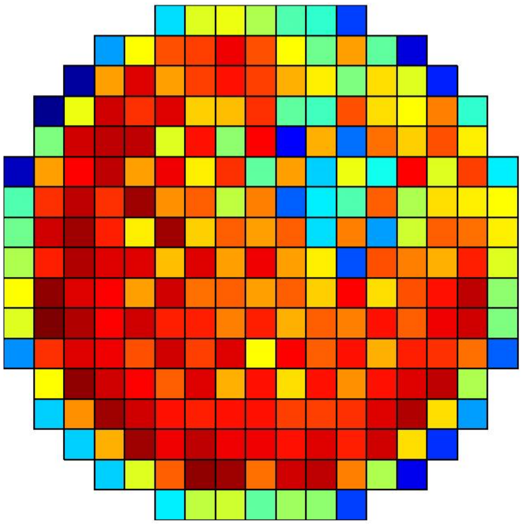

TRICOT 2010/SAFIR

The internally coupled TRAB-3D 3.0 and SMABRE 6.0 codes

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Summary

The main advantage of the internal type of coupling of the TRAB-3D 3.0 and SMABRE 6.0 codes is the possibility to handle coolant flow reversals in the core flow channels. During the latest phase of this several years project this is demonstrated for the EPR with quite an extreme test case. Typically in transients where reversed flow is expected with the TRAB-3D/SMABRE, much shorter and minor reversed core channels flow is expected. For the HPLWR reversed flow exists already in the steady state.

Another advantage of the internal coupling is modeling of cross flows in an open reactor core such as the EPR. Present models allow taking into account coarse mixing effects in the internal coupling. More detailed modeling may be expected with 3-D thermal hydraulics when PORFLO using porous media modeling is coupled to TRAB-3D based on the internal coupling realized in the project.

Results of the HPLWR cases indicate that the multichannel and moderator channel heat transfer and feedback extensions to TRAB-3D/SMABRE work properly. In EPR cases the results with internal coupling and parallel coupling are quite close to each other. Finally the earlier BWR validation cases have been recalculated with the latest code version with slightly improved results. More validation is needed to confirm several open questions encountered in this study.

Brief instructions for code users are collected in this report. In future the code manuals will be updated with features of the internally coupled code. Parts of the updates to the input options have already been included in earlier SAFIR reports.

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Contents

1 Introduction

The objective of the subtask TRAB-3D/SMABRE was to improve the thermal hydraulics in the reactor dynamics computer code, TRAB-3D, by coupling it internally to the SMABRE code. TRAB-3D /1/ is a reactor dynamics code with three-dimensional neutronics and one-dimensional thermal hydraulics in a core and in a boiling water reactors (BWR) circuit. The code can be used for transient and accident analyses of BWR and with its core model coupled to SMABRE, also for pressurized water reactors (PWR). The system code SMABRE /2/ models the thermal hydraulics of light water reactors. Both codes have been entirely developed at VTT.

TRAB-3D and SMABRE have earlier been connected with parallel coupling /3/. Main advantages of internal type of coupling are possibilities to handle coolant flow reversals in core flow channels as well as modeling of cross flows in an open reactor core like EPR. More detailed modeling may be expected with 3-D thermal hydraulics when PORFLO using porous media modeling is coupled to TRAB-3D based on the internal coupling realized in the project

In internal coupling TRAB-3D performs the neutronics calculation, SMABRE will take care of the hydraulics calculation of the whole cooling circuit including the reactor core, and the heat transfer calculation may be carried out by either code by the user's choice. On the other hand in parallel coupling TRAB-3D performs the core hydraulics and heat transfer, and the coarse SMABRE core hydraulics with fewer channels than in TRAB-3D are solved in parallel.

The basics for internal coupling were created for BWRs already in the EMERALD project as a part of the SAFIR-Programme /4-7/. In TRICOT, the work has continued for the PWR /8-11/. The internal coupling of TRAB-3D and SMABRE needed large modifications and new modules especially into SMABRE, which should still have all the old calculation capabilities with parallel coupling left in it. The unexpected death of the main developer of the code in middle 2008 forced the studies partly to new paths to make sure that finalizing of the coupling was possible.

