then we give the boundary condition constants as a real array of dimension `NG` for the East, West, North and South boundaries. The description of the boundary conditions in axial directions is performed in the same way. First we define a type of the boundary conditions for the Bottom and Top boundaries, then we give the boundary condition constants. In the case of 2D calculations, the type of the axial boundary conditions is omitted and the buckling array of dimension `NG [cm^2]` is given instead of the boundary condition constants.

Example:

The boundary conditions for NEACRP PWR rod ejection benchmark are defined as follows:

```
GMT_BND_COND # Boundary conditions (BC)
  1 0 1 0 # Type of the BC (East, West, North, South)
  0. 0.   0. 0.   0. 0.  0. 0. # BC constants
  0  0 # Type of the axial BC (Bottom, Top)
  0. 0.   0. 0. # BC constants for axial BC
```

The input data define the reflective boundary condition at the East and North boundaries and zero

flux boundary conditions on the other boundaries.

An another example is the boundary conditions for four-group 2D KOEBERG PWR benchmark.

```
GMT_BND_COND # Boundary Conditions (BC)
  1 1 1 1 # Type of the BC (East, West, North, South)
  0. 0. 0. 0.   0.5 0.5 0.5 0.5   0. 0. 0. 0.
                0.5 0.5 0.5 0.5 # BC constants
  0. 0. 0. 0. # Axial buckling
```

The input data define the reflective boundary conditions at the East and North boundaries and vacuum boundary conditions on the West and South boundaries. The problem is two-dimensional, the axial buckling is zero.

3.3.4 Control Rod Description

The set of the data related to the control rods is given under identifiers, which start with `CRD`. The list of the identifier and the data descriptions are given as follows.

`CRD_COR_LOAD`
Description: control rod types, integer array of dimension of the number of control rods `NN_Crod`.
Default value: `1`

`CRD_MAT_COMP`
Description: material compositions for each control rod type `NN_CRod_Type` and control rod element `NN_CRod_El`, integer array of dimension `(NN_CRod_El, NN_CRod_Type)`. Two control rod elements are usually defined: absorber and driver.
Default value: `1`
Input data format:

```
DO n = 1, NN_CRod_Type
   READ(io_unit,  fmt=*, iostat=ios)
&               (CR_Compos(ie, n), ie = 1, NN_CRod_El)
END DO
```

Example:
The control rod material compositions for NEACRP PWR rod ejection benchmark are defined as follows:

```
CRD_MAT_COMP
 1 3 # Material composition for 1st type of CRD
 2 3 # Material composition for 2nd type of CRD
```

`CRD_LOCATION`
Description: location of the control rods in the reactor core, an index of the assembly (bundle) covered by the control rod, an integer array of dimension `(NN_CRod_Bundle, NN_Crod)`. `NN_CRod_Bundle` is the number of assemblies (bundles) covered by control rod. In the case of PWR, `NN_CRod_Bundle=1;` in the case of BWR, `NN_CRod_Bundle=4`.
Default value: `0`
Example:
The control rod positions for NEACRP PWR rod ejection benchmark, case A1 are defined as follows:

```
CRD_LOCATION # Locations of control rods in the reactor core
```

```
 1     3           7
   11          15
19    21    23    25
         31
      38    40
   45
51    53    # index of the assembly covered by control rod
```

CRD_POSITION
Description: position of the control rods [cm]. A real array of dimension NN_Crod. In the case of PWR positions are defined from the reactor bottom; in the case of BWR positions are given from the reactor top.
Default value: 0.0

CRD_H_ROD_EL
Description: length of the control rods elements, [cm]. A real array of dimension (NN_CRod_El). NN_CRod_El is the number of the control rod elements, usually we have two elements: absorber and driver.
Default value: 0.0

The following control rod input data are read only for the neutron kinetics problems.

CRD_TOP_POSI
Description: Top in the case PWR or bottom in the case of BWR position of the control rods;
Default value: height of the reactor model.

CRD_BOT_POSI
Description: Bottom in the case PWR or top in the case of BWR position of the control rods;
Default value: 0.0

CRD_TIM_STRT
Description: start time of the control rod movement, [s].
Default value: 0.0

CRD_TIM_END
Description: end time of the control rod movement, [s].
Default value: 1.E+30

CRD_NUM_MOVE
Description: Number of the moving control rods.
Default value: 0

CRD_IND_MOVE
Description: Indexes of the moving control rods, integer array of dimension of the number of the moving control rods.
Default value: 0

CRD_MOV_TYPE
Description: A type of the control rod movement, two variants are available:
"LIN" is the linear movement of the control rods;
"SIN" is the sinusoidal movement of the control rods.
Default value: "LIN"

In the case of the linear movement of the control rods (CRD_MOV_TYPE=="LIN"), the data under identifier CRD_VEL_RODS may be given as follows

CRD_VEL_RODS
Description: Velocity of the moving control rods [cm]
Default value: 0.0

In the case of the sinusoidal movement of the control rods (CRD_MOV_TYPE=="SIN"), the data under identifiers CRD_SIN_AMPL and CRD_SIN_FREQ may be given as follows

CRD_SIN_AMPL
Description: Amplitude of the moving control rods [cm], real array of dimension of the number of the moving control rods.
Default value: 0.0

CRD_SIN_FREQ
Description: Frequency of the moving control rods [1/s], real array of dimension of the number of the moving control rods.
Default value: 1.0

CRD_FLG_SCRM
Description: Set of the data related to the reactor scram. If this identifier is given the scram is "ON", otherwise it is "OFF".
Default value: scram is "OFF"
Input data format: The following data should be given under this identifier:

```
read(io_unit,fmt=*,iostat=ios) v_rods_scram
read(io_unit,fmt=*,iostat=ios) Nrod_Scram
read(io_unit,fmt=*,iostat=ios)
   &     (Num_Rod_Scram(i), i= 1, Nrod_Scram)
read(io_unit,fmt=*,iostat=ios) Power_Scram
read(io_unit,fmt=*,iostat=ios) Time_Scram_Delay
```

where
v_rods_scram – velocity of the scram control rods;
Nrod_Scram – number of the control rods participating in scram;
Num_Rod_Scram – indexes of the control rods participating in scram;
Power_Scram – power level [MWt], when scram signal is activated;
Time_Scram_Delay – time delay [s] after the scram signal before the control rods start moving.

3.3.5 Data for Internal Thermal-Hydraulics Model

The set of the data related to the internal thermal-hydraulics model is given under identifiers, which start with TH and FRD. This data are input only the variable TH_Model="Internal" in the namelist IN_PROBLEM in the namelist file "SKETCH.INI". The list of the identifier and the data descriptions are given as follows.

TH_TEMC_INLT
Description: inlet coolant temperature, [K]
Default value: –

TH_TEMC_INLT
Description: coolant pressure, [Mpa]

Default value: -

TH_MFRT_ASSM
Description: coolant mass flow rate per assembly, [kg/(m^2 s)]
Default value: -

TH_HYDR_DIAM
Description: equivalent hydraulic diameter, [m]
Default value: -

TH_HTCF_CNST
Description: constants of the Dittus-Boelter formula for the heat transfer coefficient
Default value: 0.023, 0.4, 0.8
Example:

```
TH_HTCF_CNST # heat transfer coefficient constants (Dittus-Boelter)
   0.023  0.8  0.4 # Const_DB, Pow_Reynolds, Pow_Prandtl
```

TH_SURF_VOLM
Description: ratio of the surface area of cladding to the volume of the coolant, [1/m]
Default value: -

TH_FLOW_AREA
Description: relative flow area
Default value: -

FRD_RAD_PELT
Description: radius of fuel pellet, [m]
Default value: -

FRD_RAD_CLAD
Description: inner and outer radiuses of the cladding
Default value: -

FRD_DNS_F&CL
Description: densities of the fuel and cladding [kg/m^3]
Default value: -

FRD_GAP_COND
Description: gap conductance [watts/(K m^2)]
Default value: -

FRD_ALF_DOPL
Description: interpolation parameter to compute the Doppler fuel temperature
Default value: -

FRD_RAT_ASFL
Description: ratio of the assembly volume to fuel volume
Default value: -

FRD_POW_FROD
Description: power distribution inside a fuel rod, the real array `Power_Pin` of dimension `NN_FRD_FUEL+1`, if the identifier is missing the flat power distribution is assumed and `Power_Pin=1.0`
Default value: 1.0

3.4 Input Data for Calculations with an External Thermal-Hydraulics Model

If an external thermal-hydraulics code is used for the calculations, the code user should set the variable `TH_Model="External"` in the namelist `IN_PROBLEM` in the namelist file "SKETCH.INI" and prepare the input file with the data for the SKETCH-N interface module. A file name is specified under the variable `FILE_MAP` in the namelist INI_FILES in the file "SKETCH.INI". Till now the SKETCH-N code has been used for the calculations with the TRAC-PF1 and TRAC-BF1 codes, thus in the following we use the name TRAC as a name of the external thermal-hydraulics code. The input data of the file `FILE_MAP` contain the specification of the TRAC version, the conversion parameters between the TRAC and SKETCH units and the mapping matrices defining the mapping of the variables between the TRAC and SKETCH spatial meshes.

Before considering the input data let us describe the input format of the mapping matrices. Let us consider an example of the TRAC and SKETCH axial meshes, which is discussed in the vol. I of the SKETCH manual (Zimin, 2000) and shown again in Fig. 3.1. The mapping matrices for these spatial meshes are given as

$$\mathrm{SlD}^{\mathrm{HC}}_{\mathrm{NEUT}} = \begin{pmatrix} 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0.5 & 0 \\ 0 & 0 & 0 & 0.5 & 0.5 \\ 0 & 0 & 0 & 0 & 0.5 \end{pmatrix}; \quad \mathrm{SlD}^{\mathrm{FD}}_{\mathrm{NEUT}} = \begin{pmatrix} 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}.$$

where

$\mathrm{SlD}^{\mathrm{HC}}_{\mathrm{NEUT}}$ is the mapping matrix from the neutronics mesh into the heat conduction mesh;

$\mathrm{SlD}^{\mathrm{FD}}_{\mathrm{NEUT}}$ is the mapping matrix from the neutronics mesh into the fluid dynamics mesh.

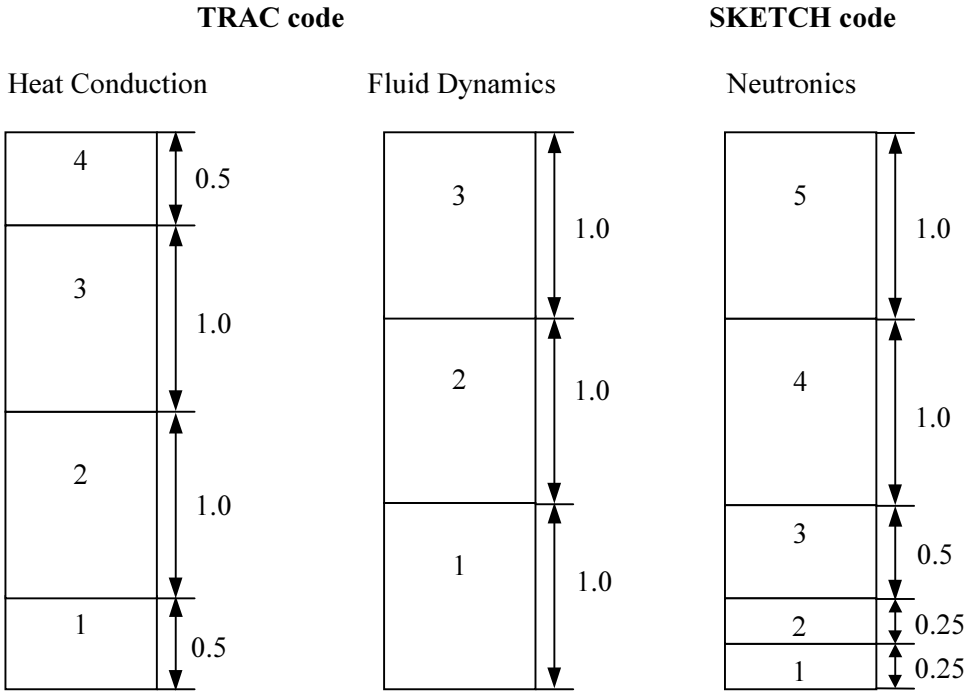


Fig. 3.1 Example of the axial meshes in the TRAC and SKETCH codes

Because the mapping matrices are very sparse, a compressed row storage (CRS) format is used for their input and storage (Barrett et al., 1994). Let us consider the sparse $M \times N$ matrix A (M rows and N columns) with NNZ nonzero entries a_{ij} (i-th row, j-column). The data structure of the CRS format consists of three arrays:

- a real array `val` of dimension NNZ contains the real nonzero entries a_{ij} stored row by row, from row 1 to M.
- an integer array `ja` of dimension NNZ contains column indexes of the elements a_{ij} as stored in the array `val`.
- an integer array `ia` of dimension $M+1$ contains the pointers to the beginning of each row in the arrays `val and ja`. Thus, the content of `ia(i)` is the position in the arrays `val and ja`, where the i-th row starts. By convention, `ia(M+1)=NNZ+1`.

The CRS format of the matrix $\mathrm{SlD}_{\mathrm{NEUT}}^{\mathrm{HC}}$ is specified by the arrays `{val, ja, ia}` given below

val	1.	1.	1.	0.5	0.5	0.5	0.5
ja	1	2	3	4	4	4	4

ia	1	3	5	7	8

The CRS format of the matrix $\mathrm{SlD}_{\mathrm{NEUT}}^{\mathrm{FD}}$ is given by the arrays `{val, ja, ia}` as

val	1.	1.	1.	1.	1.
ja	1	2	3	4	5

ia	1	4	5	6

Now let us consider the content of the input file `FILE_MAP`. The input file starts with 5 lines of the header, followed by the input data. Each data set has an identifier, which is 12 characters, actual data starts at the following line and are given in free format. Arbitrary number of the blank lines may precede or follow the data. This set of data is used by the PVM-based interface module and the identifiers start with the characters PVM. Their list is given below.

`PVM_EXT_CODE`

Description: A name of the external thermal-hydraulics code, two variants are available:
`"TRAC-PF1"` defines a coupling with the TRAC-PF1 code;
`"TRAC-BF1"` defines a coupling with the TRAC-BF1 code.
The variants are different in several ways. At first, the SKETCH-N code sends a message with two arrays of the heat generation rate on the both heat conduction and fluid dynamics meshes to the TRAC-PF1; while to the TRAC-BF1 code SKETCH-N sends only the heat generation rate for the heat conduction spatial mesh. The second difference is that the TRAC-PF1 code sends two arrays of the fuel temperatures: centerline fuel temperature and fuel rod surface temperature. The SKETCH-N code computes the Doppler fuel temperature interpolating these two values. Only a one array with the computed Doppler fuel temperature is sent by the TRAC-BF1 code. The last difference is the treatment of the coolant temperature and density. The TRAC-PF1 code gives the face-average values and the node-average values are computed by the SKETCH code using the linear interpolation. The TRAC-BF1 sends the node-averaged values and no interpolation is needed.

Default value: –

`PVM_CNV_UNIT`

Description: Conversion constants of the TRAC units for coolant density (or void); coolant and fuel temperature into the SKETCH units. Three real constants `C_RO_COOL, C_TEMP_COOL, C_TEMP_FUEL`, are given as input. The SKETCH variables from the TRAC variables are

computed as follows

```
RO_COOL_SKETCH = RO_COOL_TRAC × C_RO_COOL
TEMP_COOL_SKETCH = TEMP_COOL_TRAC + C_TEMP_COOL
TEMP_FUEL_SKETCH = TEMP_FUEL_TRAC + C_TEMP_FUEL
```

Default value: –

Example:

In the TRAC-BF1 code the unit of the coolant density is kg/m^3, the unit of the temperature is Kelvin degree. For NEACRP LWR benchmark the SEKETCH-N macro cross sections are given as functions of the coolant density in g/cm^3; coolant temperature in degrees of Celsius and Doppler fuel temperature in degrees of Kelvin. The conversion constants are given as

```
PVM_CNV_UNIT
  1.E-03   -273.15   0.
```

PVM_MAP_NTHC

Description: Mapping matrices from the neutronics spatial mesh into the heat conduction spatial mesh. At first, 2D mapping matrix describing the correspondence of the meshes in x-y plane is given. The input is performed in the CRS format. The arrays {ia, ja, val} are given. The dimension of the array ia is equal to NN_RT_HC_TRAC+1, where NN_RT_HC_TRAC is the number of the heat conduction channels in the external T/H code. The arrays ja, val have the dimensions equal to the number of the nonzero elements of the mapping matrix. Their actual dimension is computed as ia(NN_RT_HC_TRAC+1)-1. Then, 1D mapping matrix describing the correspondence of the axial meshes is given in the same CRS format. The dimension of the array ia is equal to NN_Z_HC_TRAC+1, where NN_Z_HC_TRAC is a number of the axial layers of the heat conduction mesh in the external T/H code. The dimensions of the arrays ja, val is computed as ia(NN_Z_HC_TRAC+1)-1.

Default value: –

PVM_MAP_NTFD

Description: Mapping matrices from the neutronics spatial mesh into the fluid dynamics spatial mesh. The input format is the same as above for the data under identifier PVM_MAP_NTHC. The only difference is that the parameters NN_RT_FD_TRAC and NN_Z_FD_TRAC of the fluid dynamics spatial mesh are used to define the dimension of the arrays ia.

Default value: –

PVM_MAP_HCNT

Description: Mapping matrices from the heat conduction spatial mesh into the neutronics spatial mesh. The input format is the same as described above for the data under identifier PVM_MAP_NTHC. The only difference is that the parameters N_POLY and NZR of the neutronics spatial mesh are used to define the dimension of the arrays ia. If this identifier is omitted the mapping matrices are computed as transpose of the mapping matrices from the neutronics mesh into the heat conduction mesh given under identifier PVM_MAP_NTHC.

Default value: transpose of the mapping matrices from neutronics mesh into heat conduction mesh.

PVM_MAP_FDNT

Description: Mapping matrices from the fluid dynamics spatial mesh into the neutronics spatial mesh. The input format is the same as described as above for the data under identifier PVM_MAP_NTHC. The only difference is that the parameters N_POLY and NZR of the neutronics spatial mesh are used to define the dimension of the arrays ia. If this identifier is omitted the mapping matrices are computed as transpose of the mapping matrices from the neutronics mesh into the fluid dynamics mesh given under identifier PVM_MAP_NTFD.

Default value: transpose of the mapping matrices from neutronics mesh onto the fluid dynamics mesh.

3.5 Output into the Text File "SKETCH.lst"

The code writes a summary of the input data and calculation results into the file "Output/SKETCH.lst". Please note that if the file with this name exists it is overwritten.

At first, the code writes a summary of the input data values of the code parameters from the file "sketch.fh"; data from the namelist file "SKETCH.INI"; and data from the input file FILE_INPUT. If calculation is performed with an external thermal-hydraulics model the data taken from the file FILE_MAP are also output.

In the case of the Ringhals-1 BWR calculation the next output is a summary of 3D static distributions taken from the input distribution file FILE_DIST. The static distributions include burnup, xenon, void history, control rod history, conversion history, steady-state power and void. An output form is the same as discussed below for computed distributions.

The next output data are control rod positions and summaries of computed distributions. In the steady-state calculations, initial data and computed results are given. In the transient calculations, the code writes these data at the beginner of the transient and at the time moments TTV(n), n=1,…,NP_VIEW. These time moments are defined in the namelist INI_TIME_STEP in the namelist file "SKETCH.INI". The output distributions include power distribution and feedback distributions: boron concentration, coolant density and temperature, Doppler fuel temperature. If the internal thermal-hydraulics model is used in the calculation additional distributions are written. They are fuel centerline temperature, cladding inner surface temperature and fuel enthalpy. A summary of each distribution contains a core-averaged value, minimum and maximum values and their locations, average 2D and 1D values. Please note, that the averaging is performed over a reactor core, the values in reflectors are not taken into account. The output is also performed only for the reactor core. An example of the summary of the steady-state power distribution of the NEACRP PWR rod ejection benchmark, case A1 is given below

```
!=========================================================================!
!                              SKETCH-N                                   !
!Nodal Neutron Diffusion Code for Solving Steady-State and Kinetics Problems!
!           Version 1.0 (c) Slava 2000 e-mail: na.vzimin@na-net.ornl.gov    !
!   Date & Time of Calculation :  8 August   2000   5:42:06 pm             !
!=========================================================================!
Lines of the output with control rod positions are omitted
!-------------------------------------------------------------------------!
     POWER DISTRIBUTION
!-------------------------------------------------------------------------!
     Total Reactor Power                  :  0.69375E-03 MWt
     Average Power Density                :  0.10308E-03 Wt/cm^3

     NODAL POWER PEAKING FACTORS
     Scaling Factor                       :  0.97008E+04
     Average Value                        :  1.00000

     3D Maximum Value                     :  2.87700
     Reactor Location of 3D Maximum (X,Y,Z):  4  2  9
     Core    Location of 3D Maximum (X,Y,Z):  4  2  8

     3D Minimum Value                     :  0.05613
     Reactor Location of 3D minimum (X,Y,Z):  7  3 17
     Core    Location of 3D minimum (X,Y,Z):  7  3 16

     2D Maximum Value                     :  1.91131
     Reactor Location of 2D Maximum (X,Y) :  2  4
     Core    Location of 2D Maximum (X,Y) :  2  4

     2D Minimum Value                     :  0.38227
     Reactor Location of 2D minimum (X,Y) :  3  7
     Core    Location of 2D minimum (X,Y) :  3  7
```

```
     1D Maximum                              :  1.50341
     Reactor Location of the 1D Maximum (Z):        9
     Core    Location of the 1D Maximum (Z):        8

     1D Minimum                              :  0.13638
     Reactor Location of the 1D minimum (Z):       17
     Core    Location of the 1D minimum (Z):       16
!--------------------------------------------------------------------!
      2D RADIAL ASSEMBLY-AVERAGED POWER DENSITY
!--------------------------------------------------------------------!
          1     2     3     4     5     6     7     8
      ----- ----- ----- ----- ----- ----- ----- -----
  1:  0.993 1.521 1.071 1.807 1.815 1.008 0.396 0.540
  2:  1.521 1.845 1.661 1.911 1.424 0.559 0.560 0.428
  3:  1.071 1.661 1.015 1.448 0.730 0.726 0.382
  4:  1.807 1.911 1.448 1.435 1.016 0.945 0.541
  5:  1.815 1.424 0.730 1.016 0.542 0.671
  6:  1.008 0.559 0.726 0.945 0.671
  7:  0.396 0.560 0.382 0.541
  8:  0.540 0.428
!--------------------------------------------------------------------!
      1D AXIAL AVERAGE POWER DENSITY
!--------------------------------------------------------------------!
   1:   0.1980
   2:   0.2668
   3:   0.4218
   4:   0.6821
   5:   0.9924
   6:   1.2422
   7:   1.4161
   8:   1.5034
   9:   1.4989
  10:   1.4027
  11:   1.2209
  12:   0.9645
  13:   0.6493
  14:   0.4000
  15:   0.2440
  16:   0.1364
```

The similar output is given for the other distributions, please see the output files of the computed benchmark problems.

3.6 Output into the Binary File "SKETCH.grf"

SKETCH-N output into the text file contains only the summary of the computed distributions and the transient results are given at a few time moments. The results of each time step are written into the binary file "SKETCH.grf". Please note, that if the file with this name exists it is overwritten. The binary file can be processed by a postprocessor after the calculations. The postprocessor input and output are discussed in the following section.

The output into the binary file contains several sets of the data. The first set of the data gives the reactor model description: the problem title, date and time of the calculation, reactor model geometry, etc. In the case of the Ringhals-1 BWR calculations, the next set of the data include static 3D distributions taken from the distribution file `FILE_DIST`. The static distributions include burnup, xenon, void history, control rod history, conversion history and steady-state power and void. The next set of the data

is the calculation results written at the end of the steady-state calculation and at each time step of the transient calculation. The results include scalar data, vector data and 3D distributions. The scalar data include total reactor power, reactivity, time step size of the SKETCH code and time step size proposed by the external thermal-hydraulic code. The only one set of the vector data is present; it contains the positions of the control rods. The list of the output distributions includes power distribution, boron concentration, coolant density and temperature, Doppler fuel temperature. If the internal thermal-hydraulics model is used in the calculation the additional output distributions are fuel centerline temperature, cladding inner surface temperature and fuel enthalpy.

3.7 Postprocessing of the SKETCH-N results

A postprocessor is developed to convert the contents of the SKETCH-N binary file into the text form suitable for plotting and reading. The code is written in FORTRAN 90 language. To build the postprocessor please use the Makefile in the directory Source and type

> make ../POSTPROC

The first set of the postprocessor input data is given in the namelist file "PostProc.INI". The list of the variables is given in Table 3.12.

Variable Name	Default Value	Description
FILE_GRF	"Output/SKETCH.grf"	name of the SKETCH-N binary output file
FILE_INP	""	name of the input file for postprocessor
FILE_OUT	"Output/PostProc.lst"	name of the output file with the listing of the postprocessor run
FILE_TR_OUT	"Output/Pproc_TR.lst"	name of the output file with the transient data given versus time
FILE_TM_OUT	"Output/Pproc_TM.lst"	name of the output file with the transient data given at the certain time moment
TIME_OUTPUT	0.0	Time moment of the transient data written into the file FILE_TM_OUT
FILE_ST_OUT	"Output/Pproc_ST.lst"	name of the output file with the static distributions
FMT_TR_R	"(E12.5)"	Output format for real data written in the file FILE_TR_OUT
FMT_TR_I	"(I5)"	Output format for integer data written in the file FILE_TR_OUT
FMT_TI_R	"(F6.3)"	Output format for real data written in the file FILE_TM_OUT
FMT_TI_I	"(I5)"	Output format for integer data written in the file FILE_TM_OUT
FMT_ST_R	"(F6.3)"	Output format for real data written in the file FILE_ST_OUT
FMT_ST_I	"(I5)"	Output format for integer data written in the file FILE_ST_OUT
TM_3D_OUTPUT	"YES"	Option of the output of 3D distribution: "YES" – 3D distributions are written into the output files FILE_TM_OUT, "NO" – 3D distributions are not written

Table 3.12. Variables of the namelist PostProc of the namelist file "PostProc.INI".

Another input files of the postprocessor are the SKETCH-N output binary file, which is defined by the varaiable FILE_GRF, and the postprocessor input file specified by the variable FILE_INP. If the postprocessor input file FILE_INP is not defined in the namelist, the code generates only the output listing file FILE_OUT with the description of the content of the SKETCH-N binary file FILE_GRF. The postprocessor may also generate three other output files FILE_TR_OUT, FILE_TM_OUT, and FILE_ST_OUT depending on the input in the file FILE_INP. The file FILE_TR_OUT contains the SKETCH transient results given versus time. The file FILE_TM_OUT gives the transient results at the certain time moment, which is defined by the variable TIME_OUTPUT in the namelist file. The file FILE_ST_OUT contains the static distributions. To generate any of these files, the input data in the file FILE_INP should be defined.

