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COMPLETION REPORT FOR THE TRAC-M-SPECIFIC DATA MAP ROUTINE IN THE COUPLED TRAC-M/PARCS CODE (DEC Alpha implementation)

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I. Introduction

This report describes the successful completion of the work on the TRAC-M-Specific Data Map Routine (TDMR) and the implementation within TRAC-M on the DEC Alpha computational platform. In the following section, the results from the execution of the Qualification Assessment Test Plan (QATP)[1] are presented and briefly discussed. In addition, a discussion on future improvements which could be made to the TRAC-M/TDMR source code is presented in Section III.

II. Test Plan Results

The results from both the Calculational Experiment and Functional Evaluation portions of the QATP are shown below:

II.A. Calculational Experiment

For the Calculational Experiment portion of the QATP, TRAC-M was executed in both "Stand Alone" mode and "Coupled" mode. During the "Stand Alone" execution, power data for thermal-hydraulic cells and heat structures were written to a scratch file. Once these data were obtained, TRAC-M was then run in "Coupled" mode using a dummy General Interface and neutronics module. The dummy General Interface module processed the scratch file data and sent it to the TDMR. These data were then placed in the appropriate TRAC-M memory locations and used as the heat source for both thermal-hydraulic and heat structure components coupled to the kinetics calculation.

Only five of the six test input decks listed in Appendix A of the QATP were used for the Calculational Experiment. The omitted input deck, `w4loopnb.inp`, was not used because it is functionally no different from `w4loopn.inp` with the exception of boron in the system model.

Only the TRAC-M standard output file, `TRCOUT`, was used for the analysis of the Calculational Experiment. Using the graphics output file, `TRCXTV`, would produce many false differences due to the high numerical precision of the data in this file. Because of the computational procedure of the Calculational Experiment, a loss of accuracy in the solution is expected. This was discussed in Section III.A of the QATP for the TDMR.

The Calculational Experiment was successful for the decks relating to the Westinghouse plant. The thermal-hydraulic and heat structure temperatures were closely matched using the data from the scratch file, indicating a successful implementation for decks involving VESSEL components. Slight differences existed due to the highly ill-conditioned computational nature of this input deck. The loss of accuracy due to writing the solution to disk and then re-reading to memory during the Calculational Experiment is the reason the solutions are not identical.

The Calculational Experiment for the transient heat conduction decks (based on `hcond1.inp`) was also successful. The thermal-hydraulic and heat structure temperatures were

reproduced using the data from the scratch file to displayed precision, indication a successful implementation for decks with PIPE compenents and direct coolant heating.

II.B. Functional Evaluation

The Functional Evaluation portion of the QATP was verified using 35 test cases. These test cases were described in Section III.B of the QATP for the TDMR. Table 1 lists each test case and indicates whether the execution was successful. In addition, comments are included which provide some detail concerning the result which was obtained.

One of the base cases for the Functional Evaluation was the input deck `w4loopnb.inp`, which contains soluable boron in the system model. One of the features of the TDMR is to adjust the amount of boron in the system as dictated by PARCS during a boron criticality search. This functionality was tested using the coupled code system, and behaved as expected. Any tables relating to boron concentration are also adjusted to reflect the criticality condition and to ensure continuity in the boron concentration injected into the system. See Section II.A.2 of the Software Requirements Specification(3) (SRS) for the TDMR for more information.

Table 1: Matrix of Test Results from Execution of the QATP

Test Section of QATP	Successful ?	Comments
Case 1: [QATP- Section III.B] Base test case.		
III.B.1.a	true	The initial PARCS control buffer shown in Appendix B of the QATP was received correctly and processed correctly by the TDMR.
III.B.1.b	true	The trip ID and mapping information contained in the initial neutronic control buffer was checked for decoded correctly and processed correctly.
III.B.1.c	true	The TDMR tested the option for solute tracking and the presence of non-zero initial boron concentration correctly.
III.B.1.d	true	The initial thermal-hydraulic control buffers shown in Appendix B of the QATP were processed correctly and received correctly by the General Interface.
III.B.2.a	true	The time-dependent TRAC-M control buffers shown in Appendix B of the QATP were processed correctly and received by the General Interface correctly.

