CTH-NT-302 August 2014

USER'S MANUAL OF THE COUPLED CORE SIM NEUTRONIC AND THERMO-HYDRAULIC TOOL

VICTOR DYKIN AND CHRISTOPHE DEMAZIÈRE

Division of Nuclear Engineering
Department of Applied Physics
Chalmers University of Technology
SE-412 96 Gothenburg, Sweden 2014

ABSTRACT
This report presents how to use the coupled CORE SIM neutronic/thermo-hydraulic tool. The models and algorithms used in the coupled version of CORE SIM, as well as the demonstration of the tool were already presented in two companion reports [1, 2]. The novelty of the tool resides in its versatility, since many different systems can be investigated and different kinds of calculations can be performed. More precisely, both critical systems and subcritical systems with an external neutron source can be studied, static and dynamic cases in the frequency domain (i.e. for stationary fluctuations) can be considered. For each situation, the three dimensional distributions of static neutron fluxes, all thermo-hydraulic parameters, their respective first-order noise are estimated, as well as the effective multiplication factor of the system. The main advantages of the tool, which is entirely *MATLAB* based, lie with the robustness of the implemented numerical algorithms, its high portability between different computer platforms and operative systems, and finally its ease of use since no input deck writing is required. The present version of the tool, which is based on two-group diffusion theory, is mostly suited to investigate thermal systems, both Pressurized and Boiling Water Reactors (PWR and BWR, respectively). The tool is freely available on direct request to the authors of the present report.

Contents

Chapter 1

INTRODUCTION

This report describes how to use the coupled version of the CORE SIM code. CORE SIM is a *MATLAB* code which allows calculating, for a given set of input data, the two-group static neutron fluxes of the corresponding critical system and all respective thermo-hydraulic quantities. In addition, CORE SIM also calculates the static neutron flux of the subcritical system with an external neutron source. Finally, CORE SIM estimates the first-order noise in both neutronic and thermo-hydraulic quantities in the frequency domain. The main feature of CORE SIM is its flexibility and its simplicity in use, since there is no need in writing any input deck. The models and algorithms used in CORE SIM, as well as the demonstration of the tool were already presented in two companion reports [1, 2].

This reports presents in more details:

- the required software/hardware;
- what the code package contains;
- the file architecture and required input;
- the created output;
- the format of the input and output variables;
- the variables necessary in the input files and the available variables in the output file;
- a description of how to use the code;
- some examples available within the code package;
- a description of how to obtain code support and to report bugs.

Chapter 2

REQUIRED SOFTWARE

Since CORE SIM is a *MATLAB* code, access to *MATLAB* is necessary. CORE SIM was developed and tested with *MATLAB* Version 8.2.0.701 (R2013b). Depending on the types of problems investigated, access to large RAM or swap space might be required. In case of "Out of Memory" errors within *MATLAB*, useful tips can be obtained on the MathWorks website (*http://www.mathworks.com*) in order to resolve such problems (search for 'Resolving "Out of Memory" Errors').

Chapter 3

CODE PACKAGE

The coupled neutronic/thermo-hydraulic CORE SIM package is made of the following files and directories:

- **CORE_SIM_MAIN.m**: the main executable *MATLAB* M-file in order to run the coupled neutronic/thermo-hydraulic CORE SIM tool;
- **SETTINGS.m**: a *MATLAB* M-file containing some parameters used by the CORE SIM tool and that the user might change depending on his/her needs;
- **ADDING_NEW_PATHS.m**: a *MATLAB* M-file specifying the paths to the necessary files and directories;
- **MODULE**: a directory containing the main code modules of the CORE SIM tool.
- **SPECIAL_FUNCTIONS**: a directory containing special functions for calculating additional input data.
- **MANUALS/USERS_GUIDE_CS_COUPLED.PDF**: a PDF-file of this document;
- **MANUALS/METHODOLOGY_CS_COUPLED.PDF**: a PDF-file giving an overview of the algorithms used in CORE SIM.
- **MANUALS/DEMONSTRATION_CS_COUPLED.PDF**: a PDF-file giving an overview of the demonstration cases of CORE SIM.
- **EXAMPLES**: a directory containing some examples of the CORE SIM runs for a BWR and a PWR.

Chapter 4

FILE ARCHITECTURE AND REQUIRED INPUT

In the same directory where all the above directories and files are located, a directory called "**INPUT**" should exist. All the necessary input files should be created by the user in this directory. Only .mat files are accepted as input files. The user has thus to convert all input data into mat-files, using for instance *MATLAB* for reading various types of ASCII or binary files.