3.7.1 Output of the Data versus Time

Let us consider the input data, which define the content of the output file FILE_TR_OUT. At each time step of the calculation the SKETCH-N code writes the set of the data into the binary file "SKETCH.grf". A set includes scalar data, vector data and 3D distributions. The list of these data is discussed in the previous section and printed in the postprocessing listing file given under the variable FILE_OUT. For example, the transient results of the NEACRP PWR rod ejection benchmark include

```
Transient Data :
     Scalar Data :
       1- Total Reactor Power, [MWt]
       2- Reactivity, [$]
       3- Time Step Size of the SKETCH code, [ms]
       4- Time Step Size proposed by the TRAC code, [ms]
     Vector Data :
       1- Control Rod Positions, [cm]; Dimension = 15
     3D Distributions :
       1- Power, [Wt/cm^3]
       2- Boron Concentration, [ppm]
       3- Coolant Temperature, [C]
       4- Coolant Density, [g/cm^3]
       5- Doppler Fuel Temperature, [K]
       6- Fuel Centerline Temperature, [K]
       7- Cladding Inner Surface Temperature, [K]
       8- Fuel Enthalpy, [J/Kg]
```

The data set may be extended in the future, we recommend to check a content of the postprocessing output file FILE_OUT. The output, which is given in the output file FILE_TR_OUT, is defined by the variable identifiers given in the input file. The identifiers are five characters, which may be followed the additional data. The identifiers of the variables for the output into the file FILE_TR_OUT start with the character "T". The second character encodes the data type as shown in Table 3.13.

Character	Meaning
"S"	Scalar data
"V"	Vector Data
"D"	Distribution
"M"	Maximum or minimum value of the distribution, only for the data versus time, which identifier starts with "T"
"L"	Location of the maximum or minimum value of the distribution, only for the data versus time, which identifier starts with "T"

Table 3.13. Meaning of the second character of the identifiers in the postprocessor input file FILE_INP.

The next three characters give the index of the variable in the transient data list. For example, TS001 means the first scalar variable, which is the total reactor power; TV001 is the first vector data, which contains the control rod positions; TD005 is the fifth distribution, which is the Doppler fuel temperature. In the case of the scalar variables, the identifier of five characters totally defines the output variable.
In the case of the vector data, the five character identifier is followed by the index of the vector element given in the free format. For example the input

```
TV001 1
```

means the position of the first control rod.
In the case of the distribution, the five character identifier is followed by x-y-z coordinates of the spatial node. For example

```
TD005 1 1 1
```

means the Doppler fuel temperature of the node with x-y-z coordinates (1,1,1).
Please note that the node coordinates are given for the reactor model grid, not the reactor core grid. The spatial grid includes a reactor core and reflectors. In addition to the values of distribution at the certain node of 3D spatial grid, the core-averaged values and average 2D and 1D values can be specified. The core-averaged values have the coordinates (0, 0, 0); average 1D distribution have zero x-y coordinates and nonzero z coordinates; average 2D distributions have nonezero x-y coordinates and zero z coordinate. For example, the input

```
TD005 0 0 0
```

defines the core-averaged Doppler fuel temperature; the input

```
TD005 0 0 1
```

specifies the average 1D Doppler fuel temperature at the axial layer 1; and the input

```
TD005 1 1 0
```

defines the average 2D Doppler fuel temperature of the bundle with x-y coordinates (1,1).

Maximum and minimum values of the distributions and their locations can be also given in the output file. The identifier TMxxx defines the maximum or minimum value of the distribution number xxx. This identifier is followed by the dimension index given with a "+" sign for the maximum value and "–" sign for minimum value. For example, the input

```
TM005  +3
```

means the maximum value of the 3D Doppler fuel temperature;

```
TM005  -1
```

means the minimum value of the average 1D Doppler fuel temperature.

The identifiers of the location of the maximum or minimum value are given in the similar form, they start with TLxxx, xxx stands for the number of the distribution, followed by the dimension index given with plus or minus sign.
For example, the input

```
TL005  +3
```

means the location of the maximum value of the 3D Doppler fuel temperature;

```
TM005 -1
```

means the location of the minimum value of the average 1D Doppler fuel temperature.

Finally let us consider an example of the postprocessor input for the transient results of the NEACRP PWR rod ejection benchmark. The contents of the input file is given below

```
! OUTPUT OF THE DATA VS. TIME
TS001
! Reactivity [$]
TS002
! Time Step Size, [ms]
TS003
! Position of the 1st Control Rod [cm]
TV001   1
! Average Doppler Fuel Temperature [K]
TD005 0 0 0
! Maximum Fuel Centerline Temperature [K]
```

```
TM006 3
! Location of the 3D Maximum Fuel Centerline Temperature
TL006 3
```

The output format are define as "(F9.3)" for real variables and "(I5)" for integer variables.
The postprocessor generate the output file FILE_TR_OUT, where the first column is the time in seconds and the other columns are defined by the input identifiers. The beginner of the file is given below

```
  0.000    0.001    0.000    5.000   37.700  559.152  559.152    4    1    7
  0.010    0.001    0.009    7.426   74.048  559.152  559.152    4    1    7
  0.016    0.001    0.032    2.939   95.424  559.152  559.152    4    1    7
  0.022    0.001    0.076    3.212  116.787  559.152  559.152    4    1    7
  0.025    0.001    0.111    1.347  126.846  559.152  559.152    4    1    7
  0.027    0.001    0.146    2.285  136.638  559.152  559.152    4    1    7
  0.032    0.001    0.220    1.995  153.251  559.152  559.152    4    1    7
  0.036    0.001    0.297    2.298  167.756  559.152  559.152    4    1    7
  0.040    0.001    0.394    1.883  184.463  559.152  559.152    4    1    7
  0.044    0.001    0.478    1.886  198.152  559.152  559.152    4    1    7
  0.048    0.001    0.559    1.774  211.861  559.152  559.152    4    1    7
  0.051    0.001    0.635    1.757  224.755  559.152  559.152    4    1    7
  0.055    0.002    0.701    1.687  237.530  559.152  559.152    4    1    7
```

etc.

3.7.2 Output of the Data at the Certain Time Moment

A code user often wants to know the reactor data at the time moments, which are not know before the calculation is performed, for example, at the time of the power peak or at the time before scram control rods start moving.

The postprocessor provides a capability to output the SKETCH-N computed results at the user defined time moment. The time is defined by the variable TIME_OUTPUT in the namelist file "PostProc.INI". The output is written into the file FILE_TM_OUT. The output values are computed by a linear interpolation of the SKETCH results at the time interval, which includes the specified time moment. The output is defined by the variable identifiers given in the input postprocessor file FILE_INP. The identifiers are similar to the identifiers discussed in the previous section. The identifier has five characters, which may followed by additional data. The identifier for this output starts with the character "M". The second character encode of the type of the variable: "S" stands for scalar data; "V" defines the vector data and "D" means a distribution. The last three characters are the index of the variable in the SKETCH-N output transient data list, which is written in the postprocessor output listing file FILE_OUT. The example is given in the previous section. The identifier defines the output variable. In the case of the distribution, the output scaling factor may follow the identifier. If the scaling factor is not given, the default value 1.0 is used. Scaling factor may has the value 0.0. In this case, the core-averaged value of the distribution is used as the scaling factor for output.

Let us consider an example of the postrocessor input for the output of the transient values at the given time moment. The results of the NEACRP PWR rod ejection benchmark are considered. The time moment is 5.0 s, which is the end of the transient. The input for the postprocessor is given below,

```
MS001  # Reactor power [MWt]
MD001 0.0 # Power distribution; scaling factor is the core-averaged value
```

which define the output of the total reactor power and the power distribution normalised to the core-averaged value. The output format is "(F6.3)". The postprocessor output written into the file FILE_TM_OUT is shown below. Please note that only the results of the reactor core region are given in this output.

```
!============================================================================!
!             PostProcessing of the SKETCH-N Results                         !
!              Version 1.0 (c) Slava 2000 e-mail: na.vzimin@na-net.ornl.gov  !
!============================================================================!
 Input  SKETCH   *.grf File : Output/SKETCH.grf
 Input  PostProc *.dat File : Input/PostProc_PWR_A1_KIN.dat
!============================================================================!
!                                  SKETCH-N                                  !
!  Nodal Neutron Diffusion Code for Solving Steady-State and Kinetics Problems !
!              Version 1.0 (c) Slava 2000 e-mail: na.vzimin@na-net.ornl.gov  !
!      Date & Time of Calculation :  8 August   2000  11:13:46 am            !
!============================================================================!
!----------------------------------------------------------------------------!
!   3D NEACRP PWR Rod Ejection Benchmark                                     !
!      (c) Slava March 1998 JAERI                                            !
!----------------------------------------------------------------------------!
Output of the data in time moment = 0.50000E+01
Linear interpolation in interval [ 0.48972E+01 0.50000E+01]
Interpolation factor = 1.00000
!----------------------------------------------------------------------------!
Total Reactor Power, [MWt]
Scaling Factor = 0.10000E+01
 0.13682E+03
!----------------------------------------------------------------------------!
POWER, [Wt/cm^3]
Scaling Factor = 0.49189E-01
!----------------------------------------------------------------------------!
Distribution Summary:
     Scaling Factor                       :  0.49189E-01
     Average Value                        :  1.000

     3D Maximum Value                     :  4.842
     Reactor Location of 3D Maximum (X,Y,Z):  1  1  8
     Core    Location of 3D Maximum (X,Y,Z):  1  1  7

     3D Minimum Value                     :  0.041
     Reactor Location of 3D minimum (X,Y,Z):  7  3 17
     Core    Location of 3D minimum (X,Y,Z):  7  3 16

     2D Maximum Value                     :  3.210
     Reactor Location of 2D Maximum (X,Y)  :  1  1
     Core    Location of 2D Maximum (X,Y)  :  1  1

     2D Minimum Value                     :  0.322
     Reactor Location of 2D minimum (X,Y)  :  3  7
     Core    Location of 2D minimum (X,Y)  :  3  7

     1D Maximum Value                     :  1.496
     Reactor Location of the 1D Maximum (Z):        9
     Core    Location of the 1D Maximum (Z):        8

     1D Minimum Value                     :  0.114
     Reactor Location of the 1D minimum (Z):       17
     Core    Location of the 1D minimum (Z):       16
```

```
!-------------------------------------------------------------------------------!
 2D Distribution     :
!-------------------------------------------------------------------------------!
          1     2     3     4     5     6     7     8
      ----- ----- ----- ----- ----- ----- ----- -----
  1:  3.213 2.539 1.282 1.770 1.658 0.893 0.337 0.445
  2:  2.539 2.592 1.897 1.863 1.308 0.495 0.474 0.354
  3:  1.282 1.897 1.064 1.373 0.660 0.625 0.322
  4:  1.770 1.863 1.373 1.292 0.884 0.794 0.449
  5:  1.658 1.308 0.660 0.884 0.462 0.559
  6:  0.893 0.495 0.625 0.794 0.559
  7:  0.337 0.474 0.322 0.449
  8:  0.445 0.354
!-------------------------------------------------------------------------------!
     1D Distribution
!-------------------------------------------------------------------------------!
   2 0.253
   3 0.341
   4 0.534
   5 0.842
   6 1.172
   7 1.389
   8 1.494
   9 1.498
  10 1.419
  11 1.271
  12 1.069
  13 0.825
  14 0.548
  15 0.335
  16 0.204
  17 0.114
!-------------------------------------------------------------------------------!
 3D Distribution     :
!-------------------------------------------------------------------------------!
 CHAN     1     2     3     4     5     6     7     8     9    10
      ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
   2: 0.700 0.669 0.425 0.458 0.344 0.223 0.107 0.088 0.669 0.573
   3: 1.123 0.897 0.458 0.607 0.550 0.301 0.115 0.141 0.897 0.902
   4: 1.807 1.413 0.697 0.954 0.885 0.470 0.174 0.226 1.413 1.441
   5: 2.847 2.223 1.095 1.505 1.401 0.741 0.274 0.360 2.223 2.267
   6: 3.915 3.064 1.517 2.089 1.949 1.034 0.384 0.506 3.064 3.126
   7: 4.573 3.590 1.790 2.469 2.309 1.231 0.460 0.607 3.590 3.666
   8: 4.847 3.817 1.915 2.648 2.482 1.330 0.500 0.661 3.817 3.900
   9: 4.797 3.789 1.913 2.650 2.487 1.339 0.506 0.671 3.789 3.874
  10: 4.491 3.556 1.805 2.503 2.353 1.272 0.483 0.641 3.556 3.638
  11: 3.988 3.165 1.613 2.239 2.107 1.143 0.435 0.578 3.165 3.238
  12: 3.335 2.650 1.355 1.881 1.772 0.963 0.368 0.489 2.650 2.712
  13: 2.563 2.040 1.045 1.451 1.366 0.744 0.284 0.378 2.040 2.087
  14: 1.697 1.352 0.694 0.963 0.907 0.494 0.189 0.251 1.352 1.383
  15: 1.035 0.825 0.425 0.590 0.556 0.303 0.116 0.154 0.825 0.845
  16: 0.623 0.498 0.259 0.359 0.338 0.185 0.071 0.094 0.498 0.510
  17: 0.304 0.270 0.152 0.206 0.185 0.106 0.042 0.052 0.270 0.253
```

etc. till the bundle number 47.

3.7.3 Output of the Static Distributions

In the case of BWR Ringhals-1 calculations, the static distributions taken from the SKETCH input distribution file are written into the SKETCH output binary file. The postprocessor can also output these distributions into the text form in the file `FILE_ST_OUT` defined in the namelist file "PostProc.INI". The list of the static distributions is given in the postprocessor output file `FILE_OUT`. The output variables are specified by the identifiers given in the input postprocessor file `FILE_INP`. The definition of the output variables is practically identical to that discussed in the previous section. The only difference that the identifiers for the output of the static distributions start with the character "`S`".

4. 2D FOUR-GROUP KOEBERG PWR BENCHMARK

This chapter contains the description of the SKETCH-N calculation of the 2D four-group KOEBERG PWR benchmark (Muller and Weiss, 1991). The SKETCH-N input and output files for this problem are given in the directory Samples/PWR_KOEBERG2D. The SKETCH-N results have been published in (Zimin et. al., 1999).

4.1 Benchmark Problem Description

KOEBERG benchmark is 2D four-group pure neutronics eigenvalue problem (Muller and Weiss, 1991). The beginner of life core of Unit 1 of the KOEBERG nuclear power plant is modelled. The reactor model consists of 157 homogenised fuel assemblies of three enrichments and three different absorber loadings, each assembly having a width of 21.608 cm. The core is surrounded by a 21.608 cm homogenised reflector (2.8575 cm baffle homogenised with 18.7505 cm borated water). Vacuum boundary conditions are imposed on the outer reflector surface. A quarter-core reactor configuration is shown in Fig. 4.1. Four-group macro cross sections are given in Table 4.1.

The reference solution of this problem is computed by the LABAN-PEL nodal code using 6 order expansion of the neutron flux into Legendre polynomials ((Muller and Weiss, 1991). The reference eigenvalue and 2D assembly-averaged power distribution are given in Fig. 4.2.

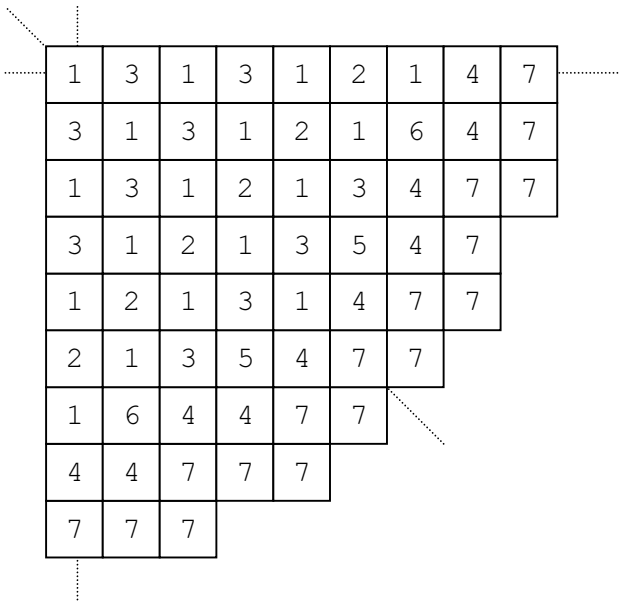


Fig. 4.1 Core configuration of the four-group KOEBERG PWR benchmark.

Zone	Group	D_g	Σ_{ag}	$\nu\Sigma_{fg}$	Σ_{sg1}	Σ_{sg2}	Σ_{sg3}	Σ_{sg4}
1	1	2.491869	0.003654	0.008228	0.0	0.0	0.0	0.0
	2	1.045224	0.002124	0.000536	0.063789	0.0	0.0	0.0
	3	0.677407	0.019908	0.007058	0.000486	0.064381	0.0	0.001245
	4	0.375191	0.067990	0.083930	0.0	0.000003	0.050849	0.0
2	1	2.492653	0.003685	0.008295	0.0	0.0	0.0	0.0
	2	1.049844	0.002215	0.000713	0.063112	0.0	0.0	0.0
	3	0.676610	0.022012	0.009230	0.000478	0.063078	0.0	0.001543
	4	0.379481	0.085052	0.108244	0.0	0.000003	0.048420	0.0
3	1	2.491978	0.003684	0.008285	0.0	0.0	0.0	0.0
	2	1.051910	0.002221	0.000713	0.062765	0.0	0.0	0.0
	3	0.677084	0.022403	0.009214	0.000473	0.062404	0.0	0.001598
	4	0.381453	0.088077	0.108087	0.0	0.000003	0.047549	0.0
4	1	2.492535	0.003740	0.008459	0.0	0.0	0.0	0.0
	2	1.045298	0.002299	0.000923	0.063737	0.0	0.0	0.0
	3	0.674684	0.022621	0.011714	0.000486	0.064330	0.0	0.001630
	4	0.374240	0.091000	0.133600	0.0	0.000003	0.049518	0.0
5	1	2.492329	0.003730	0.008409	0.0	0.0	0.0	0.0
	2	1.051953	0.002315	0.000921	0.062737	0.0	0.0	0.0
	3	0.675683	0.023822	0.011675	0.000473	0.062376	0.0	0.001797
	4	0.380606	0.100246	0.134282	0.0	0.000003	0.046859	0.0
6	1	2.491521	0.003730	0.008400	0.0	0.0	0.0	0.0
	2	1.054029	0.002321	0.000921	0.062386	0.0	0.0	0.0
	3	0.676197	0.024196	0.011651	0.000468	0.061696	0.0	0.001852
	4	0.382434	0.103283	0.133974	0.0	0.000003	0.046005	0.0
7	1	2.119737	0.000466	0.0	0.0	0.0	0.0	0.0
	2	0.980098	0.000263	0.0	0.042052	0.0	0.0	0.0
	3	0.531336	0.004282	0.0	0.000322	0.044589	0.0	0.000978
	4	1.058029	0.116918	0.0	0.0	0.0	0.052246	0.0

χ_1=0.745248; χ_2=0.254328; χ_3=0.000424; χ_4=0.0

Table 4.1 Macro cross sections for four-group KOEBERG PWR benchmark.

```
1.0058 1.0858 1.0445 1.1639 1.1319 1.2147 0.9596 0.8331
1.0858 1.0263 1.1305 1.1054 1.2430 1.0617 1.0420 0.6425
1.0445 1.1305 1.0929 1.2236 1.0581 1.0390 0.9684
1.1639 1.1054 1.2236 1.0363 0.9988 0.9813 0.6504
1.1319 1.2430 1.0581 0.9988 0.7860 0.6670
1.2147 1.0617 1.0390 0.9813 0.6670
0.9596 1.0420 0.9684 0.6504
0.8331 0.6425
```

k_{eff} = 1.007954

Fig. 4.2 Reference power distribution and eigenvalue for KOEBERG PWR benchmark.

4.2 Include and Input Files

The include and input files for the SKETCH-N code are given in the directory Samples/PWR_KOEBERG2D in the subdirectories Include and Input, respectively. The include file "koeberg2d.fh" is the file, which is used in the compilation of the code under the name "parameter.fh". The list of the input files follows below

- "SKETCH.INI.KOEBERG2D.ST" is the namelist input file;
- "KOEBERG2D.DAT" is the input file with the reactor model data;
- "KOEBERG2D.ref" is the input file with the reference solution.

The contents of the include and input files are given in the Appendix A.

The reactor model parameters, which defines the dimensions of the code arrays, are given in the file"koeberg2d.fh". The content of this file is presented in the Appendix A.1. Let us shortly outline the meaning of the input data, the detail description of the input variables is given in the Section 3.1. The quarter-core reactor model is used in the calculation. The reactor model has 64 assemblies, 47 assemblies are in the reactor core. The reactor spatial mesh 9x9 with 1 node per assembly is defined. 7 types of the assemblies are specified; in 2D calculations, they correspond to 7 material compositions. Four neutron energy groups are used. The problem is a steady-state eigenvalue problem and delayed neutron precursors are not used in the calculations. However, the number of delayed neutron groups should be given in the parameter file and the number is defined as 1. There are no thermal-hydraulics feedbacks in this problem. However, in the SKETCH-N code, the number of feedbacks is fixed to 4 and should be given in the parameter file. The problem does not require the control rods and neither internal or external thermal-hydraulics model. However, the values of the parameters related to these models should be defined, in the file "koeberg2d.fh" we set them to 1. Please note that due to the static memory allocation used in the present version of the code, these parameters could not be zero.

The content of the namelist file "SKETCH.INI.KOEBERG2D.ST" is given in the Appendix A.2. In the namelist `INI_PROBLEM`, we define that the problem type is an eigenvalue problem and that no thermal-hydraulics model is used. In the namelist `INI_FILES`, the input and restart files are given. The default convergence criterion `1.E-5` are used in the calculations. In the namelist `INI_CHEBYSHEV`, we set the inverse value of the Wieland shift to `10.0` to accelerate the convergence of the steady-state iterations.

The reactor model data are given in the file "KOEBERG2D.DAT". The content of this file is given in the Appendix A.3. The data include the description of the spatial mesh, macro cross sections, core loading by material compositions and boundary conditions. The input data are prepared in accordance with the benchmark specification. The detail description of the input data identifiers is given in the Section 3.3. Only a few comments are added. The value of the reactor power is not important in this problem, because no feedbacks are considered and normalised 2D power distribution is required for a comparison. We used the value of the 1 MWt for the reactor power. In the benchmark specification (Muller and Weiss, 1991), the energy release per fission is not defined. We use a constant value `3.204E-11` [Ws/fission] for all neutron energy groups. The reactor model is defined in the quarter-core configuration. A spatial mesh with 1 node per assembly is used. The boundary conditions are reflective at the North and West boundaries and vacuum conditions at the East and South boundaries. Zero axial buckling is used.

The file "KOEBERG2D.ref" is the input file with a reference solution. The contents of this file is shown in Appendix A.4. The file contains one line of a header, the reference eigenvalue and 2D assembly-averaged power distribution. The SKETCH-N code performs a comparison of the computed results with the given reference data.

4.3 Steady-State Calculation and Output Files

To perform the calculation we prepare the shell file "PWR_KOEBERG2D.sh", which is given in the directory Shell. The commands of the file are given below

```
>cd ../Include
>cp ../Samples/PWR_KOEBERG2D/Include/koeberg2D.fh parameters.fh
```

```
>cd ../Input
>cp ../Samples/PWR_KOEBERG2D/Input/KOEBERG2D.DAT KOEBERG2D.DAT
>cp ../Samples/PWR_KOEBERG2D/Input/KOEBERG2D.ref KOEBERG2D.ref
>cp ../Samples/PWR_KOEBERG2D/Input/SKETCH.INI.KOEBERG2D.ST SKETCH.INI
>cd ../Source
>make ../SKETCH
>cd ..
>SKETCH
```

The shell file copies the include file and the input files into the working directories, builds the code and performs the calculation. The code output is given in the directory Output in the files "Error.msg", "SKETCH.lst", "SKETCH.grf". The restart file "koeberg2d.dat" is written in the directory Restart. The error message file "Error.msg" contains some warnings, because several input identifiers are not given in the input file and default values are used. These warnings may be ignored. The input data and the calculation results are written into the text output file "SKETCH.lst". The sample of this file is "Samples/PWR_KOEBERG2D/Output/SKETCH.lst". You can compare the computed power distribution and the eigenvalue with the values given in the sample file. The binary file "SKETCH.grf" may be processed by the SKETCH postprocessor. Examples of the postprocessor use are given in the following Chapters for transient benchmarks. The file "Comparison.dat" contains a comparison of the computed eigenvalue and 2D power distribution with the reference solution taken from the input file "KOEBERG2D.ref". The content of the file "Comparison.dat" is given in the Appendix A.5. The calculation performed using the semi-analytical nodal method on the spatial mesh with one node per assembly. An error in eigenvalue is 39 pcm. The maximum error in 2D assembly-averaged power distribution is 2.0 % for assembly (1,8). An average error in power distribution is 1 %. The results may be slightly different on different computers because the code uses single precision arithmetic.

5. 3D NEACRP PWR ROD EJECTION BENCHMARK, CASE A1

This chapter contains the description of the SKETCH-N calculation of the case A1 of 3D NEACRP PWR rod ejection benchmark (Finnemann and Galati, 1992). The SKETCH-N input and output files for this problem are given in the directory Samples/PWR_NEACRP_A1.

5.1 Benchmark Problem Description

The NEACRP PWR rod ejection benchmark is proposed by H. Finnemann and A. Galati (1992) and has been widely used for the verification of coupled neutronics/thermal-hydraulics codes (Finnemann et al., 1993). A PWR core model is derived from the real reactor geometry and operational data. The transients are initiated by a rapid ejection of a control rod at the hot zero power (cases A1, B1 and C1) or full power (cases A2, B2 and C2). Only the case A1 is considered in this report, the results of all the cases computed by the J-TRAC/SKETCH-N code are given in (Zimin et. al., 1999).

The reactor geometry has 1/8 core symmetry in the case A1. The width of assemblies is 21.606 cm. The reactor core height is 367.3 cm. The core is subdivided into 16 axial layers with heights of 7.7, 11.0, 15.0, 30.0 (10 layers), 12.8 (2 layers) and 8.0 cm from bottom to top. Top and bottom axial reflectors have thickness of 30.cm.

Fuel assemblies with different U-235 enrichment and different numbers of rods of burnable absorbers are present in the core. 11 different material compositions and the corresponding sets of cross sections are defined. The material compositions may be grouped into 9 assembly types. Core loading by assembly types is shown in Fig. 5.1. Axial material composition of each assembly type is shown in Table 5.1.

The radial arrangement of control assemblies (CA) is shown in Fig. 5.2. The total length of CA, which coincides with the absorber length, is 362.159 cm. The driver device section following the top of the absorbers is distinguished from the absorber via a different cross section data set. No tips of control rods is defined. The position of the lower CA absorber edge from the bottom of the lower reflectors is 37.7 cm for a completely inserted CA, and 401.183 cm for a completely withdrawn CA. Measured in units of steps, complete insertion or withdrawal of CA corresponds to 0 and 228 steps, respectively.

Two prompt neutron groups and six delayed neutron groups are used. Zero flux boundary conditions are imposed on the outer reflector surface. Velocities and the energy release per fission are given in Table 5.2. Table 5.3 shows the time constants and fractions of the delayed neutrons. No delayed neutron energy release is considered.

