A Script for the Automated Coupling of Neutronics and Thermalhydraulics Codes for the Simulation of Fast Transients

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Abstract

This paper describes the 'rfspcb' Perl script which has been developed to automate the coupled neutronics-thermalhydraulics analyses of large-break loss-of-coolant accidents (LOCAs) using the Reactor Fuelling Simulation Program (RFSP) and the CATHENA code. The automation is useful for increasing the speed, quality and efficiency of large-break LOCA analyses. The background for large-break LOCA analyses and the automation of such analyses are discussed as an introduction to a description of the Perl script itself. The role of 'rfspcb' and its structure are covered in this context. The handling of run-time errors and the increased reliability of the runs are also discussed. This paper describes the application of industry-wide safety-analysis quality-assurance standards to the 'rfspcb' Perl script and to associated runs. A modification of this script is in use to calculate shutoff-rod-drop transients for comparison with site measurements. Another modification is being used for testing the new *CERBRRS module of RFSP. This script has already been used for both CANDU 6 and CANDU 9 analyses, as well as for testing the new Simple-Cell Model (SCM) capability in the *CERBERUS module of RFSP. These applications are also covered in this paper.

1. Introduction

The mitigation of postulated large-break loss-of-coolant accidents (LOCAs) is an important aspect of CANDU safety analysis, required as part of the licensing process. Currently, all licensing analysis of fast transients associated with this type of accident involves the coupling of neutron-kinetics and thermalhydraulics codes. The present paper is an exposition of the automated methodology used by AECL to couple the neutron-kinetics code RFSP with the thermalhydraulics code CATHENA, as well as its extension to other thermalhydraulic computer programs and other applications.

1.1. Analysis Background

The postulated large-break LOCA scenarios which are included in safety analysis, are typically breaks in large-diameter pipes of the primary heat-transport system (PHTS) with initial discharge rates over 2 Mg/s (e.g., Reference [1]). Such breaks would lead to a fast de-pressurization of the PHTS and a rapid increase in the coolant void fraction in the fuel channels. This, in turn, would interrupt the flow in the core and would result in a rapid positive-reactivity insertion at a rate and depth for which the reactor-regulating system could not compensate. As a result, it is necessary to demonstrate that the CANDU shutdown systems would mitigate the effects of these transients.

At AECL, the computer programs RFSP [2] and CATHENA [3] are executed in tandem to simulate large LOCA transients, as discussed in the next section. The results are used in subsequent fuel and fuel-channel calculations, as well as thermalhydraulic calculations, to demonstrate preservation of fuel-channel integrity. The present paper focuses on the coupling of RFSP with CATHENA.

1.2. Large-Break Loss-of-Coolant-Accident Analysis Methodology

The Reactor Fuelling Simulation Program (RFSP) is a computer program which models the neutronics of CANDU reactors. RFSP can be used for a wide range of core-neutronics calculations, including space-time neutron-kinetics calculations of fast flux transients due to large-break LOCA [2].

The CATHENA computer program is a one-dimensional, two-fluid non-equilibrium thermalhydraulics code designed to analyze two-phase flow and heat transfer behaviour in piping networks. The primary focus of recent computer-program development has been the analysis of the thermalhydraulic consequences of postulated upset scenarios in a CANDU reactor [3].

In order to manage its many options and complex calculations, RFSP is structured as a modular code. One of the major calculation modules is *CERBERUS, which solves the time-dependent two-energy-group neutron diffusion equation by means of the improved quasi-static method [4]. The *CERBERUS module requires input from CATHENA for each simulation step, namely, coolant density, coolant temperature and fuel temperature at each thermalhydraulic calculation node within the core. After the *CERBERUS calculation is complete, a set of normalized powers corresponding to the nodes in the thermalhydraulics model is made available to CATHENA. This interchange of data forms the basis of the coupling of the two codes.

Initially, the codes are used to carry out steady-state calculations and the interface data is passed between them until each of the nodal powers varies by less than 1%. Next, the large-pipe break is modelled in CATHENA and a small time step is simulated with constant nodal powers. In sequence, RFSP uses the resultant thermalhydraulic data to calculate the change in the neutronics over this initial time step. The nodal powers are then fed back to CATHENA, which then resumes the thermalhydraulic simulation to the next exchange step. This process continues over the entire time interval being simulated. This coupling of RFSP and CATHENA is illustrated in Figure 1.