In the input directory, the following files might exist:

- **XS_DATA_REF.mat**: file describing the three-dimensional distributions of the reference (extracted from core simulator) macroscopic cross-sections throughout the system (this file is compulsory);
- **KIN_DATA_REF.mat**: file describing the size of an elementary node in the $x-$, $y-$ and $z-$directions (this file is compulsory); this file also contains some additional data necessary for calculating the neutron noise (these data are optional and only required if the neutron noise has to be estimated);
- **TH_VARS_MESH_DATA.mat**: file containing grid points of thermo-hydraulic quantities which will be used as interpolation variables in the three-dimensional interpolation of the cross-sections (this file is compulsory for using a tabulated cross-section model);
- **XS_MESH_DATA.mat**: file containing grid points of cross-sections which will be used as interpolated variables in the three-dimensional interpolation of the cross-sections (this file is compulsory for using a tabulated cross-section model);
- **S_DATA.mat**: file containing the definition of an external neutron source for the problem (this file is optional and only required if the static neutron flux in the problem of a subcritical system with external neutron source has to be determined);
- **DF_DATA.mat**: file describing the three-dimensional distributions of the discontinuity factors throughout the system (this file is optional); if this file is not provided all discontinuity factors are automatically set to unity.
- **FLX_DATA_REF.mat**: file describing the three-dimensional distributions of both fast and thermal reference (extracted from core simulator) neutron fluxes throughout the system (this file is compulsory);

- **dS_DATA.mat**: file containing the definition of the cross-section (neutronic) noise source (this file is optional and only required if the neutron noise has to be determined from the external perturbations of the cross-sections);
- **TH_PARAM_REF.mat**: file containing the information about the thermo-hydraulic parameters together with the three-dimensional distributions of required reference (extracted from core simulator) thermo-hydraulic variables throughout the system (this file is compulsory);
- **FUE_TAB.mat**: file containing the fuel tables used for calculating the three-dimensional distributions of fuel density and fuel specific heat (this file is optional and only required if the noise in thermo-hydraulic quantities has to be determined);
- **XS_DATA_PERT_RHO_LM.mat**: file describing the three-dimensional distributions of the perturbed macroscopic cross-sections throughout the system (the perturbation is induced by perturbations in the coolant/moderator density; this file is only compulsory if no separate cross-section model is provided and is optional otherwise);
- **XS_DATA_PERT_TFU_LM.mat**: file describing the three-dimensional distributions of the perturbed macroscopic cross-sections throughout the system (the perturbation is induced by perturbations in the fuel temperature; this file is only compulsory if no separate cross-section model is provided and is optional otherwise);
- **dTH_DATA_REF.mat**: file containing the definition of the thermo-hydraulic noise source (this file is optional and only required if the noise has to be determined from the external perturbations of the boundary conditions in the thermo-hydraulic variables).

Chapter 5

CREATED OUTPUT

A directory called "**OUTPUT**" will be created, if it does not already exist. In this directory, all output variables are saved in two mat-files called "**STAT_VAR_CONV.mat**" and "**DYN_VAR_CONV.mat**" for the static and dynamic calculations, respectively.

Chapter 6

UNDERSTANDING THE FORMAT OF THE INPUT AND OUTPUT VARIABLES

Input variables can be point-like (i.e. zero-dimensional), two- or three-dimensional. Any three-dimensional variable represents a space-dependent variable written in a cartesian coordinate system and is generically denoted as "*VAR(I, J, K)*", where I, J and K are strictly positive integers representing the node number in the $x-$, $y-$ and $z-$directions, respectively. Similarly, any two-dimensional variable is denoted as "*VAR(I, J)*", where I and J are strictly positive integers representing the node number in the $x-$ and $y-$, respectively. In addition, there are two structure variables of much higher dimension specified for the tabulated cross-section model. The geometry of the core is defined by the set of macroscopic cross-sections defined in the file "**XS_DATA_REF.mat**". It is assumed that the core has a cylindrical shape with the axis of the cylinder being along the $z-$axis. Radially, nodes not containing any cross-section data are assumed not to belong to the system being modelled, i.e. are considered as being outside of the system being modelled. This thus provides a relatively easy way to define the radial layout of the core.

Output variables can be point-like (i.e. zero-dimensional) or three-dimensional . The three-dimensional variables use the same conventions as the input variables.

Chapter 7

NECESSARY AND OPTIONAL VARIABLES IN THE INPUT FILES

The following table describes the variables that needs to be defined/can be defined in each input file.