III.B.2.b	true	The vector of space-dependent thermal-hydraulic data shown in Appendix B of the QATP was formed correctly from data stored in TRAC-M memory locations and received correctly by the General Interface.
III.B.3.a	true	The time-dependent PARCS control buffers shown in Appendix B of the QATP were received correctly from the General Interface.
III.B.3.b	true	The vector of space-dependent neutronic powers shown in Appendix B of the QATP was received correctly from the General Interface.
III.B.3.c	true	The data were extracted from the vector and placed in the correct TRAC-M memory locations.
III.B.3.d	true	The boron concentration in the system was adjusted correctly by the ratio received from the PARCS critical boron concentration calculation.
III.B.5.a	true	Normal termination was achieved resulting from detection of a signal sent from the GI and/or PARCS processes.
III.B.5.b	true	Normal termination was achieved resulting from detection of a signal set by the TRAC-M/TDMR process.
Case 2: [QATP- Section III.B.6.a.1a] Parametric for Input error.		
III.B.4.a.1	true	Receiving a trip ID number in the initial neutronic control buffer when no trips are defined in the TRAC-M model resulted in the printing of a warning message.
Case 3: [QATP- Section III.B.6.a.1b] Parametric for Input error.		
III.B.4.a.2	true	Receiving a trip ID number in the initial neutronic control buffer which does not exist in the TRAC-M model resulted in the printing of a warning message.
Case4: [QATP - Section III.B.6.a.1c,d] Parametric for Input error.		
III.B.4.a.3	true	Receiving a trip ID number in the initial neutronic control buffer which is outside the bounds for a trip ID resulted in the printing of a warning message.
Case 5: [QATP - Section III.B.6.a.2a,e] Parametric for Input error.		
III.B.4.a.4	true	It was detected that a component number specified in the thermal-hydraulic mapping information did not exist in the TRAC-M model, which resulted in both the printing of an error message and the safe termination of all three processes.
Case 6: [QATP - Section III.B.6.a.2b,f] Parametric for Input error.		

III.B.4.a.5	true	It was detected that a component number specified in the thermal-hydraulic mapping information was neither a VESSEL nor a PIPE, which resulted in both the printing of an error message and the safe termination of all three processes.
Case 7: [QATP - Section III.B.6.a.2c] Parametric for Input error.		
III.B.4.a.6	true	It was detected that a horizontal plane cell number specified in the thermal-hydraulic mapping information did not exist in the associated VESSEL component, which resulted in both the printing of an error message and the safe termination of all three processes.
Case 8: [QATP - Section III.B.6.a.2d] Parametric for Input error.		
III.B.4.a.7	true	It was detected that an axial level specified in the thermal-hydraulic mapping information did not exist in the associcated VESSEL component, which resulted in both the printing of an error message and the safe termination of all three processes.
Case 9: [QATP - Section III.B.6.a.2g] Parametric for Input error.		
III.B.4.a.8	true	It was detected that a PIPE specified in the thermal-hydraulic mapping information did not have direct coolant heating specified, which resulted in the correction of this option and the printing of a warning message.
Case 10: [QATP - Section III.B.6.a.2h] Parametric for Input error.		
III.B.4.a.9	true	It was detected that a PIPE cell number specified in the thermal-hydraulic mapping information did not exist in the associated PIPE component, which resulted in both the printing of an error message and the safe termination of all three processes.
Case 11: [QATP - Section III.B.6.a.2i] Parametric for Input error.		
III.B.4.a.10	true	It was detected that not all cells of a PIPE component with entries in the thermal-hydraulic mapping information were mapped to the kinetics calculation, which resulted in both the printing of an error message and the safe termination of all three processes.
Case 12: [QATP - Section III.B.6.a.3a] Parametric for Input error.		
III.B.4.a.11	true	It was detected that a component number specified in the heat structure mapping information did not exist in the TRAC-M model, which resulted in both the printing of an error message and the safe termination of all three processes.

Case 13: [QATP - Section III.B.6.a.3b] Parametric for Input error.		
III.B.4.a.12	true	It was detected that a component number specified in the heat structure mapping information was neither a ROD nor a SLAB, which resulted in both the printing of an error message and the safe termination of all three processes.
Case 14: [QATP - Section III.B.6.a.3c] Parametric for Input error.		
III.B.4.a.13	true	It was detected that a ROD/SLAB specified in the heat structure mapping information did not have a heat source specified in the TRAC-M input, which resulted in both the printing of an error message and the safe termination of all three processes.
Case 15: [QATP - Section III.B.6.a.3d] Parametric for Input error.		
III.B.4.a.14	true	It was detected that a ROD/SLAB specified in the heat structure mapping information has the option for axial fine mesh renodalization activated, which resulted in the both the deactivation of this option and the printing of a warning message.
Case 16: [QATP - Section III.B.6.a.3e] Parametric for Input error.		
III.B.4.a.15	true	It was detected that a ROD/SLAB specified in the heat structure mapping information has only one radial node, which resulted in both the the printing of an error message and the safe termination of all three processes.
Case 17: [QATP - Section III.B.6.a.3f] Parametric for Input error.		
III.B.4.a.16	true	The fuel surface node was not detected for a ROD/SLAB specified in the heat structure mapping information, which resulted in the use of the last radial node as the fuel surface node and the printing of a warning message.
Case 18: [QATP - Section III.B.6.a.3g] Parametric for Input error.		
III.B.4.a.17	true	It was detected that an average ROD/SLAB specified in the heat structure mapping information did not exist in the associated heat structure component, which resulted in both the printing of an error message and the safe termination of all three processes.
Case 19: [QATP - Section III.B.6.a.3h] Parametric for Input error.		
III.B.4.a.18	true	It was detected that an axial level specified in the heat structure mapping information did not exist in the associated heat structure component, which resulted in both the printing of an error message and the safe termination of all three processes.

