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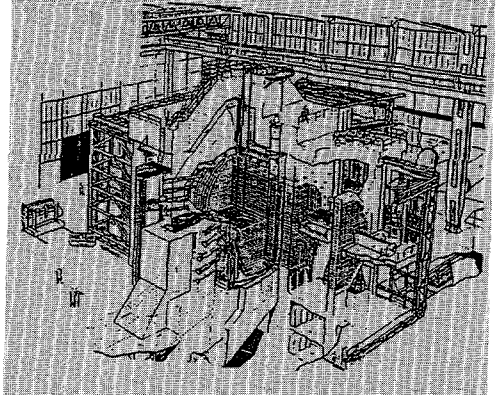

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Instrumentation and Controls Division

GRSAC USERS MANUAL

S. J. Ball and D. J. Nypaver

February 1999

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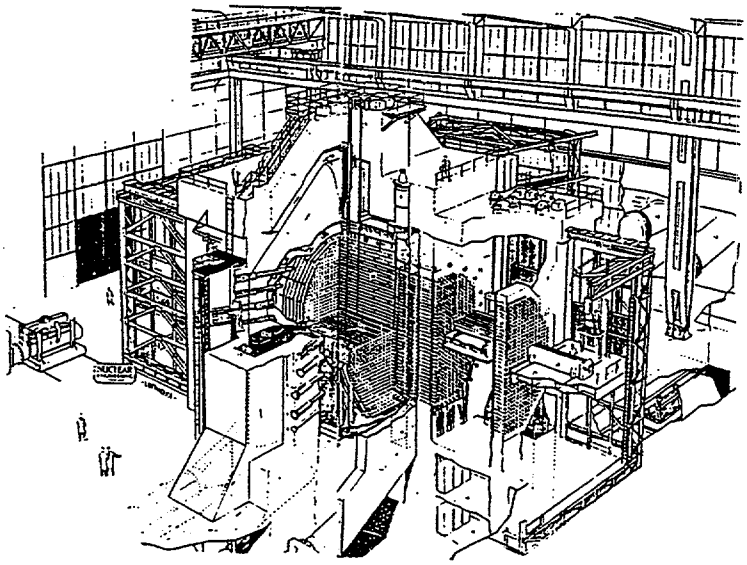

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ABSTRACT

An interactive workstation-based simulation code (GRSAC) for studying postulated severe accidents in gas-cooled reactors has been developed to accommodate user-generated input with "smart front-end" checking. Code features include on- and off-line plotting, on-line help and documentation, and an automated sensitivity study option. The code and its predecessors have been validated using comparisons with a variety of experimental data and similar codes. GRSAC model features include a three-dimensional representation of the core thermal hydraulics, and optional ATWS (anticipated transients without scram) capabilities. The user manual includes a detailed description of the code features, and includes four case studies which guide the user through four different examples of the major uses of GRSAC: an accident case; an initial conditions setup and run; a sensitivity study; and the setup of a new reactor model.

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FIGURES

ACRONYMS

APF	Axial Peaking Factor
ATWS	Anticipated Transient Without Scram
BGRR	Brookhaven Graphite Research Reactor
CB	Containment Building
DOE	Department of Energy (U.S.)
FP	Fission Product
GCR	Gas-Cooled Reactor
GRSAC	Graphite Reactor Severe Accident Code
GT-MHR	Gas-Turbine Modular Helium Reactor
HMI	Human-Machine Interface
HTGR	High-Temperature Gas-Cooled Reactor
I/O	Input/Output
IAEA	International Atomic Energy Agency
IC	Initial Condition
LOFC	Loss Of Forced Convection
MHTGR	Modular High-Temperature Gas-Cooled Reactor
NRC	Nuclear Regulatory Commission (U.S.)
O.D.	Outside Diameter
O.F.	Objective Function for sensitivity studies
ORNL	Oak Ridge National Laboratory
PCRV	Pre-stressed Concrete Reactor Vessel
RPF	Radial Peaking Factor
RV	Reactor Vessel
SCS	Shutdown Cooling System
U-nat	Natural Uranium

I. GRSAC (GRAPHITE REACTOR SEVERE ACCIDENT CODE) OVERVIEW

INTRODUCTION

The GRSAC (Graphite Reactor Severe Accident Code) software is a new general-purpose program developed at Oak Ridge National Laboratory (ORNL). It is based on the ORNL MORECA code for simulating accident scenarios for selected gas-cooled reactor (GCR) design types.[1,2] The MORECA code and its predecessors were originally developed at ORNL under the sponsorship of the U.S. Nuclear Regulatory Commission (NRC) to perform confirmatory licensing-related studies of a variety of High-Temperature Gas-Cooled Reactor (HTGR) designs, including the Fort St. Vrain HTGR and subsequently the 350-MW(t) steam-cycle Modular HTGR (MHTGR). MORECA was later developed - under U.S. Department of Energy (DOE) sponsorship - to simulate the MHTGR design for the 600 MW(t) direct cycle gas turbine modular helium reactor (GT-MHR).

Since MORECA is a "hard-wired" code, configured only for a particular reactor design, the conversion of MORECA to GRSAC was motivated by the need to generate the connectivities necessary to assemble, verify, and run simulations for a wide variety of graphite-moderated GCR designs.

Since GRSAC was developed to study a wide variety of core transient and heatup accident scenarios, it includes a detailed 3-D thermal-hydraulic model for the core, plus models for the reactor vessel, shutdown cooling system (SCS), and shield or reactor cavity cooling systems. There is an option to include neutronics (point kinetics) with xenon and samarium poisoning to study Anticipated Transients Without Scram (ATWS) transients.

The 3-D, hexagonal geometry core model allows for detailed investigations of azimuthal temperature asymmetries in addition to axial and radial profiles. Variable core thermal properties are computed functions of temperature and are dependent on orientation and radiation damage. An annealing model for graphite accounts for the increase in thermal conductivity that occurs during heatup accidents.

The primary coolant flow models cover the full ranges expected in both normal operation and accidents, including pressurized and depressurized accidents (and in between), for forced and natural circulation, for upflow and downflow, and for turbulent, laminar, and transition flow regimes. The primary loop pressure calculation can consider variable inventory (due to depressurization actions)

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[1]S. J. Ball, *MORECA: A Computer Code for Simulating Modular High-Temperature Gas-Cooled Reactor Core Heatup Accidents*, NUREG/CR-5712, ORNL/TM-11823, Oak Ridge National Laboratory, Oak Ridge, Tenn., October 1991.

[2]S. J. Ball and D. J. Nypaver, *MORECA–2: Interactive Simulator for Modular High-Temperature Gas-Cooled Reactor Core Transients and Heatup Accidents with ATWS Options*, NUREG/CR-5945, ORNL/TM-12233, Oak Ridge National Laboratory, Oak Ridge, Tenn., December 1992.

and loop temperature changes and may use a simplified model for balance-of-plant temperatures. The models for the reactor pressure vessel and the shield or cavity cooling system are different for each of the various basic reactor models. Models are also included for oxidation of graphite (including carbon deposits), cladding, and fuel. Fission product release (for metal fuel) and Wigner stored energy release models are also available.

Other GRSAC features of interest are: fast-running (typically >2000 times faster than real time on a SUN SparcStation-20 workstation), interactive user interface with on-line and off-line plotting options, automated sensitivity study capabilities, and on-line documentation and help screens. The basic designs that can be simulated using GRSAC, which the user may modify via the interface to a large (but limited) extent, include the British and French Magnox types (including the Calder Hall, G-2/3, and Bugey-2), Windscale (U.K.), G1 (France), and the HTTR (Japan). Adaptations and analyses are planned for the HTR-10 (China) and the GT-MHR Plutonium burner (U.S.-Russia).

GRSAC CODE FEATURES

Reactor Design Setup

Specific design features for a chosen reactor type can be input by the user via design screen selections in the following categories: fuel element, nuclear parameters, core layout design, primary cooling system, vessel design, reactor cavity, fission product release, and oxidation parameters. Program setup screens allow the user to activate or deactivate oxidation, Wigner energy, or ATWS features, and to select the coolant gas, core flow direction and computation time parameters. In some cases, such as for the radial and axial power peaking factor inputs and flow coastdown curves, graphical displays and automated consistency check features are included. For all of the user input screens in GRSAC, pop-up HELP windows and a choice of metric or English unit entries are available. The user can also select a "run with validation" option, which is a smart front end check of the entire set of inputs for data inconsistencies.

Initial Condition Runs

GRSAC accident sequence analyses require a large set of initial condition values which are created automatically via the Initial Condition (IC) mode. The user can change operational inputs such as power level, flow, pressure, etc., and observe the resulting detailed temperature and flow distributions attain steady state conditions. At any point in the run, one can store initial condition values in a RUN file.

Interactive and Programmed Inputs

The interactive input screen for accident simulations allows for user inputs (scram, depressurization, changes in emergency and/or cavity cooling, etc.) at any time during a run. Such inputs can also be pre-programmed, however, via a programmed input screen that is available to the user during the run setup procedure.

Accident Sequence Runs

Long-term Loss Of Forced Convection (LOFC) accidents begin with a programmed flow coastdown transient. LOFC transients in GCRs are generally characterized by slow heatups due to low power densities and large heat capacities associated with the core. They may be simulated both with and without total or partial depressurization of the primary coolant and with or without scram. Optionally, both the active or passive shutdown cooling systems can be made to be either unavailable or available only intermittently in degraded states. For helium or CO_2-cooled cores, there is an option to allow air ingress following a depressurization, and subsequently to initiate oxidation models for graphite (and clad and metal fuel, if applicable).

Sensitivity Study Option

Many variations of transient and LOFC accident scenarios have been studied to observe the sensitivities of the predictions to parametric and operational assumptions. These provide guidance in design studies for determining plant operating parameters (including design power level) and in identifying which physical properties and correlations are most crucial to the outcome of postulated accidents.

In the GRSAC automated sensitivity study feature, the rationale is to seek out a set of parameters within user-specified uncertainty bands that result in the worst (or best) case accident consequences using a gradient search algorithm. Sets of 13 model or design parameters (such as heat transfer correlations, etc.) and 12 operational/run parameters (such as time of scram) have been set up to be available for automatic variation (from run to run). The program allows the user to select up to 10 from this set for any given study. To study the effects of a single parameter variation in more detail, a single-parameter option can be used. That parameter is varied uniformly within the uncertainty band (reference run plus 4 others). A report generator, the results of which are available after the runs are completed, gives a summary of the sensitivity run results.

II. GRSAC SAMPLE CASE STUDIES

The purpose of this section is to guide the user step-by-step through four typical processes that demonstrate the use of major features of the GRSAC code. The following section (III), by contrast, has a complete description of all of the features of the code, arranged in the order in which they can be accessed via the sequence of menus. The case study paths are taken to execute particular tasks, e.g., "run an accident case," requiring the user to access only a small fraction of the available features. Users wanting more details on what is needed or happening at any given step may want to read the appropriate part of Section III for clarification.

For many of the screens, there are several buttons and toggles used for sequence control and navigation purposes. Some of the common ones are:

HELP - Displays a help file for that screen. The file may be printed ("PRINT"), and must be "DISMISSed" before continuing.

OK, SAVE or CONTINUE - Accept or go with the data entered, file selected, or option choice.

CANCEL - Do NOT accept or save changes made on the screen.

QUIT, RETURN or DONE - Return to a previous (or the MAIN) menu.

RESTORE - Call up the values of parameters entered and saved previously for that screen (or for that simulation model).

RUN - Begin or continue the simulation.

HOLD - Stop the simulation (to take more time to observe parameters or plots, to make changes to input conditions, etc.).

APPLY - When making changes on the Flow Coastdown, Accident or IC Run screens, after the functions are activated and/or numbers are entered, click on the APPLY button to implement the change. The SCRAM button on the Accident Run screen does not require use of the APPLY button.

Alt-P - Toggle used to transfer back and forth between RUN and PLOT screens.

Note that the results shown in figures in this section are dependent on the initial design values in the files at the time this version of GRSAC was created. Changes in any of these values or subsequent model upgrades may cause some differences in the results obtained by the user in following these examples.