1.3. Development of a Script To Automate the Large-Break LOCA Analysis

Historically, the stand-alone computer program CERBERUS was used, in conjunction with a number of auxiliary codes, to model the physics of large-break LOCA transients. At AECL, the CERBERUS suite of codes was coupled with the older thermalhydraulics code FIREBIRD [5,6]. The process of executing the codes was initially automated using UNIX run-scripts at AECL and Ontario Hydro [7,8]. The CERBERUS methodology was subsequently incorporated in the RFSP code [9] and the first informal UNIX script which coupled RFSP with FIREBIRD was created by Ontario Hydro for AECL. Subsequently, Ontario Hydro informally designed a short run-script in the interpreted script language Perl [10] to automate the RFSP runs for use with the thermalhydraulics code TUF. This was the starting point for development of the AECL script.

Perl has features similar to the 'awk' script language [7], but it is easier to use than 'awk' for larger tasks. Both of these languages use real arithmetic, while UNIX uses only integer arithmetic. The scripting of the large-break LOCA analysis methodology is the first step to facilitating multiple large-break LOCA sensitivity studies under the new 'uncertainty analysis' culture [1].

In 1997, AECL started from the RFSP/TUF run-script and developed the Perl script 'rfspcb', which automates the coupling of the RFSP *CERBERUS module with thermalhydraulic codes at AECL for large-break LOCA analysis. The first versions of the script coupled RFSP with FIREBIRD. The script was later updated to allow coupling with CATHENA. An option to perform the entire sequence of RFSP runs over a transient interval using pre-calculated thermalhydraulics data at each time was also included for possible future use with TUF. Currently, Ontario Power Generation is reviewing and improving this option.

Automation of the large-break LOCA analysis process is considered essential for increasing speed, quality and efficiency. Appropriate scripting of a sequence of coupled program executions also decreases the chance of input errors and decreases the amount of manual work required for analysis quality assurance.

2. The 'rfspcb' Perl Script

2.1. The Role of 'rfspcb'

The main function of 'rfspcb' is to link RFSP and CATHENA runs so that they execute in tandem and step through a transient using time steps derived from a separate run of the *TRIP_TIME module of RFSP or from pre-determined rules. The basic interrelationship of the two codes is illustrated in Figure 1, assuming that the calculational time steps are pre-determined.

The script 'rfspcb' has many different functions. Some of the main ones are summarized in Table 1.

2.2. The Structure of 'rfspcb'

'rfspcb' is a fairly compact Perl script [10] consisting of one main loop and twenty subroutines. Table 1 gives the main sequence of the subroutines used in 'rfspcb'.

An example of one of the main functions of 'rfspcb' is the creation of input files for the scientific analysis computer programs. This function is done in a subroutine called "create_input", executed near the beginning of the main program. "create_input" makes use of other subroutines as listed in Table 1.

Another important subroutine is the "error_no" subroutine. This subroutine's function is to print out specific error messages and force the program to abort after an error is detected. This subroutine is accessed by almost every other subroutine. The error messages are discussed further in Section 2.4.

2.3. Aspects of the Use of 'rfspcb'

The 'rfspcb' script acts as a driver for the sequence of physics and thermalhydraulic calculations over the transient interval. The actions performed by the script are controlled by an input file such as that shown in Table 2. This is the script input file for the functional test case, with filename '37dsgnc_data'. The script generates the coupled RFSP - CATHENA run stream for each time step, including file manipulations. The script also produces summary files for interpreting the output.

Following the methodology of the original Ontario Hydro script, a template approach is used to create RFSP and CATHENA input files. The template files must be supplied by the user. The RFSP template file looks just like an input file to RFSP, except that it contains some variables and, possibly, commands. These are interpreted by the script to produce the appropriate input file for each case.

Table 3 gives an example RFSP template file, corresponding to the functional test case in Table 2. The variables and commands used in this example template file include the following:

- *xx* - 2-character case number (this is being updated to 4 characters),
- *deltatime* - time step (in seconds),
- *sor_dstnce* - shutoff-rod position, relative to parked position (in cm), and
- *new_lines iterations* - appropriate case-dependent SCMHI card inserted.

The '*new_lines*' command is a 'catch-all' for case-dependent input that is not covered by the script. In the example case, this command uses the file 'iterations' (Table 4). In this particular instance, 3 outer iterations are required for the 2-group steady-state calculation while only 1 outer iteration is required for the time-step calculations.