Case 20: [QATP - Section III.B.6.a.3i] Parametric for Input error.		
III.B.4.a.19	true	It was detected that not all average RODs/SLABs of a heat structure component with entries in the heat structure mapping information were mapped to the kinetics calculation, which resulted in both the printing of an error message and the safe termination of all three processes.
Case 21: [QATP - Section III.B.6.a.3j] Parametric for Input error.		
III.B.4.a.20	true	It was detected that not all axial levels of a heat structure component with entries in the heat structure mapping information were mapped to the kinetics calculation, which resulted in both the printing of an error message and the safe termination of all three processes.
Case 22: [QATP - Section III.B.6.a.4a] Parametric for Input error.		
III.B.4.a.21	true	It was detected that the option for solute tracking within TRAC-M was not activated, which resulted in the deactivation of the boron criticality search and the printing of a warning message.
Case 23: [QATP - Section III.B.6.a.4b] Parametric for Input error.		
III.B.4.a.22	true	It was detected that the initial boron concentration in all the cells specified in the thermal-hydraulic mapping information is 0.0, which resulted in the deactivation of the boron criticality search and the printing of a warning message.
Case 24: [QATP - Section III.B.6.b.1 Parametric for T-H to Neutronic error.		
III.B.4.b.1	true	Decreasing the dimension of the unpermuted thermal-hydraulic vector resulted in both the printing of an error message and the safe termination of all three processes.
Case 25: [QATP - Section III.B.6.b.2a,c,e,g,i,k,m,o] Parametric for T-H to Neutronic error.		
III.B.4.b.2	true	Forcing elements of the data vector to be less than the lower bounds specified in the SDID(2) resulted in both the printing of an error message and the safe termination of all three processes.
Case 26: [QATP - Section III.B.6.b.2b,d,f,h,j,l,n,p] Parametric for T-H to Neutronic error.		
III.B.4.b.2	true	Forcing elements of the data vector to be greater than the upper bounds specified in the SDID resulted in both the printing of an error message and the safe termination of all three processes.
Case 27: [QATP - Section III.B.6.c.1a] Parametric for Neutronic to T-H error.		

III.B.4.c.1	true	Decreasing the dimension of the permuted neutronic vector during the first mapping step resulted in both the printing of an error message and the safe termination of all three processes.
Case 28: [QATP - Section III.B.6.c.1b] Parametric for Neutronic to T-H error.		
III.B.4.c.1	true	Decreasing the dimension of the permuted neutronic vector during the second mapping step resulted in both the printing of an error message and the safe termination of all three processes.
Case 29: [QATP - Section III.B.6.c.2a,c] Parametric for Neutronic to T-H error.		
III.B.4.c.2	true	Forcing elements of the data vector to be less than the lower bounds specified in the SDID resulted in both the printing of an error message and the safe termination of all three processes.
Case 30: [QATP - Section III.B.6.c.2b,d] Parametric for Neutronic to T-H error.		
III.B.4.c.2	true	Forcing elements of the data vector to be greater than the upper bounds specified in the SDID resulted in both the printing of an error message and the safe termination of all three processes.
Case 31: [QATP - Section III.B.7.a] Parametric for Process error.		
III.B.5.a	true	Setting the first, second, and third logicals in the initial neutronic control buffer to “TRUE” resulted in both the printing of an error message and the safe termination of the TRAC-M process.
Case 32: [QATP - Section III.B.7.a] Parametric for Process error.		
III.B.5.a	true	Setting the first, second, and third logicals in the time-dependent neutronic control buffer to “TRUE” resulted in both the printing of an error message and the safe termination of the TRAC-M process.
Case 33: [QATP - Section III.B.7.b] Parametric for Process error.		
III.B.5.a	true	Setting the fourth and fifth logicals in the time-dependent neutronic control buffer to “TRUE” resulted in both the printing of an error message and the safe termination of all three processes.
Case 34: [QATP - Section III.B.7.c] Parametric for Process error.		

III.B.5.b	true	Setting the first logical in the initial TRAC-M control buffer to “TRUE” resulted in both the printing of an error message and the safe termination of all three processes.
Case 35: [QATP - Section III.B.7.c] Parametric for Process error.		
III.B.5.b	true	Setting the first logical in the time-dependent TRAC-M control buffer to “TRUE” resulted in both the printing of an error message and the safe termination of all three processes.