Case Study #1: Accident Case Setup and Run Using an Existing Reactor Model

Process: Selecting a reactor model design file (Calder Hall default), selecting default units, making model changes, setting up programmed inputs via the Scenario Setup screen, checking the input via the Run With Validation option, selecting the accident run option, picking the initial condition (IC) file, setting up the on-line plots, running the simulation, switching between the accident and plot screens to monitor the progress, and generating a post-run plot file.

Step 1. At the GRSAC Main Menu press the button (Fig. 1), (i.e., click on) "Retrieve Existing Simulation."

Step 2. The Simulation File Selection Menu (Fig. 2) will appear with a listing of the available (already created) "SIM" files. This list consists of default and any modified design data files generated previously. These files have the extension ".SIM" with an initial part of the name as created by the user that identifies the model. Select the file "CalderDef.SIM" and then click on "OK." For more information on file selection, see Section III, General Help.

Step 3. The Default Units Menu (Fig. 3) will appear. Select "Metric" and "OK." This will cause all subsequent screens to show parameters in metric units. Any of the screens can be changed to English (and back to Metric) if so desired by clicking on their "Metric/English" select buttons.

Step 4. The Simulation (Edit-Run) Selection menu (Fig. 4) will appear next, providing the user with a wide choice of things to do. In this example, we will make two design changes to demonstrate error-catching features of GRSAC's smart front end. Select "Edit Design Input Selections."

Step. 5. The Edit-Design Input Selections menu (Fig. 5) appears with the name of the model file (CalderDef.SIM) appended. Note that the design categories for which any changes (from the basic Calder Hall model default values) that may have been made have red flags displayed. Select Vessel Design and enter a value of 10.0 (meters) for Vessel ID, and save it by clicking "SAVE." If this is the first change entered in the "Vessel Design" category, you can note the appearance of the red flag in the Vessel Design box. Next select Core Layout Design, and change No. of Fuel Channels to 2000 and Fuel Channel Spacing Option to "adjust diameter." Click on "Help" to read what assumptions are made in the model for these entries. The reason there are different spacing options available is that the multiple inputs (number of fuel channels, pitch, geometry, and core diameter) "overspecify" the core geometry, and so the user can relax the bounds in different ways and note the results. Save the changes by clicking "SAVE."

Step 6. Click on "Continue" on the Input Selection menu to return to the Simulation Selection menu, and then select 'Edit Run Programmed Inputs." This screen (Fig. 6) allows preprogrammed operations to take place during accident runs, and it also has inputs to control the simulation time and time steps and selections of certain model options (e.g., make shutdown cooling flow a function of primary pressure). For this case, enter 6000 (min) for Max Computation Time (i.e., end of the

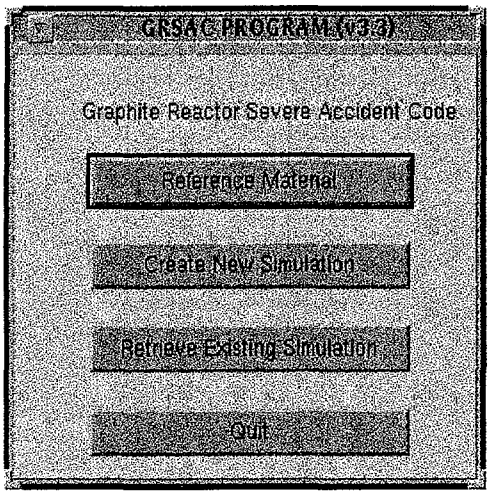

Figure 1. Main Menu

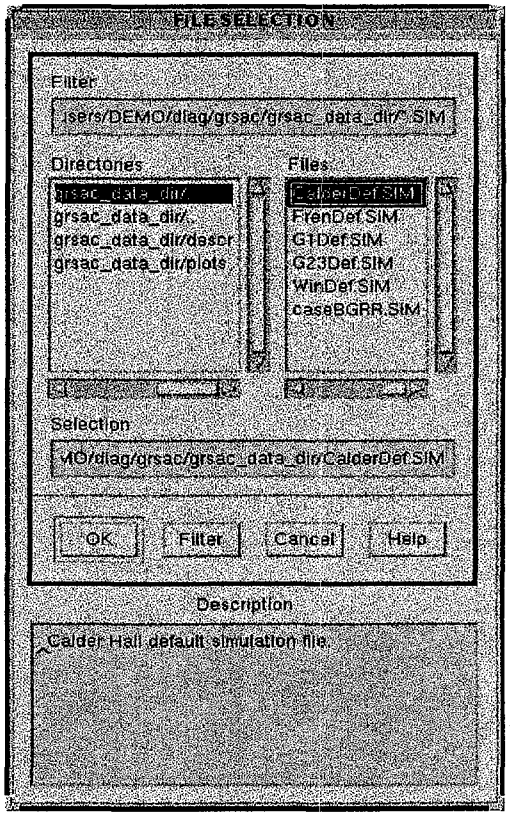

Figure 2. Typical Simulation File Selection Screen (applicable for IC, Accident, and Sensitivity Study)

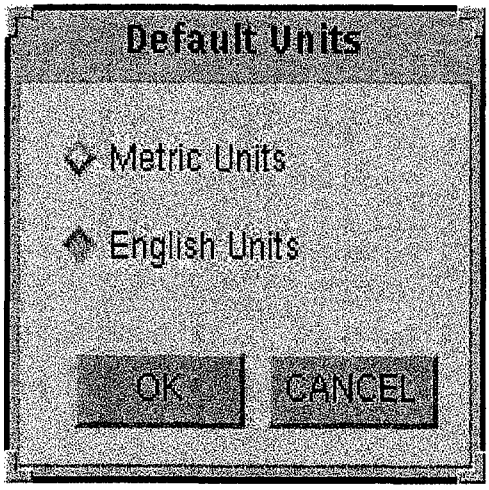

Figure 3. Choice of Units Menu

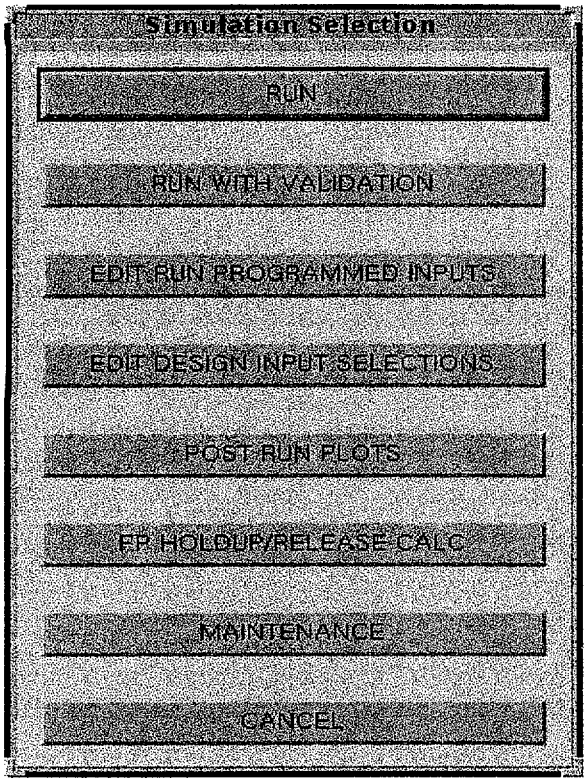

Figure 4. Simulation (Edit-Run) Selection Menu

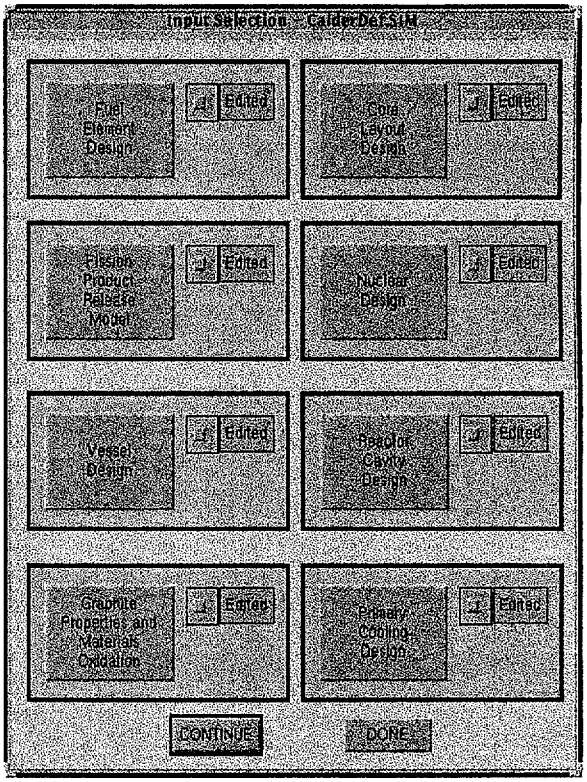

Figure 5. Edit–Design Input Selections Menu

simulation), and click on the Core Flow option to select "Core flow = % Rated SCS" flow rather than %Rated Primary. This will mean that when % core flows are specified, either on this screen or later via manual inputs on the accident screen, they will be in terms of the shutdown cooling system flow rating rather than the full primary rated flow. Next click on the button in the "DEPRESSURIZATION" box to select the Depressurization function, and click on the "Change to Air at End of Ramp?" button to select "Yes." Maintain the default start and ramp times. Select the "SHUTDOWN COOLING (SCS)" function, and enter 0.1 for Core Flow (%) and 5.0 for (SCS) Coolant Flow (%), and 9999.0 for duration (min), which is beyond the end of the run. If further clarification is desired, click on the HELP button. The resulting screen should look like Fig. 6. To save these entries, click "SAVE." Note that for subsequent runs for this Calder default model, these entries can be brought back automatically by clicking on the "RESTORE" button.

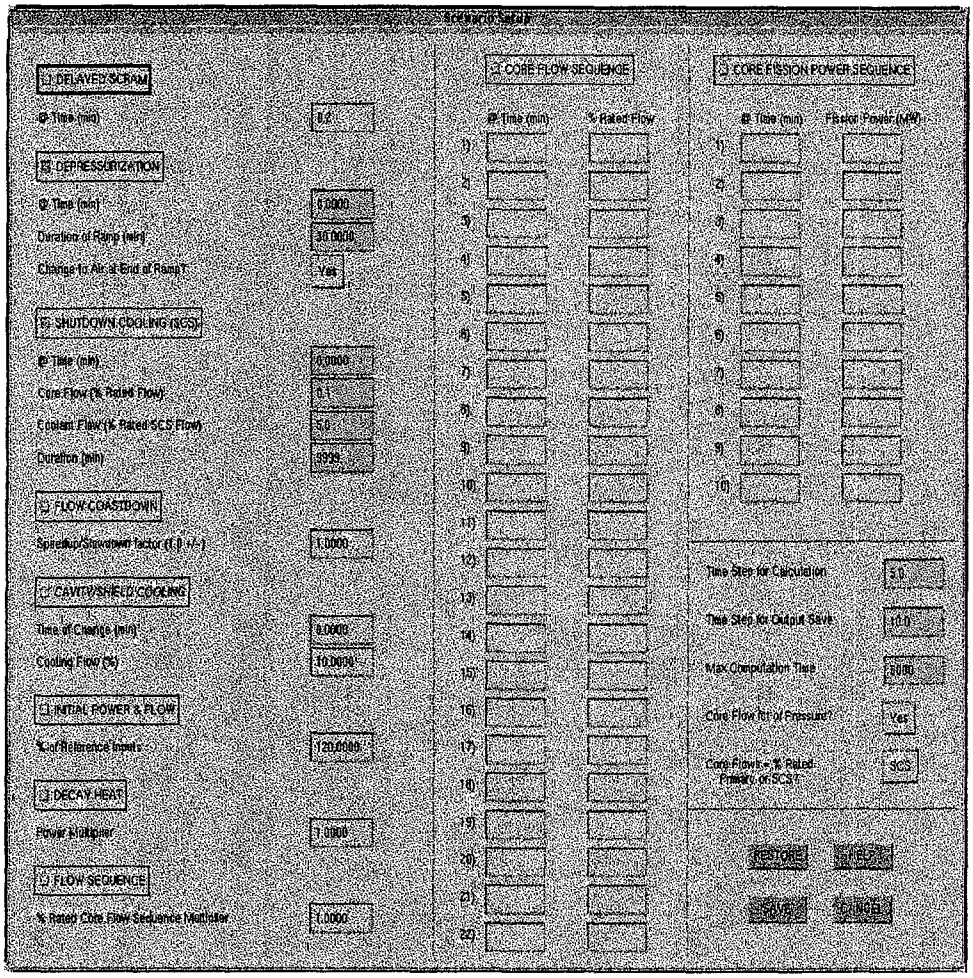

Figure 6. Case Study #1 – Programmed Inputs Screen

Step 7. From the Simulation Selection menu, select "Run With Validation" to activate GRSAC's smart front end, i.e., check the design inputs for consistency. Figure 7 shows the diagnostics that (should) result from the design entries specified in Step 5, i.e., that the vessel is too small for the reflector OD and the active core diameter is too small for the fuel channel configuration specified. Click on "EDIT" to return to the Input Selection menu, and change the variables altered in the Vessel Design and Core Layout Design back to the default values. (If they are not restored to "consistent" values, the run will bomb.) Click on Continue to return to the Simulation Selection menu.