The CATHENA template file is, essentially, a generic input file. It is manipulated by an auxiliary program, WRITEINP1, to incorporate the regional power data from RFSP. The result is an input deck used by CATHENA for a particular time step in the transient.

The script creates a log file, discussed in Section 3.2, which records all the steps in the simulation. It also creates a '*plt.txt' text file which is updated to append the time, total reactivity and total power after each sequential run of CATHENA and RFSP. This is useful for plotting the progress of the transient simulation at any point prior to completion.

Further details of the input and output files will be documented as described in Section 3.1.

2.4. Error Handling

The Perl script 'rfspcb' was designed with an automated error-detection scheme. This method reduces the likelihood of input errors and improves the quality and reliability of analyses. In 'rfspcb' when an error is detected, the 'error_no' subroutine is executed, printing an appropriate message and terminating the execution of the script. This occurs in the different situations listed in Table 5. Since the creation of multiple input files, required by RFSP and CATHENA, is automated in 'rfspcb', errors which could occur in the manual creation of the input files are much less likely to occur in the automated process.

One error check to be highlighted is used in the file-information routine, 'file_data', listed in Table 6. Generally, whenever a file is accessed, the 'file_data' routine is called to put the time and date of last modification of the file in the log file. When this is done, a check is carried out which will stop execution if the file is not found or if it has zero size. The 'file_data' and 'error_no' subroutines are scattered throughout the script and are not listed in Table 1.

3. Quality Assurance

3.1. Software Quality Assurance

In conformance with the CSA Standard N286.7-99 [11], two separate reports are in preparation: the Development Log and the Application Manual. These two documents will consolidate the quality-assurance documents required by the standard, as follows.

When the 'rfspcb Development Log' is issued, it should include:

- the Problem Definition document,
- the Qualification Plan for the legacy script as of 1999 March 1,
- the Development Plan for changes subsequent to 1999 March 1,

- the Software Requirements Specification,
- an initial version of the Theory Manual,
- the Software Design Description,
- the Programmer's Manual,
- the Verification Report for the functional test case, and
- the Validation Report covering the benchmark test case.

Before issue, the Development Log itself will be subject to independent verification, which will be documented in a separate Verification Report. This Verification Report will also provide verification for the coding. The Verification Report in the Development Log is specifically to confirm that the script functions as expected using the functional test case shown as an example in the present paper.

Validation, in this instance, is identified with benchmarking, since this script makes no scientific predictions beyond what the physics and thermalhydraulics codes do. The program will be validated by comparing a run done with the script, to a run performed manually without using the script. A benchmark was prepared and executed for the FIREBIRD code in an earlier development version of the script. The functional test case using CATHENA will be re-run manually and used as a benchmark case.

When the 'rfspcb Application Manual' is issued, it should include:

- the computer program Abstract,
- the final Theory Manual,
- the User's Manual,
- the Verification and Validation Manuals, and
- the Version Tracking Records.
- 'rfspcb' code under configuration management.

The legacy versions of 'rfspcb', and the associated files, were placed under configuration management using RCS [12]. The changes after 1999 March 1 include a number of improvements to the script which are being made at AECL. In addition, changes and improvements are being currently made by OPG to allow its use with the thermalhydraulics code TUF. Once this development is complete, the new version will be placed under RCS. The 'rfspcb Development Log' and the 'rfspcb Application Manual' will apply to this joint AECL-OPG version.

3.2. Analysis Quality Assurance

The 'rfspcb' script is designed to create a log file for each run. During each run, the program outputs information to a file called "<input_filename>.log", where 'input_filename' is the file name of the input data file which drives the execution of the Perl script. An example log file, with file name '37dsgnc_data.log' corresponding to the run from Table 2, is given in Table 7. The log file contains information such as:

- the directories and the locations of all programs used,
- the script input data,
- specific computer system information,
- time and date of modification of files used or created,
- a list of the output files,

- a transient table, and
- any warnings or errors that may have occurred.

This log file is created for every run. As a new log file is created, the old log file is renamed to "<input_filename>-old.log". Options are available to append old log files to it or to save the old log files under separate names. This keeps an accurate history of every run.

Note that although the script has not been fully qualified, the RFSP and CATHENA runs may be verified independently of the script. This allows the use of the script even in beta-test form, as long as the runs are verified independently of the script.