III. Future Improvements

The following improvements could be made to the TRAC-M/TDMR code in the future:

III.A. Direct Coolant Heating for VESSEL Components

The version of TRAC-M used for this implementation of the TDMR (version 3.295) does not have the capability for performing direct coolant heating calculations for VESSEL components. The functionality exists, however, for PIPE components. Direct coolant heating is necessary for all components which could be used to simulate a core (as well as those in relatively close proximity to the core) in order to model all relevant phenomena accurately. Providing this functionality would require modifications to both the TRAC-M and TDMR source code in order to fully implement it in the coupled TRAC-M/PARCS code.

III.B. Allowance for Supplemental RODs/SLABs

The current implementation of the TDMR does not allow supplemental RODs/SLABs in heat structure components. These elements differ from average RODs/SLABs in that the power generated is not incorporated into thermal-hydraulic feedback, as the feedback is determined using the average RODs/SLABs of the heat structure. Normally these elements are used for simulating peaking RODs/SLABs within a heat structure. The modifications made to the calculational flow for computing heat structure power temperatures disallows supplemental RODs/SLABs if the current calculation is coupled to spatial kinetics. Furthermore, the spatial kinetics calculation inherently includes peaking information within its data (through the three-dimensional power shape). Therefore, using supplemental RODs/SLABs with spatial kinetics coupling is redundant, further justifying the lack of support for this TRAC-M feature.

III.C. Control System Integration

The current implementation of the TDMR passes a logical variable in the time-dependent thermal-hydraulic control buffers which indicates whether the trip specified in the mapping information input file, `MAPTAB`, has been set to “ON.” PARCS uses this logical to determine when to

initiate a reactor scram, the parameters for which are defined in PARCS input files. A more robust control system interface between TRAC-M and PARCS would allow the coupled code to perform power maneuvering simulations and similar operational scenarios as opposed to focusing exclusively on scram events.

III.D. Mapping Input Generalization

In the current implementation, the user is required to explicitly determine the mapping between thermal-hydraulic cells/heat structures and neutronic nodes. This can become somewhat tedious for models which involve a very fine spatial discretization (e.g., AP600). Thus, in the future, it may be beneficial to examine more automated techniques to produce the necessary mapping functions with minimal user input.

III.E. Simultaneous Execution

In the current implementation, a single PVM barrier is utilized during the TDMR initialization (corresponding barriers exist in the General Interface and PARCS-Specific Data Map Routine), which synchronize the three processes such that the communication paths between the processes can be established. The design of this coding section restricts the number of simultaneous TRAC-M/PARCS processes to one. More precisely, it is possible for many simultaneous jobs to be initiated, but there is no guaranteee of safe execution. In addition, the use of the PVM barrier in this coding section limits the fault detection of the TDMR because there is no associated time limit for the length of time a process should wait on a barrier. Specifically, the TDMR will wait on a barrier until the General Interface and PARCS processes join the group. If either of these processes are not started or one of them fails to reach the barrier call, the TDMR will be suspended indefinitely with no internal mechanism for terminating the execution. Thus, implementing a more sophisticated barrier could allow for the safe execution of several simultaneous TRAC-M/PARCS jobs, and could provide better fault detection for failed or unstarted processes.

IV. Summary

The primary responsibility of the TRAC-M-Specific Data Map Routine (TDMR) is to function as a secondary interface between TRAC-M and the General Interface. In order to couple TRAC-M to the General Interface, and thus, PARCS, the TDMR controls two tasks, the first of which relates to the transfer of intial and time-dependent control information needed for calculational coherency between TRAC-M and PARCS. The TDMR also controls both the processing and transfer of the vectors of space-dependent property data both to and from the General Interface. The execution of the QATP verified that these functions were implemented correctly. In addition, the triggering of the error checking measures was successfully tested.

Thus, the basic functionality of the TDMR satisfies the requirements of the Software Requirements Specification (SRS)[3]. However, as outlined in Section III, there are several items which should be addressed in the future to expand the capabilities of the TRAC-M/TDMR module within the coupled TRAC-M/PARCS code.

V. References

1. R. Miller and T. Downar, “Qualification Assessment Test Plan for the TRAC-M-Specific Data Map Routine in the Coupled TRAC-M/PARCS Code,” Technical Report, PU/NE-98-23, Purdue University, (1998).

2. R. Miller and T. Downar, “Software Design and Implementation Document for the TRAC-M-Specific Data Map Routine in the Coupled TRAC-M/PARCS Code,” Technical Report, PU/NE-98-24, Purdue University, (1998).

3. R. Miller, D. Barber and T. Downar, “Software Requirements Specification for the TRAC-M-Specific Data Map Routine in the Coupled TRAC-M/PARCS Code,” Technical Report, PU/NE-98-22, Purdue University, (1998).