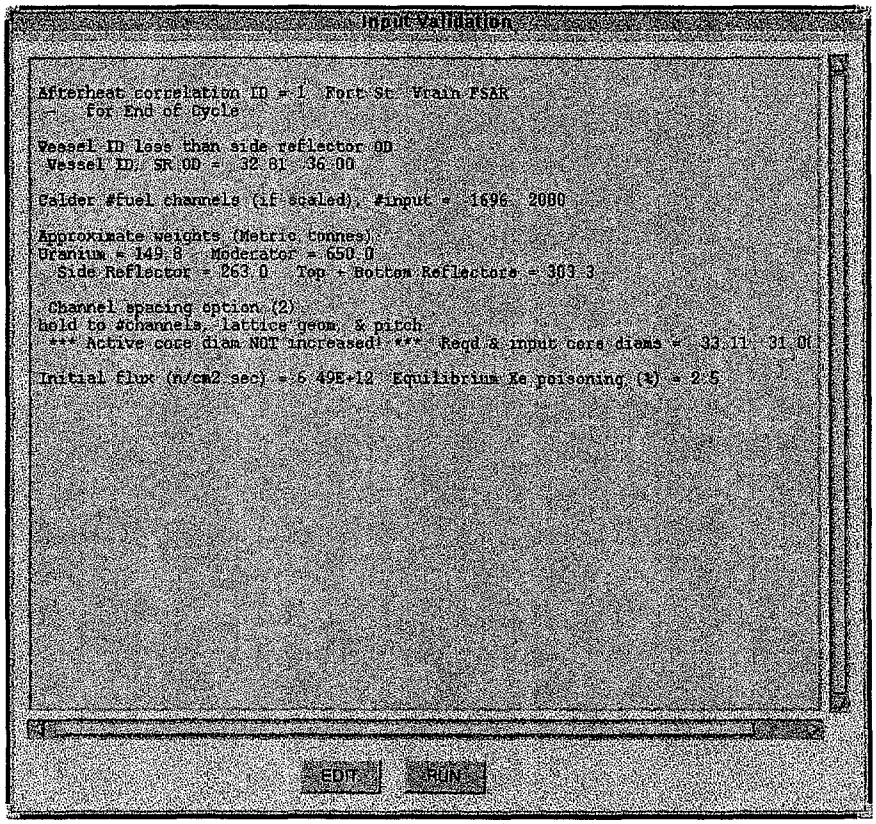

Figure 7. Case Study #1– Input Validation Report Example

Step 8. Select "Run" and then click on "Accident" and "OK" on the Run Selection menu (Fig. 8), which brings up a File Selection menu for the "RUN" files (Fig. 9). These files consist of Initial Condition (IC) data as generated previously via the IC run option. There may be several of these for each SIM file, since it may be desirable to start accident sequences from various operating points. Click on CalderDef.DEFAULT.RUN and OK. In general, certain types of design changes may cause changes in some of the core steady-state temperatures and flows. In such cases, a new IC file should be created for use in the accident runs.

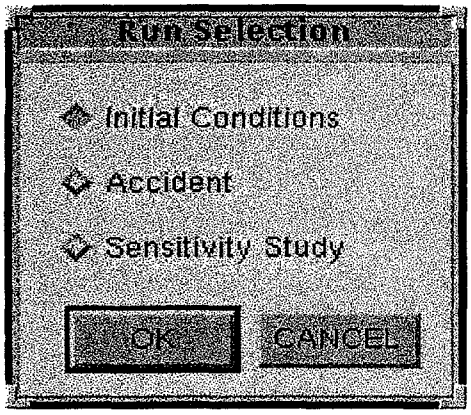

Figure 8. Run Selection Menu

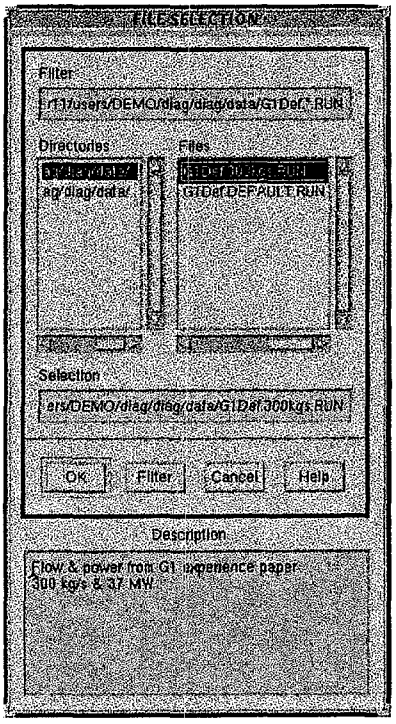

Figure 9. Run File Selection Screen (Applicable for IC, Accident, and Sensitivity Study)

Step 9. The on-line plot setup screen (Fig. 10) appears next. For each of the four plots, enter (via click and drag) the plot categories and X-Axis time/length and Y-Axis parameter designations as shown. The light background shown in the figure is obtained by clicking on the "COLORS" box and selecting Light. When the setup is completed, click on "OK" to bring up the accident screen (Fig. 11, which shows the parameter values at the end of the accident run).

Step 10. Click on "RUN" to begin, and note the progress of the accident via this screen and the plot screen (hit Alt-P to toggle between screens). The standard GRSAC accident run begins at the designated initial conditions, and at time=0 a loss of forced convection (LOFC) accident begins. The flow coasts down to a "small" value as specified by a coastdown curve, and thereafter is controlled or specified via the SCS inputs, the flow vs. time function generator setup in the "Edit Run Programmed Inputs" screen, or by a calculated natural convection "chimney" flow for air ingress accidents. On the plot screen, the oxidation rates for the core materials can alternatively be plotted in terms of kW power released. Change a Plot Category and other inputs (during the run) and click on "OK" to enter the values. To view the Fission Product release values on the Accident Screen, click on the "Fission Product Release" display toggle. When the run is complete, click on "QUIT."

In the Command Tool window ("cmdtool") in which the GRSAC program startup command was entered, a summary printout of selected simulation variables is written at each time step if the -0 option is not used when GRSAC is started. This information (in English units) is sometimes helpful for debugging or understanding a run (accident or initial condition).

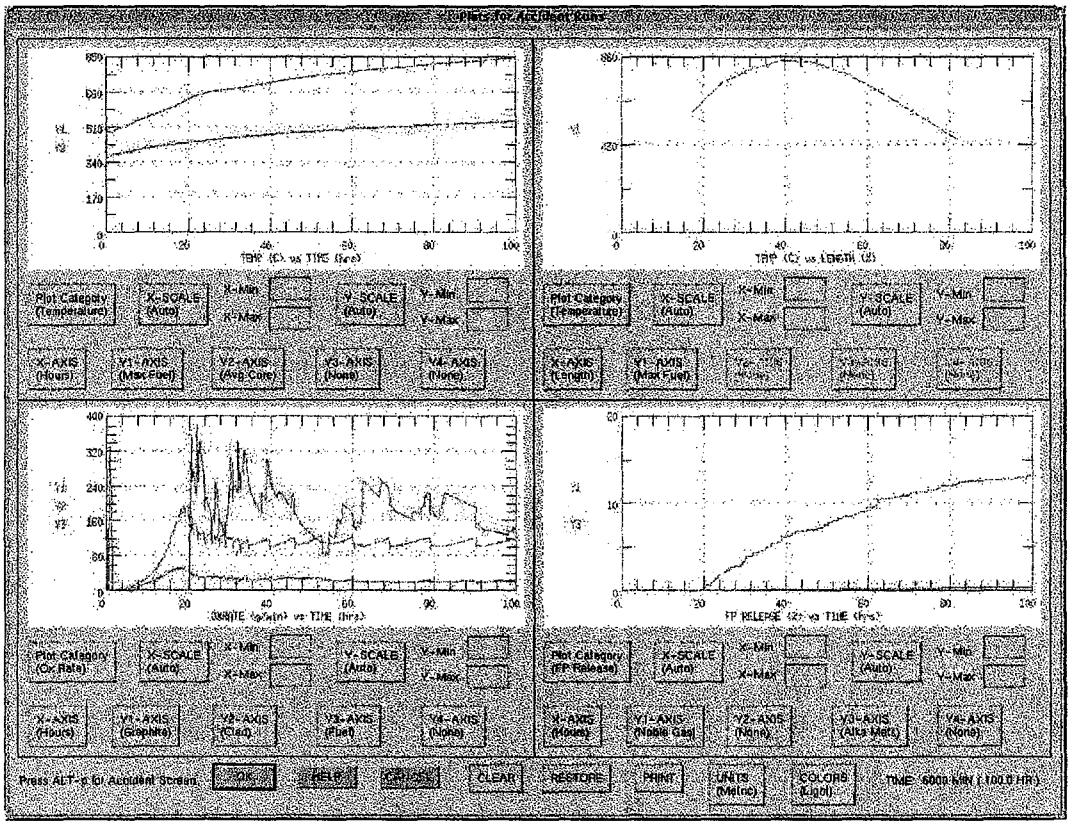

Figure 10. Case Study #1–Accident Plot Screen Showing Plot Setup Designations

Step 11. Whenever ANY plot variable is activated at the start of a run, a data file allowing for post-run plots is generated. This file may be saved for later (or current) use via the "Save Plot File?" file selection screen (Fig. 12). The files (for this Calder Hall model) will have the form "CalderDef.xxxx.AccPLOT," where the xxxx is an identifying character string. More information on entering the file name may be accessed by clicking on the "HELP" button. Existing plot files may be overwritten (with user permission). After clicking OK, the file is saved for later use (See Sect. III.3).

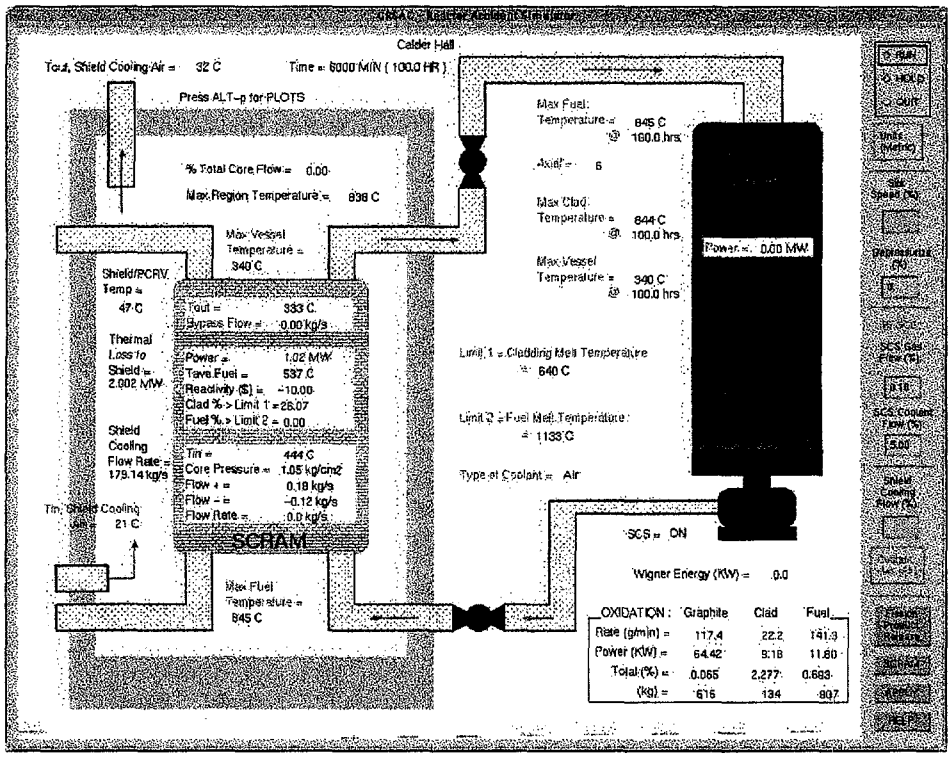

Figure 11. Case Study #1–Interactive Accident Screen at End of Run

Case Study #2: Initial Condition Case Setup and Run Using an Existing Model

Process: Selecting a reactor model, selecting units, selecting the initial condition (IC) run option, picking the IC file, setting up the on-line plots, running the simulation, switching between the IC and plot screens to monitor the progress, displaying various parameters in an axial section of the core, and others vs. length, changing selected input parameters, and saving and naming a new IC file.