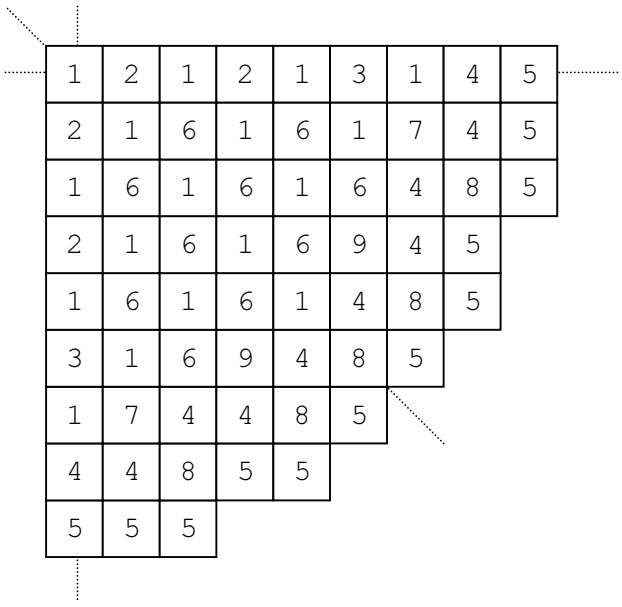


Fig. 5.1 Core loading by assembly types for 3D NEACRP PWR rod ejection benchmark, case A1.

Axial Layer	Material composition of the assembly type number N								
	1	2	3	4	5	6	7	8	9
18 (top)	1	1	1	1	1	1	1	1	1
3÷17	4	9	7	6	2	8	11	3	10
2	4	5	5	6	2	5	6	3	6
1 (bottom)	1	1	1	1	1	1	1	1	1

Table 5.1 Axial material composition of the assemblies for 3D NEACRP PWR rod ejection benchmark.

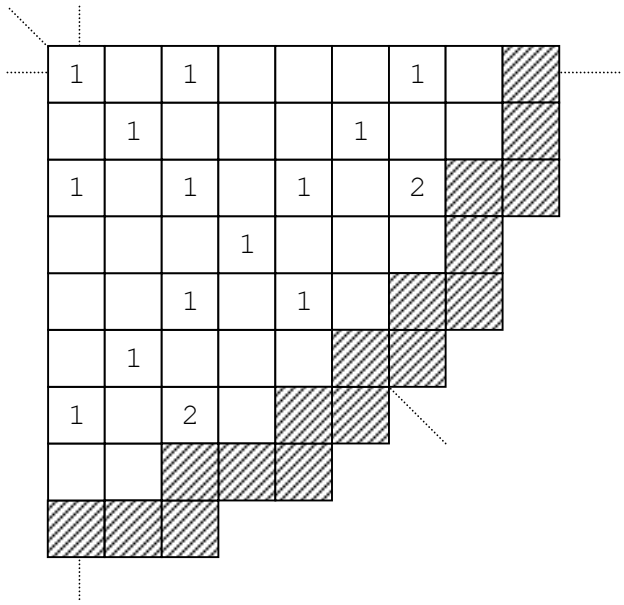


Fig. 5.2 Core loading by control assembly types for 3D NEACRP PWR rod ejection benchmark, case A1.

	fast energy group	thermal energy group
Neutron velocity [cm/s]	0.28 E+8	0.44 E+6
Energy release [Ws/fission]	0.3213E-10	0.3206E-10

Table 5.2 Velocities and energy release of prompt neutrons for 3D NEACRP PWR rod ejection benchmark.

group	Decay constant [1/s]	Relative fraction of delayed neutrons
1	0.0128	0.034
2	0.0318	0.200
3	0.1190	0.183
4	0.3181	0.404
5	1.4027	0.145
6	3.9286	0.034
Total fraction of delayed neutrons:		0.76 %

Table 5.3 Decay constants and fractions of delayed neutrons for 3D NEACRP PWR rod ejection benchmark.

For each material composition the following macro cross sections are given

Σ_{tr1}, Σ_{tr2} are the transport macro cross sections;

Σ_{a1}, Σ_{a2} are the absorption macro cross sections;

Σ_{s21} is the scattering macro cross section from the group 1 into the group 2;

Σ_{f1}, Σ_{f2} are the fission macro cross sections;

$\nu\Sigma_{f1}$, $\nu\Sigma_{f2}$ are the production macro cross sections.

The macro cross sections depend on the following feedback variables

c is the borom concentration $[ppm]$;

ρ is the coolant density $[g/cm^3]$;

T_M is the coolant temperature $[°C]$;

T_D is the Doppler fuel temperature $[°K]$.

The macro cross sections are expressed in terms of the feedback variables as

$$\Sigma = \Sigma_0 + \left(\partial\Sigma/\partial c\right)_0 (c - c_0) + \left(\partial\Sigma/\partial\rho\right)_0 (\rho - \rho_0) + \left(\partial\Sigma/\partial T_M\right)_0 (T_M - T_{M0}) +$$

$$\left(\partial\Sigma/\partial\sqrt{T_D}\right)_0 (\sqrt{T_D} - \sqrt{T_{D0}}),$$

where index 0 marks the reference values

The reference macro cross sections, their derivatives and the feedback reference values are given for each material composition. We decided not to give the values in this section referring a reader to the benchmark specification (Finnemann and Galati,1992) or to the content of the SKETCH-N input file, which is given in the Appendix B.3.

The macro cross section of the node with a control rod is determined by adding the differential cross section $\Delta\Sigma^{CR}$ to the cross section without control rod as

$$\Sigma^{\text{with CR}} = \Sigma^{\text{without CR}} + \Delta\Sigma^{CR}$$

The differential cross section $\Delta\Sigma^{CR}$ does not depend on the feedbacks. The contribution of the control rod driver is treated in the same way. The differential cross section of the absorbers and drivers are given in the benchmark specification (Finnemann and Galati,1992) and can be extracted from the SKETCH input file given in the Appendix B.3.

The Doppler fuel temperature is computed interpolating the fuel rod centerline temperature $T_{F,C}$ and the fuel rod surface temperature $T_{F,S}$ as

$$T_D = (1-\alpha) T_{F,C} + \alpha T_{F,S},$$

where α is taken equal 0.7.

Data of the fuel assembly geometry are given in Table 5.4.

The UO_2 density without dishing is 10.412 g/cm^3 (95 % of the theoretical density) at a temperature of 10 °C. The pellet dishing amounts to 1.248 %. The cladding material is Zircaloy-4 with a density of 6.6 g/cm^3. The relations for the heat conductivity λ [W/(m °K)] and specific heat capacity c_p [J/(kg °K) of fuel and cladding are defined as follows

$$\lambda_{UO2} = 1.05 + 2150/(T - 73.15)$$

$$\lambda_{Zirkaloy-4} = 7.51 + 2.09 \times 10^{-2}\, T - 1.45 \times 10^{-5}\, T^2 + 7.67 \times 10^{-9}\, T^3$$

$$c_{p,UO2} = 162.3 + 0.3038\, T - 2.391 \times 10^{-4}\, T^2 + 6.404 \times 10^{-8}\, T^3$$

$$c_{p,\,Zirkaloy-4} = 252.54 + 0.11474\, T$$

where T is the temperature [°K].
Expansion effects of fuel and cladding are not considered in the benchmark.

The flat profile of the power density inside the fuel rod in radial direction is assumed.

The reactor is at the beginner of cycle 1 (zero EPFD: no Xenon or Iodine, no fuel depletion). The steady-state operation data are defined in Table 5.5. The thermal energy output is to be released for 98.1 % in the fuel and for 1.9 % in the coolant. The inlet mass flow through the core given in Table 5.5 is distributed uniformly among the channels. A homogeneous core pressure of 155 bar is assumed. The conductance of the helium-filled gap between fuel and cladding is assumed to be constant of 10^4 [W/(m^2 °K)].

The critical steady-state parameters of the core have to be found from a search of the critical boron concentration for the given thermal power and control assembly (CA) positions. The transient is initiated by a rapid ejection of a control assembly from an initially critical core at the hot zero power condition in the case A1. The control rod ejection results in more than 1 $ reactivity insertion, which is terminated by a Doppler feedback. The time of the control rod ejection is 100 ms. No reactor scram is considered. Both the boron concentration and the positions of the other control assemblies are kept constant in the transient. The initial CA positions and location of the ejected CA are shown in Fig. 5.3. Five seconds of the transient should be computed.

A private communication of the author with Dr. M. P. Knight of Nuclear Electric Ltd. (1998) resolves some ambiguities and omissions of the benchmark specification. They are as follows

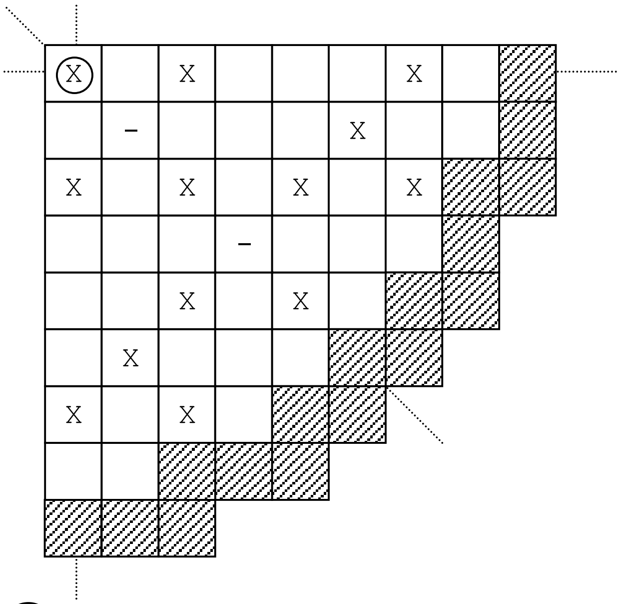
- the HZP power level is not specified, but should be 1.0E-6 of the full power;
- the control assembly driver and absorber should have zero fission cross sections in the top reflector;

Pellet diameter	8.239 mm
Clad diameter	9.517 mm
Clad wall thickness	0.571 mm
FR pitch	12.655 mm
Guide tube diameter (outside)	12.259 mm
Guide tube diameter (inside)	11.448 mm
Geometry	17x17 – 25
Number of fuel pins	264
Number of guide tubes	25

Table 5.4 Data of the fuel assembly geometry for 3D NEACRP PWR rod ejection benchmark.

Core thermal output	2775 MW
Core inlet temperature	286 °C
Core pressure	155 bar
Net mass flow rate through core	12893 kg/s

Table 5.5 Steady-state operation data for 3D NEACRP PWR rod ejection benchmark.



Ⓧ = CA to be ejected

CA type	X	–
Position in steps	0	228

Fig. 5.3 Initial positions of the control assemblies for 3D NEACRP PWR rod ejection benchmark, case A1.

- the Doppler fuel temperature dependence is on $\sqrt{T_D}$ with T_D taken in the degrees of Kelvin, even though the values of $(T_D)_0$ given in the benchmark tables are in the degrees of Celsius.

A reference solution of the benchmark is computed by the PANTHER code using fine temporal and spatial meshes (Finnemann et al., 1993). Recently, Knight and Bryce (1997) are published a refined reference solution, where additional sensitivity analysis is performed and uncertainties of the reference results are significantly decreased. The reference solution contains several key steady-state and transient parameters: critical boron concentration, 3D nodal power peaking factors, control rod worth, time and value of the power peak, power at the time 5 s, maximum fuel centerline temperature at time 5 s etc. The given reference parameters are representative and provide compact representation of the both global and local data of the rod ejection transient.

5.2 Include File "pwr_neacrp_a1.fh"

The include file "pwr_neacrp_a1.fh" is the file, which is used under the name "parameters.fh" in the code compilation. The file is given in the directory Samples/PWR_NEACRP_A1/Include. The content of the file is shown in the Appendix B.1.

Let us shortly outline a meaning of the input data, the detail description of the input variables is given in the Section 3.1. The quarter-core reactor model has 64 assemblies subdivided into 18 axial layers. The spatial mesh 17x17x18 is used with 4 nodes per assembly in x-y plane. The mesh has 221 nodes in each axial layers. 9 assembly types are defined.

Eleven material compositions are defined with the corresponding set of the macro cross sections. Two prompt neutron groups and six delayed neutron groups are used. Four feedback variables are boron concentration, moderator temperature, moderator density and Doppler fuel temperature.

The reactor model contains 15 control rods of 2 types. Each control rod consists of two control rod elements: absorber and driver. Three types of the control rod materials are defined: two types of the control rod absorbers and driver material, which is the same for the both types of the control rods.

Spatial mesh of the heat conduction model in the fuel rod has 9 zones in the fuel and 2 zones in the cladding.

The parameters of the external thermal-hydraulics model describes the spatial mesh of the J-TRAC code, which has been used in the coupled J-TRAC/SKETCH-N calculations of this problem (Zimin et. al., 1999). These parameters are not used in the present calculation.

5.3 Input Files for the Steady-State Calculation

The input files for the SKETCH-N code are given in the directory Samples/PWR_NEACRP_A1/Input. The list of the input files follows below

- "SKETCH.INI.PWR_A1.ST" is the namelist input file;
- "PWR_NEACRP_A1.DAT" is the input file with the reactor model data.

The content of the namelist file "SKETCH.INI.PWR_A1.ST" is given in the Appendix B.2. In the namelist `INI_PROBLEM`, we define that the problem type is a critical boron search and that the internal thermal-hydraulics model is used. In the namelist `INI_FILES`, the input and restart files are given. The default convergence criterion `1.E-5` are used in the calculations.

The reactor model data are given in the file "PWR_NEACRP_A1.DAT". The content of this file is given in the Appendix B.3. The data include the description of the spatial mesh, macro cross sections and their derivations with respect to feedbacks, core loading by material compositions, boundary conditions, the description of the control rods and the data for the internal thermal-hydraulics model. The input data are prepared in accordance with the benchmark specification. The detail description of the input data identifiers is given in the Section 3.3. Only a few comments are added. The reactor power is 693.75 W for the quarter-core reactor model. Two-group macro cross sections and their derivatives with respect to the boron concentration, the moderator temperature, the moderator density and square root of the Doppler fule temperature are given for eleven material compositions. The differential macro cross sections are specified for three types of the control rod materials. The spatial mesh 17x17x18 is defined with a mesh size of 10.803 cm in x and y directions. The core is loaded by 9 assembly types, which contains 11 material compositions. The boundary conditions are reflective at the North and West boundaries and zero flux conditions at the East, South, Bottom and Top boundaries. The control rod data contains the description of the control rod ejection, which is used only in transient calculation. The control rod velocity 3634.3 cm/s provides a control rod ejection in 100 ms. The data for the thermal hydraulics model are prepared based on the benchmark specification. The Dittus-Boelter correlation is used to compute the heat transfer coefficient between the cladding and coolant. The radial heat conduction spatial mesh in the fuel rods is determined by the code, the mesh size provide an equal area of the heat conduction zones.

5.4 Steady-State Calculation and Output Files

To perform the steady-state calculation we prepare the shell file "PWR_NEACRP_A1_ST.sh", which is given in the directory Shell. The commands of the file are given below

```
>cd ../Include
>cp ../Samples/PWR_NEACRP_A1/Include/pwr_neacrp_a1.fh parameters.fh
>cd ../Input
>cp ../Samples/PWR_NEACRP_A1/Input/PWR_NEACRP_A1.DAT PWR_NEACRP_A1.DAT
>cp ../Samples/PWR_NEACRP_A1/Input/SKETCH.INI.PWR_A1.ST SKETCH.INI
>cd ../Source
>make ../SKETCH
>cd ..
>SKETCH
```

The shell file copies the include file and the input files into the working directories, builds the code and performs the calculation. The code output is given in the directory Output in the files "Error.msg", "SKETCH.lst", "SKETCH.grf". The restart file for the transient calculation "pwr_neacrp_A1_0.dat" is written in the directory Restart. The error message file "Error.msg" contains some warnings, because several input identifiers are not given in the input file and default values are used. These warnings may be ignored. The input data and the calculation results are written into the text output file "SKETCH.lst". The sample of this file is "Samples/PWR_NEACRP_A1/Output/SKETCH.lst.PWR_A1_ST". A comparison of the SKETCH-N steady-state results with the PANTHER reference solution is given in the Table 5.6. You can compare the computed results with the values given in the Table 5.6 and in the sample file. The binary file "SKETCH.grf" may be processed by the SKETCH postprocessor. Examples of the postprocessor use are given in the section 5.7 for the transient results.

Parameter	SKETCH-N result	Derivation from the reference	PANTHER reference
Critical boron concentration, ppm	561.9	+0.7 ppm	561.20
3D nodal power peaking factor	2.8770	-0.08 %	2.8792

Table 5.6 A comparison of the steady-state SKETCH-N results with the PANTHER reference solution for the case A1 of the 3D NEACRP PWR rod ejection benchmark.

5.5 Input Files for the Transient Calculation

The input files for the SKETCH-N transient calculation are given in the directory Samples/PWR_NEACRP_A1/Input. The list of the input files follows below

- "SKETCH.INI.PWR_A1.KIN" is the namelist input file;
- "PWR_NEACRP_A1.DAT" is the input file with the reactor model data.

The content of the namelist file "SKETCH.INI.PWR_A1.KIN" is given in the Appendix B.4. In the namelist `INI_PROBLEM`, we define that the problem type is a transient problem and that the internal thermal-hydraulics model is used. In the namelist `INI_FILES`, the input and restart files are given. The file "Restart/pwr_neacrp_A1_0.dat" generated in the steady-state calculation is used as an input restart file for the transient calculation. The default convergence criterion `1.E-4` is used in the calculations. In the namelist `INI_TIME_STEP`, the data for time stepping are defined. An automatic time step selection is used. Five seconds of the transient are computed. An initial guess of the first time step is 0.005 s. Accuracy criteria of the automatic time step control is 5.E-03.

The reactor model data are given in the file "PWR_NEACRP_A1.DAT", which is already used in the steady-state calculation. The content of this file is given in the Appendix B.3 and is described in the section 5.3.

5.6 Transient Calculation and Output Files

To perform the transient calculation we prepare the shell file "PWR_NEACRP_A1_KIN.sh", which is given in the directory Shell. The commands of the file are given below

```
>cd ../Input
>cp ../Samples/PWR_NEACRP_A1/Input/SKETCH.INI.PWR_A1.KIN SKETCH.INI
>cd ..
>SKETCH
```

The file copies the namelist file into the working input directory and run the code. The code output is given in the directory Output in the files "Error.msg", "SKETCH.lst", "SKETCH.grf". The input data and the calculation results at the beginner and the end of the transient are written into the text listing file "SKETCH.lst". A sample is "Samples/PWR_NEACRP_A1/Output/SKETCH.lst.PWR_A1_KIN". A comparison of the SKETCH-N results at the time of 5 s with the PANTHER reference results is given in the Table 5.7. You can compare the computed results with the values given in the Table 5.7 and in the sample file. Other transient results can be extracted from the binary file "SKETCH.grf" by the SKETCH postprocessor. The postprocessor input and output files are discussed in the following section 5.7.

Parameter	SKETCH-N result	Derivation from the reference	PANTHER reference
Power at 5 s, %	19.72	+0.15 %	19.69
Average Doppler fuel temperature at 5 s, °C	324.87	-0.02 °C	324.89
Maximum fuel centerline temperature at 5 s, °C	681	+2 °C	679.30
Coolant outlet temperature at 5 s, °C	293.1	-0.1 °C	293.22

Table 5.7 A comparison of the SKETCH-N results at the time of 5 s with the PANTHER reference results for the case A1 of the 3D NEACRP PWR rod ejection benchmark.

5.7 Postprocessing the Transient Results

In addition to the SKETCH-N results at the time of 5 s, which are available from the listing file "SKETCH.lst", we are interested in the following data

- total reactor power versus time;
- reactivity versus time;
- time step size used by the code versus time;
- average Doppler fuel temperature versus time;
- maximum fuel centerline temperature versus time.

To extract this data from the SKETCH-N binary file "SKETCH.grf" the postprocessor is used. As discussed in the section 3.7, the postprocessor requires two input files: the namelist input file "PostProc.INI" and the input data file. The files are given in the directory Samples/PWR_NEACRP_A1/Input as

- "PostProc.INI.PWR_A1_KIN" is the namelist input file;
- "PostProc_PWR_A1_KIN.dat" is the input data file for the postprocessor.

The content of the namelist file "PostProc.INI.PWR_A1_KIN" is given in the Appendix B.5. The meaning of the namelist variables is discussed in the section 3.7. We specify the input data file "PostProc_PWR_A1_KIN.dat", the output file "PostProc_PWR_A1_TIME.lst" for the data versus time and the output format of the real output data.

The content of the input data file for the postprocessor is given in the Appendix B.6. The meaning of the input identifiers is discussed in the section 3.7.1. The identifiers specify that the following variables are given versus time:

- total reactor power [MWt];
- reactivity [$];
- time step size used by the code [ms];
- average Doppler fuel temperature [°K];
- maximum fuel centerline temperature [°K].
- location of the maximum fuel centerline temperature [°K].

To run the postprocessor we prepare the shell file ""PP_PWR_NEACRP_A1_KIN.sh""", which is given in the directory Shell. The commands of the file are given below

```
>cd ../Input
>cp ../Samples/PWR_NEACRP_A1/Input/PostProc.INI.PWR_A1_KIN PostProc.INI
>cp ../Samples/PWR_NEACRP_A1/Input/PostProc_PWR_A1_KIN.dat
                                                PostProc_PWR_A1_KIN.dat
>cd ../Source
>make ../POSTPROC
>cd ..
>POSTPROC
```

The file copies the input files into the working input directory, compile and run the postprocessor. As a result two output postprocessor files are generated: the postprocessor listing file "PostProc.lst" and the output file "PostProc_PWR_A1_TIME.lst", which contains the data versus time. The examples of these files can be found in the directory Samples/PWR_NEACRP_A1/Output. A code user can use these data to analyse the transient and plot the graphs. Table 5.8 contains a comparison of the time and value of the power peak taken from the file "PostProc_PWR_A1_TIME.lst" with the PANTHER reference solution. Fig. 5.4 till 5.7 present the graphs plotted using the postprocessor output data. Please note that the reactor power in Table 5.8 and in Fig. 5.4 is normalised on the steady-state value.

Parameter	SKETCH-N result	Derivation from the reference	PANTHER reference
Time to the power peak, s	0.546	0.01 s	0.5375
Power at the peak, %	128.8	1.6 %	126.78

Table 5.8 A comparison of the SKETCH-N transient results with the PANTHER reference results for the case A1 of the 3D NEACRP PWR rod ejection benchmark.

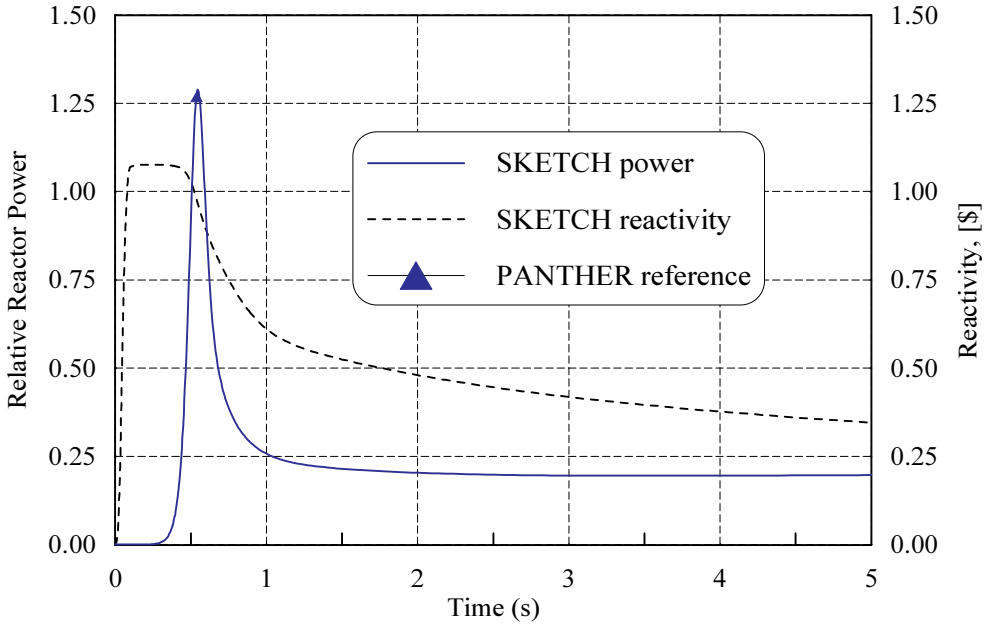


Fig. 5.4 Power and reactivity versus time for 3D NEACRP PWR rod ejection benchmark, case A1.

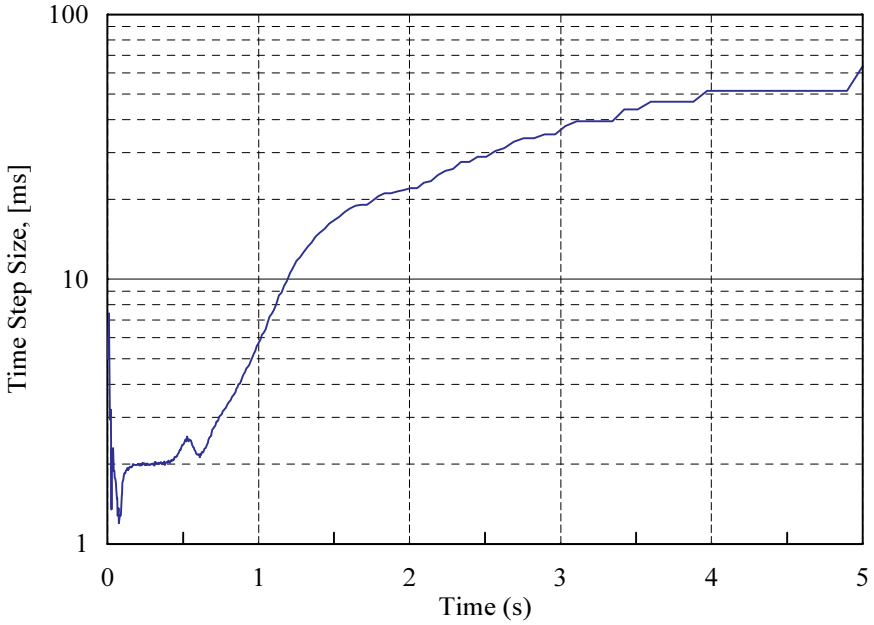


Fig. 5.5 Time step size used by the SKETCH-N code for 3D NEACRP PWR rod ejection benchmark, case A1.