Table 7.1: Content of the input files

Input file name	Variable name	Description of variable	Dimension of the variable	Unit
XS_DATA_REF.mat	ABS1	Fast macroscopic absorption cross-section	3	cm^{-1}
	ABS2	Thermal macroscopic absorption cross-section	3	cm^{-1}
	D1	Fast diffusion coefficient	3	cm
	D2	Thermal diffusion coefficient	3	cm
	NUFIS1	Fast macroscopic fission cross-section times ν[1]	3	cm^{-1}
	NUFIS2	Thermal macroscopic fission cross-section times ν[1]	3	cm^{-1}
	KAPPAFIS1	Fast macroscopic fission cross-section times κ[2]	3	$J \cdot cm^{-1}$
	KAPPAFIS2	Thermal macroscopic fission cross-section times κ[2]	3	$J \cdot cm^{-1}$
	REM	Macroscopic removal cross-section	3	cm^{-1}
KIN_DATA_REF.mat	DX	Size of the elementary node in the $x-$direction	0	cm
	DY	Size of the elementary node in the $y-$direction	0	cm
	DY	Size of the elementary node in the $z-$direction	0	cm
	betaeff	Effective fraction of delayed neutrons (one group)	0	1
	lambda	Decay constant of the neutron precursors (one group)	0	s^{-1}
	V1	Average neutron speed in the fast group	0	$cm \cdot s^{-1}$
	V2	Average neutron speed in the thermal group	0	$cm \cdot s^{-1}$
TH_VARS_MESH_DATA.mat	TH_VARS_MESH[3]	Structure variable with TH-grid points used for the interpolation	6	–
XS_MESH_DATA.mat	XS_MESH[3]	Structure variable with cross-section grid points used for the interpolation	9	–

[1] ν stands for the average number of neutrons released per fission event.
[2] κ stands for the energy released per fission event.
[3] Since these structure variables contain the spatial distributions of different kinds of quantities, the units of the variables can not be specified explicitly.

Input file name	Variable name	Description of variable	Dimension of the variable	Unit
S_DATA.mat	S1	Fast external neutron source	0	$n \cdot cm^{-2} \cdot s^{-1}$
	S2	Thermal external neutron source	0	$n \cdot cm^{-2} \cdot s^{-1}$
DF_ DATA.mat	F1N	Fast discontinuity factor north face	3	1
	F1S	Fast discontinuity factor south face	3	1
	F1E	Fast discontinuity factor east face	3	1
	F1W	Fast discontinuity factor west face	3	1
	F2S	Thermal discontinuity factor south face	3	1
	F2N	Thermal discontinuity factor north face	3	1
	F2E	Thermal discontinuity factor east face	3	1
	F2W	Thermal discontinuity factor west face	3	1
FLX_DATA_ REF.mat	FLX1	Reference fast static neutron flux	3	$n \cdot cm^{-2} \cdot s^{-1}$
	FLX2	Reference thermal static neutron flux	3	$n \cdot cm^{-2} \cdot s^{-1}$
	KEFF_ REF	Reference multiplication factor	0	1
dS_ DATA.mat	dABS1	Perturbation of the fast macroscopic absorption cross-section	3	cm^{-1}
	dABS2	Perturbation of the thermal macroscopic absorption cross-section	3	cm^{-1}
	dNUFIS1	Perturbation of the fast macroscopic fission cross-section times ν	3	cm^{-1}
	dNUFIS2	Perturbation of the thermal macroscopic fission times ν cross-section	3	cm^{-1}
	dREM	Perturbation of the macroscopic removal cross-section	3	cm^{-1}
	dS1	Perturbation of the fast external neutron source (if any)	3	$n \cdot cm^{-2} \cdot s^{-1}$
	dS2	Perturbation of the thermal external neutron source (if any)	3	$n \cdot cm^{-2} \cdot s^{-1}$

Input file name	Variable name	Description of variable	Dimension of the variable	Unit
TH_PARAM_REF.mat	RHO_REF[4]	Reference coolant/ moderator density	3	$g \cdot cm^{-3}$
	TFU_REF	Reference fuel temperature	3	K
	TMO_REF[5]	Reference coolant/ moderator temperature	3	K
	SLIP	Slip ratio	3	1
	HEFF[6]	Reference effective heat transfer coefficient	3	$Watt \cdot cm^{-3} \cdot K^{-1}$
	FLOW_AREA_ PER_NODE	Coolant/moderator flow area per node	0	cm^2
	FUEL_VOL_ PER_NODE	Fuel volume per node	0	cm^3
	HYD_DIA	Hydraulic diameter	0	cm
	GRAV_CONST	Gravitational constant	0	$cm \cdot s^{-2}$
	MASS_FLUX	Mass flux	0	$kg \cdot cm^{-2} \cdot s^{-1}$
	HINL	Core inlet coolant/ moderator enthalpy	0	$J \cdot kg^{-1}$
	PEXIT	Core exit coolant/ moderator pressure	0	Bar
	THERM_ POW_REF	Total core thermal power	0	$Watt$
	dRHO[7]	Perturbation in coolant/ moderator density	0	$g \cdot cm^{-3}$
	dTFU[7]	Perturbation in fuel temperature	0	K
	dTHVAR[8]	Perturbation in thermo-hydraulic quantities	0	relative terms %
	TINL	Core inlet coolant/ moderator temperature	0	K