Step 1. At the GRSAC Main Menu (Fig. 1), select "Retrieve Existing Simulation."

Step 2. The File Selection Menu (Fig. 2) appears with a listing of the available "SIM" files containing default and modified design data generated previously. These files have the extension ".SIM" with an initial part of the name as created by the user that identifies the model. Select the file "G23Def.SIM" and click "OK."

Step 3. The Default Units Menu (Fig. 3) will appear. Select "Metric" and "OK," causing subsequent screens to appear with metric units.

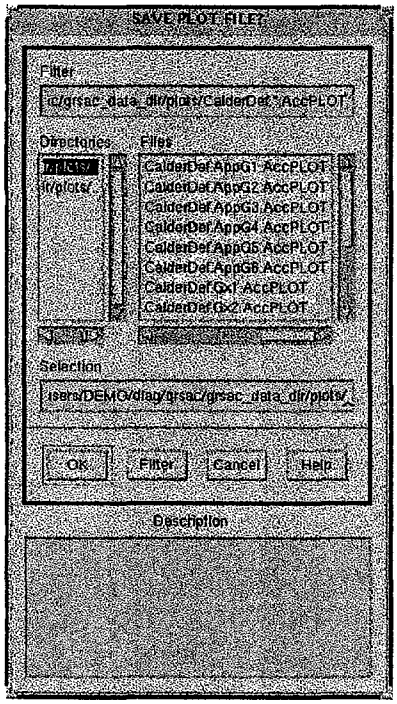

Figure 12. Calder Plot File Selection

Step 4. The Simulation (Edit-Run) Selection menu (Fig. 4) will appear next, providing the user with a choice of design change options. Make any changes desired for the example, but if any of the changes are significantly different from the default values, the "Run With Validation" option described in the first case study example should be exercised.

Step 5. Select "Run" and then click on "Initial Conditions" and "OK" on the Run Selection menu (Fig. 8), which brings up a File Selection menu for the G23 Def "RUN" file (Fig. 13). This consists of an IC data file as generated previously via the IC run option. There may be several of these for each SIM file, allowing for starts from various operating points. Click on G23Def.DEFAULT.RUN and OK.

Step 6. The on-line plot setup screen appears next. For each of the four plots, enter (via the drop-down menu selections) the plot categories and X-Axis time/length/radial and Y-Axis parameter designations as shown in Fig. 14. A light background may be obtained by clicking on the "COLORS" box and selecting Light. Note that entries for the temperature vs time parameters (upper left screen) cannot be altered during the run, while radial and length temperature profile plots can be changed at any time. When the setup is completed, click on "OK" to bring up the IC screen (Fig. 15, which shows the parameter values at 17 hr into the IC run).

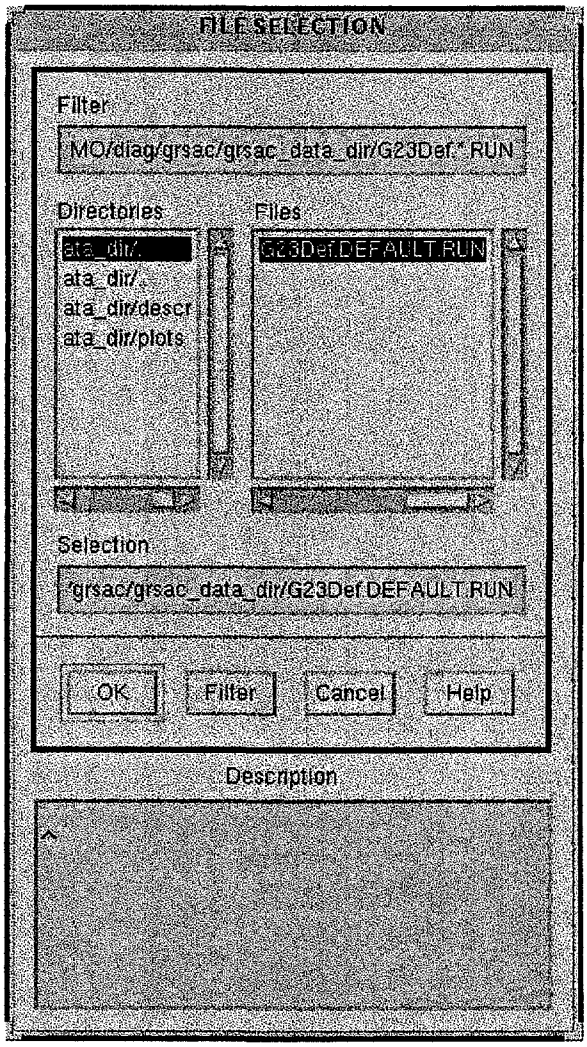

Figure 13. G2 Run File Selection

Step 7. Click on "RUN" to begin, and note the progress of the IC run via this screen and the plot screen (hit Alt-P to toggle between screens). The IC run begins at the designated initial conditions and seeks equilibrium for the specified input parameters as shown or as input via the screen. A time step of 0.5 min is used, and unless the final (stop) time is altered via the Programmed Inputs screen, the stop time will be 10000 min. The default core map display for the 163 radial regions is the set of region coolant outlet temperatures. The display can be changed by clicking on the TEMP/FLOW display box at the right of the screen - for example, to display the 163 region flows, or bulk core or fuel temperatures at selected axial positions (1 = inlet core, and 14 = exit). On the plot screen, several temperature parameters vs. time can be viewed in the upper left box, and various temperature profiles can be selected in the other boxes. Return to the IC run screen (ALT-P) and change the power or flow by 10% or an inlet temperature by 20 degrees and note the temperatures (or flows) change and seek a new equilibrium.

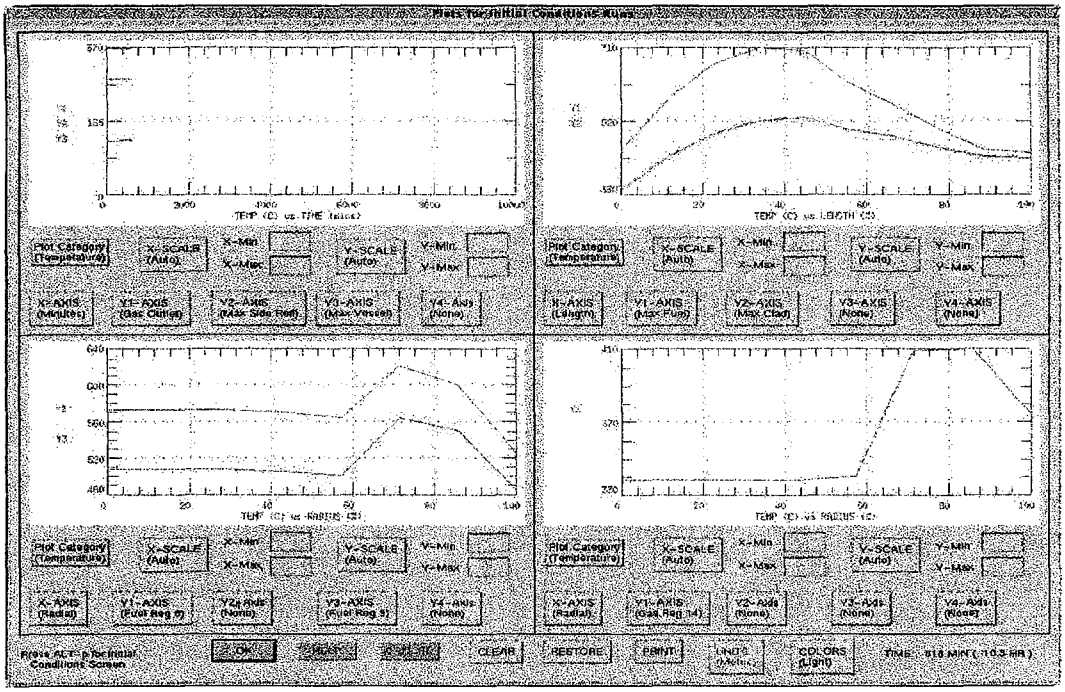

Figure 14. Case Study #2–IC Plot Screen Showing Plot Setup Designations

Step 8. To save a new IC file at the desired new steady-state conditions, click on the SAVE button. For guidance on how well the simulation has reached steady-state, look at the vessel temperature vs time plot. Also check the heat balance (HEAT BAL. I/O should settle near 100%). The "SAVE" brings up a file name selection screen (Fig. 16), where the user can either enter a new file name or overwrite an existing one (with permission). When done, click on "QUIT."

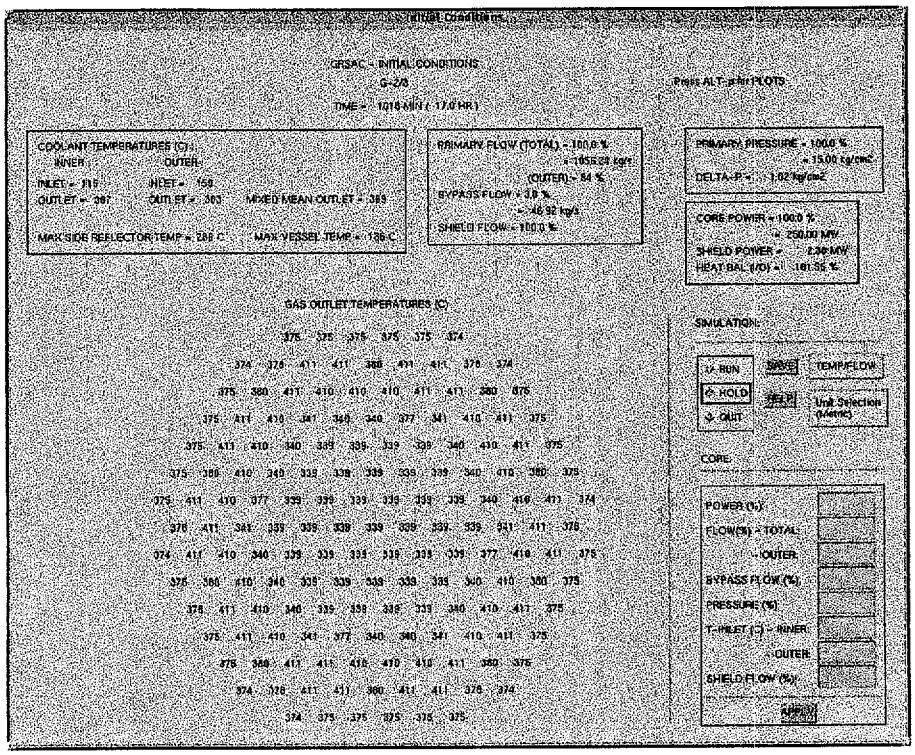

Figure 15. Case Study #2 – IC Run Screen After 17 Hours

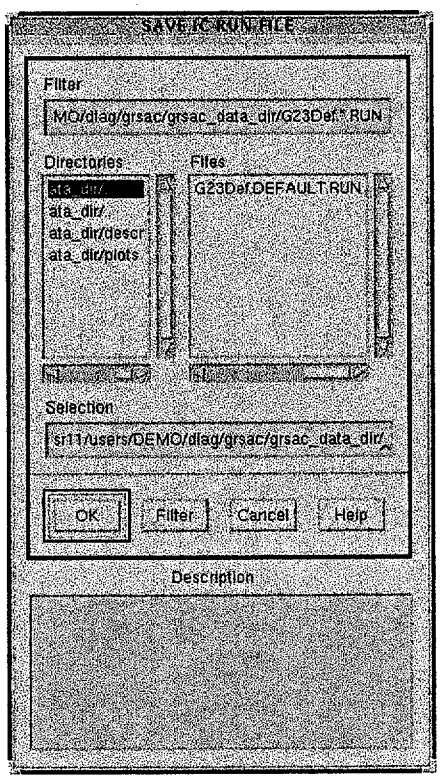

Figure 16. Run File Selection Save for G23 Default

Step 9. Whenever ANY plot variable is activated at the start of a run, a file allowing for post-run IC plots is generated. This file may be saved for later use via a "Save Plot File?" file selection screen (Fig.17). The files for this G2 model will have the form "G23Def.xxxx.ICPLOT," where the "xxxx" is a user-defined identifying character string. More information on entering the file name may be accessed by clicking on the "HELP" button. Existing plot files may be overwritten (with user permission). After clicking OK, the program returns to the Run Selection menu, allowing immediate follow-up of an accident or other run.