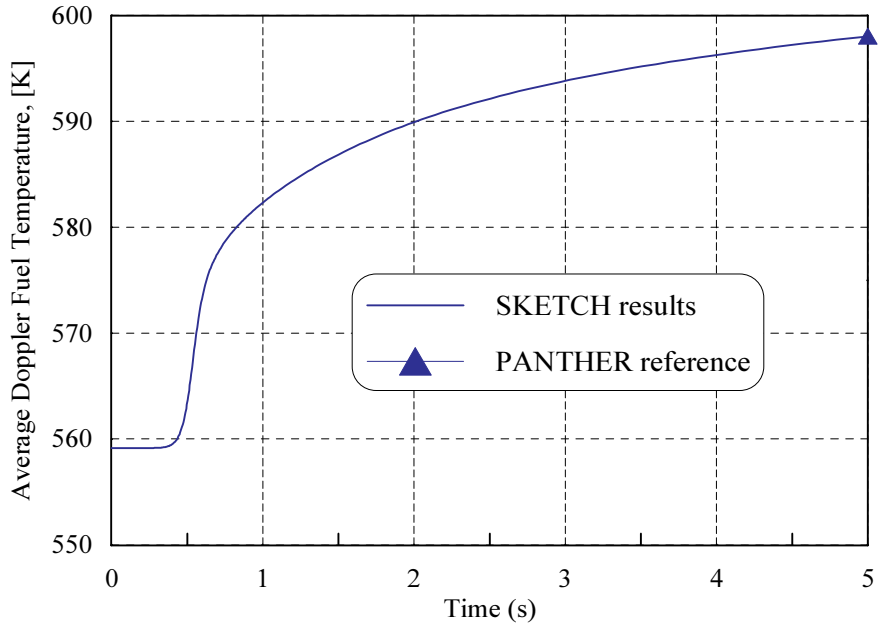


Fig. 5.6 Average Doppler fuel temperature versus time for 3D NEACRP PWR rod ejection benchmark, case A1.

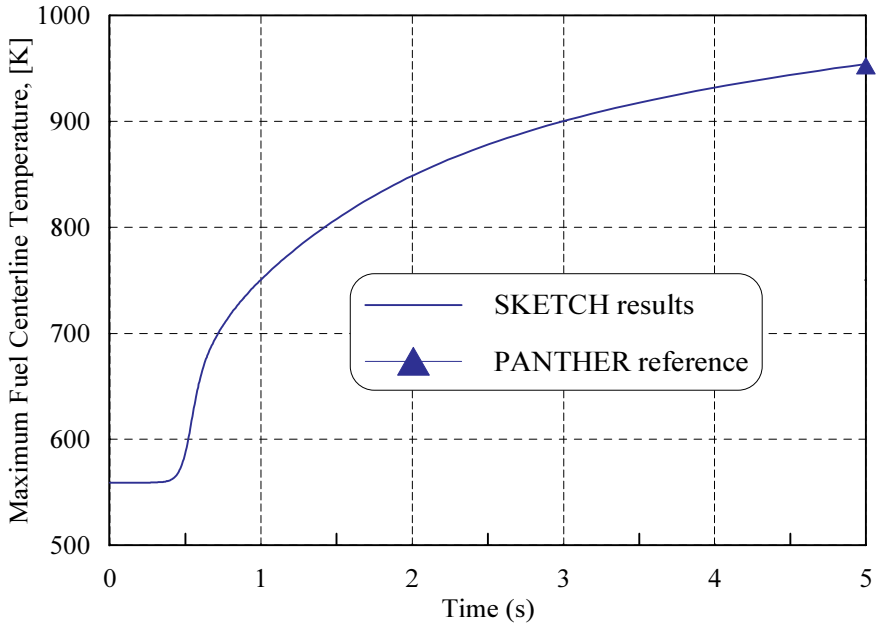


Fig. 5.7 Maximum fuel centerline temperature versus time for 3D NEACRP PWR rod ejection benchmark, case A1.

6. 3D NEACRP BWR COLD WATER INJECTION BENCHMARK

This chapter contains the description of the TRAC-BF1/SKETCH-N calculation of the 3D NEACRP BWR cold water injection benchmark (Finnemann and Galati, 1992). The SKETCH-N input and output files for this problem are given in the directory Samples/BWR_NEACRP_D1. The numerical results of the TRAC-BF1/SKETCH code system and a comparison with the TRAB-3D code (Kaloinen and Kyrki-Rajamäki, 1997) are published in (Zimin et. al., 2000). Please, not that to compute this problem, a code user need the installation of the TRAC-BF1 code and a PVM system.

6.1 Benchmark Problem Description

NEACRP BWR cold water injection benchmark is the case D1 of the LWR 3D core transient benchmarks proposed by H. Finnemann and A. Galati (1992). The reactor core consists of 185 fuel and 64 reflector macroelements; each represents four regular subassemblies homogenized with a control blade. An introduction of macroelements simplifies actual BWR core configuration reducing the number of nodes in the x-y plane by a factor of four. A side of the macroelement is 30.48 cm. 10 types of the macroelements are defined. The reactor loading by the macroelement types is shown in Fig. 6.1. Each macroelement is subdivided into 14 axial layers of 30.48 cm height. A material composition is associated to each axial layer of each macroelement type as shown in Table 6.1.

				0	0	0	0	0	0	0	0	0			
			0	0	2	2	2	2	1	2	1	0	0		
		0	0	2	2	3	2	4	2	3	2	2	0	0	
	0	0	2	5	6	6	6	6	6	6	6	5	2	0	0
0	0	2	2	9	6	9	6	7	6	9	6	9	5	2	0	0
0	1	2	6	6	6	6	6	6	6	6	6	6	6	2	1	0
0	1	3	6	9	6	7	6	9	6	7	6	9	6	3	2	0
0	1	2	6	6	6	6	6	6	6	6	6	6	6	2	1	0
0	1	4	6	7	6	9	6	8	6	9	6	7	6	4	2	0
0	1	2	6	6	6	6	6	6	6	6	6	6	6	2	2	0
0	1	3	6	9	6	7	6	9	6	7	6	9	6	3	2	0
0	1	2	6	6	6	6	6	6	6	6	6	6	6	2	2	0
0	0	2	5	9	6	9	6	7	6	9	6	9	5	2	0	0
	0	0	2	5	6	6	6	6	6	6	6	2	2	0	0	
		0	0	2	2	3	2	4	2	3	2	2	0	0	
			0	0	1	1	1	1	1	1	1	0	0		
				0	0	0	0	0	0	0	0	0			

Fig. 6.1 Core loading by macroelement types for 3D NEACRP BWR benchmark.

Axial Layer	Material composition of the macroelement type N									
	1	2	3	4	5	6	7	8	9	0
14 (top)	4	4	4	4	4	4	4	4	4	19
13	2	5	7	7	9	16	16	16	16	19
12	2	5	7	7	9	16	13	16	16	19
11	2	5	5	7	10	17	14	14	16	19
10	2	5	5	7	10	17	14	14	17	19
9	2	5	5	7	10	17	14	14	17	19
8	2	5	5	7	12	18	15	15	17	19
7	3	6	6	8	11	18	15	15	18	19
6	3	6	6	8	11	18	15	15	18	19
5	3	6	6	8	10	17	14	14	18	19
4	3	6	6	6	10	17	14	14	17	19
3	3	6	6	6	10	17	14	14	14	19
2	2	5	5	5	9	16	13	13	13	19
1 (bottom)	1	1	1	1	1	1	1	1	1	19

Table 6.1 Axial material composition of the macroelements for 3D NEACRP BWR benchmark.

	fast energy group	thermal energy group
Neutron inverse velocity [s/cm]	3.57 E-08	2.27 E-06
Energy release [J/fission]	3.20 E-11	3.20 E-11

Table 6.2 Inverse velocities and energy release of prompt neutrons for 3D NEACRP BWR benchmark.

group	Decay constant [1/s]	Fraction of delayed neutrons
1	0.013	0.00026
2	0.032	0.00152
3	0.119	0.00139
4	0.318	0.00307
5	1.403	0.00110
6	3.929	0.00026
Total fraction of delayed neutrons:		0.76 %

Table 6.3 Decay constants and fractions of delayed neutrons for 3D NEACRP BWR benchmark.

Two prompt neutron groups and six delayed neutron groups are used. The inverse values of the neutron velocities and the energy release per fission are given in Table 6.2. Table 6.3 shows the time constants and fractions of the delayed neutrons. No delayed neutron energy release is considered. . Zero flux boundary conditions are imposed on the outer reflector surface.

For each material composition the following macro cross sections are given

Σ_{tr1}, Σ_{tr2} are the transport macro cross sections;

Σ_{a1}, Σ_{a2} are the absorption macro cross sections;

Σ_{s21} is the scattering macro cross section from the group 1 into the group 2;

Σ_{f1}, Σ_{f2} are the fission macro cross sections;

$\nu\Sigma_{f1}$, $\nu\Sigma_{f2}$ are the production macro cross sections.

The macro cross sections depend on the following feedback variables

ρ is the coolant density $[g/cm^3]$;

T_D is the Doppler fuel temperature $[°K]$.

The macro cross sections are expressed in terms of the feedback variables as

$$\Sigma = \Sigma_0 + \left(\partial\Sigma/\partial\rho\right)_0 (\rho - \rho_0) + \left(\partial\Sigma/\partial\sqrt{T_D}\right)_0 (\sqrt{T_D} - \sqrt{T_{D0}}),$$

where index 0 marks the reference values

The reference macro cross sections, their derivatives and the feedback reference values are given for each material composition. We decided not to give the values in this section referring a reader to the benchmark specification (Finnemann and Galati,1992) or to the content of the SKETCH-N input file, which is given in the Appendix C.3.

The Doppler fuel temperature is computed interpolating the fuel rod centerline temperature $T_{F,C}$ and the fuel rod surface temperature $T_{F,S}$ as

$$T_D = (1-\alpha) T_{F,C} + \alpha T_{F,S},$$

where α is taken equal 0.7.

Data of the fuel assembly geometry are given in Table 6.4. The thermophysical properties of the UO_2 fuel and Zircaloy-4 cladding are the same as that used in 3D NEACRP PWR benchmark, which are described in the section 5.1. The flat profile of the power density inside the fuel rod in radial direction is assumed.

At the beginner of the transient the reactor is in equilibrium. The steady-state operation data are defined in Table 6.5. The inlet mass flow through the core must be properly distributed to obtain the same pressure drop across the whole core.. The conductance of the helium-filled gap between fuel and cladding is assumed to be constant of 3.5 10^3 [W/(m^2 °K)].

Number of fuel rods	196
Outer clad diameter	1.430 cm
Inner clad diameter	1.267 cm
Pellet diameter	1.237 cm
Fuel rod pitch	1.875 cm
Flow cross-section	400.78 cm^2
Heated perimeter	880.5256 cm
Hydraulic diameter	1.7730 cm

Table 6.4 Data of the macroelement geometry for 3D NEACRP BWR benchmark.

Core thermal power	1800 MW
Total inlet mass flow rate	13000 kg/s
Core pressure	67.0 bar
Core inlet subcooling	46.52 kJ/kg

Table 6.5 Steady-state operation data for 3D NEACRP BWR benchmark.

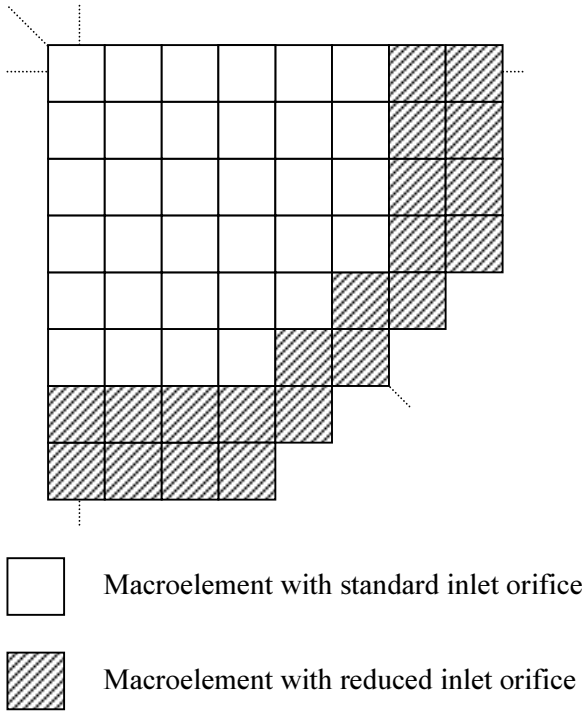


Fig. 6.2 Map of the macroelement orifices for 3D NEACRP BWR benchmark.

The inlet orifice diameter is reduced in the peripheral core macroelements as shown in Fig. 6.2. Inlet pressure drop is defined as

$$\Delta P = c\, G^2 ,$$

where

ΔP is the inlet pressure drop [bar];

$c = 2.23 \times 10^{-4}$ for standard macroelement and $c = 3.79 \times 10^{-4}$ for peripheral macroelement;

G is the macroelement mass flow rate [kg/s].

Frictional pressure drop inside a channel is given as

$$\partial p / \partial z = 2. \times 10^{-6} G^2 f(x) ,$$

where

$\partial p / \partial z$ is the frictional pressure gradient [bar/cm];

G is the bundle mass flow rate [kg/s];

x is the steam quality;

$f(x)$ is the frictional factor.

The frictional factor dependence on the steam quality is given in the Table 6.6.

Please note that in the expression for frictional pressure drop, G is the bundle mass flow rate, not the macroelement mass flow rate as stated in the benchmark specification. This misprint is explained by E. Sartori in the letter to benchmark participants (1992).

x	$f(x)$	x	$f(x)$	x	$f(x)$	x	$f(x)$	x	$f(x)$
0.00	1.00	0.15	7.25	0.30	11.75	0.45	15.50	0.60	19.25
0.01	1.70	0.16	7.55	0.31	12.00	0.46	15.75	0.61	19.50
0.02	2.30	0.17	7.85	0.32	12.25	0.47	16.00	0.62	19.75
0.03	2.80	0.18	8.15	0.33	12.50	0.48	16.25	0.63	20.00
0.04	3.20	0.19	8.45	0.34	12.75	0.49	16.50	0.64	20.25
0.05	3.60	0.20	8.75	0.35	13.00	0.50	16.75	0.65	20.50
0.06	4.00	0.21	9.05	0.36	13.25	0.51	17.00	0.66	20.75
0.07	4.40	0.22	9.35	0.37	13.50	0.52	17.25	0.67	21.00
0.08	4.80	0.23	9.65	0.38	13.75	0.53	17.50	0.68	21.20
0.09	5.15	0.24	9.95	0.39	14.00	0.54	17.75	0.69	21.40
0.10	5.50	0.25	10.25	0.40	14.25	0.55	18.00	0.70	21.60
0.11	5.85	0.26	20.55	0.41	14.50	0.56	18.25	0.71	21.75
0.12	6.20	0.27	10.85	0.42	14.75	0.57	18.50	0.72	21.90
0.13	6.55	0.28	11.15	0.43	15.00	0.58	18.75	0.73	22.05
0.14	6.90	0.29	11.45	0.44	15.25	0.59	19.00	0.74	22.30

Table 6.6 Friction factor versus steam quality for 3D NEACRP BWR benchmark.

The initial steady-state condition is obtained by dividing the number ν of neutron produced per fission by the computed effective multiplication factor k_{eff}. The transient is initiated by a cold water injection, which may be due to increase of cold feedwater flow rate or to failure of preheaters. The inlet water enthalpy is given as follows

$$\Delta H = 46.52 \left(2 - \exp[-0.4\, t] \right),$$

where

ΔH is the inlet subcooling enthalpy (kJ/kg);

t is time (s).

Twenty seconds of the transient are computed.

The final benchmark report provides the results of this problem presented by eight national and industrial institutions from five countries (Finnemann et al., 1993). However, only a few reactor parameters are given and discrepancies between the results are large. For example, the reactor multiplication factors differ by 600 pcm (1 pcm = 0.001 %) and the reactor power peaks in the transient differ by 200 %. It is difficult to make a comparison with these results. Recently we performed an intercomparison of the TRAC-BF1/SKETCH-N results with the results of the TRAB-3D code (Kaloinen and Kyrki-Rajamäki, 1997) provided by VTT Energy, Finland. The TRAB-3D results taken from (Zimin et. al., 2000) are used in the following sections.

6.2 Include File "bwr_neacrp_d1.fh"

The include file "bwr_neacrp_d1.fh" is the file, which is used under the name "parameters.fh" in the code compilation. The file is given in the directory Samples/BWR_NEACRP_D1/Include. The content of the file is shown in the Appendix C.1.

Let us shortly outline a meaning of the input data, the detail description of the input variables is given in the Section 3.1. The reactor model has 249 macroelements subdivided into 26 axial layers. 185 macroelements are in the reactor core. The spatial mesh 17x17x26 is used with 1 node per macroelement in x-y plane. The axial mesh has 24 layers in the reactor core and 2 layers of the top and bottom reflectors. 10 macroelement types are defined.

Nineteen material compositions are defined with the corresponding set of the macro cross sections. Two prompt neutron groups and six delayed neutron groups are used. Four feedback variables are

applied in the code: boron concentration, moderator temperature, moderator density and Doppler fuel temperature. In the benchmark, only two feedback variables are actually used: the moderator density and Doppler fuel temperature.

The problem does no require the control rod simulation and the internal thermal-hydraulics model is also not used. However, the values of the parameters related to these models should be defined, we set them to 1. Please note that due to a static memory allocation used in the present version of the code, these parameters could not be zero.

The parameters of the external thermal-hydraulics model describes the model of the TRAC-BF1 code. The model has 185 channels, which correspond to the 185 core macroelements. Axial mesh has 24 layers, which coincide with the SKETCH-N axial layers in the reactor core. No axial and radial reflectors are modelled in the TRAC-BF1 code.

6.3 Input Files for the Steady-State Calculation

The input files for the SKETCH-N code are given in the directory Samples/BWR_NEACRP_D1/Input. The list of the input files follows below

- "SKETCH.INI.BWR_D1.ST" is the namelist input file;
- "BWR_NEACRP_D1.DAT" is the input file with the reactor model data;
- "TRAC_BWR_Map_185_26_185_24.DAT" is the input file with the data for the PVM-based interface module.

The content of the namelist file "SKETCH.INI.BWR_D1.ST" is given in the Appendix C.2. In the namelist `INI_PROBLEM`, we define that the problem type is an eigenvalue problem and that the external thermal-hydraulics model is used. In the namelist `INI_FILES`, the input and restart files are given. The default convergence criterion `1.E-5` are used in the calculation.

The reactor model data are given in the file "BWR_NEACRP_D1.DAT". The content of this file is given in the Appendix C.3. The data include the description of the spatial mesh, macro cross sections and their derivations with respect to feedbacks, core loading by material compositions and the boundary conditions. The input data are prepared in accordance with the benchmark specification. The detail description of the input data identifiers is given in the Section 3.3. Only a few comments are added. The reactor power is 1800 MW. Two-group macro cross sections and their derivatives with respect to the moderator density and square root of the Doppler fuel temperature are given for nineteen material compositions. The spatial mesh 17x17x26 is defined with a mesh size of 30.48 cm in x and y directions. Axial mesh size is 15.24 cm in the reactor core and 30.48 cm in the axial reflectors. The core is loaded by 10 macroelement types, which contains 19 material compositions. The boundary conditions are zero flux at all the boundaries.

The input data of the interface module are given in the file "TRAC_BWR_Map_185_26_185_24.DAT". The content of this file is given in the Appendix C.4. The data include the name of the TRAC code version, the conversion constants from the TRAC units into the SKETCH units and the mapping matrices defining the correspondence between the TRAC and SKETCH spatial meshes. The input data format is described in the section 3.4, only a few comments are added. The TRAC-BF1 code is used as an external thermal-hydraulics model. In the TRAC-BF1 code the units of the coolant density is kg/m^3, the units of the temperature is degree of Kelvin. In the SKETCH code, the macro cross sections are given as functions of the coolant density in g/cm^3, the coolant temperature in degrees of Celsius and Doppler fuel temperature in degrees of Kelvin. The conversion constants given under identifier `PVM_CNV_UNIT` specify the conversion from the TRAC units into the SKETCH units. The mapping matrices describe the correspondence between the SKETCH and TRAC spatial meshes. The TRAC model contains 185 channels with 24 axial layers. The heat conduction mesh coincides with the fluid dynamics mesh. The radial and axial reflectors are not modelled. The spatial meshes of the TRAC and SKETCH code coincide in the reactor core region. The mapping matrices are given in the compressed row storage format as described in the section 3.4. The mapping matrices from the SKETCH neutronics mesh into the TRAC meshes define one-to-one correspondence of the nodal power of the reactor core region. The mapping from the TRAC spatial meshes into SKETCH neutronics mesh define one-to-one radial correspondence of the channels to macroelements in the reactor core. In axial direction, the first layer of the TRAC spatial mesh is mapped

into the bottom axial reflector layer and the first axial layer of the reactor core of the SKETCH spatial mesh. In the similar way we treat the last axial layer of the TRAC spatial meshes. The TRAC values of this layer are mapped into the last axial layer of the reactor core and into the top axial reflector layer of the SKETCH spatial mesh.

6.4 Steady-State Calculation and Output Files

To perform the steady-state calculation the PVM system and the TRAC-BF1 code should be installed on the computer. The PVM is a public domain software available from NETLIB at the address: http://www.epm.ornl.gov/pvm/pvm_home.html. The installation procedure is described in the report (Geist et al., 1994). The report is also available from the PVM homepage. The information on the TRAC-BF1 code is available from Mr. H. Asaka of JAERI. Please, contact him on the address given in Cahpter 1.

Before running the TRAC-BF1/SKETCH-N code system we need to copy the include and input files into the SKETCH working directories and to compile the SKETCH_PVM code. The shell file "BWR_NEACRP_D1_ST.sh" doing this job is given in the directory Shell. The commands of the file are given below

```
>cd ../Include
>cp ../Samples/BWR_NEACRP_D1/Include/BWR_NEACRP_D1.fh parameters.fh
>cd ../Source
>make ../SKETCH
>cd ../Input
>cp ../Samples/BWR_NEACRP_D1/Input/BWR_NEACRP_D1.DAT BWR_NEACRP_D1.DAT
>cp ../Samples/BWR_NEACRP_D1/Input/SKETCH.INI.BWR_D1.ST SKETCH.INI
>cp ../Samples/BWR_NEACRP_D1/Input/TRAC_BWR_Map_185_26_185_24.DAT
      TRAC_BWR_Map_185_26_185_24.DAT
>cd ..
>SKETCH
>cd ../Source
>make ../SKETCH_PVM
```

In addition to the SKETCH_PVM code, the shell file also build the SKETCH code (without PVM interface) and performs the test calculations. It is done simply to check that the input files of the SKETCH code do not contain errors. The results of this test calculation may be ignored.

In the next step, you need to start PVM. In the PVM host file, you need to specify the SKETCH-N home directory as a PVM working directory and the PVM pass to the SKETCH_PVM executable. An example of the host file .hostfile is shown below

```
# Hostfile for SKETCH & TRAC Coupling
* ep=$HOME/sketch_100:$PVM_ROOT/bin/$PVM_ARCH wd=$HOME/sketch_100
```

To start the PVM, type the command

```
>pvm .hostfile
```

As a result, the PVM console appears and you can start using PVM.

To start the coupled code system you need to start the TRAC-BF1 code. After performing the input, the TRAC-BF1 code spawns the child process SKETCH_PVM and the coupled calculation begins. The steady-state calculation takes about 40 minutes on Sun Ultra-10 workstation with 440 MHz processor.

The results of the TRAC-BF1 code are given in the TRAC output files, which are not considered in this report. The SKETCH-N code output is written in the directory Output in the files "Error.msg", "SKETCH.lst", "SKETCH.grf". The restart file for the transient calculation "bwr_neacrp_D1_0.dat" is written in the directory Restart. The error message file "Error.msg" contains some warnings, because several input identifiers are not given in the input file and default values are used. These warnings may be ignored. The input data and the calculation results are written into the text output file "SKETCH.lst". The sample of this file is "Samples/BWR_NEACRP_D1/Output/SKETCH.lst.BWR_D1_ST". A comparison of the SKETCH-N steady-state results with the TRAB-3D results is given in the Table 6.7. The TRAB-3D results computed using the EPRI void fraction correlation are taken from (Zimin et. al., 2000). The axial power distributions are shown in Fig. 6.3. The distributions are normalised on the value of the axial peaking factor. Please note that the values are given for the axial mesh of 30.48 cm height as requested in the benchmark specification. The axial profiles of the coolant density are compared in Fig. 6.4. 2D power distributions computed by the SKETCH-N and TRAB-3D codes are given in Fig. 6.5. A code user can compare the computed results with the shown values. More results and their analysis are given in our paper (Zimin et. al., 2000). Please note that the TRAC-BF1/SKETCH-N results given in this report and in the paper (Zimin et. al., 2000) are slightly different. The difference is due to a treatment of the coolant temperature and density computed by the TRAC-BF1 code. The results given in the paper are computed assuming that the TRAC-BF1 code gives the face-averaged values for the coolant density and temperature. The node-averaged values used in the SKETCH code are computed by linear interpolation of the TRAC values. In the calculation presented in this report, the TRAC-BF1 values are considered as the node-average values and no interpolation is applied. Practically, the differences between two results are not large.

Parameter	TRAC-BF1/ SKETCH-N Results	TRAB-3D Results
Eigenvalue	0.98312	0.98312 -
1D axial power peaking factor	1.410	1.391 *-1.3 %*
2D radial power peaking factor	1.947	1.983 *+1.8 %*
3D power peaking factor	3.151	3.198 *+1.5 %*
Core-averaged Doppler fuel temperature, [°C]	499	512 *+13 °C*
Maximum Doppler fuel temperature, [°C]	1057	1119 *+62 °C*
Outlet coolant temperature, [°C]	282.1	282.1 -
Outlet coolant density, [kg/m^3]	445.0	444.6 *-0.4 kg/m^3*

Table 6.7 A comparison of the steady-state TRAC-BF1/SKETCH-N results with the TRAB-3D results for 3D NEACRP BWR cold water injection benchmark.

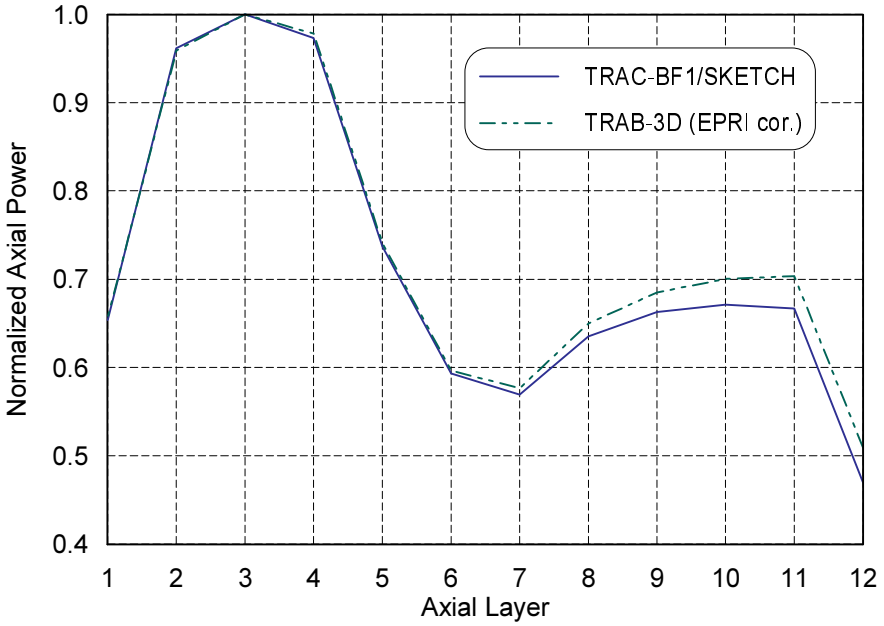


Fig. 6.3 Normalised axial power for 3D NEACRP BWR cold water injection benchmark.