Several extensions to internal coupling have included such calculation capabilities and features in internal coupling which already exist in separate codes, such as deviation of number of fuel assemblies and fluid channels for both codes, several initial axial power profiles or two sided heat structures for code nodes in SMABRE. The EPR and High Pressure Light Water Reactor (HPLWR) reactors have been used for the test cases because the development of the HPLWR version has been performed simultaneously with the internal coupling. Even though the HPLWR is not included in the SAFIR project, the main findings and test case calculations for HPLWR have created useful cross-checking possibilities for both code versions. Finally the earlier BWR test cases have been recalculated with the latest code version.

The main idea for the HPLWR version was to extend the capability of the code to supercritical conditions. Thus in the HPLWR project new material properties, which are created from a large international data base, have been implemented in the code and they may be used also for the general TRAB-3D/SMABRE in subcritical area. In first tests for an EPR no significant differences were found between these material properties. Further, the SMABRE point kinetics was modified in order to take into account the fluid temperature in the moderator channels /12/ of HPLWR for feed backs in HPLWR. This feature is available for internal coupling and 3-D calculations, too. The application could be e.g. a water cross of BWR assembly modeled as a bypass.

Calculation system of coupled code is presently somewhat tricky for users because of several files and procedures and possibilities of using the codes by various ways. For new users or in case of possible change of calculation system to PCs due to PORFLO coupling, at this state the basic instructions for running TRAB-3D and SMABRE with all files and procedures needed and use of help routines are reported here for the first time.

2 Recalculated BWR cases

After renewal of TRAB-3D / SMABRE capability for PWR with parallel coupling and function of basic features were tested for internal coupling, the capability for BWR was checked. This was done by analyzing the four BWR disturbancer with the same inputs already used at the end of previous SAFIR /7/ at the beginning of 2007. In this phase it was necessary to take several options as a part of SMABRE input. For instance the two phase loss coefficients are now separated for BWR and PWR in the core.

The results, distributions and time histories with the internally coupled code were basically at same level compared to stand-alone TRAB-3D calculations. Figure 1 presents the differences of internally coupled TRAB-3D / SMABRE comparison to stand-alone TRAB-3D calculation result of core outlet void fraction distribution in nominal state. Somewhat better agreement between the results of the codes than in 2007 has been achieved.

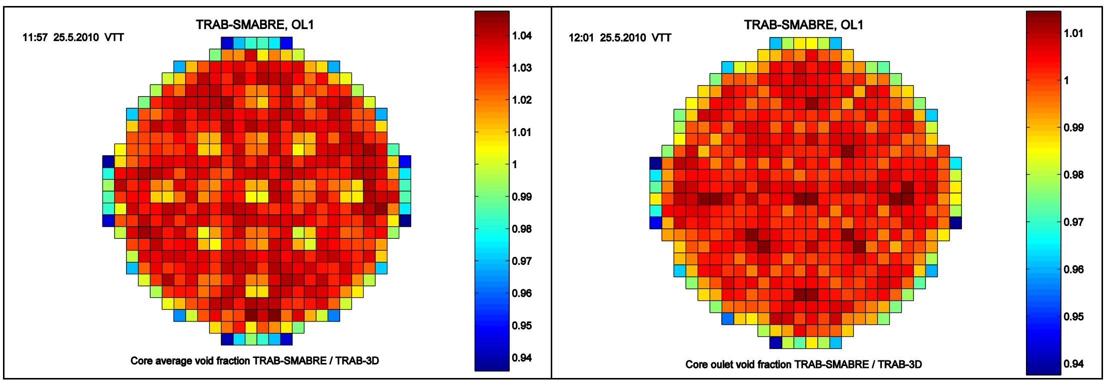

Figure 1. Relative core average void fraction distributions between TRAB-3D/SMABRE and stand-alone TRAB-3D in steady state in 2007 and 2010

Figure 2 shows the fission power and flow out of reactor in the case with the turbine valve disturbance. The delay at the beginning of transient in both parameters in stand-alone TRAB-3D calculation was not achieved in 2007 or with

2010 code version. The core outlet values of the average void fraction and average coolant density of the 2010 version are in closer agreement with the stand-alone TRAB-3D results than in 2007, comparison shown in Figure 3.

In disturbance with partial scram still large deviations exist between internal coupling and stand-alone results in fission power, but clear improvements have been achieved in power to coolant, shown in Figure 4.