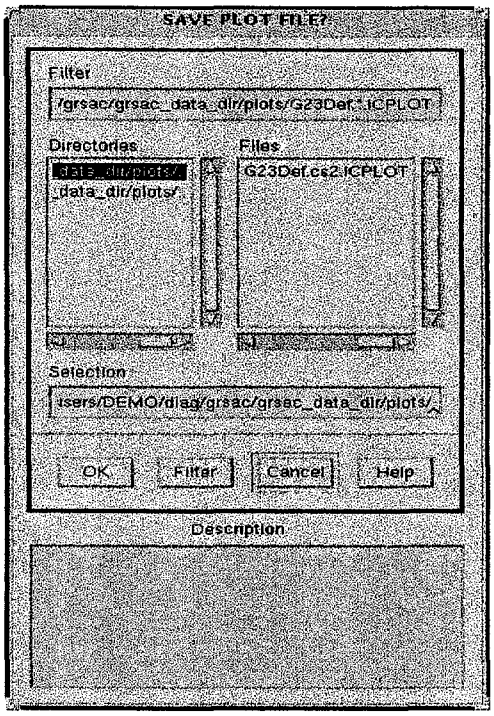

Figure 17. IC Plot File Selection for G2

Case Study #3: Sensitivity Study Case Setup and Run Using an Existing Model

Process: Selecting a reactor model, selecting units, setting up programmed inputs via the Scenario Setup screen, selecting the sensitivity run option, selecting design input parameters for sensitivity determination, picking the IC file, setting up the on-line plots, running the simulation, and switching between the accident and plot screens to monitor the progress. A general discussion of the Sensitivity Study option is given in the REFERENCE MATERIAL (accessed via the main menu) by selecting "HELP," and then scrolling down to Section XVIII of "GENERAL HELP."

Step 1. At the GRSAC Main Menu (Fig. 1), select "Retrieve Existing Simulation."

Step 2. The File Selection Menu (Fig. 2) will appear with a listing of the available "SIM" files with an initial part of the name as created by the user that identifies the model. Select "CalderDef.SIM" and click "OK."

Step 3. The Default Units Menu (Fig. 3) will appear. Select "Metric" and "OK."

Step 4. The Simulation (Edit-Run) Selection menu (Fig. 4) will appear next, where any desired "design changes" may be made by selecting "Edit Design Input Selections" and subsequent categories as explained in Case Study #1.

Step 5. If changes were made, click on "Continue" on the Design Input Selection menu to return to the Simulation Selection menu. Select "Edit Run Programmed Inputs." Besides setting up preprogrammed operations to take place during the accident-sensitivity runs, the options for flow or power history multipliers must be selected on this screen if they are to be used as sensitivity parameters. Only those functions selected (such as depressurization time, scram delay time, etc.) can be selected later as sensitivity parameters. For this case, enter 3000 (min) for Max Computation Time (i.e., end of the simulation), and click on the Core Flow option to select %Rated SCS rather than %Rated Primary flow. This will mean that when % core flows are specified, they will be in reference to the shutdown cooling system flow rating rather than the full primary rated flow. Next click on the button in the "DEPRESSURIZATION" box to select the Depressurization function, and click on the "Change to Air at End of Ramp?" button to select "Yes." Maintain the default depressurization start and ramp times. Select the "SHUTDOWN COOLING (SCS)" function, and enter 0.1 for Core Flow (%) and 5.0 for (SCS) Coolant Flow (%), and 9999.0 min. for duration (beyond the end of the run). Also click on the Decay Heat Power Multiplier button and leave the default value (1.0) in tact, allowing it to be selected later as a sensitivity parameter. If further clarification is desired, click on the HELP button. The resulting screen should look like Fig. 18. Save these entries and exit by selecting "SAVE."

Step 6. Select "Run" and then click on "Sensitivity Study" and "OK" on the Run Selection menu (Fig. 8).

Step 7. The screen for selecting design parameters to be used as sensitivity study variables (Sensitivity Study Curve and Parameter Selection screen, Fig. 19) appears next. Use the Multi-Variable, Peak Fuel Temperature vs Time Plot, and Maximize Objective Function (O.F.) default options, along with default O.F. multipliers (1.0) for each of the parameters figuring into the calculation of accident severity (click on HELP for more discussion). Click on the parameters "Core Cp (specific heat) Multiplier," "RPF Decay Heat Smear Factor 0-1," and "Graphite Oxidation Multiplier." The - and + limit values are defaults and can be modified. Note that the counter has tallied "3" as "Currently Selected out of 10." The screen should look like Fig. 19 except for any differences in design parameter values that may have been made subsequently. Click on "RUN," bringing up the File Selection menu for the "RUN" files (Fig. 9). Click on CalderDef.DEFAULT.RUN and OK to proceed to the accident screen for the reference run.

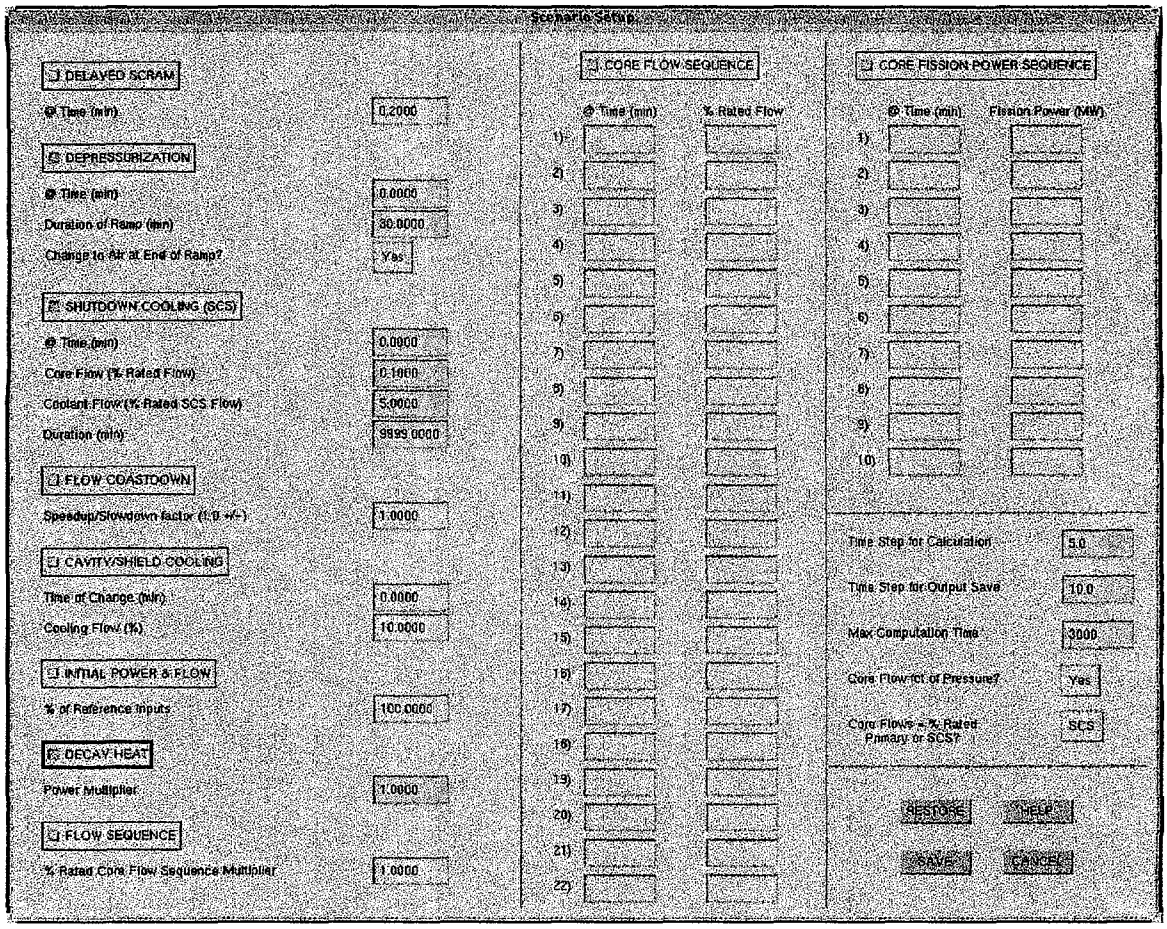

Figure 18. Case Study #3 – Programmed Inputs for Sensitivity Study Example

Step 8. The on-line plot setup screen appears next just as it did for the accident run (Case Study # 1). For each of the four plots, enter the plot categories and X-Axis time/length and Y-Axis parameter designations as desired. When the setup is completed, click on "OK" to bring up the accident screen. (Note: for some machines, it has been observed that having these plots running at the same time as the sensitivity screen plots slows down the process significantly. If this is the case, avoiding this step, i.e., not selecting any variables for the accident plots, is suggested.)

Step 9. Click on "RUN" to begin, and note the progress of the run via this screen and the plot screen (hit Alt-P to toggle between screens). This is the reference case GRSAC accident run for the sensitivity study, which will be used for comparison with subsequent sensitivity runs to be done later (automatically). It **MUST** run to completion to be valid as a basis for comparison with later runs. No manual input parameter changes via the accident screen are allowed during sensitivity runs. Figure 20 shows the accident screen at the completion of the reference run. When the run is complete, click "QUIT."