[4]This input parameter is optional and required only in case of tabulated linear cross-section model.

[5]If the reference moderator temperature is not provided as an input data, it will be automatically calculated by using the reference (calculated from reference data) enthalpy, core exit pressure and water tables (for the water table a *MATLAB*-based tool by [3] was used). If the reference moderator temperature is given as an input parameter, it will be used instead in the calculations whereas the reference density will be ignored.

[6]If the effective heat transfer coefficient is not provided as an input data, it will be automatically calculated by using the reference neutron flux, fission cross-sections, fuel temperature and moderator temperature.

[7]These node-wise perturbations induced in the static coolant/moderator density and fuel temperature are used to calculate the "perturbed" cross-sections (see the Tables on pages 17-18) which thereafter are used in the linear cross-section model and coupled noise calculations to evaluate the relationship between the perturbations in the thermo-hydraulic parameters and the respective perturbations in the cross-sections.

[8]These node-wise perturbations induced in the static coolant/moderator density and pressure are used to calculate the corresponding perturbations in other thermo-hydraulic quantities which thereafter are used in thermo-hydraulic noise calculations to evaluate additional relationships between different thermo-hydraulic parameters. These perturbations are given in relative terms, i.e. in percentage from a static value.

Input file name	Variable name	Description of variable	Dimension of the variable	Unit
FUE_ TAB.mat	RHO_FUEL_ TAB	UO_2-fuel density	2	$g \cdot cm^{-3}$
	SPEC_HEAT_ FUEL_TAB	Specific heat of UO_2-fuel	2	$J \cdot g^{-1} \cdot K^{-1}$
	PMAX	Upper limit for pressure	0	Bar
	PMIN	Lower limit for pressure	0	Bar
	TFUMAX	Upper limit for fuel temperature	0	K
	TFUMIN	Lower limit for fuel temperature	0	K
XS_DATA_ PERT_RHO_ LM.mat	ABS1_RHO[9]	Perturbed fast macroscopic absorption cross-section	3	cm^{-1}
	ABS2_RHO[9]	Perturbed thermal macroscopic absorption cross-section	3	cm^{-1}
	D1_RHO[9]	Perturbed fast diffusion coefficient	3	cm
	D2_RHO[9]	Perturbed thermal diffusion coefficient	3	cm
	NUFIS1_ RHO[9]	Perturbed fast macroscopic fission cross-section times ν	3	cm^{-1}
	NUFIS2_ RHO[9]	Perturbed thermal macroscopic fission cross-section times ν	3	cm^{-1}
	KAPPAFIS1_ RHO[9]	Perturbed fast macroscopic fission cross-section times κ	3	$J \cdot cm^{-1}$
	KAPPAFIS2_ RHO[9]	Perturbed thermal macroscopic fission cross-section times κ	3	$J \cdot cm^{-1}$
	REM_RHO[9]	Perturbed macroscopic removal cross-section	3	cm^{-1}
XS_DATA_ PERT_TFU_ LM.mat	ABS1_TFU[9]	Perturbed fast macroscopic absorption cross-section	3	cm^{-1}
	ABS2_TFU[9]	Perturbed thermal macroscopic absorption cross-section	3	cm^{-1}
	D1_TFU[9]	Perturbed fast diffusion coefficient	3	cm
	D2_TFU[9]	Perturbed thermal diffusion coefficient	3	cm

Input file name	Variable name	Description of variable	Dimension of the variable	Unit
	NUFIS1_TFU[9]	Perturbed fast macroscopic fission cross-section times ν	3	cm^{-1}
	NUFIS2_TFU[9]	Perturbed thermal macroscopic fission cross-section times ν	3	cm^{-1}
	KAPPAFIS1_TFU[9]	Perturbed fast macroscopic fission cross-section times κ	3	$J \cdot cm^{-1}$
	KAPPAFIS2_TFU[9]	Perturbed thermal macroscopic fission cross-section times κ	3	$J \cdot cm^{-1}$
	REM_TFU[9]	Perturbed macroscopic removal cross-section	3	cm^{-1}
dTH_DATA_REF.mat	dPOUT	External perturbation in core exit pressure	2	Bar
	dTINL	External perturbation in core inlet temperature	2	K
	dVINL	External perturbation in core inlet velocity	2	$cm \cdot s^{-1}$