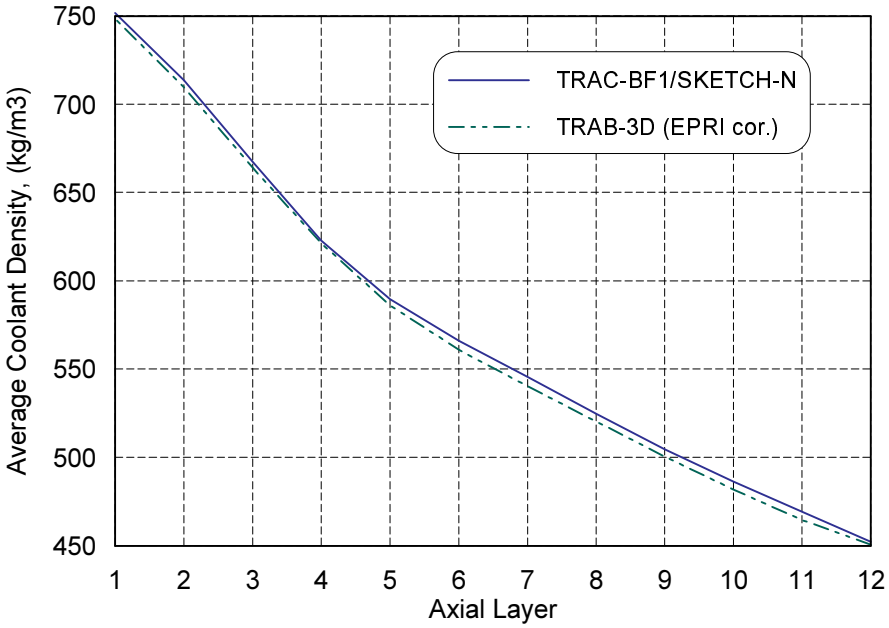


Fig. 6.4 Average axial coolant density for 3D NEACRP BWR cold water injection benchmark.

```
        1      2      3      4      5      6      7      8
     -----  -----  -----  -----  -----  -----  -----  -----
1:                                0.055  0.086  0.112  0.144     TRAB-3D
1:                                0.058  0.088  0.115  0.146     SKETCH-N
1:                                 -4.5   -1.8   -2.9   -1.6     Dif.(%)

2:                         0.125  0.290  0.424  0.457  0.635
2:                         0.127  0.296  0.433  0.474  0.657
2:                          -1.6   -1.9   -2.2   -3.7   -3.4

3:                  0.142  0.407  0.991  1.214  1.232  1.184
3:                  0.145  0.417  1.013  1.229  1.249  1.207
3:                   -2.2   -2.3   -2.2   -1.2   -1.3   -1.9

4:           0.128  0.418  1.026  1.511  1.558  1.577  1.145
4:           0.130  0.428  1.041  1.515  1.553  1.574  1.148
4:            -1.5   -2.4   -1.4   -0.3    0.3    0.2   -0.3

5:    0.062  0.294  0.996  1.513  1.753  1.731  1.836  1.780
5:    0.064  0.300  1.018  1.517  1.739  1.715  1.812  1.760
5:     -3.9   -2.1   -2.2   -0.3    0.8    0.9    1.3    1.1

6:    0.095  0.427  1.217  1.560  1.731  1.325  1.854  1.851
6:    0.098  0.437  1.232  1.555  1.716  1.312  1.828  1.825
6:     -2.6   -2.3   -1.2    0.3    0.9    1.0    1.4    1.4

7:    0.123  0.460  1.235  1.579  1.836  1.854  1.983  1.933
7:    0.127  0.478  1.251  1.575  1.813  1.828  1.947  1.901
7:     -3.0   -3.8   -1.3    0.2    1.3    1.4    1.8    1.7

8:    0.157  0.639  1.186  1.146  1.780  1.851  1.933  1.496
8:    0.159  0.662  1.209  1.149  1.760  1.825  1.901  1.472
8:     -1.1   -3.5   -1.9   -0.3    1.1    1.4    1.7    1.6

Max. difference in 2D power distribution: =-4.69%;  Location (x,y): (1,11)
Average difference in 2D power distribution: 1.7%
2D Power Peaking Factor (SKETCH-N):  1.9470  Location (x,y):(7,7)
2D Power Peaking Factor (TRAB-3D) :  1.9827  Location (x,y):(7,7)
Difference in 2D Power Peaking Factors: 1.8%
```

Fig. 6.5 A comparison of the SKETCH-N and TRAB-3D (EPRI correlation) 2D power distributions for 3D NEACRP BWR cold water injection benchmark.

6.5 Input Files for the Transient Calculation

The input files for the SKETCH-N transient calculation are given in the directory Samples/BWR_NEACRP_D1/Input. The list of the input files follows below

- "SKETCH.INI.BWR_D1.KIN" is the namelist input file;
- "BWR_NEACRP_A1.DAT" is the input file with the reactor model data.
- TRAC_BWR_Map_185_26_185_24.DAT" is the input file with the data for the PVM-based interface module.

The reactor model data are given in the file "BWR_NEACRP_D1.DAT", which is already used in the steady-state calculation. The content of this file is given in the Appendix C.3. The input data of the interface module are given in the file "TRAC_BWR_Map_185_26_185_24.DAT". The content of this file is given in the Appendix C.4. The both files are described in the section 6.3.

The content of the namelist file "SKETCH.INI.BWR_D1.KIN" is given in the Appendix C.5. In the namelist INI_PROBLEM, we define that the problem type is a transient problem and that the external thermal-hydraulics model is used. In the namelist INI_FILES, the input and restart files are given. The file "Restart/bwr_neacrp_D1_0.dat" generated in the steady-state calculation is used as an input restart file for the transient calculation. The default convergence criterion 1.E-4 is used in the calculations. In the namelist INI_TIME_STEP, the data for time stepping are defined. An automatic time step selection is used. Twenty seconds of the transient are computed. An initial guess of the first time step is 0.005 s. Accuracy criteria of the automatic time step control is 5.E-03.

6.6 Transient Calculation and Output Files

To perform the transient calculation we need only copy the namelist file into the working directory. It can be done using the shell file "BWR_NEACRP_D1_KIN.sh", which is given in the directory Shell. The commands of the file are given below

```
>cd ../Input
>cp ../Samples/BWR_NEACRP_D1/Input/SKETCH.INI.BWR_D1.KIN SKETCH.INI
```

Now we can run the TRAC-BF1 code. The TRAC-BF1 code spawns the child process SKETCH_PVM and the TRAC-BF1/SKETCH-N calculation is performed. The transient TRAC-BF1/SKETCH-N calculation takes about 2 hours 15 minutes on Sun Ultra-10 workstation with 440 MHz processor. The SKETCH-N code consumes about 23 minutes of CPU time or 17 % of the total computing time.

The SKETCH-N code output is given in the directory Output in the files "Error.msg", "SKETCH.lst", "SKETCH.grf". The input data and the calculation results at the beginner and the end of the transient are written into the text listing file "SKETCH.lst". A sample is "Samples/BWR_NEACRP_D1/Output/SKETCH.lst.BWR_D1_KIN". A comparison of the SKETCH-N results at the time of 20 s with the TRAB-3D results computed using EPRI correlation is given in the Table 6.8. You can compare the computed results with the values given in the Table 6.8 and in the sample file. Other transient results can be extracted from the binary file "SKETCH.grf" by the SKETCH postprocessor. The postprocessor input and output files are discussed in the following section 6.7.

Parameter	TRAC-BF1/ SKETCH-N Results	TRAB-3D Results
Reactor power [%]	125.9	126.3 *+0.3 %*
3D power peaking factor	3.513	3.546 *0.9 %*
Average Doppler fuel temperature, [°C]	563	580 *+17 °C*
Maximum Doppler fuel temperature, [°C]	1377	1426 *+49 °C*
Outlet coolant temperature, [°C]	279.9	280.0 *+0.1 °C*
Outlet coolant density, [kg/m^3]	467.0	462.2 *-4.8 kg/m^3*

Table 6.8 A comparison of the SKETCH-N/TRAC-BF1 results at the time of 20 s with the TRAB-3D results for 3D NEACRP BWR cold water injection benchmark.

6.7 Postprocessing the Transient Results

In addition to the SKETCH-N results at the time of 5 s, which are available from the listing file "SKETCH.lst", we are interested in the following data

- total reactor power versus time;
- reactivity versus time;
- time step size used by the code versus time;
- time step size proposed by the TRAC-BF1 code;
- average Doppler fuel temperature versus time;
- core-averaged coolant density versus time;
- outlet-averaged coolant density versus time;
- 3D, 2D and 1D power peaking factors versus time.

To extract this data from the SKETCH-N binary file "SKETCH.grf" the postprocessor is used. As discussed in the section 3.7, the postprocessor requires two input files: the namelist input file "PostProc.INI" and the input data file. The files are given in the directory Samples/BWR_NEACRP_D1/Input as

- "PostProc.INI.BWR_D1_KIN" is the namelist input file;
- "PostProc_BWR_D1_KIN.dat" is the input data file for the postprocessor.

The content of the namelist file "PostProc.INI.BWR_D1_KIN" is given in the Appendix C.6. The meaning of the namelist variables is discussed in the section 3.7. We specify the input data file "PostProc_BWR_D1_KIN.dat", the output file "PostProc_BWR_D1_TIME.lst" for the data versus time and the output format of the real output data.

The content of the input data file for the postprocessor is given in the Appendix C.7. The meaning of the input identifiers is discussed in the section 3.7.1. The identifiers specify that the following variables are given versus time:

- total reactor power [MWt];
- reactivity [$];
- time step size used by the code [ms];
- time step size proposed by the TRAC-BF1 code [ms];
- average Doppler fuel temperature [°K];
- core-averaged coolant density [g/cm^3];
- outlet-averaged coolant density [g/cm^3];
- maximum fuel centerline temperature [°K].
- values and locations of the maximum power density for 3D, 2D and 1D distributions [W/cm^3].

To run the postprocessor we prepare the shell file ""PP_BWR_NEACRP_D1_KIN.sh"", which is given in the directory Shell. The commands of the file are given below

```
> cd ../Input
>cp ../Samples/BWR_NEACRP_D1/Input/PostProc.INI.BWR_D1_KIN PostProc.INI
>cp ../Samples/BWR_NEACRP_D1/Input/PostProc_BWR_D1_KIN.dat
                                                PostProc_BWR_D1_KIN.dat
>cd ../Source
>make ../POSTPROC
>cd ..
>POSTPROC
```

The file copies the input files into the working input directory, compile and run the postprocessor. As a result two output postprocessor files are generated: the postprocessor listing file "PostProc_BWR_D1_INFO.lst" and the output file "PostProc_BWR_D1_TIME.lst", which contains the data versus time. The examples of these files can be found in the directory Samples/BWR_NEACRP_D1/Output. A code user can use the data of the file "PostProc_BWR_D1_TIME.lst" to analyse the transient and plot the graphs. Table 6.9 contains a

comparison of the SKETCH-N results with the results of the TRAB-3D code. Fig. 6.6 till 6.12 present the graphs plotted using the postprocessor output data. Please note that some additional normalisation is needed to present the output data into the form used in these figures.

Parameter	TRAC-BF1/ SKETCH-N results	TRAB-3D Results
Maximum reactor power (%)	172.0	168.4 *-2.1 %*
Time of maximum power, (s)	1.66	1.68 *+0.02 s*
3D power peaking factor at time of power peak	3.544	3.531 *-0.4 %*

Table 6.9 A comparison of the SKETCH-N/TRAC-BF1 transient results with the TRAB-3D results for 3D NEACRP BWR cold water injection benchmark.

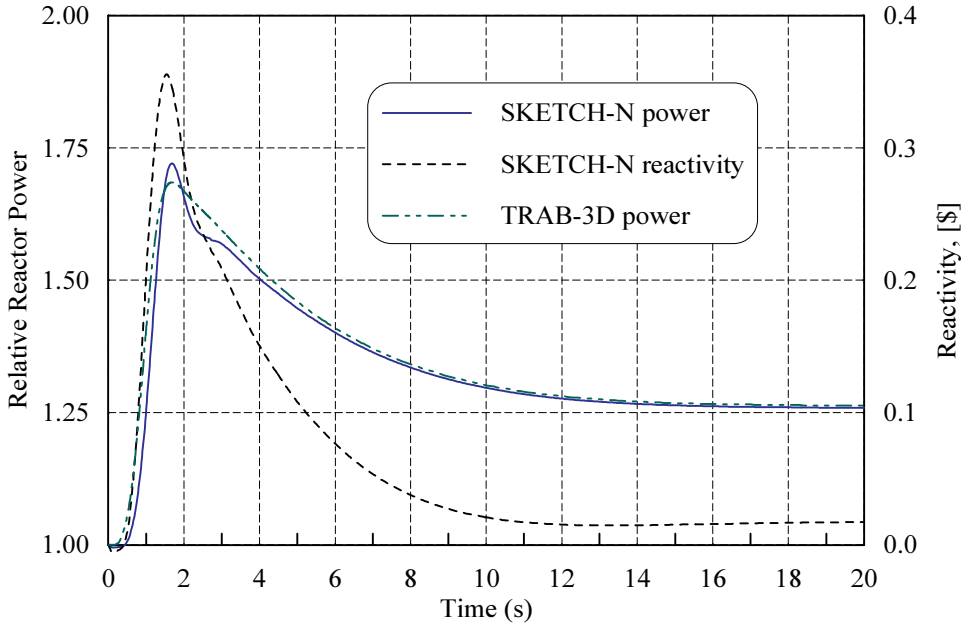


Fig. 6.6 Power and reactivity versus time for 3D NEACRP BWR cold water injection benchmark.

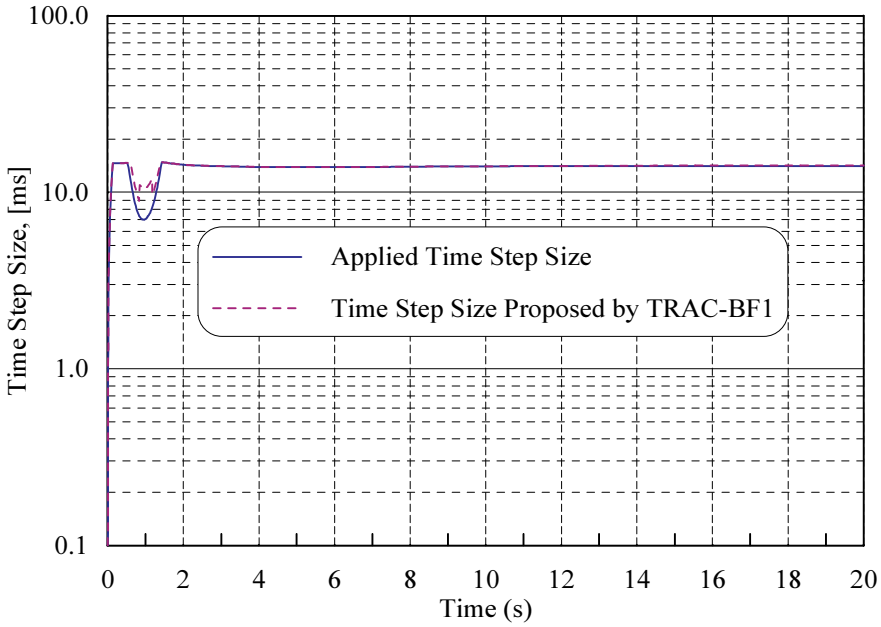


Fig. 6.7 Time step size for 3D NEACRP BWR cold water injection benchmark.

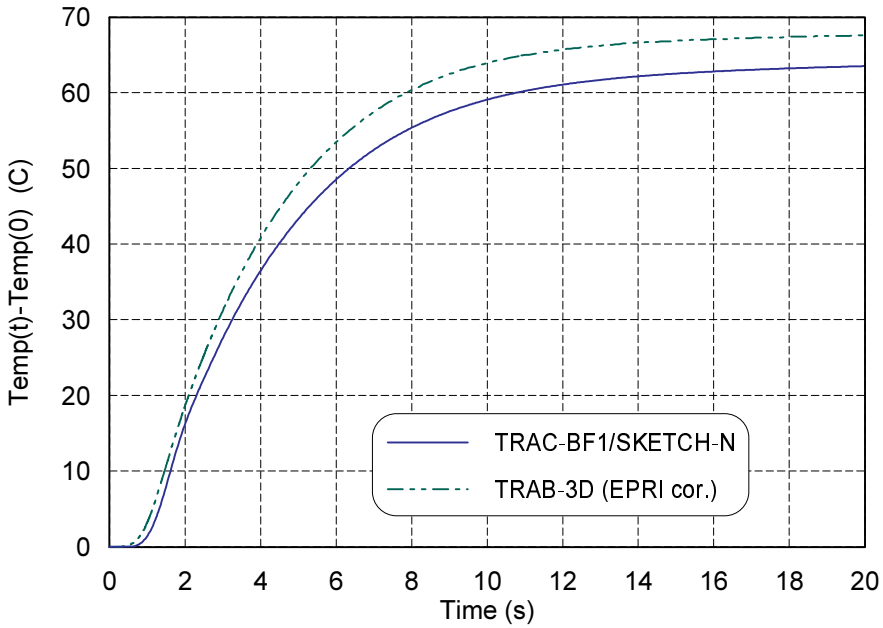


Fig. 6.8 Change in average Doppler fuel temperature versus time for 3D NEACRP BWR cold water injection benchmark.

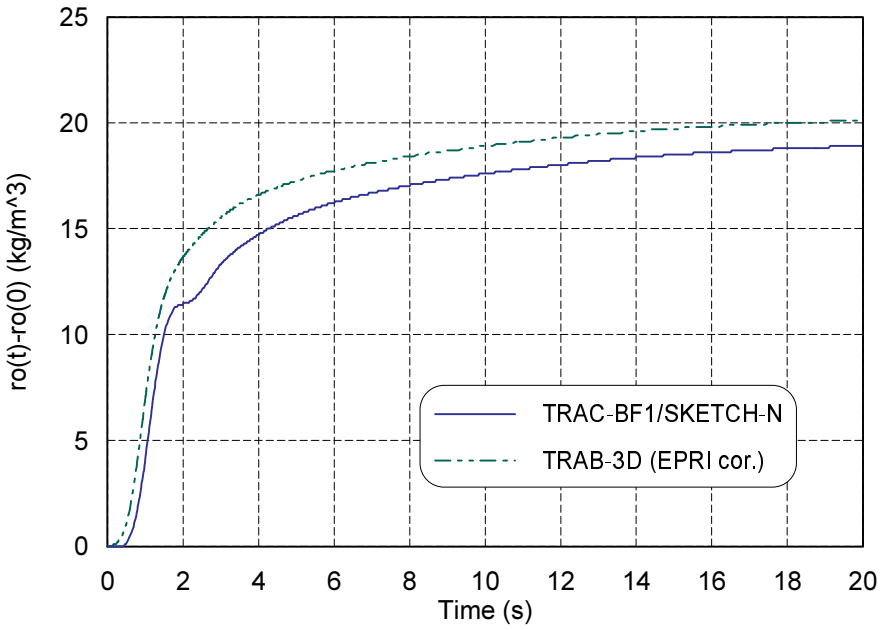


Fig. 6.9 Change in core-averaged coolant density with respect to the steady-state value versus time for 3D NEACRP BWR cold water injection benchmark.

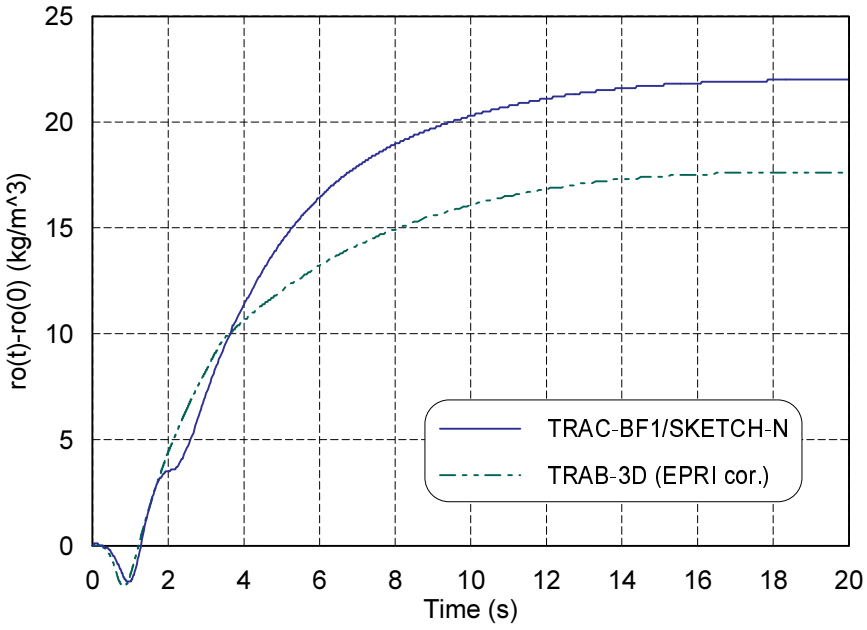


Fig. 6.10 Change in outlet-averaged coolant density with respect to the steady-state value versus time for 3D NEACRP BWR cold water injection benchmark.

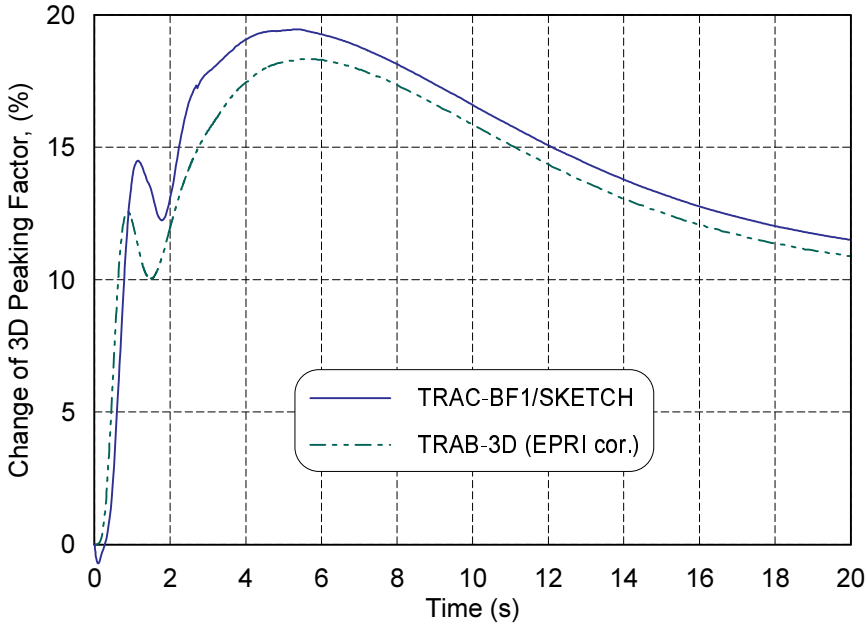


Fig. 6.11 Change in 3D power peaking factor with respect to the steady-state value versus time for 3D NEACRP BWR cold water injection benchmark.

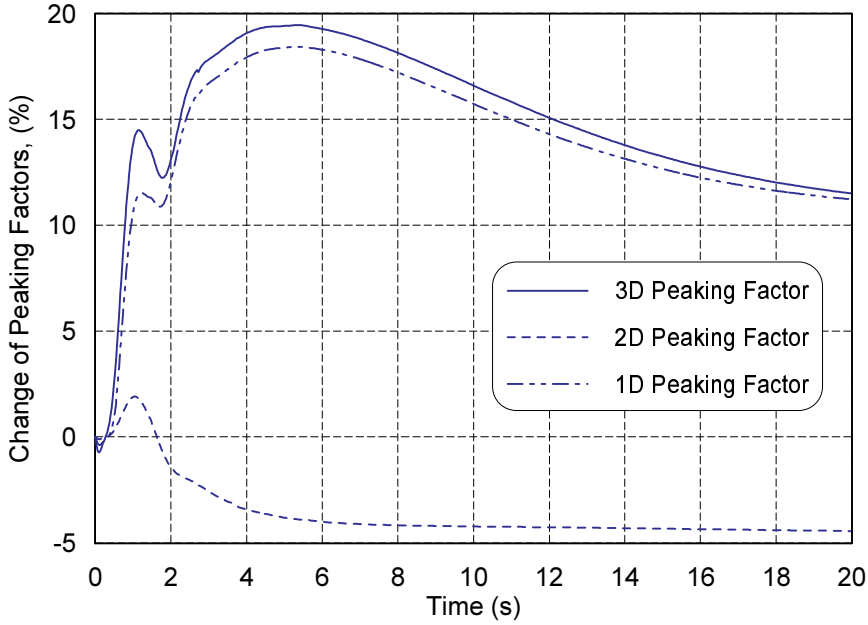


Fig. 6.12 Change in 3D, 2D and 1D power peaking factors with respect to the steady-state value versus time for 3D NEACRP BWR cold water injection benchmark.

7. CONCLUSIONS AND FUTURE PLANS

The basic features of the nodal three-dimensional neutron kinetics code SKETCH-N are summarized in the following:

- diffusion approximation;
- 3D, 2D and 1D reactor models in Cartesian geometry with arbitrary mesh size in any direction;
- arbitrary number of neutron energy groups and delayed neutron precursors;
- transverse-integrated polynomial, semi-analytic and analytic nodal methods with quadratic leakage approximation for spatial discretization;
- nonlinear iteration procedure for a solution of the nodal equations;
- fully-implicit scheme with analytic integration of the delayed neutron precursors for time discretization;
- adaptive time step control based on the step doubling technique;
- inverse iterations with Wieland shift accelerated by Chebyshev polynomials for the steady-state eigenvalue problems;
- adaptive Chebyshev acceleration procedure for the neutron kinetics problems;
- block symmetric Gauss-Seidel method as a preconditioner;
- consistent point kinetics option, where the point kinetics parameters are computed at each time step using the values of macro cross sections;
- internal thermal-hydraulics model for PWR operational transients with single-phase coolant flow;
- interface module based on the message passing library PVM for the coupling with external thermal-hydraulics codes, such as TRAC.

This user guide describes the code installation, input and output files. The examples of the code application to the following benchmark problem

- 2D four-group KOEBERG checker-board-loaded PWR (Muller and Weiss, 1991);
- 3D NEACRP PWR rod ejection benchmark, Case A1 (Finneman and Galati, 1992);
- 3D NEACRP BWR cold water injection benchmark, Case D1 (Finneman and Galati, 1992).

are considered.

The code has been also used for the other steady-state and transient problems:

- classical 2D & 3D International Atomic Energy Agency (IAEA) PWR problems;
- 2D Biblis PWR checker-board-loaded core;
- 2D Zion-1 PWR problem with explicit modeling of the baffle;
- 3D Langenbuch-Maurer-Werner (LMW) operational transient in a small PWR model;
- 2D & 3D super-prompt-critical rod drop accident in BWR;
- NEA/NSC PWR benchmark on uncontrolled rod withdrawal at zero power.

The results are given in the papers (Zimin et. al., 1998; Zimin and Ninokata, 1998; Asaka et. al., 2000).

The code has been also adapted for NEA/NSC Ringhals-1 BWR stability benchmark (Lefvert, 1994). Analysis of this problem by the TRAC-BF1/SKETCH-N code system is presently in progress. The most important code modification is a new table model of the macro cross sections developed for the data provided in the benchmark. Because only preliminary results are available we decided do not include this problem as an example in this user's guide.