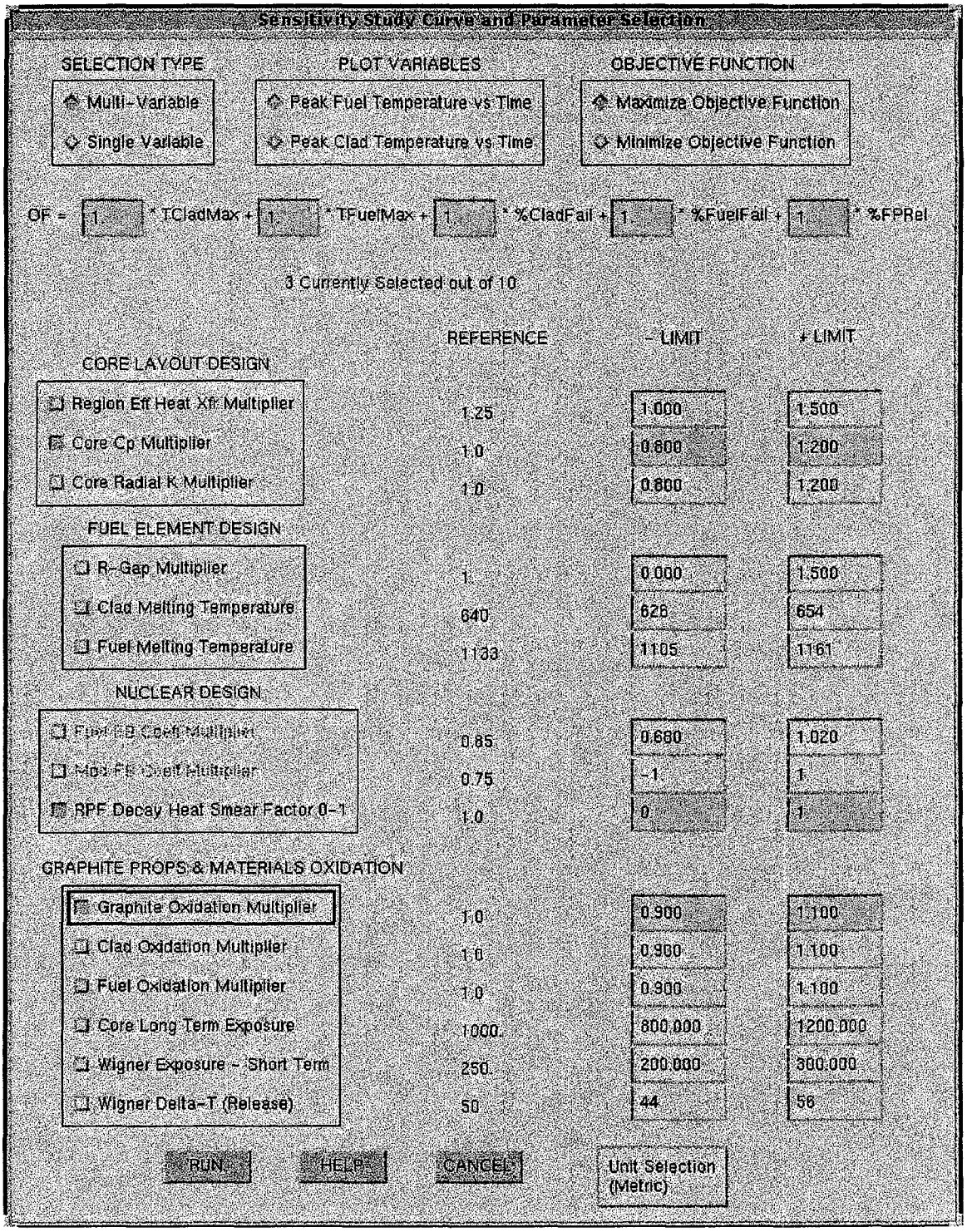

Figure 19. Case Study #3 – Design Input Selections for Sensitivity Study Example

Step 10. The screen for selection of operational parameters used in the sensitivity study (Fig. 21) appears next. Click on "DEPRESSURIZATION - @ Time (min)" and "DECAY HEAT: Power Multiplier," which brings the total number of parameters selected to 5. Change any of the - or + LIMIT entries if desired. At this point, the screen should look like Fig. 21 except for any parameter value changes made subsequently. Click on "OK" to begin the sensitivity runs.

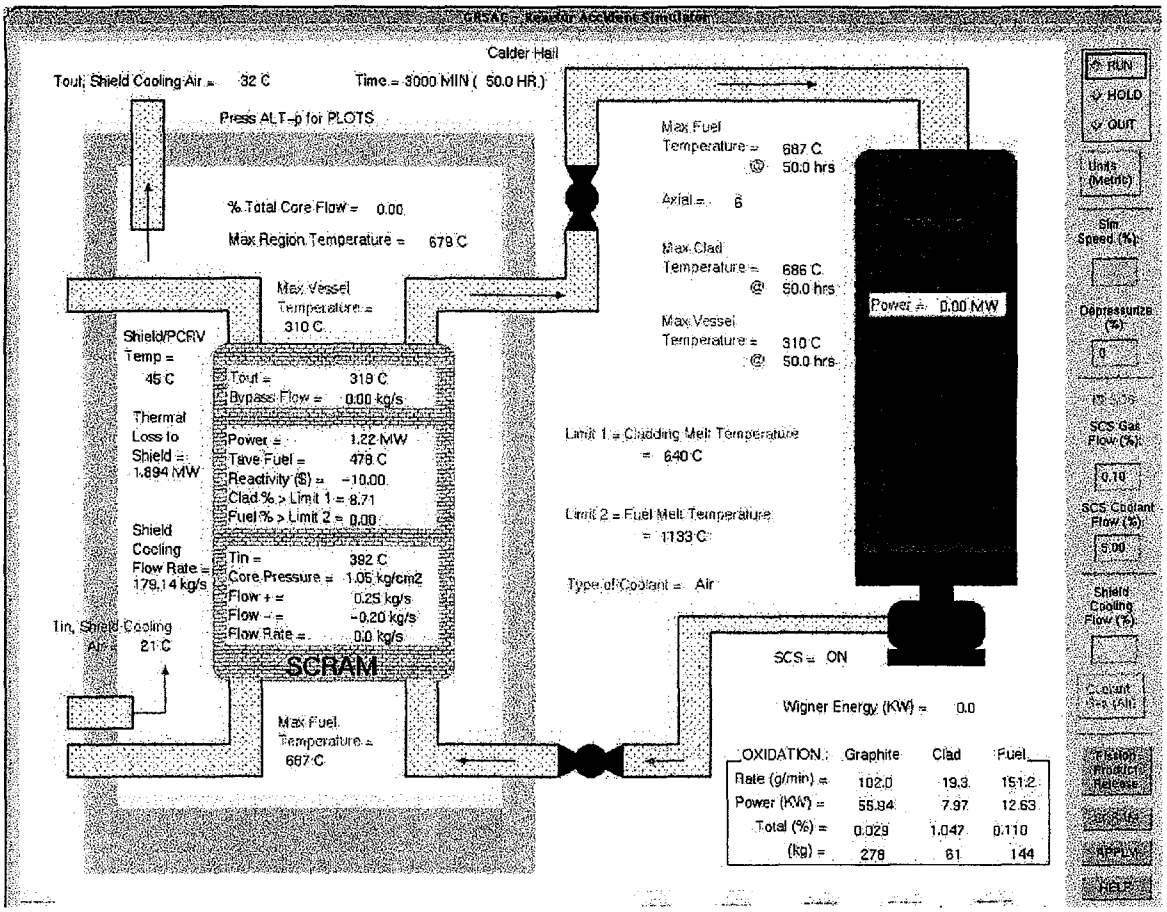

Figure 20. Case Study #3 – Accident Screen After Completion of Reference Run for Sensitivity Study Example

Step 11. The Sensitivity Study Run screen (Fig. 22) appears next, and each parameter variation run is set up and executed automatically. The user can monitor the progress of each run via this screen or by toggling to and from the accident screen (via ALT-p). The plots of maximum fuel temperature and objective function (O.F.) vs. time compare the current run with the reference case, and the tally box in the upper right keeps track of current and "best" cases vs. the reference for several parameters of interest. After the fifth parameter change run is completed, a sixth run is made with all the parameters set to their "best case" value in an attempt to maximize the O.F. Figure 22 shows the sensitivity screen at the end of the run.

Step 12. When the final sensitivity run is completed, a summary report of the study may be viewed by clicking on "REPORT." A printout of the example report is shown in Fig. 23. Exit the program by clicking on "RETURN."

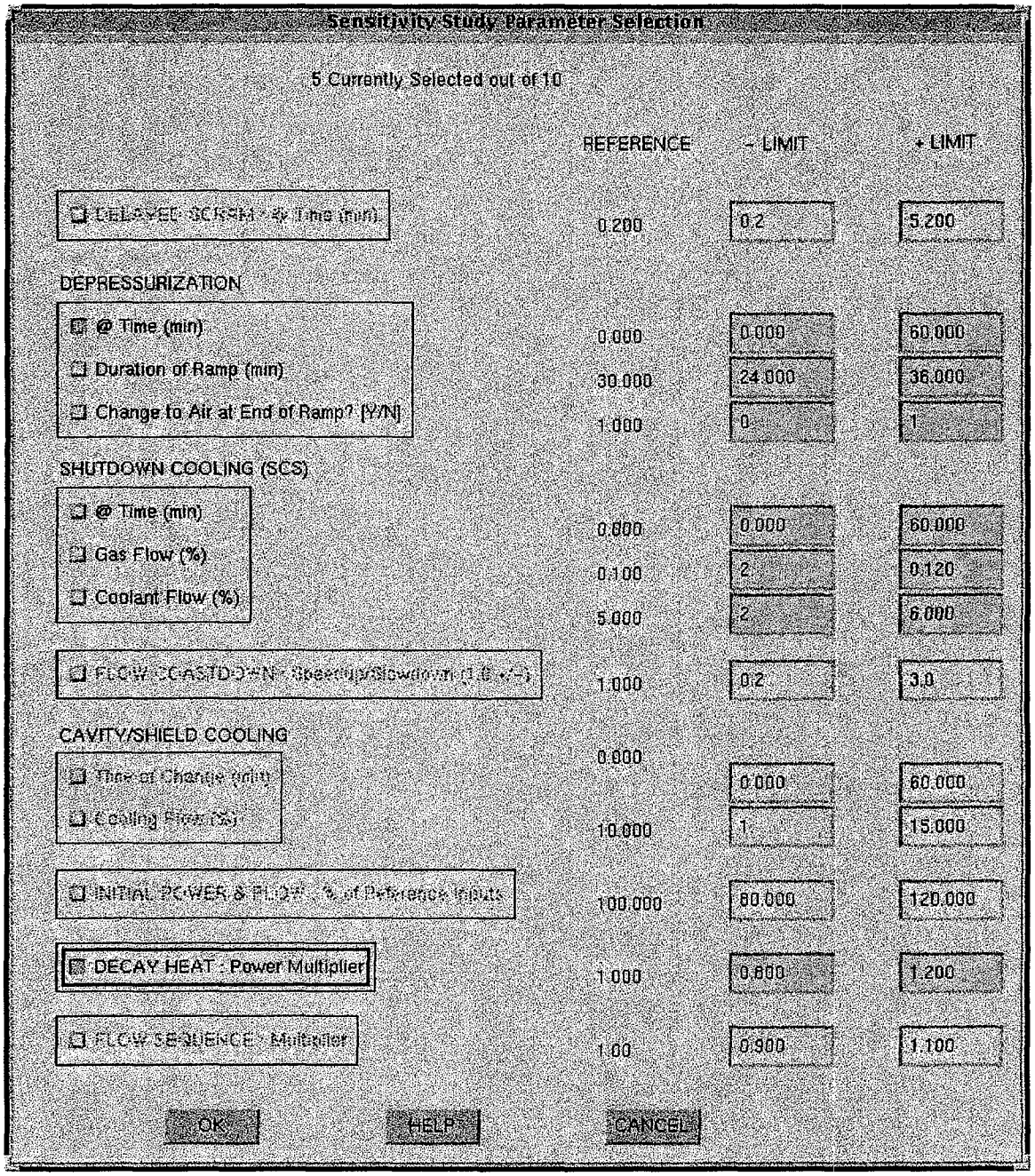

Figure 21. Case Study #3 – Operational Parameter Selection for Sensitivity Study Example