Description of tabulated cross-section model
All the files related to the table-based cross-section model are placed in the **INPUT** directory in a separate folder called "**XS_MODEL_INPUT**". This folder contains two files:

- **TH_VARS_MESH_DATA.mat**.
  This file contains only one variable called "*TH_VARS_MESH*" representing a structure with grid points of thermo-hydraulic quantities which will be used as interpolation variables in the three-dimensional interpolation of the cross-sections.
  Structure of variable: "*TH_VARS_MESH*"=*TH_VARS_MESH(V).vec(I).vec(J).vec(K,* 1), where $V = 1...6$ defines the thermo-hydraulic quantity to be used as an interpolation variable (in the present case these are density ($V = 3$) and fuel temperature ($V = 5$)); $I = 1...M$, $J = 1...N$, $K = 1...K$- spatial coordinates, where M, N, K are the number of nodes in $x-$, $y-$ and $z-$direction respectively. All four indexes V, I, J and K are strictly positive integer numbers.

- **XS_MESH_DATA.mat** This file contains only one variable called "XS_MESH" representing a structure with grid points of all cross-sections which will be used as interpolated variables in the three-dimensional interpolation of the cross-sections.
  Structure of variable: "XS_MESH"=$XS\_MESH(V).vec(I).vec(J).vec(K, 1)$, where $V = 1...6$ defines the cross-section type to be used as an interpolated variable (in the present case these are diffusion coefficient in the fast ($V = 1$) and thermal

[9]These "perturbed" cross-sections are calculated by adding a fixed node-wise perturbation either in the coolant/moderator density or fuel temperature (see the Table on page 16) to the respective static values. The perturbed cross-sections are thereafter used in the linear cross-section model and coupled noise calculations.

groups ($V = 2$), removal cross-section ($V = 3$), absorption cross-section in the fast (V=4) and thermal (V=5) groups, fission cross-section times the averaged number of neutrons per fission in the fast ($V = 6$) and thermal ($V = 7$) groups, the averaged number of neutrons per fission ν ($V = 8$) and the energy released per fission event γ ($V = 9$); the rest of the notations are similar to the ones described above.

For the interpolation, the *MATLAB* built-in function *griddata* performing three-dimensional interpolation is used.

Description of fuel tables

All the data necessary for the fuel tables are summarized in one mat-file called **FUE_TAB.mat** placed directly in the **INPUT** directory. As was shown in Table 7.1, this file contains 6 variables: two are two -dimensional and the remaining 4 variables are of zero dimension. The first two variables RHO_FUEL_TAB and $SPEC\_HEAT\_FUEL\_TAB$ have the following format *VAR(I, J)* with I, $J = 1...Q$, where Q is the total number of elements in the corresponding vectors and provide the grid points of the fuel density and fuel specific heat which will be used as interpolated variables in a two-dimensional interpolation of these quantities, respectively. Both quantities, i.e. the fuel density and fuel specific heat, are assumed to be two-dimensional variables and depend on both the pressure and fuel temperature. They thus will be interpolated in a two-dimensional space. The two indexes I and J are strictly positive integer numbers. The other two variables $PMAX$ and $PMIN$ specify the range of the first interpolating variable, the pressure (i.e. its maximum and minimum values). The last two variables $TFUMAX$ and $TFUMIN$ define the range of the interpolation for the fuel temperature (i.e. its maximum and minimum values). The interpolation vectors (the pressure and fuel temperature) will be automatically generated by dividing the corresponding interpolation ranges into Q intervals, specified by the size of RHO_FUEL_TAB and $SPEC\_HEAT\_FUEL\_TAB$. For the interpolation the *MATLAB* built-in function *interp2* performing a two-dimensional interpolation is used.

Chapter 8

AVAILABLE VARIABLES IN THE OUTPUT FILES

The following table describes the variables that can be found in the output file. Note that some of the listed variables are only available when the corresponding calculations are required by the user.