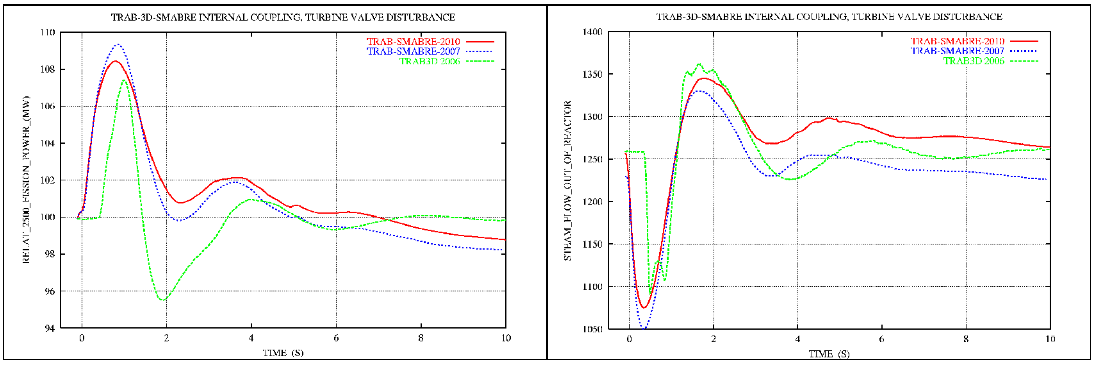

Figure 2. Fission power and flow out of reactor in TRAB-3D/SMABRE and TRAB-3D results 2007 and 2010 in turbine valve disturbance transient.

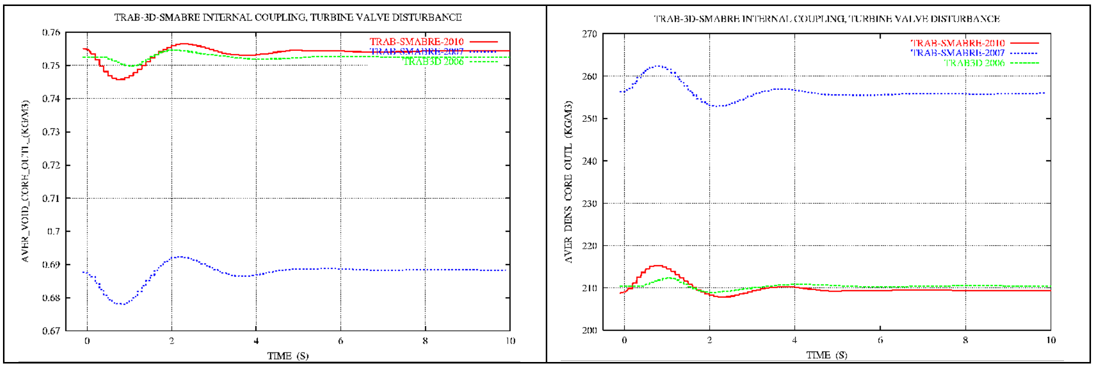

Figure 3. Average void fraction and density at core outlet in TRAB-3D/SMABRE and TRAB-3D results 2007 and 2010 in turbine valve disturbance transient.

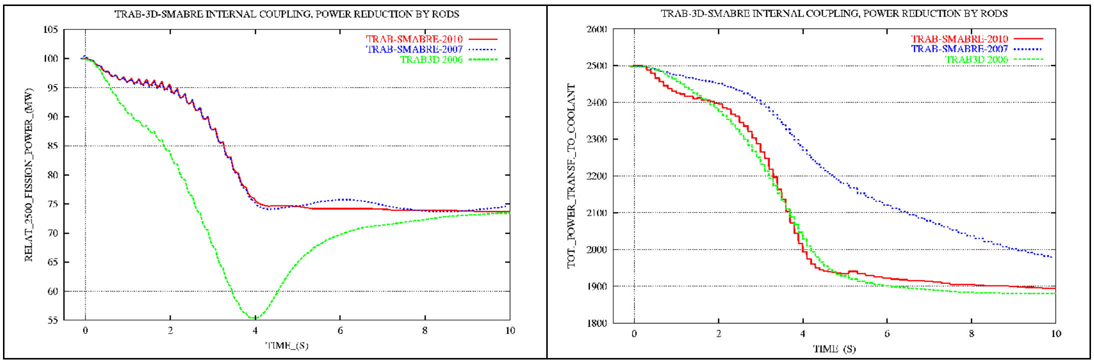

Figure 4. Fission power and power to coolant in partial scram with TRAB-3D/SMABRE and TRAB-3D results 2007 and 2010

3 Reversed core flow in EPR

The PWR test case for the coupling is in a geometry resembling the EPR reactor core with 241 hydraulic channels and 20 axial core nodes. The modeled fuel is a typical PWR fuel. The whole primary loop and the secondary loop from the feedwater tank to the turbine valves have been modeled in SMABRE. The model is quite similar to, but not exactly identical to the model of the EPR plant. As a dynamic test case a pump seizure transient has been performed.