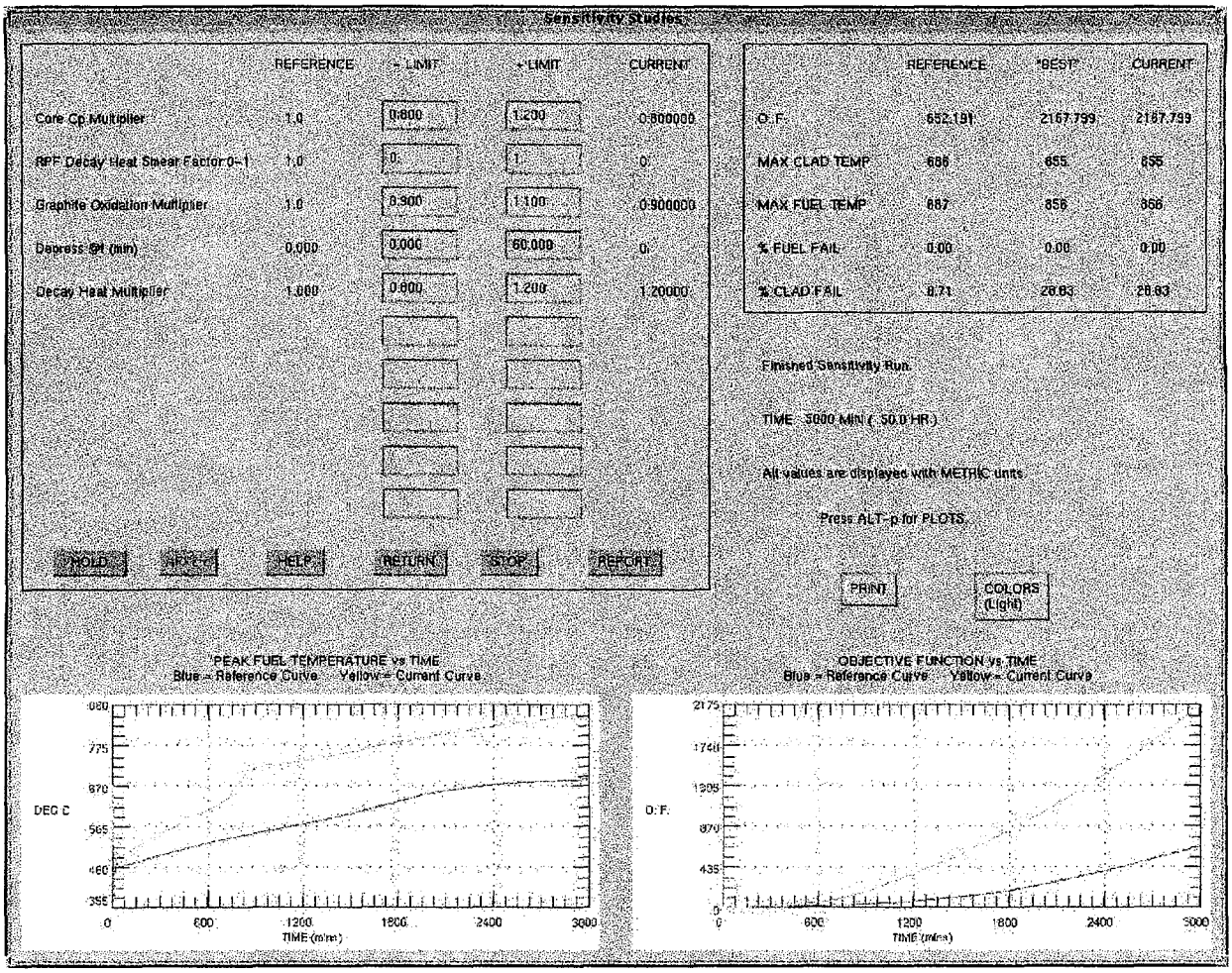

Figure 22. Case Study #3 – Sensitivity Study Example Run Screen After the Last Run

Case Study #4: New Reactor Simulation Model Setup with Initial Condition Run

Process: Selecting a reactor model type (G1), entering a new Simulation File name, selecting units, making model design changes to correspond to the Brookhaven (gas-cooled) Graphite Research Reactor (BGRR, which has a configuration similar to G1), selecting the IC run option, picking the IC file, setting up the on-line plots, running the IC simulation, and saving a new Brookhaven default RUN file.

GRSAC Sensitivity Study Report: 07/09/97 12:30 hrs

Reference Run: # Variables= 5 **Reference O.F.=** 652.191
T-max clad&fuel= 1267. 1268. **%Clad&fuel fail=** 8.71 0.00 **Sum %FP rel=** 0.80
Param # 2 **Core Cp multiplier**
Param # 9 **Radial peaking factor decay ht smear**
Param #10 **Graphite oxidation multiplier**
Param #17 **Depressurization @ time (min)**
Param #27 **Decay heat power multiplier**

Run # 1 **Param #** 2 **Default Value =** 1.000
New Param= 1.200 **New O.F.=** 461.215 **d(O.F.)/d(Param)= -0.95488E+03**
T-max clad&fuel= 1228. 1229. **%Clad&fuel fail=** 4.17 0.00 **Sum %FP rel=** 0.35

Run # 2 **Param #** 9 **Default Value =** 1.000
New Param= 0.000 **New O.F.=** 1109.229 **d(O.F.)/d(Param)= -0.45704E+03**
T-max clad&fuel= 1376. 1377. **%Clad&fuel fail=** 14.23 0.00 **Sum %FP rel=** 2.00

Run # 3 **Param #** 10 **Default Value =** 1.000
New Param= 1.100 **New O.F.=** 647.948 **d(O.F.)/d(Param)= -0.42430E+02**
T-max clad&fuel= 1264. 1265. **%Clad&fuel fail=** 8.59 0.00 **Sum %FP rel=** 0.70

Run # 4 **Param #** 17 **Default Value =** 0.000
New Param= 60.000 **New O.F.=** 631.897 **d(O.F.)/d(Param)= -0.33823E+00**
T-max clad&fuel= 1264. 1265. **%Clad&fuel fail=** 8.16 0.00 **Sum %FP rel=** 0.72

Run # 5 **Param #** 27 **Default Value =** 1.000
New Param= 1.200 **New O.F.=** 959.261 **d(O.F.)/d(Param)= 0.15353E+04**
T-max clad&fuel= 1352. 1353. **%Clad&fuel fail=** 19.63 0.00 **Sum %FP rel=** 2.02

Run # 6 **All params set to give best O.F.**
Param # 2 **Core Cp multiplier** **Param =** 0.800
Param # 9 **Radial peaking factor decay ht smear** **Param =** 0.000
Param # 10 **Graphite oxidation multiplier** **Param =** 0.900
Param # 17 **Depressurization @ time (min)** **Param =** 0.000
Param # 27 **Decay heat power multiplier** **Param =** 1.200
Final (Best) O.F.= 2167.799
T-max clad&fuel= 1571. 1573. **%Clad&fuel fail=** 28.83 0.00 **Sum %FP rel=** 4.16

Figure 23. Case Study #3 – Sensitivity Study Example Report

In this exercise, a typical process used for specifying the design data needed by GRSAC to create a new reactor model is demonstrated. The example use of the BGRR is appropriate because it has the same unusual horizontal coolant flow configuration as the reference model of the French G1 reactor (primary coolant air entering at the core midplane and exiting in opposite directions), but other characteristics such as power level, fuel element and channel configurations, and cavity cooling are different. Some typical "startup" problems, including coping with both incomplete and bad data, are demonstrated as well.

The reference data used to create the new model are taken from the IAEA description of the BGRR (Ref. IAEA Directory of Nuclear Reactors, Vol. 1: Power Reactors, IAEA, Vienna, 1959). At the time of the IAEA publication, the BGRR had been converted from a natural uranium (U-nat) core loading to one that used 93%-enriched-U and a bent-plate fuel element. A flow diagram for the converted case is shown in Fig. 24. The supplementary information given in the reference for the original U-nat fuel loading will be used for the Case 4 study, however.

Since parameters given in the IAEA reference are in English units, it is more convenient to use them for the data entry process. Running the program or revisiting the parameters in metric units is readily done by selecting the units option default as metric after the data entry process is completed.

Step 1. Derive core and fuel parameters:

The BGRR core is a rectangular prism, as opposed to a right cylinder as assumed in the standard GRSAC radial geometry core model. The active core dimensions are given as 11 ft 4 in. X 17 ft 4 in. X 16 ft 7 in. long. A volume-equivalent core diameter is 15.8 ft, with a length of 16.58 ft. The reflector outside dimensions are 25 ft square (and 25 ft long), giving an equivalent diameter of 28.2 ft. The two end reflector lengths would be (25 - 16.58)/2 = 4.21 ft. In this case, both ends are outlet reflectors. Average lengths of the two end plenums = 10 ft.

There are 670 fuel element channels in each of the two core sections on an 8-in. (0.667 ft) square pitch, with channel diameters of 2.67 in. (0.2225 ft). When entering this data for a new reactor model, it is advisable to use Fuel channel spacing option = "adjust diameter" (Option 2), since this provides a consistency check between core size and channel spacing. For the fuel element specification, the fuel rod diameter is given as 1.1 in. (0.0917 ft), cladding thickness 0.03 in. (0.0026 ft), and element O.D. (with fins) of 2.37 in. (0.1975 ft). Cladding material is aluminum (Al).

The rated thermal power for the U-nat core is given as 28 MW, as compared to the newer enriched core power of 16 MW; however, primary flow and outlet temperature data are not given for the U-nat case.

In the absence of other information, one option is to select a primary flow that gives the same outlet temperature as the one specified for the 16 MW case (256 lb/s): (28/16) * 256 lb/s = 448 lb/s or 26,880 lb/min. However, that is 75% greater than the newer value of flow, and thus would be a "suspect" assumption. Hence a compromise value of 23,040 lb/min (50% higher) is selected, along with a corresponding outlet temperature of about 325°F. Both G1 and the BGRR are cooled with

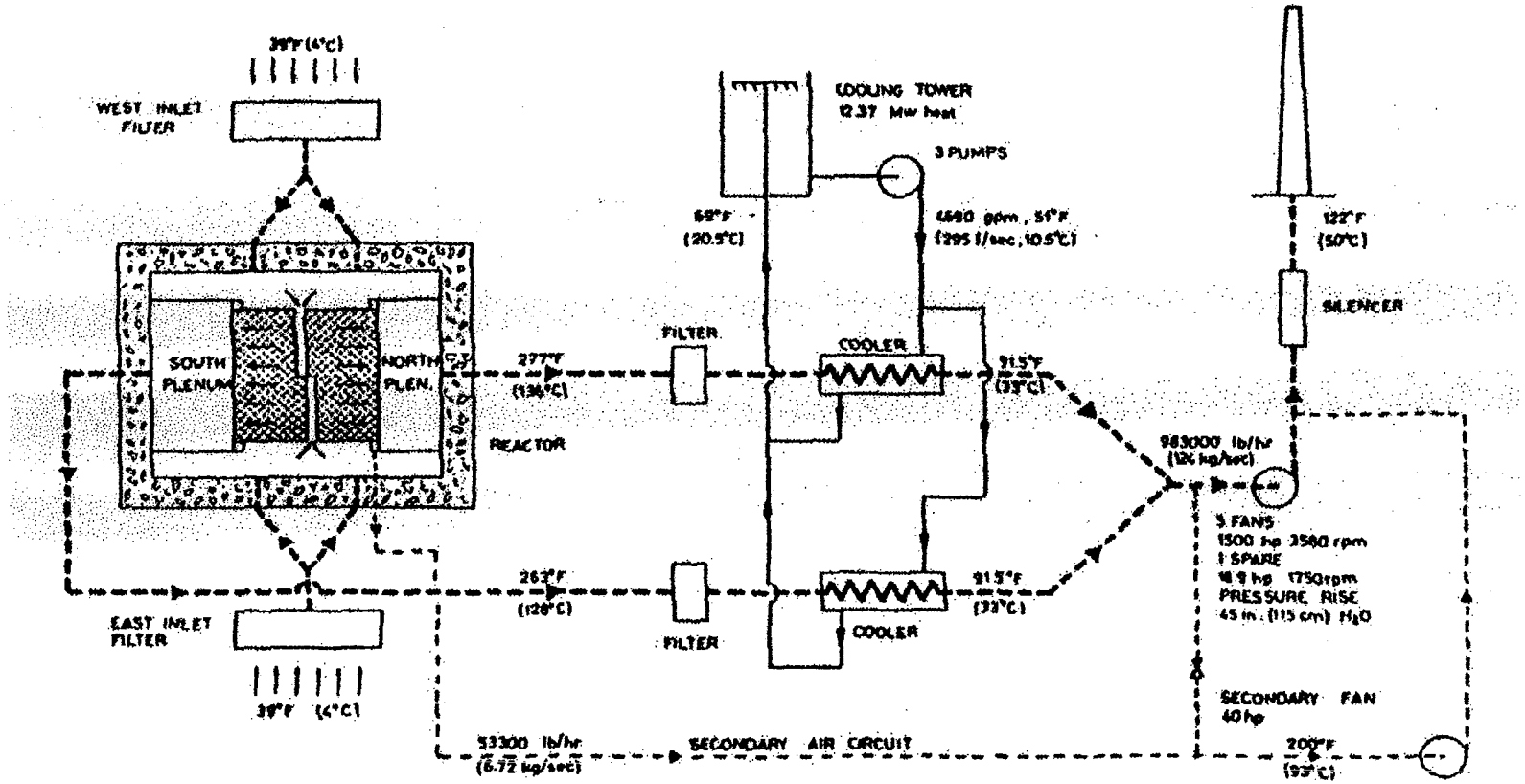

Figure 24. Flow Diagram of Brookhaven Graphite Research Reactor

atmospheric pressure air; however, the blowers are downstream of the core for the BGRR, vs upstream for G1. Hence the core inlet pressure, due to some pressure drop across the inlet filters, would be slightly less than atmospheric and is assigned a value of 14.65 psia.