Table 8.1: Content of the output files

Input file name	Variable name	Description of variable	Dimension of the variable	Unit
STAT_VAR_CONV.mat	ABS1	Fast macroscopic absorption cross-section	3	cm^{-1}
	ABS2	Thermal macroscopic absorption cross-section	3	cm^{-1}
	D1	Fast diffusion coefficient	3	cm
	D2	Thermal diffusion coefficient	3	cm
	NUFIS1	Fast macroscopic fission cross-section times ν	3	cm^{-1}
	NUFIS2	Thermal macroscopic fission cross-section times ν	3	cm^{-1}
	KAPPAFIS1	Fast macroscopic fission cross-section times κ	3	$J \cdot cm^{-1}$
	KAPPAFIS2	Thermal macroscopic fission cross-section times κ	3	$J \cdot cm^{-1}$
	REM	Removal macroscopic cross-section	3	cm^{-1}
	FLX1	Fast static neutron flux	3	$n \cdot cm^{-2} \cdot s^{-1}$
	FLX2	Thermal static neutron flux	3	$n \cdot cm^{-2} \cdot s^{-1}$
	KEFF	Effective multiplication factor	0	1
	ALPHA	Coolant/moderator void fraction	3	1
	QUAL	Flow quality	3	1
	ENTH	Coolant/moderator enthalpy	3	$J \cdot g^{-1}$
	TMO	Coolant/moderator temperature	3	K
	VEL	Coolant/moderator velocity	3	$cm \cdot s^{-1}$
	PRES	Coolant/moderator pressure	3	Bar
	FRIC_COEFF	Two-phase friction coefficient	3	1
	TFU	Fuel temperature	3	K

Input file name	Variable name	Description of variable	Dimension of the variable	Unit
DYN_VAR_CONV.mat	dABS1	Noise in fast macroscopic absorption cross-section	3	cm^{-1}
	dABS2	Noise in thermal macroscopic absorption cross-section	3	cm^{-1}
	dNUFIS1	Noise in fast macroscopic fission cross-section times ν	3	cm^{-1}
	dNUFIS2	Noise in thermal macroscopic fission cross-section times ν	3	cm^{-1}
	dREM	Noise in macroscopic removal cross-section	3	cm^{-1}
	dFLX1	Fast neutron noise	3	$n \cdot cm^{-2} \cdot s^{-1}$
	dFLX2	Thermal neutron noise	3	$n \cdot cm^{-2} \cdot s^{-1}$
	dENTH	Noise in coolant/ moderator enthalpy	3	$J \cdot g^{-1}$
	dTMO	Noise in coolant/ moderator temperature	3	K
	dVEL	Noise in coolant/ moderator velocity	3	$cm \cdot s^{-1}$
	dPRES	Noise in coolant/ moderator pressure	3	Bar
	dTFU	Noise in fuel temperature	3	K

Chapter 9

HOW TO USE CORE SIM

Prior to use CORE SIM, the user might want to fine-tune some parameters in the file named "**SETTINGS.m**" (default parameters will be used if the user does not modify anything in this file):

- Variable XSM.
  Variable allowing choosing the type of cross-section model.
  $XSM = 0$ for launching linear cross-section model (two files **XS_DATA_PERT_RHO_LM.mat** and **XS_DATA_PERT_TFU_LM.mat** with perturbed cross-sections with respect to both density and fuel temperature should be provided by the user), $XSM = 1$ for launching table-based cross-section model (default, files with cross-section tables should be provided by the user and placed in the directory **XS_MODEL_INPUT**), otherwise $XSM = 2$ for launching linear cross-section model based on tabulated cross-sections (files with cross-section tables should be provided by the user and placed in the directory **XS_MODEL_INPUT**).

- Variable $FLAG\_NOISE\_SWITCH$.
  Variable allowing choosing whether noise calculations should be performed.
  $FLAG\_NOISE\_SWITCH = 0$ for launching noise calculations (default), otherwise $FLAG\_NOISE\_SWITCH = 1$.

- Variable $MAX\_NUM\_ITER\_STATCAL$.
  $MAX\_NUM\_ITER\_STATCAL = 10$ (default): maximum number of iterations in static coupled calculations.

- Variable $MAX\_NUM\_ITER\_DYNCAL$.
  $MAX\_NUM\_ITER\_DYNCAL = 10$ (default): maximum number of iterations in dynamical (noise) coupled calculations.

- Variable $MAX\_NUM\_TH\_ITER\_STATCAL$.
  $MAX\_NUM\_TH\_ITER\_STATCAL = 10$ (default): maximum number of iterations in static thermo-hydraulic (inner) calculations.

- Variable $MAX\_NUM\_TH\_ITER\_DYNCAL$.
  $MAX\_NUM\_TH\_ITER\_DYNCAL = 10$ (default): maximum number of iterations in dynamical (noise) thermo-hydraulic (inner) calculations.

- Variable $FREQ$.
  $FREQ = 0.5$ (default): frequency at which noise calculations should be performed.