Already in /8-10/ good results were reported in comparing the core distributions for fission power, channel mass flows and fuel temperatures with stand-alone TRAB-3D and internal coupling, and also when using parallel coupling. As a final test case the capability of calculating reversed assembly-wise core flow for PWR was performed. TRAB-3D/SMABRE is not intended for LOCAs and that is why only the starting phase of blowdown was used as a demonstration. A middle size break in a cold leg was chosen to have reversed core flows early in the transient. In Figure 5 three distribution of assembly-wise core flow is depicted, about the time of flow reversal, at time with up and down flow situation and totally reversed flow in the LOCA test case for EPR. In Figure 6 void fractions at core outlet at time of flow reversal and with totally reversed flow with high steam partition. With reversed flows only part of the TRAB-3D type thermal hydraulic models included in SMABRE are usable and original SMABRE models are used instead. The result of this LOCA case has only demonstration value of internal coupling achieving reversed flows and high voiding in the core. The only general remark could be that with this kind of core model and codes the results indicates that timing of flow reversals in all core assemblies is about the same.

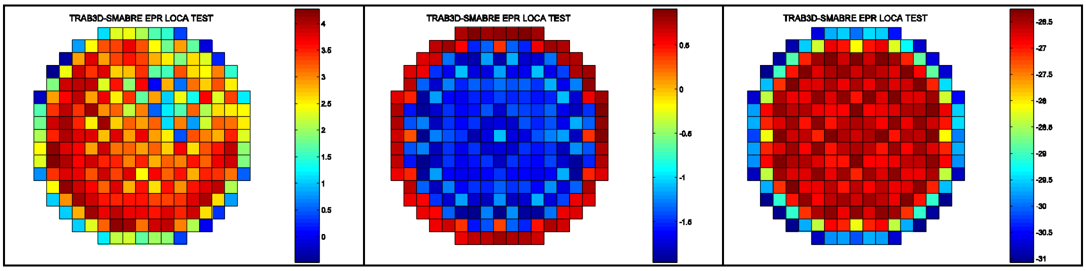

Figure 5. Assembly-wise core inlet mass flows about at time of flow reversal, at time with up and down flow situation and totally reversed flow in the LOCA test case for EPR with TRAB-3D / SMABRE.

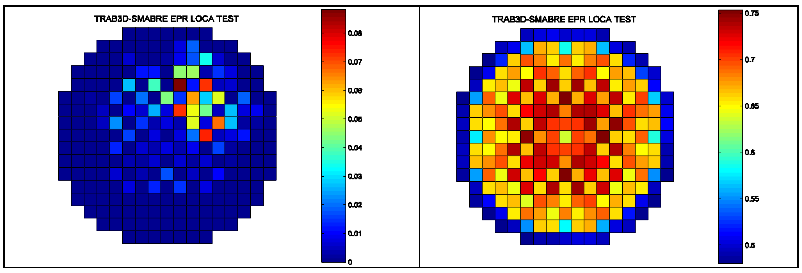

Figure 6. Assembly-wise core outlet void fraction about at time of flow reversal and with totally reversed flow in the LOCA test case for EPR with TRAB-3D / SMABRE.

4 Two sided heat structures in the core island

The two sided heat structures in the core island is demonstrated using the HPLWR- model where heating in the moderator channels offer an excellent test case. The HPLWR-model for TRAB-3D / SMABRE consists of 156 fluid channels where in third of the channels flow is downwards. With two lower and upper mixing chambers such a flow path is created where fluid goes three times through the core (upwards, downwards, upwards, Figure 8) and already before the core inlet, downwards and upwards in the moderator and gap channels. The number of fuel assemblies is 1404, nine in each fluid channel. Figure 7 illustrates the 1404 fuel assemblies with control rods and on the right 156 fluid channels with initial flow rates at the core inlet. The reversed initial flow rates in third of the core reflect the basic ideas and needs for internal coupling. Also models of 1404 and 3 fluid channel exist for TRAB-3D / SMABRE.