4. Applications of the 'rfspcb' Script

The 'rfspcb' script has been successfully used with many different applications. The benchmark problem and the verification case which are required for quality-assurance purposes are both based on the CANDU 6 system. It has also been used for CANDU 9 [13] analyses, as well as to test Simple-Cell model capability in the *CERBERUS module of RFSP (following up on [2]).

5. 'Spin-Offs' of the Perl Script

The script has been stripped down and modified to produce the SORTEST script which is being used for the CANDU Core Health Monitoring System [14]. The SORTEST script is evolving as a separate computer script from 'rfspcb'.

'rfspcb' is also in the process of being modified to automate the coupling of the *CERBRRS module [15] with CATHENA.

6. Conclusions

This paper has given an overview of the Perl script 'rfspcb'. The 'rfspcb' script has already been successfully used for automating the coupling of the *CERBERUS module of RFSP with the thermalhydraulics code CATHENA for large-break LOCA analyses. The script not only increases the speed and efficiency of the simulations, helping analysts to meet project scheduling requirements, but it also reduces the amount of manual work that needs to be done for analysis quality assurance. Automating the link between *CERBERUS and CATHENA is also essential for increasing the reliability of the runs, by minimizing the chance of input errors, in order to meet quality objectives in a timely way.

7. References

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Table 1. Sequence of Main Operations for the 'rfspcb' Script

Step Number	Associated Subroutine(s)	Action
1.	usage process_input test_input	Process input file and set up variable and file access
1.1	*sor_cases*	*Prepare shutoff-rod data for input files ('process_input')*
2.	echo_input header	Print input file and interpreted data to log file
3.	sys_info	Print computer (HP) system information to log file
4.		Enter main loop (step through major calculation time steps)
5.	create_inputs	Create input file for current time step
5.1	*step_time*	*Calculation of time steps and total time to be used ('create_inputs')*
5.2	*create_thinput*	*Creation of thermalhydraulics standard input ('create_inputs')*
5.3	*create_rfsp*	*Creation of RFSP input files ('create_inputs')*
5.3.1	*get_new_lines*	*Get and insert new lines corresponding to current case number from given file ('create_rfsp')*
5.4	*create_trip*	*Creation of RFSP input for *TRIP_TIME calculation*
6.	th_calculation ph_calculation	Complete the thermalhydraulics transient and physics transient calculation sequence for the current time step
7.	trip_calculation	Calculate the shutdown-system actuation times subsequent to the physics calculation at appropriate case numbers
7.1	*sor_character*	*Print shutoff rod insertion curve in log file ('trip_calculation')*
7.2	*sor_cases*	*Prepare shutoff-rod data for input files ('trip_calculation')*
8.	extract	Create a plot file from physics results at each time step or append to existing plot file
9.	print_powers get_bundle	Extract the total thermal power and the hot bundle thermal power transients
10.		After loop is complete, close log file containing run and file information and exit

Note: Subroutines called by the main subroutines are indicated in italics. The calling subroutine is indicated in parentheses.

Table 2. Example Input File for the 'rfspcb' Script

```
/home/donnellj/src/rfsp_ist   Directory containting (Y2K) RFSP executable
DEV_3-00HP       ist          RFSP version (Blachot)
#/SAC/AECL/Y2K_CODES/RFSP/bin   Directory containting (Y2K) RFSP executable
#REL_3-00HP      ist           RFSP version (Blachot)
/SAC/CATHENA/bin        Directory containing thermalhydraulics executable
# Thermalhydraulics code & type of code + CATHENA utility dir. & code:
cat3_5brev0-y2k.exe cathena    /home/maoa/RFSPCB/src    writeinp1.exe
37dsgnc          4560  12      Transient label and total number of bundles
1    delete tape  append       1st case, delete penult. TAPE, append log
29               0.3485             Last case and transient start time (s) - no blank
#
# Input data for *CERBERUS run
#
 0.100  s   Initial time step
 1.000  s   Final time step
step !
 5.000  s   Total transient time
7  cfxrefc  Case number after which *TRIP_TIME is executed + ref. label
0.0265  s   SDS1 ROP detector relay delay ($sds1_rop_delay)
0.0390  s   SDS1 high rate-of-log-power IC relay delay ($sds1_hrl_delay)
0.0160  s   SDS1 translation delay ($sds1_translat)
0.0195  s   SDS2 ROP detector relay delay ($sds2_rop_delay)
0.0320  s   SDS2 high rate-of-log-power IC relay delay ($sds2_hrl_delay)
0.0320  s   SDS2 translation delay ($sds2_translat)
13.39   cm  Position of bottom of long shutoff rods above core
#
# Shutoff-rod position versus time (s) at lattice planes
# (TTR-224 shutoff-rod insertion curve - design centre transient)
#
# TIME  POSITION
# (s)     (cm)
#
 0.213   11.375
 0.300   39.950
 0.372   68.525
 0.439   97.100
 0.498  125.675
 0.555  154.250
 0.606  182.825
 0.656  211.400
 0.703  239.975
 0.749  268.550
 0.794  297.125
 0.838  325.700
 0.882  354.275
 0.968  411.425
 1.053  468.575
 1.144  525.725
 1.233  582.875
 1.363  640.025
```