- Variable EIG_MET.
  Variable allowing choosing whether the Explicitely Restarted Arnoldi Method (ERAM) or the power iteration method (POW) is to be used. Please note that the power iteration method uses Wielandt's method to calculate the different eigenmodes and a first guess of the eigenvalues is required. Such a guess of the eigenvalues is provided by an Arnoldi run without restart. In case of convergence problem for ERAM, it is recommended to switch to POW. $EIG\_MET = 1$ for ERAM (default) or $EIG\_MET = 2$ for POW.

- Variable BYP.
  Variable allowing getting the results even if some of the eigenmodes have not converged. $BYP = 0$ (default) if you want to interrupt the program when the eigenmodes have not converged after $MAX\_NUM\_RESTARTS$ restarts (for ERAM) or after $MAX\_NUM\_NEUT\_ITER$ iterations (for POW). $BYP = 1$ permits the execution of the program even if the eigenmodes have not converged.

- Variables $DIM\_KRYL\_SUBSPACE$, $MAX\_NUM\_RESTARTS$, and $CONV\_NEUT\_ITER\_ERAM$.
  Parameters used for the Explicitely Restarted Arnoldi Method (ERAM). If the user is not familiar with ERAM, it is recommended not to change these settings. Nevertheless, if convergence problems are experienced during the calculation of the eigenmodes, changing the following parameters could help resolve such problems. $DIM\_KRYL\_SUBSPACE = 150$ (default): dimension of the Krylov subspace. $MAX\_NUM\_RESTARTS = 20$ (default): number of maximum restarts. $CONV\_NEUT\_ITER\_ERAM = 100 * eps$ (default): convergence criteria on the residuals, with eps being the machine precision.

- Variables $MAX\_NUM\_NEUT\_ITER$ and $CONV\_NEUT\_ITER\_POW$.
  Parameters used for the power iteration method (POW). $MAX\_NUM\_NEUT\_ITER$ (default): maximum number of iterations. $CONV\_NEUT\_ITER\_POW$ (default): convergence criteria on the residual, with eps being the machine precision.

- Variables *CONV_VAR_TH_ITER* and *E_VAR_TH_ITER*, $VAR = RHO, VEL, PRES$.
  Parameters used for the static thermo-hydraulic (inner) iterations. *CONV_VAR_TH_*$ITER = 10^{-3}$, *VAR=RHO, VEL, PRES* (default): maximum allowed error in coolant/ moderator density, velocity and pressure in static TH-iterations. *E_VAR_TH_*$ITER = 1$, *VAR=RHO, VEL, PRES* (default, no need to be changed by the user): initial error in coolant/moderator density, velocity and pressure in static TH-iterations.

- Variables *CONV_VAR* and *E_VAR*, $VAR = RHO, VEL, PRES$.
  Parameters used for the static coupled iterations. *CONV_VAR* $= 10^{-4}$, *VAR=RHO,* $VEL, TFU, ENTH, PRES$ (default): maximum allowed error in coolant/moderator density, velocity, fuel temperature, coolant/moderator enthalpy and pressure in static coupled iterations. *E_VAR* $= 1$, *VAR=RHO, VEL, TFU, ENTH, PRES* (default, no need to be changed by the user): initial error in coolant/moderator density, coolant velocity, fuel temperature, coolant/moderator enthalpy and pressure in static coupled iterations.

- Variables *CONV_dVAR_TH_ITER* and *E_dVAR_TH_ITER*, *VAR=RHO, VEL* $PRES$.

Parameters used for the dynamical thermo-hydraulic (inner) iterations. $CONV\_dVAR\_TH\_ITER = 10^{-3}$, *VAR=RHO, VEL, PRES* (default): maximum allowed error in coolant/moderator density, velocity, and pressure in dynamical TH-iterations. $E\_dVAR\_TH\_ITER = 1$, $VAR = RHO, VEL, PRES$ (default, no need to be changed by the user): initial error in coolant/moderator density, velocity, and pressure in dynamical TH- (Thermo-Hydraulic)iterations.

- Variables *CONV_dVAR* and *E_dVAR*, $VAR = RHO, VEL, TFU, ENTH, PRES$. Parameters used for the dynamical coupled iterations. *CONV_dVAR* $= 10^{-4}$, *VAR*= $RHO, VEL, TFU, ENTH, PRES$ (default): maximum allowed error in coolant/moderator density, velocity, fuel temperature, coolant/moderator enthalpy and pressure in dynamical coupled iterations. *E_dVAR* $= 1$, *VAR=RHO, VEL, TFU, ENTH,* $PRES$ (default, no need to be changed by the user): initial error in coolant/moderator density, velocity, fuel temperature, coolant/moderator enthalpy and pressure in dynamical coupled iterations.