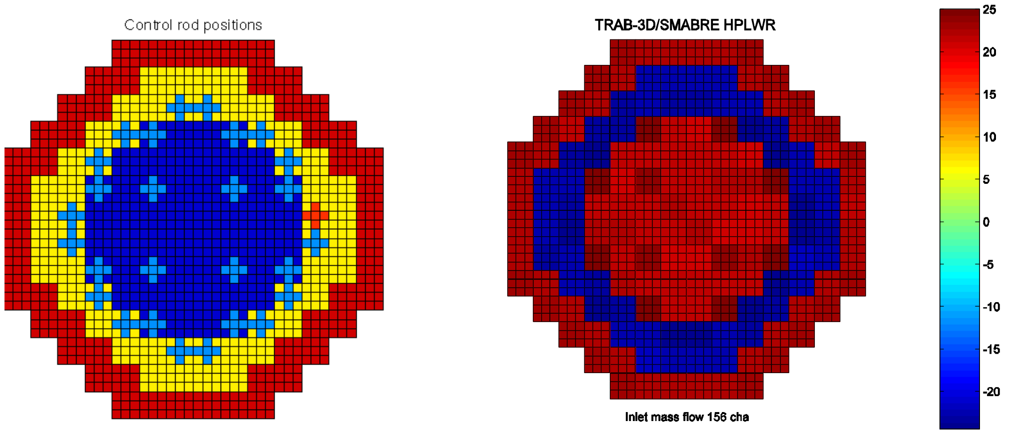

Figure 7. Cross section of HPLWR three-way core with positions of sets of five control rods among 1404 assemblies and distribution of core inlet mass flows of 156 fluid channels with TRAB-3D / SMABRE.

Modeling of the two-sided heat structure was also included in the code. The two sided heat structure may be used for a heavy reflector of PWR where heat input of heavy reflector is considered. Different kind of bypasses may now be modeled so that some of them contain heating while others do not. In BWR the complex fuel assemblies may be supported by assembly-wise heated bypasses or a bypass connected to four quadratic assemblies and having a shroud around as a heat structure.

The modeled new type of heat structure is given in SMABRE input. At least one core node should be connected to the structure in order to have splitting of heat structure as the channels are split for the core island. The optional fluid volume on the other side of the structure should not be core a node.

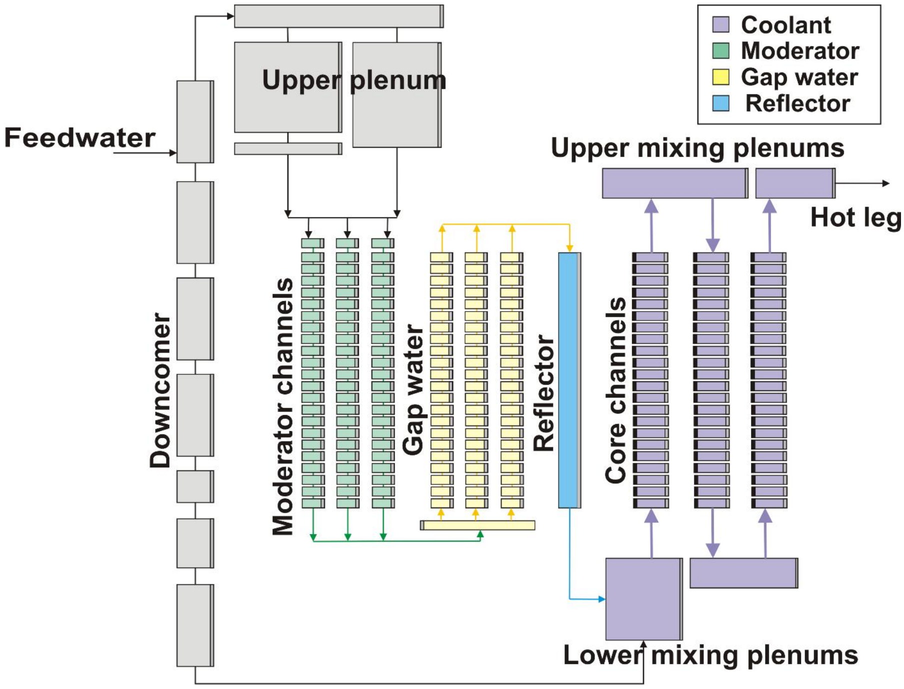

Figure 8. SMABRE nodalization for HPLWR pressure vessel and three-way core. The moderator channels and gap water is flowing between the core 156 channels, grouped here in three group.