Table 3. Example RFSP Template File for the 'rfspcb' Script

```
*START    A.C. MAO
 CERBERUS PTL 93APR SNAPSHOT TO GENERATE A DESIGN CENTRE MODEL
 CANFLEX NO TILT, BORON 0.1PPM,COOLANT 99.0 ATM%, SAME CREEP AND 100%FP
*MODEL    LOCA0493
$
*CERBERUS PLGSUNIT1  17411773637DSGNC xx deltatime
C         LZCR01     0.328     LZCR03     0.412     LZCR06     0.379
C         LZCR02     0.474     LZCR04     0.341     LZCR07     0.527
C                              LZCR05     0.734
$
C         LZCR08     0.233     LZCR10     0.296     LZCR13     0.229
C         LZCR09     0.488     LZCR11     0.338     LZCR14     0.609
C                              LZCR12     0.435
$
C         SOR01      sor_dstnceSOR02      sor_dstnceSOR03      sor_dstnce
C         SOR04      sor_dstnceSOR05      sor_dstnceSOR06      sor_dstnce
C         SOR07      sor_dstnceSOR08      sor_dstnceSOR09      sor_dstnce
C         SOR10      sor_dstnceSOR11      sor_dstnceSOR12      sor_dstnce
C         SOR13      sor_dstnceSOR14      sor_dstnceSOR15      sor_dstnce
C         SOR16      sor_dstnceSOR17      sor_dstnceSOR18      sor_dstnce
C         SOR19      sor_dstnceSOR20      sor_dstnceSOR21      sor_dstnce
C         SOR22      sor_dstnceSOR23      sor_dstnceSOR24      sor_dstnce
C         SOR25      sor_dstnceSOR26      sor_dstnceSOR27      sor_dstnce
C         SOR28      sor_dstnce
E    0    4 1958330.0    0.95612    0.00002 1.5                0.05       0  10 400
N                  6
$
$ Modified velocities received from JVD on Aug 06, 1998.
$ Modification by Uditha Senaratne
$
V         9.2003E+060.2817E+06
$
THRMALCODECATHENA
TH GROUPS          10ch10grps   37dsgnczzz
new_lines iterations
*DELETE   FUEL PARMS
*DISPLAY
CERBPOWERSSIMULDATA PLGSUNIT1   159298800 17411773637DSGNC    37DSGNC xx
*PRNT MASS
*CLOSE    NORMAL TERMINATION
```

Table 4. Example 'new_lines' File for the 'rfspcb' Script (abridged)

File Name: iterations

```
1:
SCMHI     modboron 0.100 coolp 100.0 ngroup 2 edit 0 stoperr no iter 3
%%
2:
SCMHI     modboron 0.100 coolp 100.0 ngroup 2 edit 0 stoperr no iter 1
%%
3:
SCMHI     modboron 0.100 coolp 100.0 ngroup 2 edit 0 stoperr no iter 1
%%
4:
```

... (repeated for subsequent case numbers)