The computed problems show acceptable accuracy and efficiency of the code for LWR applications. However, there are always ways to improve the code. Possible directions to extend the code capabilities and to improve the code efficiency are given in vol. I of the SKETCH manual (Zimin, 2000). Here we only add that we are planning to add graphics into the code postprocessing module.

Any suggestions about the code improvement and proposals to extend the code capabilities for the user's problems are welcome. The author's address is given in Chapter 1.

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APPENDIX A

2D FOUR-GROUP KOEBERG PWR BENCHMARK

A.1. Content of the include file "koeberg2d.fh"
A.2. Content of the input namelist file "SKETCH.INI.KOEBERG2D.ST"
A.3. Content of the input file "KOEBERG2D.DAT"
A.4. Content of the input file with the reference solution "KOEBERG2D.ref"
A.5. Content of the output file "Comparison.dat"

A.1 CONTENT OF THE INCLUDE FILE “KOEBERG2D.FH”

```
!=====================================================================
! PARAMETERS FOR KOEBERG-2D PWR  BENCHMARK                           !
! (c) Slava 2 August 2000                                            !
!=====================================================================
! GeoMTry Module                                                     !
!  N_POLY - number of the bundles (assemblies) in the reactor;       !
!  NH - number of the nodes in radial (X-Y) plane                    !
!       with 1 node per assembly NH = N_POLY;                        !
!  NZR - number of axial layers defining materail composition        !
!     of the bundle                                                 !
!  NZ - number of axial lalers used for the calculations             !
!  NXR - maximum number of bundles in X directions                   !
!  NX - maximum number of nodes in X direction                       !
!  NYR - maximum number of bundles in Y directions                   !
!  NY - maximum number of nodes in Y direction                       !
!  NCHM - maximum number of nodes per bundle (assembly)              !
!       in X-Y plane                                                 !
!  NDD - reactor geometry dimensions                                 !
!    (3D calculations NDD = 3; 2D calculations NDD = 2 ;             !
!     1D calculations NDD = 3)                                       !
!  N_BUNDLE_TYPE - number of different bundle types                  !
!---------------------------------------------------------------------
      INTEGER N_POLY, NH, NZR, NZ, NXR, NYR, NX, NY,
     &          NCHM, NDD,N_BUNDLE_TYPE

      PARAMETER (N_BUNDLE_TYPE = 7)
      PARAMETER (N_POLY   = 64, NH = 64 ) !
      PARAMETER (NZR = 1,   NZ = 1 )
      PARAMETER (NXR = 9,   NYR = 9 )
      PARAMETER (NX  = 9, NY  = 9 )
      PARAMETER (NCHM = 1)
      PARAMETER (NDD = 2)
!---------------------------------------------------------------------
! End GeoMTry Module                                                 !
!=====================================================================
! TH_Model                                                           !
!   NP_Reactor_Core - number of fuel bundles in the reactor core     !
!   NZ_Core - number of axial layers in the reactor core (planes)    !
!---------------------------------------------------------------------
      INTEGER NP_Reactor_Core, NZR_Core
      PARAMETER (NP_Reactor_Core = 47, NZR_Core = 1)
!---------------------------------------------------------------------
! End TH_Model                                                       !
!=====================================================================
! XS Module (Cross Section & Neutron Kinetics Constant)              !
!   NG - number of neutron energy groups                             !
!   NNODE number of material compositions (dimension of the XS arrays) !
!   MD - number of delayed neutron groups                            !
!   N_FEEDBACKS - number of feedbacks (boron concentration, moderator  !
!    temperature, moderator density or void, doppler fuel temperature) !
!---------------------------------------------------------------------
      INTEGER NNODE, NG, MD, N_FEEDBACK
      PARAMETER(NNODE = 7, NG = 4)
      PARAMETER(MD = 1)
      PARAMETER(N_FEEDBACK = 4)
!---------------------------------------------------------------------
! End End TH_Model                                                   !
!=====================================================================
! CRD control rod Module                                             !
!     NN_CRod_Comp - Number of Control Rod Compositions              !
!     NN_CRod -  Number of Control Rods                              !
!     NN_CRod_El -  Number of the Rod Materials (Absorber + Driver = 2)!
```

```
!     NN_CRod_Type - Number of Control Rod Types                          !
!     NN_Crod_Bundle - Number of the Bundles covered by CR                !
!                                ("PWR" - 1, "BWR" - 4)                   !
!-------------------------------------------------------------------------
      INTEGER NN_CRod, NN_CRod_Comp, NN_CRod_El, NN_CRod_Type,
     &  NN_Crod_Bundle
      PARAMETER (NN_CRod_El = 1, NN_CRod = 1, NN_CRod_Comp = 1,
     &  NN_CRod_Type = 1, NN_Crod_Bundle = 1 )
!-------------------------------------------------------------------------
! End CRD control rod Module                                             !
!=========================================================================
! Fuel RoD (FRD) Heat Conduction Model                                   !
!     NN_FRD_FUEL - Number of the heat conduction nodes in the fuel      !
!     NN_FRD_CLAD - Number of the heat conduction nodes in the cladding!
!     NN_FRD_TOTAL - Total number of the heat conduction nodes           !
!                    in the fuel rod                                     !
!-------------------------------------------------------------------------
      INTEGER NN_FRD_FUEL, NN_FRD_CLAD, NN_FRD_TOTAL
      PARAMETER ( NN_FRD_FUEL=1, NN_FRD_CLAD = 1,
     &           NN_FRD_TOTAL = NN_FRD_FUEL + NN_FRD_CLAD )
!-------------------------------------------------------------------------
! End Fuel RoD (FRD) Heat Conduction Model                               !
!=========================================================================
! PVM Interface Module for TRAC                                          !
!  NN_RT_HC_TRAC-Number of nodes of heat conduction R-T spatial mesh     !
!  NN_RT_FD_TRAC-Number of nodes of fluid dynamics R-T spatial mesh      !
!  NN_Z_HC_TRAC-Number of axial layers of heat conduction spatial mesh  !
!  NN_Z_FD_TRAC-Number of axial layers of fluid dynamics spatial mesh    !
!-------------------------------------------------------------------------
      INTEGER NN_RT_HC_TRAC, NN_RT_FD_TRAC, NN_Z_HC_TRAC, NN_Z_FD_TRAC
      PARAMETER ( NN_Z_HC_TRAC = 1, NN_Z_FD_TRAC = 1,
     &              NN_RT_HC_TRAC = 1, NN_RT_FD_TRAC = 1)
!-------------------------------------------------------------------------
! End PVM Interface Module for TRAC                                      !
!=========================================================================
!                      THAT'S ALL                                        !
!=========================================================================
```

A.2 CONTENT OF THE INPUT NAMELIST FILE "SKETCH.INI.KOEBERG2D.ST"

```
c=========================================================================c
c          SKETCH-N version 1.0: Nodal Neutron Diffusion Code for         c
c            Solving Steady-State & Kinetics Problems                     c
c=========================================================================

&INI_PROBLEM
   Problem_Type = "Eigenvalue"
   TH_Model = "None"
 &END

 &INI_FILES
  FILE_INPUT   =    "Input/KOEBERG2D.DAT"
  File_Reference =  "Input/KOEBERG2D.ref"
  FILE_DMP_OUT_ST = "Restart/koeberg2d.dat"
 &END

 &INI_CONVERGENCE
 &END

 &INI_CHEBYSHEV
  Delta_Shift = 10.
 &END

 &INI_TIME_STEP
 &END
```

A.3 CONTENT OF THE INPUT FILE "KOEBERG2D.DAT"

```
!------------------------------------------------------------------------------!
! KOEBERG-2D PWR BENCHMARK                                                     !
!      (c) Slava August 2000 JAERI                                             !
!                                                                              !
!------------------------------------------------------------------------------!

CNT_RCT_TYPE ## REACTOR TYPE

 "PWR"

CNT_RCT_POWR ## REACTOR POWER (MWt)

 1.

XS_BASE_DATA ## Basic set of the Macro Cross Section Data

    2.491869 0.003654 0.008228 0.008228
    1.045224 0.002124 0.000536 0.000536
    0.677407 0.019908 0.007058 0.007058
    0.375191 0.067990 0.083930 0.083930

      0.0      0.0      0.0      0.0
      0.063789 0.0      0.0      0.0
      0.000486 0.064381 0.0      0.001245
      0.0      0.000003 0.050849 0.0       1 Type

    2.492653 0.003685 0.008295 0.008295
    1.049844 0.002215 0.000713 0.000713
    0.676610 0.022012 0.009230 0.009230
    0.379481 0.085052 0.108244 0.108244

      0.0      0.0      0.0      0.0
      0.063112 0.0      0.0      0.0
      0.000478 0.063078 0.0      0.001543
      0.0      0.000003 0.048420 0.0       2 Type

    2.491978 0.003684 0.008285 0.008285
    1.051910 0.002221 0.000713 0.000713
    0.677084 0.022403 0.009214 0.009214
    0.381453 0.088077 0.108087 0.108087

      0.0      0.0      0.0      0.0
      0.062765 0.0      0.0      0.0
      0.000473 0.062404 0.0      0.001598
      0.0      0.000003 0.047549 0.0       3 Type

    2.492535 0.003740 0.008459 0.008459
    1.045298 0.002299 0.000923 0.000923
    0.674684 0.022621 0.011714 0.011714
    0.374240 0.091000 0.133600 0.133600

      0.0      0.0      0.0      0.0
      0.063737 0.0      0.0      0.0
      0.000486 0.064330 0.0      0.001630
      0.0      0.000003 0.049518 0.0        4 Type

    2.492329 0.003730 0.008409 0.008409
    1.051953 0.002315 0.000921 0.000921
    0.675683 0.023822 0.011675 0.011675
    0.380606 0.100246 0.134282 0.134282
```

```
      0.0      0.0      0.0      0.0
      0.062737 0.0      0.0      0.0
      0.000473 0.062376 0.0      0.001797
      0.0      0.000003 0.046859 0.0       5 Type

    2.491521 0.003730 0.008400 0.008400
    1.054029 0.002321 0.000921 0.000921
    0.676197 0.024196 0.011651 0.011651
    0.382434 0.103283 0.133974 0.133974

     0.0      0.0      0.0      0.0
     0.062386 0.0      0.0      0.0
     0.000468 0.061696 0.0      0.001852
     0.0      0.000003 0.046005 0.0         6 Type

    2.119737 0.000466      0.0      0.0
    0.980098 0.000263      0.0      0.0
    0.531336 0.004282      0.0      0.0
    1.058029 0.116918      0.0      0.0

      0.0      0.0      0.0      0.0
      0.042052 0.0      0.0      0.0
      0.000322 0.044589 0.0      0.000978
      0.0      0.0      0.052246 0.0        7 Type

XS_DIFF_FLAG

  1 ## Parameter 1 - Diffusion Coefficient, 0 - Transport XS

XS_NEUT_SPEC

   0.745248 0.254328 0.000424 0.0  ## xp(NG)

XS_POWR_CONV

   3.204E-11 3.204E-11  3.204E-11 3.204E-11 ## pow_conv

GMT_NUM_BNDL ## Numbering of the reactor assdemblies (bundles)

   1  2  3  4  5  6  7  8  9
  10 11 12 13 14 15 16 17 18
  19 20 21 22 23 24 25 26 27
  28 29 30 31 32 33 34 35  0
  36 37 38 39 40 41 42 43  0
  44 45 46 47 48 49 50  0  0
  51 52 53 54 55 56  0  0  0
  57 58 59 60 61  0  0  0  0
  62 63 64  0  0  0  0  0  0

GMT_MSH_XDIR ## Spatial Mesh in X direction

  1  10.804  1 21.608  1 21.608 1 21.608 1 21.608  1 21.608 1 21.608
         1 21.608   1 21.608 ##npx(NXR),hx(NXR)

GMT_MSH_YDIR ## Spatial Mesh in Y direction

  1  10.804  1 21.608  1 21.608 1 21.608 1 21.608  1 21.608 1 21.608
         1 21.608   1 21.608 ##npy(NYR),hy(NYR)
```

```
GMT_COR_LOAD ## Core Loading with Bundle Types

 1 3 1 3 1 2 1 4 7
 3 1 3 1 2 1 6 4 7
 1 3 1 2 1 3 4 7 7
 3 1 2 1 3 5 4 7
 1 2 1 3 1 4 7 7
 2 1 3 5 4 7 7
 1 6 4 4 7 7
 4 4 7 7 7
 7 7 7       l(N_POLY,NZR)

  1 1 ## nb = 1
  2 2 ## nb = 2
  3 3 ## nb = 3
  4 4 ## nb = 4
  5 5 ## nb = 5
  6 6 ## nb = 6
  7 7 ## nb = 7

GMT_BND_COND ## Boundary Conditions

   1 1 1 1 ## i_DR
   0. 0. 0. 0.  0.5 0.5 0.5 0.5  0. 0. 0. 0.  0.5 0.5 0.5 0.5  ## DR

   0. 0. 0. 0. ## Buckling

!=============================================================================!
! End of the Koeberg-2D PWR Input Data                                        !
!=============================================================================!
```

A.4 CONTENT OF THE INPUT FILE WITH THE REFERENCE SOLUTION "KOEBERG2D.REF"

```
PWR KOEBERG 2D 4-group Reference Solution

 1.007954

 1.0058 1.0858 1.0445 1.1639 1.1319 1.2147 0.9596 0.8331
 1.0858 1.0263 1.1305 1.1054 1.2430 1.0617 1.0420 0.6425
 1.0445 1.1305 1.0929 1.2236 1.0581 1.0390 0.9684
 1.1639 1.1054 1.2236 1.0363 0.9988 0.9813 0.6504
 1.1319 1.2430 1.0581 0.9988 0.7860 0.6670
 1.2147 1.0617 1.0390 0.9813 0.6670
 0.9596 1.0420 0.9684 0.6504
 0.8331 0.6425

*=================================================================*
* The reference assembly-averaged core power distribution         *
* for the KOEBERG 2D 4-group Benchmark Higher-Order RM Method     *
* 1x1 P6 E. Z. Muller & Z. J. Weiss                               *
*   Annals of Nuclear Energy, vol. 18, pp 535-544, 1991           *
*=================================================================*
```

A.5 CONTENT OF THE OUTPUT FILE "COMPARISON.DAT"

```
!=========================================================================!
!                                SKETCH-N                                 !
! Nodal Neutron Diffusion Code for Solving Steady-State & Kinetics Problems !
!          Version 1.0 (c) Slava 2000 e-mail: na.vzimin@na-net.ornl.gov    !
!   Date & Time of Calculation :  8 August   2000   5:08:53 pm            !
!=========================================================================!
 A Comparison of the SKETCH Results with  Input/KOEBERG2D.ref
  PWR KOEBERG 2D 4-group Reference Solution

 SEMI-ANALYTICAL NODAL METHOD

k_ef_Ref        :  1.007954
k_ef_Sketch     :  1.008350
Error_k_ef, pcm :  39.

Comparison of the 2D Power Distribution

            1       2       3       4       5       6       7       8
       ------  ------  ------  ------  ------  ------  ------  ------
  1:   1.0058  1.0858  1.0445  1.1639  1.1319  1.2147  0.9596  0.8331
  1:   0.9870  1.0666  1.0294  1.1502  1.1256  1.2131  0.9694  0.8497
  1:    -1.87   -1.76   -1.44   -1.18   -0.56   -0.13    1.02    1.99

  2:   1.0858  1.0263  1.1305  1.1054  1.2430  1.0617  1.0420  0.6425
  2:   1.0666  1.0102  1.1126  1.0946  1.2356  1.0637  1.0536  0.6541
  2:    -1.76   -1.57   -1.59   -0.97   -0.60    0.19    1.11    1.81

  3:   1.0445  1.1305  1.0929  1.2236  1.0581  1.0390  0.9684
  3:   1.0294  1.1126  1.0813  1.2126  1.0554  1.0447  0.9820
  3:    -1.44   -1.59   -1.07   -0.90   -0.25    0.55    1.40

  4:   1.1639  1.1054  1.2236  1.0363  0.9988  0.9813  0.6504
  4:   1.1502  1.0946  1.2126  1.0323  1.0004  0.9966  0.6552
  4:    -1.18   -0.97   -0.90   -0.39    0.16    1.56    0.73

  5:   1.1319  1.2430  1.0581  0.9988  0.7860  0.6670
  5:   1.1256  1.2356  1.0554  1.0004  0.8002  0.6755
  5:    -0.56   -0.60   -0.25    0.16    1.80    1.27

  6:   1.2147  1.0617  1.0390  0.9813  0.6670
  6:   1.2131  1.0637  1.0447  0.9966  0.6755
  6:    -0.13    0.19    0.55    1.56    1.27

  7:   0.9596  1.0420  0.9684  0.6504
  7:   0.9694  1.0536  0.9820  0.6552
  7:     1.03    1.11    1.40    0.73

  8:   0.8331  0.6425
  8:   0.8497  0.6541
  8:     1.99    1.81

Average Error in Power Distribution, (%):   1.01
Maximum Error in Power Distribution, (%):   1.99
X, Y Coordinates of the Maximum Error Assembly :  1  8
Number of Nonlinear Iterations :  10
Number of Source Iterations    :  67
```

APPENDIX B

3D NEACRP PWR ROD EJECTION BENCHMARK

B.1. Content of the include file “pwr_neacrp_a1.fh”
B.2. Content of the input namelist file “SKETCH.INI.PWR_A1.ST”
B.3. Content of the input file “PWR_NEACRP_A1.DAT”
B.4. Content of the input namelist file “SKETCH.INI.PWR_A1.KIN”
B.5. Content of the postprocessor input namelist file “PostProc.INI.PWR_A1_KIN”
B.6. Content of the postprocessor input data file “PostProc_PWR_A1_KIN.dat”

B.1 CONTENT OF THE INCLUDE FILE “PWR_NEACRP_A1.FH”

```
!=======================================================================
! PARAMETERS FOR NEACRP PWR ROD EJECTION PROBLEM, CASE A1              !
! (c) Slava 10 December 1999                                          !
!=======================================================================
! GeoMTry Module                                                      !
!  N_POLY - number of the bundles (assemblies) in the reactor;        !
!  NH - number of the nodes in radial (X-Y) plane                     !
!       with 1 node per assembly NH = N_POLY;                         !
!  NZR - number of axial layers defining materail composition         !
!     of the bundle                                                   !
!  NZ - number of axial lalers used for the calculations              !
!  NXR - maximum number of bundles in X directions                    !
!  NX - maximum number of nodes in X direction                        !
!  NYR - maximum number of bundles in Y directions                    !
!  NY - maximum number of nodes in Y direction                        !
!  NCHM - maximum number of nodes per bundle (assembly)               !
!       in X-Y plane                                                  !
!  NDD - reactor geometry dimensions                                  !
!    (3D calculations NDD = 3; 2D calculations NDD = 2 ;              !
!     1D calculations NDD = 3)                                        !
!  N_BUNDLE_TYPE - number of different bundle types                   !
!-----------------------------------------------------------------------
      integer N_POLY, NH, NZR, NZ, NXR, NYR, NX, NY,
     &          NCHM, NDD,N_BUNDLE_TYPE
         parameter (N_POLY   = 64, NH = 221 ) ! 221; 884
         parameter (NZR = 18, NZ = 18 )
         parameter (NXR =  9, NYR = 9 )
         parameter (NX  =  17, NY  = 17 )
         parameter (NCHM = 4)
         parameter (NDD = 3)
         parameter (N_BUNDLE_TYPE = 9)
!-----------------------------------------------------------------------
! End GeoMTry Module                                                  !
!=======================================================================
! TH_Model                                                            !
!   NP_Reactor_Core - number of fuel bundles in the reactor core      !
!   NZ_Core - number of axial layers in the reactor core (planes)     !
!-----------------------------------------------------------------------
         integer NP_Reactor_Core, NZR_Core
         parameter (NP_Reactor_Core = 47, NZR_Core = 16 )
!-----------------------------------------------------------------------
! End TH_Model                                                        !
!=======================================================================
! XS Module (Cross Section & Neutron Kinetics Constant)               !
!   NG - number of neutron energy groups                              !
!   NNODE number of material compositions (dimension of the XS arrays) !
!   MD - number of delayed neutron groups                             !
!   N_FEEDBACKS - number of feedbacks (boron concentration, moderator  !
!    temperature, moderator density or void, doppler fuel temperature) !
!-----------------------------------------------------------------------
      integer   NNODE, NG, MD,  N_FEEDBACK
      parameter(NNODE = 11, NG = 2)
      parameter(MD = 6)
      parameter(N_FEEDBACK = 4)
!-----------------------------------------------------------------------
! End End TH_Model                                                    !
!=======================================================================
! CRD control rod Module                                              !
!     NN_CRod_Comp - Number of Control Rod Compositions               !
!     NN_CRod -  Number of Control Rods                               !
!     NN_CRod_El -  Number of the Rod Materials (Absorber + Driver = 2)!
!     NN_CRod_Type - Number of Control Rod Types                      !
```

```
!     NN_Crod_Bundle - Number of the Bundles covered by CR             !
!                                ("PWR" - 1, "BWR" - 4)                !
!----------------------------------------------------------------------
      INTEGER NN_CRod, NN_CRod_Comp, NN_CRod_El, NN_CRod_Type,
     &  NN_Crod_Bundle
      PARAMETER (NN_CRod_El = 2, NN_CRod = 15, NN_CRod_Comp = 3,
     &  NN_CRod_Type = 2, NN_Crod_Bundle = 1)
!----------------------------------------------------------------------
! End CRD control rod Module                                           !
!======================================================================
! Fuel RoD (FRD) Heat Conduction Model                                 !
!     NN_FRD_FUEL - Number of the heat conduction nodes in the fuel    !
!     NN_FRD_CLAD - Number of the heat conduction nodes in the cladding!
!     NN_FRD_TOTAL - Total number of the heat conduction nodes         !
!                      in the fuel rod                                 !
!----------------------------------------------------------------------
      INTEGER NN_FRD_FUEL, NN_FRD_CLAD, NN_FRD_TOTAL
      PARAMETER ( NN_FRD_FUEL=9, NN_FRD_CLAD = 2,
     &           NN_FRD_TOTAL = NN_FRD_FUEL + NN_FRD_CLAD )
!----------------------------------------------------------------------
! End Fuel RoD (FRD) Heat Conduction Model
!======================================================================
! PVM Interface Module for TRAC                                        !
!  NN_RT_HC_TRAC-Number of nodes of heat conduction R-T spatial mesh   !
!  NN_RT_FD_TRAC-Number of nodes of fluid dynamics R-T spatial mesh    !
!  NN_Z_HC_TRAC-Number of axial layers of heat conduction spatial mesh !
!  NN_Z_FD_TRAC-Number of axial layers of fluid dynamics spatial mesh  !
!----------------------------------------------------------------------
      INTEGER NN_RT_HC_TRAC, NN_RT_FD_TRAC, NN_Z_HC_TRAC, NN_Z_FD_TRAC
      PARAMETER ( NN_Z_HC_TRAC = 15, NN_Z_FD_TRAC = 14,
     &              NN_RT_HC_TRAC = 27, NN_RT_FD_TRAC = 27)
!----------------------------------------------------------------------
! End PVM Interface Module for TRAC                                    !
!======================================================================
!                      THAT'S ALL                                      !
!======================================================================
```

B.2 CONTENT OF THE INPUT NAMELIST FILE "SKETCH.INI.PWR_A1.ST"

```
c=========================================================================c
c         SKETCH-N version 1.0: Nodal Neutron Diffusion Code for          c
c           Solving Steady-State & Kinetics Problems                      c
!=========================================================================!

 &INI_PROBLEM
   Problem_Type = "BoronSearch"
   TH_Model = "Internal"
 &END

 &INI_FILES
  FILE_INPUT      =  'Input/PWR_NEACRP_A1.DAT'
  FILE_DMP_OUT_KIN = 'Restart/pwr_neacrp_A1_0.dat'
 &END

 &INI_CONVERGENCE
 &END

 &INI_CHEBYSHEV
 &END

 &INI_TIME_STEP
 &END
```