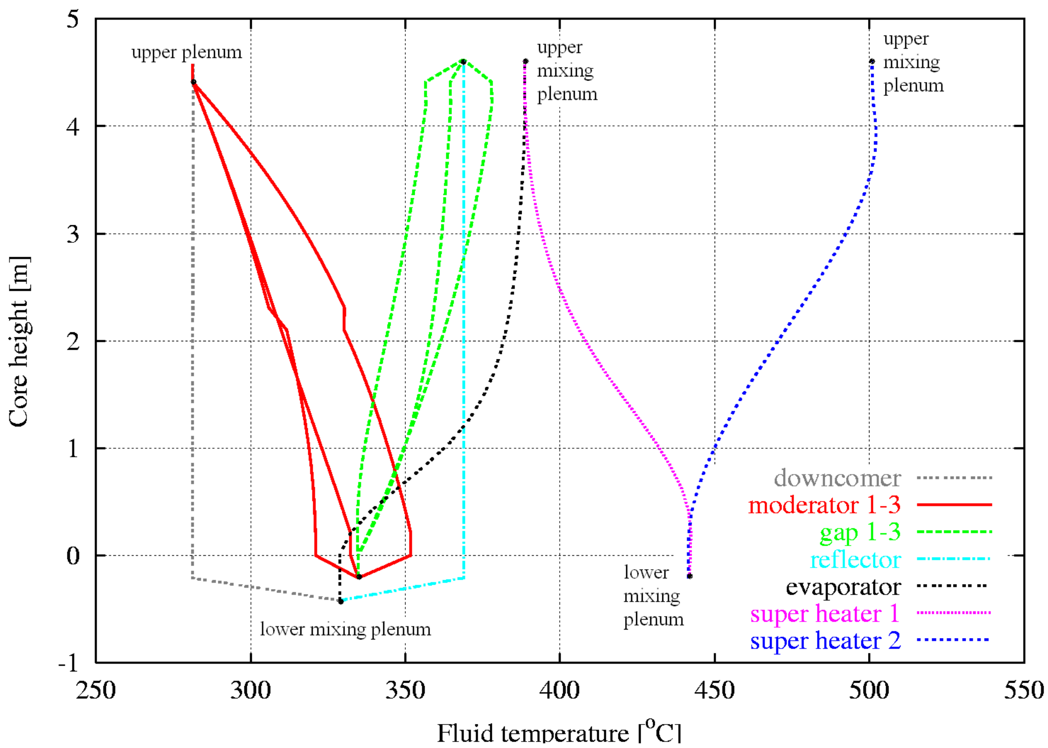

Figure 9: Axial fluid temperature profiles of flow paths in HPLWR three-way core, three moderator and gap channels, reflector and downcomer volumes before the core.

Two sided heat structures are essential in modeling the HPLWR pressure vessel because about half of the vessel inlet flow falls from the upper plenum in three moderator channels, continuing upwards in three gaps. In these flow paths heat input is taken from the core channels. In figure 9 all the flow paths at core elevation are described. The increasing of fluid temperatures in supercritical pressures as well sizes of heat structures are not fine tuned with 3-D neutronics, but the availability of this feature in internal coupling is illustrated. Here fluid temperatures in the downcomer or inside the reflector are not increased even though the same system could be used for the reflector fluid volume too.

Results of the HPLWR cases indicate that the multichannel and moderator channel heat transfer and feedback extensions to TRAB-3D/SMABRE work properly.

5 TRAB-3D/SMABRE instructions

The calculation system of the coupled codes is presently somewhat tricky for the users because a large number of files is needed, and there are several procedures and possibilities of using the codes. The basic instructions for running TRAB-3D and SMABRE with all files and procedures needed and the use of help routines are reported here for the first time. Besides being helpful for new users of the codes, this is necessary for clarifying the transferring of the calculation system to PCs due to PORFLO coupling.

The original code manuals for the separate codes /13, 14/ do not include at all the instructions for creating the calculation system. The names of files and procedures reflect the computation environment existing today at VTT under the unix operating system. Different procedures exist for HP Unix and True64 Unix, the latter indicated with the ending '_d' in the names of the procedures. Presently the codes are almost exclusively run under True64 Unix at VTT. The mark '*' in the files indicates the name of case.