Table 5. Errors Explicitly Sought Out by the 'rfspcb' Script

Error Number	Description
10	Print 'usage' information to standard output if missing command-line input or if file specified by command-line input is not long enough.
30	The first case number specified in the input is outside the range [0,80]. (This will be updated to a maximum of 9999).
32	The last case number specified in the input is outside the range [0,80]. (This will be updated to a maximum of 9999).
33	The first case number specified in the input is greater than the last case number specified in the input.
40	The type of thermalhydraulics code is improperly specified. It is not one of FIREBIRD, CATHENA, TUF, NUCIRC, RFSP or TRIP. (Specifying RFSP or TRIP means that no thermalhydraulics calculation is done.)
50	Total time of present case exceeds specified transient interval.
60	The time remaining from the first integer number of seconds after full shutoff-rod insertion to the end of the transient interval is not divisible by the final time-step specified in the input.
70	Blank lines are not allowed in the command-line input file.
71	Second item of data missing in one of the input lines 4 to 7.
75	Line 10 should start with 'step' (lower case), followed by the pairs: (case number, time-step subsequent to that case), and ending with an exclamation '!'.
76	Case number is greater than 99!
100	File does not exist or has zero size.
120	Cannot redirect STDOUT.
125	Cannot duplicate STDERR.
200	TransientTable UNIX script does not exist in the specified directory.
210	Error in execution of TransientTable UNIX script.
300	Error in thermalhydraulics file manipulations.
310	Error in execution of file.
350	The number of lines in the TAPE2 file for the present case and the TAPE2 file for the previous case differ. This may be due to ECC injection or loop isolation signals. It may be necessary to manually edit the present TAPE2 file and to change the thermalhydraulics code type to RFSP (IMPORTANT!) before re-starting the run at this case.
360	Missing direct-access file for initial RFSP model. The direct-access file for the initial model is assumed to have a file name of the form STORE_<case_label>, where <case_label> is a 7-character label used throughout the script to represent the case.
400	Error in RFSP file manipulations. If this is a run beyond case 3, please check to see if the following files are required (among others): a channel-types file, <case_label>001.t15, <case_label>001.fbi (FIREBIRD only), <case_label>003.rst, <case_label>001.t02, <case_label>003.t02. Other input files required are: the initial-model direct-access file, the command-line input files for this Script and the *TRIP_TIME RFSP input file.
420	Fatal error in RFSP run.
430	Error condition found in thermalhydraulics output.
500	Cannot open file.
520	Cannot link file.
530	Cannot rename file.
600	Error in extracting results from RFSP output file: Total reactor power is not printed after the last reactivity value in the output file - possible error in RFSP output.
610	The SDS1 transient start time was not found.
615	The SDS1 transient start time is undefined.
620	The time-origin of the shutoff-rod insertion curve either occurs more than 400 ms before the present case $n, or else there is something wrong with it.
650	There is something wrong with the search for maximum integrated energy in RFSP.
660	The hot-bundle search is having trouble skipping case 2

Table 6. File-Information Routine in the 'rfspcb' Script

```
sub file_data {
# Print file modification date and time

    $directory = $_[0];
    $target = $_[1];
    $description = $_[2];

    $entry_dir = `pwd`;
#   $entry_dir = "$ENV{'PWD'}";
    chop($entry_dir);
    chdir $directory;
    $current_dir = `pwd`;
#   $current_dir = "$ENV{'PWD'}";
    chop ($current_dir);
    $current_dir =~ s/\/tmp_mnt//;
    $target_file = "$current_dir/$target";
    unless ("$description" eq "") { print "$description:\n"; }
    unless (-e "$target_file") { &error_no(100,"$target_file"); }
    print "$target_file last modified ";
    (@FSTATS) = stat $target_file;
    $mtime = $FSTATS[10];
    $target_date = &ctime($mtime);
    print "$target_date\n";
    chdir $entry_dir;
}
```

Table 7. Sample Log File from the 'rfspcb' Script (abridged)

```
            PERL Script for Simulating LOCA Transients
            ------------------------------------------

                  Script rfspcb version dev_1-03

        User snells on Wed Jul 12  8:56:15 EDT 2000

Echo of input file 37dsgnc_data:
```