CORE SIM has then to be run within the *MATLAB* command window, by simply typing **CORE_SIM_MAIN** once being in the directory containing the code.

CORE SIM then creates a .mat output file located in the directory "**OUTPUT**" (if this directory does not exist, it will be automatically created). All the results of the calculations are saved in the file named "**STAT_VAR_CONV.mat**" for static and for dynamic "**DYN_VAR_CONV.mat**" calculations, respectively.

Chapter 10

EXAMPLES

CORE SIM is delivered with a couple of examples located in the directory called examples, as detailed in the table below. In this directory, subdirectories each containing one example of a CORE SIM run are located. In each of these subdirectories, the input/output directories and corresponding files for each of the run examples are available, as well as the "**SETTINGS.m**" file. All the examples correspond to a heterogeneous core, i.e. the input data are spatially heterogeneous (i.e. node-wise quantities) throughout the core.

Table 10.1: Description of the examples provided with the code package.

name of the subdirectory	description of the case
STATIC_SIM_PWR	calculation of the static neutronic and thermo-hydraulic quantities for a PWR
DYNAMIC_SIM_PWR	calculation of the noise in both neutronic and thermo-hydraulic quantities induced by a perturbation in the inlet flow for a PWR (two examples: one for an out-of-phase and one for a point-wise perturbations)
STATIC_SIM_BWR	calculation of the static neutronic and thermo-hydraulic quantities for a BWR
DYNAMIC_SIM_BWR	calculation of the noise in both neutronic and thermo-hydraulic quantities induced by a perturbation in the inlet flow for a BWR (two examples: one for an out-of-phase and one for a point-wise perturbations)

Chapter 11

SUPPORT/BUG REPORTS

In case of problem/question, please contact:

Victor Dykin
Chalmers University of Technology
Department of Applied Physics
Division of Nuclear Engineering
SE-412 96 Gothenburg, Sweden
Tel: +46-31-772 3086
Fax: +46-31-772 3079
E-mail: victor@nephy.chalmers.se

Professor Christophe Demazière
Chalmers University of Technology
Department of Applied Physics
Division of Nuclear Engineering
SE-412 96 Gothenburg, Sweden
Tel: +46-31-772 3082
Fax: +46-31-772 3079
E-mail: demaz@chalmers.se

As a registered user of the coupled CORE SIM tool, you are endorsed to provide bug reports when such bugs are detected. In such a case, please send your input files to the above e-mail address.

Feedback about the tool, its use, and the accompanying manuals is also greatly appreciated.

ACKNOWLEDGEMENTS

The development of the reported computational tool would not have been possible without active discussions with and participations of some students from the Division of Nuclear Engineering, Department of Applied Physics, Chalmers University of Technology. The authors thus wishe to express their appreciation to Dr. Augusto Hernández-Solís, Dr. Viktor Larsson, Dr. Carl Sunde, and MSc. Filippo Zinzani. Prof. Imre Pézsit is acknowledged for his long-term support during this project.

The continued financial support from the Swedish nuclear industry via different projects, for which the development of the tool was necessary, is also deeply acknowledged, and among others Ringhals AB (research contracts: 522351-003, 531970-003, 543672-002, 557700-003, 566379-003, and 578254-003), the Swedish Radiation Safety Authority SSM, formerly the Swedish Nuclear Power Inspectorate SKI (research contracts: 14.5-991060-99180, 14.5-000983-00156, 14.5-010892-01161, 14.5-011142-01261, SSM 2012-3299 and SSM 2013-903), and the Nordic Thermal-Hydraulic Network NORTHNET [research contracts: 4500131026 (Forsmark Kraftgrupp AB), 581422-025 (Ringhals AB), SKI 2007/1588/20070-5015 (Swedish Radiation Safety Authority SSM formerly the Swedish Nuclear Power Inspectorate), and SE 08-018 (Westinghouse Electric Sweden AB)].

References

[1] Dykin V. and Demazière C., "Description of the models and algorithms used in the coupled CORE SIM neutronic/thermo-hydraulic tool", *CTH-NT-300 report*, Chalmers University of Technology (2014).

[2] Dykin V. and Demazière C., "Demonstration of the coupled CORE SIM neutronic/thermo-hydraulic tool", *CTH-NT-301 report*, Chalmers University of Technology (2014).

[3] Holmgren M. "XSTEAM", *MATLAB*-based programm for water tables, *http://www.x-eng.com/* (1997).