B.3 CONTENT OF THE INPUT FILE "PWR_NEACRP_A1.DAT"

```
!------------------------------------------------------------------------!
! 3D NEACRP PWR Rod Ejection Benchmark, case A1                          !
!      (c) Slava March 1998 JAERI                                        !
!                                                                        !
!------------------------------------------------------------------------!

CNT_RCT_TYPE # REACTOR TYPE

 "PWR"

CNT_RCT_POWR # REACTOR POWER (MWt)

 693.75E-06

XS_BASE_DATA # Basic set of the Macro Cross Section Data

 0.532058E-01 0.264554E-01 0.373279E-03 0.000000E-00 0.000000E-00
 0.386406E-00 0.177215E-01 0.000000E-00 0.000000E-00            1

 0.295609E-00 0.231613E-01 0.118782E-02 0.000000E-00 0.000000E-00
 0.245931E+01 0.252618E-00 0.000000E-00 0.000000E-00            2

 0.295609E-00 0.200808E-01 0.118782E-02 0.000000E-00 0.000000E-00
 0.245931E+01 0.252618E-00 0.000000E-00 0.000000E-00            3

 0.222117E-00  0.182498E-01  0.871774E-02  0.498277E-02  0.190224E-02
 0.803140E-00  0.652550E-01  0.839026E-01  0.343581E-01             4

 0.221914E-00  0.180040E-01  0.906133E-02  0.557659E-02  0.214498E-02
 0.795538E-00  0.723354E-01  0.998629E-01  0.408938E-01             5

 0.221715E-00  0.177670E-01  0.938496E-02  0.615047E-02  0.237972E-02
 0.789253E-00  0.789203E-01  0.114667E-00  0.469561E-01             6

  0.222039E-00  0.171381E-01  0.931692E-02  0.555010E-02  0.213629E-02
  0.776230E-00  0.796328E-01  0.985576E-01  0.403596E-01             7

  0.222083E-00  0.168501E-01  0.940032E-02  0.554083E-02  0.213318E-02
  0.769969E-00  0.821087E-01  0.980059E-01  0.401338E-01             8

  0.222127E-00  0.165626E-01  0.948286E-02  0.553137E-02  0.213003E-02
  0.763813E-00  0.845912E-01  0.974109E-01  0.398902E-01             9

  0.221836E-00  0.169043E-01  0.963720E-02  0.612382E-02  0.237097E-02
  0.770705E-00  0.861187E-01  0.113241E-00  0.463724E-01            10

  0.221878E-00  0.166175E-01  0.971937E-02  0.611444E-02  0.236781E-02
  0.764704E-00  0.885488E-01  0.112635E-00  0.461246E-01            11

XSP_POL_COEF # Macro Cross Sections polynomila coefficients

 0.611833E-07 0.791457E-09 0.187731E-06 0.000000E-00 0.000000E-00
 0.517535E-05 0.102635E-04 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.745756E-01 0.371310E-01 0.207688E-03 0.000000E-00 0.000000E-00
 0.533634E-00 0.758421E-02 0.000000E-00 0.000000E-00       0.7125
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       891.45  # 1

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.776184E-03 0.844695E-04 0.000000E-00 0.000000E-00       1200.2
```

```
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       0.7125
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       891.45  # 2

0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.776184E-03 0.844695E-04 0.000000E-00 0.000000E-00       1200.2
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       0.7125
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       891.45 # 3

 0.347809E-07 -0.108590E-06  0.128505E-06 -0.112099E-08 -0.548361E-09
-0.976510E-05  0.708807E-05 -0.243045E-05 -0.995273E-06        1200.2
-0.203310E-05  0.809676E-06  0.212191E-06  0.124709E-06  0.445177E-07
-0.108674E-03 -0.315597E-04 -0.416439E-04 -0.170531E-04         306.6
 0.135665E-00  0.293195E-01  0.155185E-02  0.920694E-03  0.318680E-03
 0.992628E-00  0.252662E-01  0.247746E-01  0.101452E-01        0.7125
-0.309197E-04 -0.275536E-04  0.349709E-04  0.640134E-06  0.222662E-06
-0.137292E-03 -0.371806E-04 -0.563037E-04 -0.230564E-04        891.45 # 4

 0.353826E-07 -0.106951E-06  0.126709E-06 -0.167880E-08 -0.777980E-09
-0.850169E-05  0.682311E-05 -0.272445E-05 -0.111566E-05        1200.2
-0.198080E-05  0.858474E-06  0.226000E-06  0.135145E-06  0.488317E-07
-0.906150E-04 -0.321435E-04 -0.453102E-04 -0.185545E-04         306.6
 0.135748E-00  0.292696E-01  0.161491E-02  0.964160E-03  0.336573E-03
 0.981985E-00  0.286667E-01  0.314993E-01  0.128990E-01        0.7125
-0.308607E-04 -0.276766E-04  0.351798E-04  0.997431E-06  0.369389E-06
-0.117481E-03 -0.377039E-04 -0.604155E-04 -0.247402E-04        891.45 # 5

 0.359838E-07 -0.105374E-06  0.124986E-06 -0.221038E-08 -0.996653E-09
-0.746251E-05  0.659798E-05 -0.295883E-05 -0.121164E-05        1200.2
-0.192434E-05  0.903494E-06  0.239939E-06  0.149084E-06  0.545978E-07
-0.762786E-04 -0.323776E-04 -0.478475E-04 -0.195937E-04         306.6
 0.135827E-00  0.292154E-01  0.168015E-02  0.101410E-02  0.357207E-03
 0.972267E-00  0.319571E-01  0.381097E-01  0.156060E-01        0.7125
-0.309165E-04 -0.278390E-04  0.353841E-04  0.141847E-05  0.542384E-06
-0.101337E-03 -0.377558E-04 -0.630960E-04 -0.258379E-04        891.45 # 6

 0.337806E-07 -0.100873E-06  0.119869E-06 -0.171323E-08 -0.777980E-09
-0.673744E-05  0.629310E-05 -0.255359E-05 -0.104561E-05        1200.2
-0.269634E-05  0.701311E-06  0.248530E-06  0.140773E-06  0.488317E-07
-0.762435E-04 -0.300119E-04 -0.420202E-04 -0.172074E-04         306.6
 0.131033E-00  0.282489E-01  0.168397E-02  0.981951E-03  0.336573E-03
 0.934697E-00  0.314240E-01  0.351588E-01  0.144016E-01        0.7125
-0.313746E-04 -0.273550E-04  0.348699E-04  0.945431E-06  0.369389E-06
-0.108271E-03 -0.372748E-04 -0.579662E-04 -0.237320E-04        891.45 # 7

 0.332495E-07 -0.988578E-07  0.117585E-06 -0.172421E-08 -0.793325E-09
-0.619725E-05  0.611904E-05 -0.248880E-05 -0.101904E-05        1200.2
-0.307905E-05  0.617380E-06  0.261854E-06  0.143235E-06  0.522555E-07
-0.733397E-04 -0.291929E-04 -0.407701E-04 -0.166956E-04         306.6
 0.129379E-00  0.278895E-01  0.171972E-02  0.988437E-03  0.346474E-03
 0.918171E-00  0.324715E-01  0.363251E-01  0.148808E-01        0.7125
-0.315503E-04 -0.272381E-04  0.347274E-04  0.926078E-06  0.339044E-06
-0.105521E-03 -0.371808E-04 -0.571108E-04 -0.233804E-04        891.45 # 8

 0.327201E-07 -0.968489E-07  0.115319E-06 -0.173502E-08 -0.796917E-09
-0.568220E-05  0.594711E-05 -0.242240E-05 -0.991817E-06        1200.2
-0.353877E-05  0.516547E-06  0.274313E-06  0.146019E-06  0.534283E-07
```

```
 -0.713711E-04 -0.283041E-04 -0.394319E-04 -0.161475E-04         306.6
  0.127682E-00  0.275202E-01  0.174989E-02  0.995175E-03  0.349236E-03
  0.901293E-00  0.335945E-01  0.374499E-01  0.153431E-01        0.7125
 -0.317281E-04 -0.271169E-04  0.346026E-04  0.905802E-06  0.330425E-06
 -0.102525E-03 -0.370201E-04 -0.561543E-04 -0.229872E-04         891.45 # 9

  0.343859E-07 -0.993312E-07  0.118186E-06 -0.224335E-08 -0.996653E-09
 -0.586898E-05  0.608443E-05 -0.277657E-05 -0.113696E-05        1200.2
 -0.263907E-05  0.744320E-06  0.264289E-06  0.155858E-06  0.545978E-07
 -0.639554E-04 -0.303509E-04 -0.444431E-04 -0.181997E-04         306.6
  0.131116E-00  0.281877E-01  0.175528E-02  0.103522E-02  0.357207E-03
  0.924925E-00  0.349853E-01  0.420693E-01  0.172298E-01        0.7125
 -0.314192E-04 -0.275049E-04  0.350637E-04  0.135642E-05  0.542384E-06
 -0.938886E-04 -0.371403E-04 -0.605052E-04 -0.247739E-04        891.45 # 10

  0.338559E-07 -0.973291E-07  0.115917E-06 -0.225369E-08 -0.101112E-08
 -0.538345E-05  0.591697E-05 -0.270780E-05 -0.110878E-05        1200.2
 -0.302147E-05  0.659521E-06  0.279060E-06  0.158814E-06  0.586765E-07
 -0.616984E-04 -0.295626E-04 -0.431588E-04 -0.176738E-04         306.6
  0.129463E-00  0.278259E-01  0.179499E-02  0.104291E-02  0.368921E-03
  0.908456E-00  0.361032E-01  0.433215E-01  0.177435E-01        0.7125
 -0.315908E-04 -0.273835E-04  0.349119E-04  0.133336E-05  0.506596E-06
 -0.917126E-04 -0.369909E-04 -0.596284E-04 -0.244141E-04        891.45 # 11

XS_DIFF_FLAG

  0 # Parameter 1 - Diffusion Coefficient, 0 - Transport XS

XS_FEED_INIT

 0.0  286.0 0.7540387 559.15 # Boron, T_Coolant, Ro_coolant, T_fuel

XS_CROD_COEF

   0.373220E-02 -0.319253E-02  0.247770E-02 -0.102786E-03 -0.377989E-04
  -0.219926E-01  0.255875E-01 -0.282319E-02 -0.115483E-02

   0.374092E-02 -0.314239E-02  0.242926E-02 -0.122634E-03 -0.459250E-04
  -0.167503E-01  0.256478E-01 -0.328086E-02 -0.134262E-02

   0.697102E-02 -0.119034E-02  0.879034E-04 -0.655496E-04 -0.197926E-04
  -0.113498E-01  0.170043E-02 -0.146252E-02 -0.599154E-03

XS_NEUT_SPEC

   1.0 0.0  # xp(NG)

XS_POWR_CONV

   3.213E-11 3.206E-11 # pow_conv

XS_POWR_COOL

   0.019 # Percent of the Power Directly Deposited into coolant


XS_NEUT_VELC

 0.28E+08 0.44E+06 # v(NG)

XS_PREC_ALFA

 0.0128 0.0318 0.1190 0.3181 1.4027 3.9286 # alfa(MD)
```

```
XS_PREC_BETA

 1 # Relative Beta
 0.0076 # bet
 0.034 0.200 0.183 0.404 0.145 0.034 # bet(MD)

XS_PREC_SPEC

 1.0 0.0 # xm(NG)

GMT_NUM_BNDL # Numbering of the reactor assdemblies (bundles)

   1  2  3  4  5  6  7  8  9
  10 11 12 13 14 15 16 17 18
  19 20 21 22 23 24 25 26 27
  28 29 30 31 32 33 34 35  0
  36 37 38 39 40 41 42 43  0
  44 45 46 47 48 49 50  0  0
  51 52 53 54 55 56  0  0  0
  57 58 59 60 61  0  0  0  0
  62 63 64  0  0  0  0  0  0

GMT_MSH_XDIR # Spatial Mesh in X direction

  1 10.803 2 21.606 2 21.606 2 21.606 2 21.606 2 21.606
  2 21.606 2 21.606 2 21.606 #npx(NXR),hx(NXR)

GMT_MSH_YDIR # Spatial Mesh in Y direction

  1 10.803  2 21.606 2 21.606 2 21.606 2 21.606 2 21.606
  2 21.606 2 21.606 2 21.606 #npy(NXR),hy(NXR)

GMT_MSH_ZDIR # Spatial Mesh in Z direction

  1 30.0  1  7.7  1 11.0  1 15.0  1 30.0  1 30.0  1 30.0  1 30.0  1 30.0
  1 30.0  1 30.0  1 30.0  1 30.0  1 30.0  1 12.8  1 12.8  1  8.0  1 30.
        # npz(NZR),hz(NZR)

GMT_COR_LOAD # Core Loading with Bundle Types

  1  2  1  2  1  3  1  4  5
  2  1  6  1  6  1  7  4  5
  1  6  1  6  1  6  4  8  5
  2  1  6  1  6  9  4  5
  1  6  1  6  1  4  8  5
  3  1  6  9  4  8  5
  1  7  4  4  8  5
  4  4  8  5  5
  5  5  5  # CORE_LOAD

  1  4  15*4  1 # nb =   1
  1  5  15*9  1 # nb =   2
  1  5  15*7  1 # nb =   3
  1  6  15*6  1 # nb =   4
  2  2  15*2  2 # nb =   5
  1  5  15*8  1 # nb =   6
  1  6  15*11  1 # nb =   7
  3  3  15*3  3 # nb =   8
  1  6  15*10  1 # nb =   9

GMT_BND_COND # Boundary Conditions

   1 0 1 0 # i_DR
   0. 0.   0. 0.   0. 0.  0. 0. # DR
```

```
   0  0 # i_DZ
   0. 0.  0. 0. # DZ

CRD_COR_LOAD

  1     1           1
     1           1
  1     1     1     2
           1
        1     1
     1
  1     2

CRD_MAT_COMP

 1 3 # Material Composition for 1st type of CR
 2 3 # Material Composition for 2nd type of CR

CRD_LOCATION # Locations of the control rods in the reactor core

   1     3           7
     11          15
  19    21    23    25
           31
        38    40
     45
  51    53      # nrods(IRODS)

CRD_POSITION # Position of the control rods (PWR from the Bottom of the
Reactor)

  37.7  37.7        37.7
    401.183      37.7
  37.7  37.7  37.7  37.7
          401.183
        37.7  37.7
     37.7
  37.7  37.7    # zrods(IRODS)


CRD_ROD_CUSP # homogenization of XS for partially rodded nodes

"FLUX_WEIGHTING"

CRD_H_ROD_EL # Height of the control rod elements

  362.159 1000. H_Rod_El(NESUZ)

CRD_TIM_STRT # Time when control rods start moving

 0.0

CRD_VEL_RODS # velocities of the moving rods

   3634.830  # Velocity of the Control Rod (cm/sec)

CRD_NUM_MOVE # Total Number of the moving crods

  1 # Total Number of the Ejected CR

CRD_IND_MOVE # Index of the moving rods

  1 # Index of the Ejected CR
```

```
CRD_TOP_POSI # Maximum Top position of the Moving Control Rods

  401.183

CRD_BTM_POSI # Minimum Bottom Position of the Moving Control Rod

   37.7

TH_TEMC_INLT # Inlet Coolant Temperature, K

   559.15

TH_PRES_COOL #  Coolant Pressure (Mpa)

   15.5

TH_MFRT_ASSM # Coolant Flow Rate per Assembly ! Kg/(m^2*sec)

  3291.266

TH_HYDR_DIAM # Equivalent Diameter (m)

 1.1909E-02

TH_HTCF_CNST # Heat Transfer Coefficient Constants (Dittus-Boelter)

 0.023  0.8  0.4 ! Const_DB, Pow_reynolds, Pow_Prandtl

TH_SURF_VOLM # Ratio of the Surface Area of Coolant to the Coolant Volume
(1/m)

 3.163461E+2

TH_FLOW_AREA # Relative Flow Area

 0.5344937

FRD_RAD_PELT # Radius of Fuel Pellet (m)

 4.1195001E-03

FRD_RAD_CLAD # Radius of the Cladding (Inner, Outer)

 4.1875001E-03  4.7585000E-03

FRD_DNS_F&CL # Density of the Fuel, Cladding (KG/m^3)

 1.0412E+04 6.6E+03

FRD_GAP_COND #  Gap Conductance watts/(K m^2)

 1.E+04

FRD_ALF_DOPL #  Parameter to compute the Doppler Temperature

 0.7

FRD_RAT_ASFL # Ratio of the Assembly Volume to Fuel Volume

 3.316698

!=========================================================================!
! End of the  PWR NEACRP, case A1 Input Data                              !
!=========================================================================!
```

B.4 CONTENT OF THE INPUT NAMELIST FILE "SKETCH.INI.PWR_A1.KIN"

```
c=========================================================================c
c         SKETCH-N version 1.0: Nodal Neutron Diffusion Code for          c
c          Solving Steady-State & Kinetics Problems                       c
c=========================================================================c

 &INI_PROBLEM
   Problem_Type = "Kinetics"
   TH_Model = "Internal"
 &END

 &INI_FILES
  FILE_INPUT      =  'Input/PWR_NEACRP_A1.DAT'
  File_DMP_In     =  'Restart/pwr_neacrp_A1_0.dat'
  FILE_DMP_OUT_KIN = 'Restart/pwr_neacrp_A1_5.dat'
 &END

 &INI_CONVERGENCE
 &END

 &INI_CHEBYSHEV
 &END

 &INI_TIME_STEP
  i_auto = 1
  NP_VIEW = 1
  TTV(1) = 5.
  dt_input(1) = 0.005
  ST_EPS = 5.E-03
 &END
```

B.5 CONTENT OF THE POSTPROCESSOR INPUT NAMELIST FILE "POSTPROC.INI.PWR_A1_KIN"

```
!=============================================================================!
! File_grf - *.grf file generated by SKETCH.exe       "Output/SKETCH.grf"   !
! File_Inp - ASCII Input File for PostProcessor       ""                    !
! File_Out - ASCII Output File                        "Output/PostProc.lst" !
! File_TR_Out - ASCII Output File                     "Output/PProc_TR.lst" !
! File_TM_Out - ASCII Output File                     "Output/PProc_TM.lst" !
! File_ST_Out - ASCII Output File                     "Output/PProc_ST.lst" !
! fmt_tr_r - Output Format for Transient Real Data              "(E12.5)"  !
! fmt_tr_i - Output Format for Transient Integer Data           "(I5)"     !
! fmt_ti_r - Output Format for Time Moment Real Data            "(F6.3)"   !
! fmt_ti_i - Output Format for Time_Moment Integer Data         "(I5)"     !
! fmt_st_r - Output Format for Steady-State Distributions       "(F6.3)"   !
! fmt_st_i - Output Format for Staedy-State Distributions       "(I5)"     !
! Time_Output - Output Time for Distributions                   "0.0"      !
!=============================================================================!

 &PostProc
   File_grf =    "Output/SKETCH.grf"
   File_Inp =    "Input/PostProc_PWR_A1_KIN.dat"
   File_TR_Out = "Output/PostProc_PWR_A1_TIME.lst"
   fmt_tr_r = "(F9.3)"
 &END
```

B.6 CONTENT OF THE POSTPROCESSOR INPUT DATA FILE "POSTPPROC_PWR_A1_KIN.DAT"

```
! INPUT OF THE DATA VS. TIME
! Reactor Power [MWt]
TS001
! Reactivity [$]
TS002
! SKETCH-N Time Step Size, [ms]
TS003
! Average Doppler Fuel Temperature
TD005 0 0 0
! Maximum Fuel Centerline Temperature
TM006 3
! Location of the 3D Maximum Fuel Centerline Temperature
TL006 3
```

APPENDIX C

3D NEACRP BWR COLD WATER INJECTION BENCHMARK

C.1 Content of the include file "bwr_neacrp_d1.fh"
C.2 Content of the input namelist file "SKETCH.INI.BWR_D1.ST"
C.3 Content of the input file "BWR_NEACRP_D1.DAT"
C.4 Content of the input file "TRAC_BWR_Map_185_26_185_24.DAT"
C.5 Content of the input namelist file "SKETCH.INI.BWR_D1.KIN"
C.6 Content of the postprocessor input namelist file "PostProc.INI.BWR_D1_KIN"
C.7 Content of the postprocessor input data file "PostProc_BWR_D1_KIN.dat"

C.1 CONTENT OF THE INCLUDE FILE “BWR_NEACRP_D1.FH”

```
!=======================================================================
! PARAMETERS FOR NEACRP BWR COLD WARTER INJECTION BENCHMARK (CASE D1) !
! (c) Slava 30 November 1999                                           !
!=======================================================================
! GeoMTry Module                                                       !
!  N_POLY - number of the bundles (assemblies) in the reactor;         !
!  NH - number of the nodes in radial (X-Y) plane                      !
!       with 1 node per assembly NH = N_POLY;                          !
!  NZR - number of axial layers defining materail composition          !
!     of the bundle                                                   !
!  NZ - number of axial lalers used for the calculations               !
!  NXR - maximum number of bundles in X directions                     !
!  NX - maximum number of nodes in X direction                         !
!  NYR - maximum number of bundles in Y directions                     !
!  NY - maximum number of nodes in Y direction                         !
!  NCHM - maximum number of nodes per bundle (assembly)                !
!       in X-Y plane                                                   !
!  NDD - reactor geometry dimensions                                   !
!    (3D calculations NDD = 3; 2D calculations NDD = 2 ;               !
!     1D calculations NDD = 3)                                        !
!  N_BUNDLE_TYPE - number of different bundle types                    !
!-----------------------------------------------------------------------
      integer N_POLY, NH, NZR, NZ, NXR, NYR, NX, NY,
     &          NCHM, NDD,N_BUNDLE_TYPE
      parameter (N_POLY   = 249, NH = 249 ) !
      parameter (NZR =  26,  NZ = 26 )
      parameter (NXR =  17, NYR = 17 )
      parameter (NX  =  17, NY  = 17 )
      parameter (NCHM = 1)
      parameter (NDD = 3)
      parameter (N_BUNDLE_TYPE = 10)
!-----------------------------------------------------------------------
! End GeoMTry Module                                                   !
!=======================================================================
! TH_Model                                                             !
!   NP_Reactor_Core - number of fuel bundles in the reactor core       !
!   NZ_Core - number of axial layers in the reactor core (planes)      !
!-----------------------------------------------------------------------
      integer NP_Reactor_Core, NZR_Core
      parameter (NP_Reactor_Core = 185, NZR_Core = 24)
!-----------------------------------------------------------------------
! End TH_Model                                                         !
!=======================================================================
! XS Module (Cross Section & Neutron Kinetics Constant)                !
!   NG - number of neutron energy groups                               !
!   NNODE number of material compositions (dimension of the XS arrays) !
!   MD - number of delayed neutron groups                              !
!   N_FEEDBACKS - number of feedbacks (boron concentration, moderator  !
!    temperature, moderator density or void, doppler fuel temperature) !
!-----------------------------------------------------------------------
      integer   NNODE, NG, MD,  N_FEEDBACK
      parameter(NNODE = 19, NG = 2)
      parameter(MD = 6)
      parameter(N_FEEDBACK = 4)
!-----------------------------------------------------------------------
! End End TH_Model                                                     !
!=======================================================================
!=======================================================================
! CRD control rod Module                                               !
```

```
!     NN_CRod_Comp - Number of Control Rod Compositions                 !
!     NN_CRod -  Number of Control Rods                                 !
!     NN_CRod_El -  Number of the Rod Materials (Absorber + Driver = 2)!
!     NN_CRod_Type - Number of Control Rod Types                        !
!     NN_Crod_Bundle - Number of the Bundles covered by CR              !
!                               ("PWR" - 1, "BWR" - 4)                  !
!-----------------------------------------------------------------------
      INTEGER NN_CRod, NN_CRod_Comp, NN_CRod_El, NN_CRod_Type,
     &  NN_Crod_Bundle
      PARAMETER (NN_CRod_El = 2, NN_CRod = 1, NN_CRod_Comp = 1,
     &  NN_CRod_Type = 1, NN_Crod_Bundle = 4 )
!-----------------------------------------------------------------------
! End CRD control rod Module                                           !
!=======================================================================
! Fuel RoD (FRD) Heat Conduction Model                                 !
!     NN_FRD_FUEL - Number of the heat conduction nodes in the fuel    !
!     NN_FRD_CLAD - Number of the heat conduction nodes in the cladding!
!     NN_FRD_TOTAL - Total number of the heat conduction nodes         !
!                     in the fuel rod                                  !
!-----------------------------------------------------------------------
      INTEGER NN_FRD_FUEL, NN_FRD_CLAD, NN_FRD_TOTAL
      PARAMETER ( NN_FRD_FUEL=9, NN_FRD_CLAD = 2,
     &           NN_FRD_TOTAL = NN_FRD_FUEL + NN_FRD_CLAD )
!-----------------------------------------------------------------------
! End Fuel RoD (FRD) Heat Conduction Model
!=======================================================================
! PVM Interface Module for TRAC                                        !
!  NN_RT_HC_TRAC-Number of nodes of heat conduction R-T spatial mesh   !
!  NN_RT_FD_TRAC-Number of nodes of fluid dynamics R-T spatial mesh    !
!  NN_Z_HC_TRAC-Number of axial layers of heat conduction spatial mesh !
!  NN_Z_FD_TRAC-Number of axial layers of fluid dynamics spatial mesh  !
!-----------------------------------------------------------------------
      INTEGER NN_RT_HC_TRAC, NN_RT_FD_TRAC, NN_Z_HC_TRAC, NN_Z_FD_TRAC
      PARAMETER ( NN_Z_HC_TRAC = 24, NN_Z_FD_TRAC = 24,
     &              NN_RT_HC_TRAC = 185, NN_RT_FD_TRAC = 185)
!-----------------------------------------------------------------------
! End PVM Interface Module for TRAC                                    !
!=======================================================================
!                     THAT'S ALL                                       !
!=======================================================================
```

C.2 CONTENT OF THE INPUT NAMELIST FILE "SKETCH.INI.BWR_D1.ST"

```
c=========================================================================c
c        SKETCH-N version 1.0: Nodal Neutron Diffusion Code for           c
c          Solving Steady-State & Kinetics Problems                       c
c=========================================================================c
&INI_PROBLEM
   Problem_Type = "Eigenvalue"
   TH_Model = "External"
 &END

 &INI_FILES
  FILE_INPUT       =  'Input/BWR_NEACRP_D1.DAT'
  FILE_MAP         =  'Input/TRAC_BWR_Map_185_26_185_24.DAT'
  FILE_DMP_OUT_KIN =  'Restart/bwr_neacrp_D1_0.dat'
 &END

 &INI_CONVERGENCE
 &END

 &INI_CHEBYSHEV
 &END

 &INI_TIME_STEP
 &END
```