... <intermediate lines deleted> ....

```
         RFSP-CERBERUS/FIREBIRD or CATHENA Simulations
         ---------------------------------------------

  Script:          rfspcb_y2k.pl
    User:          snells
    Date:          Wed Jul 12  8:56:15 EDT 2000

    Computer:      ffc1
    Input file:    37dsgnc_data
    Code versions: RFSP-IST version DEV_3-00HP
                   CATHENA code cat3_5brev0-y2k.exe
    Case label:    37dsgnc
    Template file: 37dsgnc_template
    Case numbers:  1 to 29
    Total Time:    5.000 s
    Log file:      37dsgnc_data.log
    Old log file:  37dsgnc_data-old.log
                   Old log files will be appended to it.

PERL Script for this run:
/home/snells/RFSPCB/src/rfspcb_y2k.pl last modified Tue Jun 27 13:55:34 EDT 2000

Auxiliary routines for rfspcb script are assumed to be in /home/snells/RFSPCB/src.

Input file from command line:
/home/snells/RFSPCB_runs/37dsgnc/37dsgnc_data last modified Wed Jun 28 16:02:42 EDT 2000

Old log file has been appended to::
/home/snells/RFSPCB_runs/37dsgnc/37dsgnc_data-old.log last modified Wed Jul 12  8:55:08 EDT 2000

New log file:
/home/snells/RFSPCB_runs/37dsgnc/37dsgnc_data.log last modified Wed Jul 12  8:55:08 EDT 2000

RFSP executable:
```

... <intermediate lines deleted> ....

```
$cathkeep[19] = voidcore.out
Thermalhydraulics executable:
/SAC/CATHENA/bin/cat3_5brev0-y2k.exe last modified Thu Mar  9 10:38:43 EST 2000

standard CATHENA input:
/home/snells/RFSPCB_runs/37dsgnc/cathenainp last modified Wed Jul 12  8:55:07 EDT 2000

Other CATHENA inputs:

Main CATHENA input mainplbnew.inp will be created by writeinp1.exe
(Note:  only this file contains break information -- from blc.inp)

/home/snells/RFSPCB_runs/37dsgnc/blc.inp last modified Tue Jun 27 13:45:03 EDT 2000
```

... <intermediate lines deleted> ....

```
/home/snells/RFSPCB_runs/37dsgnc/userplot.inp last modified Tue Jun 27 13:45:06 EDT 2000

/home/snells/RFSPCB_runs/37dsgnc/valvemods.inp last modified Tue Jun 27 13:45:06 EDT 2000


     Initial time step                                      = 0.100 s
     Final time step                                        = 1.000 s
     Total transient time                                   = 5.000 s
     *TRIP_TIME case number                                 = 7
     SDS1 ROP detector relay delay                          = 0.0265 s
     SDS1 high rate-of-log-power ion-chamber relay delay    = 0.0390 s
     SDS1 translation delay                                 = 0.0160 s
     SDS2 ROP detector relay delay                          = 0.0195 s
     SDS2 high rate-of-log-power ion-chamber relay delay    = 0.0320 s
     SDS2 translation delay                                 = 0.0320 s
     Parked position of long SOR bottom                     = 13.39 cm

  Origin of shutoff-rod insertion curve:  0.3485 s

     SOR insertion characteristic:
```

... <intermediate lines deleted> ....

```
COMPUTER SYSTEM INFORMATION -- Wed Jul 12 08:56:16 EDT 2000

Computer model:   9000/800/K260
Operating System: HP-UX ffc1 B.10.20 A 9000/800 414671341 two-user license
```

... <intermediate lines deleted> ....

```
  make                        3.77           make
  perl                        5.004_04       perl
  rcs                         5.7            rcs

The transient will now be executed:
```