In the following chapters steps for running TRAB-3D / SMABRE are listed. The first three steps (5.1, 5.2 and 5.3) are always needed while the rest of them are needed only occasionally. The numerous input/output files as well as auxiliary help procedures are described. Names of the procedures are *highlighted*.

5.1 SMABRE-run from beginning or restart

A SMABRE run is typically started from a negative time because it is convenient and faster to have stabilizing control systems operating during negative time with higher response than in reality.

1. SMABRE input data in file *_smabre.dat from beginning or smabre_restrt.dat in SMABRE restart. Restart input file consist of commands for debugging, output and some calculational options.
2. *smabrun50_d* or *smabrun60_d* procedures to start running

5.2 TRAB-3D / SMABRE run from beginning or restart

Analyses of long transients are typically carried out in several runs, creating restarts and restarting from them. The naming convention adopted for restart runs is typically *b_smabre.f08, *c_smabre.f08 and so on.

Present procedures expect the ending time in a SMABRE restart file to be greater than the end time in TRAB-3D input.

In the initial TRAB-3D input the parameters describing system pressure, core inlet flow rate and enthalpy, as well as the core pressure drop should be updated from the last time step output of the SMABRE output file *b_smabre.f10.

Additionally, for parallel coupling the help procedures *intra5.0* and *intra6.0* may be used to update individual channel input flow rates and enthalpies as well core inlet and outlet pressures from SMABRE .f10 output to TRAB-3D input.

Input files:

1. Transient input data in file trasma_trarun.dat with several options
2. TRAB-3D input data from tr3d_*a.dat, for a restart file only a small fraction of the original input is needed, typically the time regions/time steps/printout steps/restart times, printout frequences, convergence criteria etc.
3. *b_restrt2.dat TRAB-3D restart file for starting from restart
4. Cross sections from file tr3d.mat, not needed in restart
5. File of xenon distribution depending on TRAB-3D input, not needed in restart
6. SMABRE input data in smabre_restrt.dat
7. SMABRE calculation restart data as a file *a_smabre.f08
8. SMABRE calculation plot data as a file *a_smabre.f07
9. SMABRE calculation plot variable list as a file *a_smabre.f09
10. Procedure *trasma2351_d* or *trasma3060_d* to start running

Output files

The output files may be as numerous as below. Empty files are not saved.

*_smabre.log	Main log file including error messages and signal output
*_trpath.log	Indicates the calculation path with help outputs at each time step in TRAB-3D and coupling subroutines
*_trarun.dat	Used transient input with several options
*_trab3d.dat	TRAB-3D input
*_dissla.dat	Time histories of single or array variables from TRAB-3D (eg assemblywise distributions for plotting; boundary conditions for hot channels)
*_funtim.dat	Time histories of single variables from TRAB-3D (eg for plotting)
*_trab3d.lis	Main TRAB-3D listing
*_nodesl.dat	Time histories of nodewise variables from TRAB-3D: single variable, axial or radial distribution, all nodes in the core; eg axial distributions for hot channels
*_restrt.dat	TRAB-3D restart file for storing a restart

*_smabre.dat	Listing of used SMABRE input
*_smabre.f03	Spooled output from smabre input file, smabre_*.dat
*_smabre.lis	Major SMABRE output listing
*_smabre.f10	Report output from calculation, includes whole set of parameters at certain time points in suitable format and the trip logic output like all the signal on or off commands
*_smabre.f07	Binary plot file, plotted every DTOUT2 time
*_smabre.f08	Binary restart file, nearly all SMABRE common variables at the end of calculation
*_smabre.f09	List of plot variables
*_smabre.f16	Plot data written using output formats, described in 5.3
*_smabre.f17	Plot data in large table for plotting, described in 5.3
*_smabre.f20	Used for testing input
*_smabre.f22	Binary restart file at the end of calculation, in a successful run nearly same as *_smabre.f08
*_follo…dat	Several help output files used in development and for debugging
*_trloca.log	Tells the locations with help outputs at each time step inTRAB-3D and coupling subroutines
*_trloca2.log	Tells the locations with help outputs at each time step in SMABRE

5.3 Plotting of results

1. Use MATLAB and *Radmap* /15 / to plot radial and axial 2D distributions from TRAB-3D output file *b_dissla.dat or *d_nodesl.dat
2. Use script *fun2dat* to create a suitably formatted table file *b_funtim_dat.dat from the TRAB-3D output file *b_funtim.dat
3. *smblist50_d* or *smblist60_d* (twice) to create a table format file *b_smabre.f17 from SMABRE binary plot file *b_smabre.f07. In the first round *_smabre.f16 is created with formatted plot data output and in second round the *b_smabre.f17 file. If the run did not terminate properly, the binary output *_smabre.f07 file may be fixed with the help routine *ploterr.bat*.
4. Plotting of results with eg gnuplot. Typically the plot commands are in *.gp files or the procedure *gpplot* can be used to create a command file using data from *_funtim_dat.dat or *b_smabre.f17 files.