C.3 CONTENT OF THE INPUT FILE "BWR_NEACRP_D1.DAT"

```
*=====================================================================*
*    INITIAL DATA FOR BWR NEACRP D1 PROBLEM                           *
*  (c) Slava March 1998 JAERI                                         *
*   Cross-Sections, Boundary Conditions, Material Composition         *
*=====================================================================*

CNT_RCT_TYPE ## REACTOR TYPE

 "BWR"

CNT_RCT_POWR ## REACTOR POWER (MWt)

 1800.

XS_BASE_DATA ## Basic set of the Macro Cross Section Data

 0.111030E+00 0.225950E-01 0.392000E-03 0.000000E+00 0.000000E+00
 0.830012E+00 0.148010E-01 0.000000E+00 0.000000E+00            1

 0.189784E+00 0.141764E-01 0.102352E-01 0.446986E-02 0.181431E-02
 0.694136E+00 0.749127E-01 0.828220E-01 0.336177E-01            2

 0.188554E+00 0.142295E-01 0.103417E-01 0.446539E-02 0.181220E-02
 0.693963E+00 0.768592E-01 0.804386E-01 0.326449E-01            3

 0.134270E+00 0.181770E-01 0.553000E-03 0.000000E+00 0.000000E+00
 0.730050E+00 0.622329E-02 0.000000E+00 0.000000E+00            4

 0.189186E+00 0.143548E-01 0.101071E-01 0.413061E-02 0.167631E-02
 0.693475E+00 0.683185E-01 0.738611E-01 0.299759E-01            5

 0.188264E+00 0.143946E-01 0.101869E-01 0.412726E-02 0.167472E-02
 0.693345E+00 0.697783E-01 0.720736E-01 0.292463E-01            6

 0.199654E+00 0.164565E-01 0.709736E-02 0.416239E-02 0.169163E-02
 0.718647E+00 0.484724E-01 0.649081E-01 0.263796E-01            7

 0.198692E+00 0.165185E-01 0.715434E-02 0.416026E-02 0.169070E-02
 0.719003E+00 0.490908E-01 0.636570E-01 0.258699E-01            8

 0.189151E+00 0.143552E-01 0.101112E-01 0.413003E-02 0.167607E-02
 0.693476E+00 0.683829E-01 0.738046E-01 0.299530E-01            9

 0.188381E+00 0.143893E-01 0.101774E-01 0.412816E-02 0.167512E-02
 0.693427E+00 0.696467E-01 0.723935E-01 0.293768E-01           10

 0.187960E+00 0.144036E-01 0.102185E-01 0.412665E-02 0.167439E-02
 0.693550E+00 0.704713E-01 0.716701E-01 0.290810E-01           11

 0.188575E+00 0.143771E-01 0.101653E-01 0.412888E-02 0.167544E-02
 0.693636E+00 0.694981E-01 0.728618E-01 0.295674E-01           12

 0.189081E+00 0.143562E-01 0.101196E-01 0.412887E-02 0.167559E-02
 0.693478E+00 0.685118E-01 0.736916E-01 0.299070E-01           13

 0.188616E+00 0.143789E-01 0.101582E-01 0.412995E-02 0.167592E-02
 0.693591E+00 0.693833E-01 0.730336E-01 0.296377E-01           14

 0.187354E+00 0.144216E-01 0.102817E-01 0.412543E-02 0.167370E-02
 0.693960E+00 0.718573E-01 0.708631E-01 0.287502E-01           15

 0.199871E+00 0.164480E-01 0.708533E-02 0.415877E-02 0.169022E-02
```

```
 0.722345E+00 0.482128E-01 0.650624E-01 0.264432E-01           16

 0.198410E+00 0.165210E-01 0.717808E-02 0.416892E-02 0.169414E-02
 0.718597E+00 0.500243E-01 0.643471E-01 0.261493E-01           17

 0.197215E+00 0.165982E-01 0.725399E-02 0.416619E-02 0.169287E-02
 0.719295E+00 0.509656E-01 0.626218E-01 0.254457E-01           18

 0.184542E+00 0.375790E-01 0.359000E-03 0.000000E+00 0.000000E+00
 0.136864E+01 0.108680E-01 0.000000E+00 0.000000E+00           19

XSP_POL_COEF ## Macro Cross Sections polynomila coefficients

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.219320E-06 0.219320E-06 0.856719E-09 0.000000E+00 0.000000E+00
 0.701825E-05 0.109660E-06 0.000000E+00 0.000000E+00 0.850000E+00
 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 5.731500E+02 ## 1

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.130164E+00 0.196627E-01 0.238730E-02 0.111084E-02 0.464362E-03
 0.759141E+00 0.126336E-01 0.246360E-01 0.102472E-01 0.550000E+00
 0.000000E+00 -.160580E-04 0.200902E-04 0.000000E+00 0.000000E+00
 -.823459E-04 -.262873E-04 -.350770E-04 -.142416E-04 5.731500E+02  ## 2

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.128750E+00 0.197654E-01 0.247360E-02 0.111093E-02 0.464733E-03
 0.752907E+00 0.127195E-01 0.236482E-01 0.984506E-02 0.550000E+00
 0.000000E+00 -.161574E-04 0.201801E-04 0.000000E+00 0.000000E+00
 -.825240E-04 -.270360E-04 -.341409E-04 -.138593E-04 5.731500E+02 ## 3

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.175456E-05 0.219320E-06 0.000000E+00 0.000000E+00 0.000000E+00
 0.140365E-04 -.685375E-08 0.000000E+00 0.000000E+00 0.550000E+00
 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 5.731500E+02 ## 4

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.129802E+00 0.198449E-01 0.227347E-02 0.960766E-03 0.402857E-03
 0.771240E+00 0.108673E-01 0.211180E-01 0.879825E-02 0.550000E+00
 0.000000E+00 -.162970E-04 0.204046E-04 0.000000E+00 0.000000E+00
 -.824488E-04 -.239924E-04 -.313155E-04 -.127127E-04 5.731500E+02 ## 5

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.128744E+00 0.199218E-01 0.233817E-02 0.960828E-03 0.403124E-03
 0.766559E+00 0.109320E-01 0.203775E-01 0.849679E-02 0.550000E+00
```

```
0.000000E+00 -.163716E-04 0.204720E-04 0.000000E+00 0.000000E+00
-.825824E-04 -.245539E-04 -.306135E-04 -.124259E-04 5.731500E+02 ## 6

0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
0.127443E+00 0.197129E-01 0.170083E-02 0.696670E-03 0.290777E-03
0.750235E+00 0.126452E-01 0.130177E-01 0.540898E-02 0.550000E+00
0.000000E+00 -.189002E-04 0.231603E-04 0.000000E+00 0.000000E+00
-.867114E-04 -.172597E-04 -.277381E-04 -.112749E-04 5.731500E+02 ## 7

0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
0.126783E+00 0.197951E-01 0.171473E-02 0.693127E-03 0.289441E-03
0.746987E+00 0.125016E-01 0.124660E-01 0.518429E-02 0.550000E+00
0.000000E+00 -.189895E-04 0.232572E-04 0.000000E+00 0.000000E+00
-.868472E-04 -.174963E-04 -.272325E-04 -.110690E-04 5.731500E+02 ## 8

0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
0.129752E+00 0.198434E-01 0.228093E-02 0.959197E-03 0.402219E-03
0.771049E+00 0.108792E-01 0.211062E-01 0.879375E-02 0.550000E+00
0.000000E+00 -.162923E-04 0.203980E-04 0.000000E+00 0.000000E+00
-.824204E-04 -.240056E-04 -.312795E-04 -.126980E-04 5.731500E+02 ## 9

0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
0.128909E+00 0.199168E-01 0.232403E-02 0.962980E-03 0.403946E-03
0.766905E+00 0.109351E-01 0.205383E-01 0.856259E-02 0.550000E+00
0.000000E+00 -.163709E-04 0.204749E-04 0.000000E+00 0.000000E+00
-.826201E-04 -.245168E-04 -.307625E-04 -.124867E-04 5.731500E+02 ## 10

0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
0.128450E+00 0.199429E-01 0.236219E-02 0.963165E-03 0.404145E-03
0.762266E+00 0.110489E-01 0.204017E-01 0.850699E-02 0.550000E+00
0.000000E+00 -.163872E-04 0.204833E-04 0.000000E+00 0.000000E+00
-.826179E-04 -.248087E-04 -.304546E-04 -.123607E-04 5.731500E+02 ## 11

0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
0.129158E+00 0.198915E-01 0.231898E-02 0.963117E-03 0.403967E-03
0.765378E+00 0.110057E-01 0.208959E-01 0.870788E-02 0.550000E+00
0.000000E+00 -.163375E-04 0.204384E-04 0.000000E+00 0.000000E+00
-.825289E-04 -.244344E-04 -.309227E-04 -.125519E-04 5.731500E+02 ## 12

0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
0.129650E+00 0.198407E-01 0.229584E-02 0.956030E-03 0.400945E-03
0.770663E+00 0.109047E-01 0.210825E-01 0.878421E-02 0.550000E+00
0.000000E+00 -.162829E-04 0.203849E-04 0.000000E+00 0.000000E+00
```

```
 -.823634E-04 -.240320E-04 -.312074E-04 -.126688E-04 5.731500E+02 ## 13

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.129248E+00 0.199065E-01 0.229551E-02 0.967291E-03 0.405584E-03
 0.767578E+00 0.109412E-01 0.208614E-01 0.869330E-02 0.550000E+00
 0.000000E+00 -.163695E-04 0.204806E-04 0.000000E+00 0.000000E+00
 -.826954E-04 -.244425E-04 -.310605E-04 -.126082E-04 5.731500E+02 ## 14

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.127871E+00 0.199848E-01 0.241000E-02 0.967730E-03 0.406160E-03
 0.753668E+00 0.112829E-01 0.204502E-01 0.852695E-02 0.550000E+00
 0.000000E+00 -.164185E-04 0.205059E-04 0.000000E+00 0.000000E+00
 -.826889E-04 -.253184E-04 -.301369E-04 -.122304E-04 5.731500E+02 ## 15

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.127402E+00 0.197119E-01 0.169762E-02 0.692305E-03 0.289009E-03
 0.738630E+00 0.127121E-01 0.127594E-01 0.530426E-02 0.550000E+00
 0.000000E+00 -.188723E-04 0.231300E-04 0.000000E+00 0.000000E+00
 -.866561E-04 -.171504E-04 -.277728E-04 -.112893E-04 5.731500E+02 ## 16

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.126972E+00 0.197836E-01 0.172207E-02 0.704641E-03 0.294266E-03
 0.745357E+00 0.126051E-01 0.137254E-01 0.569860E-02 0.550000E+00
 0.000000E+00 -.189906E-04 0.232614E-04 0.000000E+00 0.000000E+00
 -.867723E-04 -.178265E-04 -.277559E-04 -.112813E-04 5.731500E+02 ## 17

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.126127E+00 0.198932E-01 0.173860E-02 0.701297E-03 0.293073E-03
 0.741955E+00 0.125542E-01 0.126783E-01 0.527268E-02 0.550000E+00
 0.000000E+00 -.191256E-04 0.234010E-04 0.000000E+00 0.000000E+00
 -.870674E-04 -.182100E-04 -.268636E-04 -.109176E-04 5.731500E+02 ## 18

 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00       1200.2
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00
 0.000000E-00 0.000000E-00 0.000000E-00 0.000000E-00        306.6
 0.000000E+00 0.109660E-06 0.428360E-09 0.000000E+00 0.000000E+00
 0.175456E-05 0.109660E-06 0.000000E+00 0.000000E+00 0.766370E+00
 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
 0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00 5.731500E+02 ## 19

XS_DIFF_FLAG

  0 ## Parameter 1 - Diffusion Coefficient, 0 - Transport XS

XS_FEED_INIT

 1200.2  273.0  0.762300E+00  5.471500E+02
                     # Feedback0 (Boron, T_Coolant, Ro_coolant, T_fuel)
```

```
XS_NEUT_SPEC

   1.0 0.0  ## xp(NG)

XS_POWR_CONV

   3.20E-11 3.20E-11 ## pow_conv

XS_NEUT_VELC

 0.2800112E+08 0.440529E+06 ## v(NG)

XS_PREC_ALFA

 0.013 0.032 0.119 0.318 1.403 3.929 ## alfa(MD)

XS_PREC_BETA

 0 ## Absolute Beta
 0.00026 0.00152 0.00139 0.00307 0.00110 0.00026 ## bet(MD)

XS_PREC_SPEC

 1.0 0.0 ## xm(NG)
GMT_NUM_BNDL ## Numbering of the reactor assdemblies (bundles)

    0   0   0   0   1   2   3   4   5   6   7   8   9   0   0   0   0
    0   0   0  10  11  12  13  14  15  16  17  18  19  20   0   0   0
    0   0  21  22  23  24  25  26  27  28  29  30  31  32  33   0   0
    0  34  35  36  37  38  39  40  41  42  43  44  45  46  47  48   0
   49  50  51  52  53  54  55  56  57  58  59  60  61  62  63  64  65
   66  67  68  69  70  71  72  73  74  75  76  77  78  79  80  81  82
   83  84  85  86  87  88  89  90  91  92  93  94  95  96  97  98  99
  100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116
  117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133
  134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150
  151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167
  168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184
  185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201
    0 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216   0
    0   0 217 218 219 220 221 222 223 224 225 226 227 228 229   0   0
    0   0   0 230 231 232 233 234 235 236 237 238 239 240   0   0   0
    0   0   0   0 241 242 243 244 245 246 247 248 249   0   0   0   0

GMT_MSH_XDIR ## Spatial Mesh in X direction

 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48
 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48
                                                  # npx(NXR),hx(NXR)

GMT_MSH_YDIR ## Spatial Mesh in X direction

 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48
 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48 1 30.48
                                                    #  npy(NYR),hy(NYR)

GMT_MSH_ZDIR ## Spatial Mesh in X direction

 1 30.48
 1 15.24 1 15.24 1 15.24 1 15.24 1 15.24 1 15.24 1 15.24 1 15.24 1 15.24
 1 15.24 1 15.24 1 15.24 1 15.24 1 15.24 1 15.24 1 15.24 1 15.24 1 15.24
 1 15.24 1 15.24 1 15.24 1 15.24 1 15.24 1 15.24
 1 30.48 ## npz(NZR),hz(NZR)
```

```
GMT_COR_LOAD ## Core Loading with Bundle Types

                        10  10  10  10  10  10  10  10  10
                    10  10   2   2   2   2   1   2   1  10  10
                10  10   2   2   3   2   4   2   3   2   2  10  10
            10  10   2   5   6   6   6   6   6   6   6   5   2  10  10
        10  10   2   2   9   6   9   6   7   6   9   6   9   5   2  10  10
        10   1   2   6   6   6   6   6   6   6   6   6   6   6   2   1  10
        10   1   3   6   9   6   7   6   9   6   7   6   9   6   3   2  10
        10   1   2   6   6   6   6   6   6   6   6   6   6   6   2   1  10
        10   1   4   6   7   6   9   6   8   6   9   6   7   6   4   2  10
        10   1   2   6   6   6   6   6   6   6   6   6   6   6   2   2  10
        10   1   3   6   9   6   7   6   9   6   7   6   9   6   3   2  10
        10   1   2   6   6   6   6   6   6   6   6   6   6   6   2   2  10
        10  10   2   5   9   6   9   6   7   6   9   6   9   5   2  10  10
            10  10   2   5   6   6   6   6   6   6   6   2   2  10  10
                10  10   2   2   3   2   4   2   3   2   2  10  10
                    10  10   1   1   1   1   1   1   1  10  10
                        10  10  10  10  10  10  10  10  10

1   2  2  3  3  3  3  3  3  3  3  3  3  2  2  2  2  2  2  2  2  2  2  2  4 # Type 1
1   5  5  6  6  6  6  6  6  6  6  6  6  5  5  5  5  5  5  5  5  5  5  5  4 # Type 2
1   5  5  6  6  6  6  6  6  6  6  6  6  5  5  5  5  5  5  5  5  7  7  7  4 # Type 3
1   5  5  6  6  6  6  8  8  8  8  8  8  7  7  7  7  7  7  7  7  7  7  7  4 # Type 4
1   9  9 10 10 10 10 10 10 11 11 11 11 12 12 10 10 10 10 10 10  9  9  9  4 # Type 5
1  16 16 17 17 17 17 17 17 18 18 18 18 18 18 17 17 17 17 17 17 16 16 16 16  4 # Type 6
1  13 13 14 14 14 14 14 14 15 15 15 15 15 15 14 14 14 14 14 14 13 13 16 16  4 # Type 7
1  13 13 14 14 14 14 14 14 15 15 15 15 15 15 14 14 14 14 14 14 16 16 16 16  4 # Type 8
1  13 13 14 14 14 14 17 17 18 18 18 18 18 18 17 17 17 17 17 17 16 16 16 16  4 # Type 9
19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 # Type
                                                                          10

GMT_BND_COND ## Boundary Conditions

   0 0 0 0 ## i_DR
   0. 0.   0. 0.   0. 0.  0. 0. ## DR
   0  0 ## i_DZ
   0. 0.  0. 0. ## DZ

*=========================================================================*
*    End of input data for  BWR NEACRP D1 problem                         *
*=========================================================================*
```

C.4 CONTENT OF THE INPUT FILE “TRAC_BWR_MAP_185_26_185_24.DAT”

```
*=========================================================================*
*    INITIAL DATA FOR BWR NEACRP 3D REA PROBLEM (Case D1 185 CHANNELS) *
*     MAPPING TO THE TRAC GEOMETRY (185x26 mapping into 185x24)        *
*  (c) Slava 17.VI.1999 JAERI                                          *
*=========================================================================*

PVM_EXT_CODE # name of the external T/H code: "TRAC-BF1", "TRAC-PF1")

"TRAC-BF1"

PVM_CNV_UNIT # Conversion constants for TRAC units:

1.E-03 -273.15 0.  # Coolant Density (or Void); Coolant and Fuel Temperature

PVM_MAP_NTHC # 2D & 1D Mapping matrices Neutronics => Heat Conduction

                     1   2   3   4   5   6   7
                 8   9  10  11  12  13  14  15  16
            17  18  19  20  21  22  23  24  25  26  27
        28  29  30  31  32  33  34  35  36  37  38  39  40
    41  42  43  44  45  46  47  48  49  50  51  52  53  54  55
    56  57  58  59  60  61  62  63  64  65  66  67  68  69  70
    71  72  73  74  75  76  77  78  79  80  81  82  83  84  85
    86  87  88  89  90  91  92  93  94  95  96  97  98  99 100
   101 102 103 104 105 106 107 108 109 110 111 112 113 114 115
   116 117 118 119 120 121 122 123 124 125 126 127 128 129 130
   131 132 133 134 135 136 137 138 139 140 141 142 143 144 145
       146 147 148 149 150 151 152 153 154 155 156 157 158
           159 160 161 162 163 164 165 166 167 168 169
               170 171 172 173 174 175 176 177 178
                   179 180 181 182 183 184 185    186  # IA_2D_NTHC

                     12  13  14  15  16  17  18
                 23  24  25  26  27  28  29  30  31
            36  37  38  39  40  41  42  43  44  45  46
        51  52  53  54  55  56  57  58  59  60  61  62  63
    67  68  69  70  71  72  73  74  75  76  77  78  79  80  81
    84  85  86  87  88  89  90  91  92  93  94  95  96  97  98
   101 102 103 104 105 106 107 108 109 110 111 112 113 114 115
   118 119 120 121 122 123 124 125 126 127 128 129 130 131 132
   135 136 137 138 139 140 141 142 143 144 145 146 147 148 149
   152 153 154 155 156 157 158 159 160 161 162 163 164 165 166
   169 170 171 172 173 174 175 176 177 178 179 180 181 182 183
       187 188 189 190 191 192 193 194 195 196 197 198 199
           204 205 206 207 208 209 210 211 212 213 214
               219 220 221 222 223 224 225 226 227
                   232 233 234 235 236 237 238  # JA_2D_NTHC

 185*1. # MAP_2D_NTHC

   1 2 3 4 5 6 7 8  9 10 11 12 13 14 15 16 17 18 19 20
     21 22 23 24 25  # IA_1D_NTHC
   2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
     22 23 24 25 # JA_1D_NTHC
24*1. # MAP_1D_NTHC
```

```
PVM_MAP_NTFD # 2D & 1D Mapping matrices Neutronics => Fluid Dynamics

                      1   2   3   4   5   6   7
                  8   9  10  11  12  13  14  15  16
              17  18  19  20  21  22  23  24  25  26  27
          28  29  30  31  32  33  34  35  36  37  38  39  40
      41  42  43  44  45  46  47  48  49  50  51  52  53  54  55
      56  57  58  59  60  61  62  63  64  65  66  67  68  69  70
      71  72  73  74  75  76  77  78  79  80  81  82  83  84  85
      86  87  88  89  90  91  92  93  94  95  96  97  98  99 100
     101 102 103 104 105 106 107 108 109 110 111 112 113 114 115
     116 117 118 119 120 121 122 123 124 125 126 127 128 129 130
     131 132 133 134 135 136 137 138 139 140 141 142 143 144 145
         146 147 148 149 150 151 152 153 154 155 156 157 158
             159 160 161 162 163 164 165 166 167 168 169
                 170 171 172 173 174 175 176 177 178
                     179 180 181 182 183 184 185    186  # IA_2D_NTFD

                      12  13  14  15  16  17  18
                  23  24  25  26  27  28  29  30  31
              36  37  38  39  40  41  42  43  44  45  46
          51  52  53  54  55  56  57  58  59  60  61  62  63
      67  68  69  70  71  72  73  74  75  76  77  78  79  80  81
      84  85  86  87  88  89  90  91  92  93  94  95  96  97  98
     101 102 103 104 105 106 107 108 109 110 111 112 113 114 115
     118 119 120 121 122 123 124 125 126 127 128 129 130 131 132
     135 136 137 138 139 140 141 142 143 144 145 146 147 148 149
     152 153 154 155 156 157 158 159 160 161 162 163 164 165 166
     169 170 171 172 173 174 175 176 177 178 179 180 181 182 183
         187 188 189 190 191 192 193 194 195 196 197 198 199
             204 205 206 207 208 209 210 211 212 213 214
                 219 220 221 222 223 224 225 226 227
                     232 233 234 235 236 237 238  # JA_2D_NTFD

 185*1. # MAP_2D_NTFD

   1 2 3 4 5 6 7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25  #
IA_1D_NTFD
   2 3 4 5 6 7 8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 #
JA_1D_NTFD
 24*1. # MAP_1D_NTFD


PVM_MAP_HCNT # 2D & 1D Mapping matrices Heat Conduction => Neutronics

                      1   1   1   1   1   1   1   1   1
                  1   1   1   2   3   4   5   6   7   8   8
              8   8   8   9  10  11  12  13  14  15  16  17  17
          17  17  17  18  19  20  21  22  23  24  25  26  27  28  28
      28  28  28  29  30  31  32  33  34  35  36  37  38  39  40  41  41
      41  41  42  43  44  45  46  47  48  49  50  51  52  53  54  55  56
      56  56  57  58  59  60  61  62  63  64  65  66  67  68  69  70  71
      71  71  72  73  74  75  76  77  78  79  80  81  82  83  84  85  86
      86  86  87  88  89  90  91  92  93  94  95  96  97  98  99 100 101
     101 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116
     116 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131
     131 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146
     146 146 146 147 148 149 150 151 152 153 154 155 156 157 158 159 159
         159 159 159 160 161 162 163 164 165 166 167 168 169 170 170
             170 170 170 171 172 173 174 175 176 177 178 179 179
                 179 179 179 180 181 182 183 184 185 186 186
                     186 186 186 186 186 186 186 186 186   186 # IA_2D_HCNT
```

```
                    1   2   3   4   5   6   7
                8   9  10  11  12  13  14  15  16
            17  18  19  20  21  22  23  24  25  26  27
        28  29  30  31  32  33  34  35  36  37  38  39  40
    41  42  43  44  45  46  47  48  49  50  51  52  53  54  55
    56  57  58  59  60  61  62  63  64  65  66  67  68  69  70
    71  72  73  74  75  76  77  78  79  80  81  82  83  84  85
    86  87  88  89  90  91  92  93  94  95  96  97  98  99 100
   101 102 103 104 105 106 107 108 109 110 111 112 113 114 115
   116 117 118 119 120 121 122 123 124 125 126 127 128 129 130
   131 132 133 134 135 136 137 138 139 140 141 142 143 144 145
       146 147 148 149 150 151 152 153 154 155 156 157 158
           159 160 161 162 163 164 165 166 167 168 169
               170 171 172 173 174 175 176 177 178
                   179 180 181 182 183 184 185    #  JA_2D_HCNT

 185*1. # Map_2D_HCNT

  1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
    21 22 23 24 25 26 27 # IA_1D_HCNT
  1 1 2 3 4 5 6 7 8  9 10 11 12 13 14 15 16 17 18 19
    20 21 22 23 24 24 # JA_1D_HCNT
  26*1. # MAP_1D_HCNT

PVM_MAP_FDNT # 2D & 1D Mapping matrices  Fluid Dynamics => Neutronics

                    1   1   1   1   1   1   1   1   1
                1   1   1   2   3   4   5   6   7   8   8
            8   8   8   9  10  11  12  13  14  15  16  17  17
        17  17  17  18  19  20  21  22  23  24  25  26  27  28  28
    28  28  28  29  30  31  32  33  34  35  36  37  38  39  40  41  41
    41  41  42  43  44  45  46  47  48  49  50  51  52  53  54  55  56
    56  56  57  58  59  60  61  62  63  64  65  66  67  68  69  70  71
    71  71  72  73  74  75  76  77  78  79  80  81  82  83  84  85  86
    86  86  87  88  89  90  91  92  93  94  95  96  97  98  99 100 101
   101 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116
   116 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131
   131 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146
   146 146 146 147 148 149 150 151 152 153 154 155 156 157 158 159 159
       159 159 159 160 161 162 163 164 165 166 167 168 169 170 170
           170 170 170 171 172 173 174 175 176 177 178 179 179
               179 179 179 180 181 182 183 184 185 186 186
                   186 186 186 186 186 186 186 186 186        186 #
IA_2D_FDNT

                    1   2   3   4   5   6   7
                8   9  10  11  12  13  14  15  16
            17  18  19  20  21  22  23  24  25  26  27
        28  29  30  31  32  33  34  35  36  37  38  39  40
    41  42  43  44  45  46  47  48  49  50  51  52  53  54  55
    56  57  58  59  60  61  62  63  64  65  66  67  68  69  70
    71  72  73  74  75  76  77  78  79  80  81  82  83  84  85
    86  87  88  89  90  91  92  93  94  95  96  97  98  99 100
   101 102 103 104 105 106 107 108 109 110 111 112 113 114 115
   116 117 118 119 120 121 122 123 124 125 126 127 128 129 130
   131 132 133 134 135 136 137 138 139 140 141 142 143 144 145
       146 147 148 149 150 151 152 153 154 155 156 157 158
           159 160 161 162 163 164 165 166 167 168 169
               170 171 172 173 174 175 176 177 178
                   179 180 181 182 183 184 185    #  JA_2D_FDNT


 185*1. # Map_2D_FDNT
```

```
  1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
    21 22 23 24 25 26 27 # IA_1D_FDNT
  1 1 2 3 4 5 6 7 8  9 10 11 12 13 14 15 16 17 18 19
    20 21 22 23 24 24    # JA_1D_FDNT
  26*1. # MAP_1D_FDNT

!========================================================================!
!                     End of the Input Data                              !
!========================================================================!
```

C.5 CONTENT OF THE INPUT NAMELIST FILE "SKETCH.INI.BWR_D1.KIN"

```
c=========================================================================c
c         SKETCH-N version 1.0: Nodal Neutron Diffusion Code for          c
c           Solving Steady-State & Kinetics Problems                      c
c=========================================================================c

 &INI_PROBLEM
   Problem_Type = "Kinetics"
   TH_Model = "External"
 &END

 &INI_FILES
  FILE_INPUT       = 'Input/BWR_NEACRP_D1.DAT'
  FILE_MAP         = 'Input/TRAC_BWR_Map_185_26_185_24.DAT'
  File_DMP_In      = 'Restart/bwr_neacrp_D1_0.dat'
  FILE_DMP_OUT_KIN = 'Restart/bwr_neacrp_D1_20.dat'
 &END

 &INI_CONVERGENCE
 &END

 &INI_CHEBYSHEV
 &END

 &INI_TIME_STEP
  i_auto = 1
  NP_VIEW = 1
  TTV(1) = 20.
  dt_input(1) = 0.005
  ST_EPS = 5.E-03
 &END
```

C.6 CONTENT OF THE POSTPROCESSOR INPUT NAMELIST FILE "POSTPROC.INI.BWR_D1_KIN"

```
!=============================================================================!
! File_grf - *.grf file generated by SKETCH.exe         "Output/SKETCH.grf" !
! File_Inp - ASCII Input File for PostProcessor         ""                  !
! File_Out - ASCII Output File                        "Output/PostProc.lst" !
! File_TR_Out - ASCII Output File                     "Output/PProc_TR.lst" !
! File_TM_Out - ASCII Output File                     "Output/PProc_TM.lst" !
! File_ST_Out - ASCII Output File                     "Output/PProc_ST.lst" !
! fmt_tr_r - Output Format for Transient Real Data              "(E12.5)"  !
! fmt_tr_i - Output Format for Transient Integer Data           "(I5)"     !
! fmt_ti_r - Output Format for Time Moment Real Data            "(F6.3)"   !
! fmt_ti_i - Output Format for Time_Moment Integer Data         "(I5)"     !
! fmt_st_r - Output Format for Steady-State Distributions       "(F6.3)"   !
! fmt_st_i - Output Format for Staedy-State Distributions       "(I5)"     !
! Time_Output - Output Time for Distributions                   "0.0"      !
!=============================================================================!

 &PostProc
   File_grf =    "Output/SKETCH.grf"
   File_Inp =    "Input/PostProc_BWR_D1_KIN.dat"
   File_Out =    "Output/PostProc_BWR_D1_INFO.lst"
   File_TR_Out = "Output/PostPRoc_BWR_D1_TIME.lst"
   fmt_tr_r = "(F10.4)"
 &END
```

C.7 CONTENT OF THE POSTPROCESSOR INPUT DATA FILE "POSTPPROC_BWR_D1_KIN.DAT"

```
! INPUT OF THE DATA VS. TIME
! Reactor Power [MWt]
TS001
! Reactivity [$]
TS002
! Time Step Size, [ms]
TS003
! Time Step Size proposed by the TRAC-BF1 code, [ms]
TS004
! Average Power Density
TD001 0 0 0
! Average Doppler Fuel Temperature
TD005 0 0 0
! Core-Averaged Coolant Density
TD004   0 0 0
! Outlet-Averaged Coolant Density
TD004   0 0 25
! Maximum 3D Power Density
TM001   3
! Location of the Maximum Power Density
TL001   3
! Maximum 2D Power Density
TM001   2
! Location of the Maximum 2D Power Density
TL001   2
! Maximum 1D Power Density
TM001   1
! Location of the Maximum 1D Power Density
TL001   1
```