Table 7 (continued)

```
Plot file '37dsgncplt.txt' created

Case  1:  delta-t = 0.0000 s, total time = 0.0000 s
Template for creation of RFSP input:
/home/snells/RFSPCB_runs/37dsgnc/37dsgnc_template last modified Tue Jun 27 13:45:02 EDT 2000

RFSP Case 1 input has been created:
/home/snells/RFSPCB_runs/37dsgnc/rfsp_input_37dsgnc001 last modified Wed Jul 12  8:55:13 EDT 2000

No thermalhydraulics calculation will be carried out

Case 1 RFSP is now being run:
... <intermediate lines deleted> ..............................................................
Case  3:  delta-t = 0.1000 s, total time = 0.1000 s
Template for creation of RFSP input:
/home/snells/RFSPCB_runs/37dsgnc/37dsgnc_template last modified Tue Jun 27 13:45:02 EDT 2000

RFSP Case 3 input has been created:
/home/snells/RFSPCB_runs/37dsgnc/rfsp_input_37dsgnc003 last modified Wed Jul 12  9:42:59 EDT 2000

Thermalhydraulics Case 3 standard input has been created:
/home/snells/RFSPCB_runs/37dsgnc/th37dsgnc003 last modified Wed Jul 12  9:42:59 EDT 2000

... <intermediate lines deleted> ..............................................................
Case 3 CATHENA is now being run:
/home/snells/RFSPCB_runs/37dsgnc/37DSGNC001.t15 last modified Wed Jul 12  9:26:33 EDT 2000

37dsgnc001.t15 copied from 37DSGNC001.t15
/home/snells/RFSPCB_runs/37dsgnc/37dsgnc001.t15 last modified Wed Jul 12  9:43:00 EDT 2000

CATHENA restart file:
/home/snells/RFSPCB_runs/37dsgnc/37dsgnc001.rst last modified Wed Jul 12  8:50:10 EDT 2000

/home/snells/RFSPCB_runs/37dsgnc/th37dsgnc003 last modified Wed Jul 12  9:42:59 EDT 2000

... <intermediate lines deleted> ..............................................................
STOP  ****END OF RUN, RESTART RECORD WRITTEN
/home/snells/RFSPCB_runs/37dsgnc/coredenp.out last modified Wed Jul 12  9:45:06 EDT 2000

/home/snells/RFSPCB_runs/37dsgnc/mainplbnew.lis last modified Wed Jul 12  9:45:06 EDT 2000

/SAC/CATHENA/bin/cat3_5brev0-y2k.exe run successful!

... <intermediate lines deleted> ..............................................................
/home/snells/RFSPCB_runs/37dsgnc/37dsgnc003.rst last modified Wed Jul 12  9:45:08 EDT 2000

The *.bin files created by CATHENA are being deleted:
headerbc.bin deleted
... <intermediate lines deleted> ..............................................................
The *.out files will be appended by subsequent CATHENA runs:
blcterml.out kept
... <intermediate lines deleted> ..............................................................

Case 3 RFSP is now being run:
/home/snells/RFSPCB_runs/37dsgnc/37dsgnc002 last modified Wed Jul 12  9:42:55 EDT 2000

TAPE file 37dsgnc001 deleted
/home/snells/RFSPCB_runs/37dsgnc/37dsgnch03 last modified Wed Jul 12  9:45:13 EDT 2000

/home/donnellj/src/rfsp_ist/rfsp-ist.DEV_3-00HP executed at Wed Jul 12  9:46:20 EDT 2000

RFSP run successful!

Output file rfsp_37dsgnc003_output written

/home/snells/RFSPCB_runs/37dsgnc/ph37dsgnc003.out last modified Wed Jul 12 10:00:01 EDT 2000

/home/snells/RFSPCB_runs/37dsgnc/rfsp_37dsgnc003_output last modified Wed Jul 12 10:00:01 EDT 2000

... <intermediate lines deleted> ..............................................................
Plot file for gnuplot display:
/home/snells/RFSPCB_runs/37dsgnc/37dsgncplt.txt last modified Wed Jul 12  9:26:33 EDT 2000

... <intermediate lines deleted> ..............................................................
Files accessed for TransientTable2.2 calculation:
rfsp_37dsgnc001_output
... <intermediate lines deleted> ..............................................................
rfsp_37dsgnc029_output

        CASE    TIME    REACT   PTOTAL  PTREL   HTILT   VTILT   ATILT   PLX     PLXREL  PHX     PHXREL  PLY     PLYPREL PHY
        PHYTREL PLZ     PLZPREL PHZ     PHZPREL
        1       .0000   .000    1958.3  1.0000  .01     -.80    1.99    979.0   1.0000  979.3   1.0000  987.0   1.0000  971.4
        1.0000  959.7   1.0000  998.6   1.0000
... <intermediate lines deleted> ..............................................................
/home/snells/RFSPCB_runs/37dsgnc/37dsgnc.tbl last modified Wed Jul 12 20:09:00 EDT 2000

Case 29 >= end-case 29
Files accessed for extraction of hot bundle transient:
Warning -- the hot bundle is found by searching on "MAXIMUM VALUE" only.
(Requires *DISPLAY INTEGPOWERS to precede *DISPLAY CERBPOWERS in output.)
The maximum integrated energy is 2274.3 x 1.0E0 kW.s at location Q06/7
(Please check output to verify units.)
/home/snells/RFSPCB_runs/37dsgnc/37dsgnc.bdl last modified Wed Jul 12 20:09:01 EDT 2000
```

Figure 1. Interrelationships between RFSP/*CERBERUS and CATHENA