5.4 Useful help routines

1. *smblook50_d*/*smblook60_d* to look at or change restart data in *_smabre.f08 file. Typical is the option of pump stopping mode, seizure or coast down, which should be changed during the transient because only one stopping mode is active at time.
2. *smbnode* to look at results node by node from *_smabre.f08 file
3. *smbinit50_d* or *smbinit60_d* to create a new thermal hydraulic state for SMABRE input from the *_smabre.f10 file. The result file is smabre_*.dat_new which should then be renamed. The first output set from file *_smabre.f10 is copied to the new input and that is why typically other than the latest output set is removed by editing the f10 file. Use *smbinit60_hplwr_d* for HPLWR because in the supercritical state node steam enthalpies are also needed in input.

5.5 Creation of a new thermal hydraulic input

Totally new SMABRE inputs created from scratch are not needed very often. Typically creating the geometry and trip logic takes a lot of time. For the initial conditions, pressures, enthalpies, void fractions and structure temperatures as well as for liquid and steam flow rates, the help routines may be used. First steps of creating a totally new input go like this.

1. Set in input the correct node pressure at least in one node in each independent system and change the corresponding node number into negative. Pressure in a node with a negative node number is stable during the calculation.
2. Set in input the correct junction flow at least in one junction in each flow path and change the corresponding junction number into negative. Volumetric flow in junction with negative junction number is stable during the calculation.
3. Procedures *smabrun50_d* or *smabrun60_d* for calculation
4. *Smbinit50_d* or *smbinit60_d* to create new input based on *_smabre.f10 file, copied state is the first set of node output in a .f10 file.
5. Change negative indexes into positive ones. Set up the proper pressure loss coefficients to junctions to stabilize the flow and pressure distributions around the loops. Initialize the partly open valve positions.
6. For coupled code calculations, the axial and radial power distribution given to SMABRE in its initial input should be revised a few times, after the stand-alone SMABRE has first run to a stable state, and a coupled steady state calculation has been completed.

5.6 SMABRE internal type input

TRAB-3D may have exactly the same input for old parallel and new parallel or the internally coupled code. For internal coupling not all of the TRAB-3D input is needed in TRAB-3D, but with several options, the TRAB-3D input data is read and used for SMABRE models. Regardless of parallel or internal coupling type, SMABRE6.0 needs clearly more input data than SMABRE 5.0 with parallel coupling. The reason is the initialization calculation performed only with SMABRE and the possibility to apply the TRAB-3D models in the coupled calculation. In such a case, the transition to coupled calculation is not stable without proper initialization already with SMABRE. The additional data, such as axial and radial distributions, may often be copied from the earlier created TRAB-3D or SMABRE output files. Also a help routine *smapower.bat* may be used, which creates the axial power profile for as many groups as are used in SMABRE. In the following, main additional input for SMABRE6.0 compared to smabre5.0 is listed. The input manual is still waiting for updating of the detailed description of these input parameters even though the options are already reported in SAFIR reports.

1. Radial maps of assembly and channel numbers and fuel classes
2. Assembly-wise radial map of power distribution
3. Average axial and assembly-wise radial map of burnup distribution (should be replaced with a nodewise distribution, as burnup may be used as a parameter

in the dependencies for material properties of the fuel, most notably thermal conductivity)
4. Heat transferred directly to coolant axially
5. Parameters for TRAB-type material properties to fuel, cladding and gas gap
6. Several general options and additional options for each junction
7. Link nodes to create the core island and junctions to and from these nodes

6 Summary

The main advantage of the internal type of coupling of the TRAB-3D 3.0 and SMABRE 6.0 codes is the possibility to handle coolant flow reversals in the core flow channels. During the latest phase of this several years project this is demonstrated for the EPR with quite an extreme test case. Typically in transients where reversed flow is expected with the TRAB-3D/SMABRE, much shorter and minor reversed core channels flow is expected. For the HPLWR reversed flow exists already in the steady state.

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