Another key parameter is the core pressure drop. For the enriched core the pressure rise across the primary cooling fans (Fig. 24) is noted as 45 in. water (1.62 psi). In another place in the IAEA reference, the core outlet pressure is given as 12.75 psia, so with atmospheric pressure, the pressure drop would be 14.7 - 12.75 = 1.95 psi, which would include the inlet filters but exclude the outlet filters and coolers (as in the first estimate). Hence there is clearly some inconsistency in this data. The pressure drop characteristics for the U-nat fuel elements would be different in any case, so the initial entry of core delta-P is arbitrary (1.5 psi).

An important factor in the pressure drop calculation is the actual flow area in the fuel channel. The fuel element diameter specified usually refers to the outer diameter of the fins; however, the effective flow area depends on the orientation of the fins. Assuming that they are longitudinal (vs. transverse - the default case) the effective flow area is larger. For the G1 reference case, (G1 had longitudinal fins), the correction is made via the region flow area multiplier term (1.601 for G1). A similar correction term for the BGRR, assuming 8 longitudinal fins with the same thickness as the cladding, was calculated and equals 1.51.

Values for the core nuclear parameters are not given, so they will be assumed equal to the values used for the G1 core. Note that values for the Axial Peaking Factors (APFs) for G1 (and the BGRR) must be entered manually (see Fig. 25 for values to be used). Other parameters typically not specified, but which can have a significant effect on fuel temperatures, are the core bypass flow fraction (especially) and the fraction of the total nuclear heat that is generated in the reflectors. For this exercise, it is assumed that the flow bypass fraction is 0.03 and the reflector heating fraction is 0.015.

Step 2. Derive cavity and shield cooling parameters:

From dimensions given in the IAEA reference, the average thickness of the concrete and steel shield (vessel) = 4.2 ft, with an average gap between the reflector and shield of about 1.8 ft, and the effective heat transfer area for the shield (for shield cooling) = 2,500 ft sq. The reference is not clear about the shield and secondary (shutdown system?) cooling flows; however, it will be assumed from the data that the shield cooling flow is 44,000 lb/hr (12.2 lb/s) and the rated shutdown cooling flow is 53,300 lb/hr (14.8 lb/s). Note also that these values are given for the enriched core (16 MW rating), so they may in fact be larger for the U-nat rating of 28 MW.

The power removed by the shield cooler is not specified, and no information is given about properties of insulation (if any) inside the concrete shell, hence the inputs for cooling air outlet temperature (80 °F) and insulation thickness (default: 0.001 ft) are arbitrary. The computed air outlet temperature will eventually seek its own equilibrium value (for the initial condition calculation); however, the heat removal rate by the shield will be influenced by the insulation, as well as by the surface emissivity values, which are all assumed to be the default values.

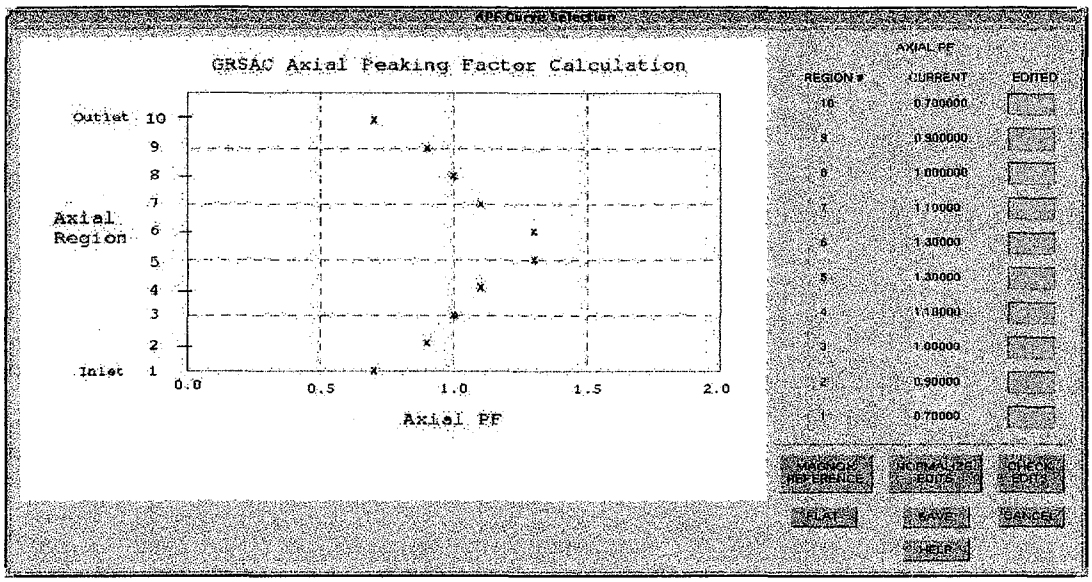

Figure 25. Case Study #4 – Axial Peaking Factors (APFs) Used for G1 Model

For natural convection calculations, note that a chimney is referred to and shown in the flow diagram, but a height is not given in the data sheet. Assume its effective height is 200 ft.

Step 3. Summary of design input changes from G1 defaults (English units), from discussions in Steps 1 and 2:

Fuel Element Design:

Fuel rod diameter	ft	0.0919
Fuel element diameter	ft	0.1499
Clad thickness	ft	0.0026
Clad material		Al

Fission Product Release Model: (no changes)

Vessel Design:

Outlet reflector length	ft	4.21
Inlet reflector length	ft	4.21
Side reflector O.D.	ft	28.2
Vessel inside diameter	ft	29.0
Vessel thickness	ft	0.5
Outlet plenum length	ft	10.0

Graphite Properties and Materials Oxidation:

Clad & fuel oxidation flag	Off
Graphite oxidation flag	Off
Wigner energy - anneal flag	Off

Core Layout Design:

Core (active) diameter	ft	15.8
Core (active) length	ft	16.58
No. of fuel channels		670
Pitch - fuel channel spacing	ft	0.667
Coolant channel diameter	ft	0.2225
Fuel channel spacing option		"Adjust Diameter"
Core bypass flow fract (SR)		0.03
Region flow area mult		1.51

Nuclear Design:

Core full (rated) power	MW	28.0
APF curve		(see Fig. 21)

Reactor Cavity Design:

Shield cooler HT area ft^2	2500.	
Reactor cavity effective ID	ft	33.6
Shield thickness	ft	4.2
T-shield cooler gas outlet	F	80.0
Flow-shield cooler gas	lb/s	12.2
Chimney height	ft	200.0
Ambient air temperature	F	39.0

Primary Cooling Design:

Initial primary pressure	psia	14.65
Initial total mass flow	lb/min	23040.
Core pressure drop	psi	1.5
Core inlet temp	F	39.0
Core outlet temp	F	325.0
SCS rated (primary) flow	lb/s	14.8

Step 4. Initial setup and detection of problems:

At the GRSAC Main Menu (Fig. 1) select "Create New Simulation," and from the Create New Simulation menu (Fig. 26), select G1 and "OK." At the Simulation Filename Entry Screen (Fig. 27), enter a new master simulation filename (e.g., caseBGRR) along with any comments in the description field, and click on "OK." The .SIM extension is added to the filename automatically. The next screen to appear is the Default Units Menu (Fig. 3): select "English" and "OK." From the Simulation (Edit-Run) Menu (Fig. 4), click on Edit Design Input Selections, and for each of the design input categories requiring a change in input (see Step 3), add the appropriate data, in each case clicking on Save after verifying that the correct entries have been made. For additional guidance about any of the data entries, click on the appropriate help button.

After all the design data changes have been made, click on the Continue button on the Edit-Design Input Selection Menu, and then proceed to click on the "Run With Validation" option in the Simulation (Edit-Run) Selection Menu. The resulting validation analysis display should provide the following information about the setup:

1. The gap between the reactor and the shield was less than a nominal minimum value of 3 ft (1.8 ft). This should not present a problem to the simulation.

2. The computed weights of U-nat and the graphite components are displayed. The value for natural uranium, 35 metric tonnes = 77,000 lb, is compared to the value noted in the IAEA Reference of 110,000 lb. This type of inconsistency should prompt a revisitation of the input data; however, it is common for such reference sheets. No graphite weights are listed in the reference sheets.

3. The calculation of an effective active core diameter needed to accommodate the 670 fuel channels in a square lattice with a pitch of 0.667 ft indicated that the diameter required to accommodate these channels would be 19.48 ft, vs. the input value of 15.8 ft. This clearly indicates an error in the input specification. From inspection of the core drawings in the reference, it is seen that the core cross section is nearly square. If we assume that the core section was 17 ft 4 in. square, instead of having one side 11 ft 4 in. as listed, the equivalent active core diameter would be 19.56 ft, which is consistent with the calculated value of 19.48 ft required to accommodate the 670 channels. With this problem resolved, it is recommended that the channel spacing option be changed to "adjust pitch" (Option 3), which holds the input value of core diameter and alters the pitch to accommodate any differences. In general, this option gives a better representation of cores that have non-fuel elements (experiment holes, etc.) interspersed.

4. Exit the Input Validation screen by clicking on the Edit button, and then on the Input Selection screen that appears next. Click on Core Layout Design to make the corrections as noted above: Core (active) diameter = 19.56 (ft), and Fuel channel spacing option = "adjust pitch." After exiting the screen via the Save button, it is a good idea to revisit the validation routine. Click on the Continue button on the Edit-Design Input Selection Menu, and then proceed to the "Run With Validation" option from the Simulation (Edit-Run) Selection menu.

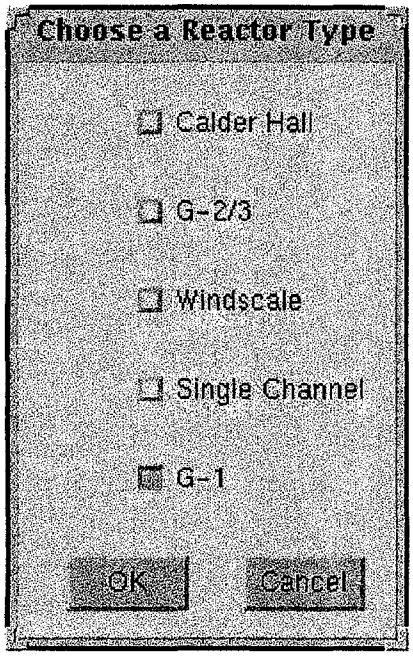

Figure 26. Create New Simulation Menu

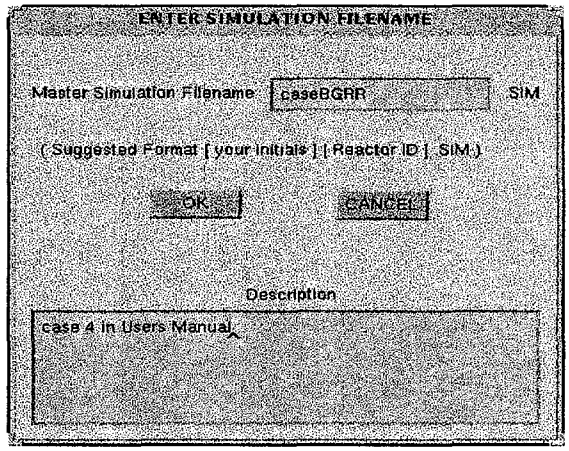

Figure 27. Simulation Filename Entry Screen

The resulting validation analysis displays the adjusted pitch with the revised core diameter and the channel spacing option (3) as 0.6697 ft, vs. the value of 0.667 ft that was input.

Step 5. Run an Initial Condition case:

Exit the Input Validation screen by clicking Run, and then Initial Condition and OK on the Run Selection Menu (Fig. 8). On the File Selection menu that appears next (Fig. 9), click on the default file that was created for this new model, which in this case is called caseBGRR.DEFAULT.RUN, and "OK." This brings up the Initial Condition Plotting screen (Fig. 14), allowing the user to specify variables to be observed during the IC run. In the upper left screen, which can display up to three temperatures vs. time, select all three. For the other three screens, in at least two cases, select a gas outlet temperature vs. length and a fuel temperature vs. length to observe the wing-shaped profiles obtained with the coolant entering at the core midplane.

Click "OK" when done, and then RUN on the Initial Conditions screen (Fig. 28). Observe the progress of the run from this screen and via the plot screen (toggle between the two via "Alt-p"). Also observe other variations of the core map on the IC screen (e.g., fuel temperatures at various axial planes and flow distribution). Profile plot parameters can be re-specified during the run. Fig. 29 shows plots of the temperature trends, along with various radial and axial temperature profiles.

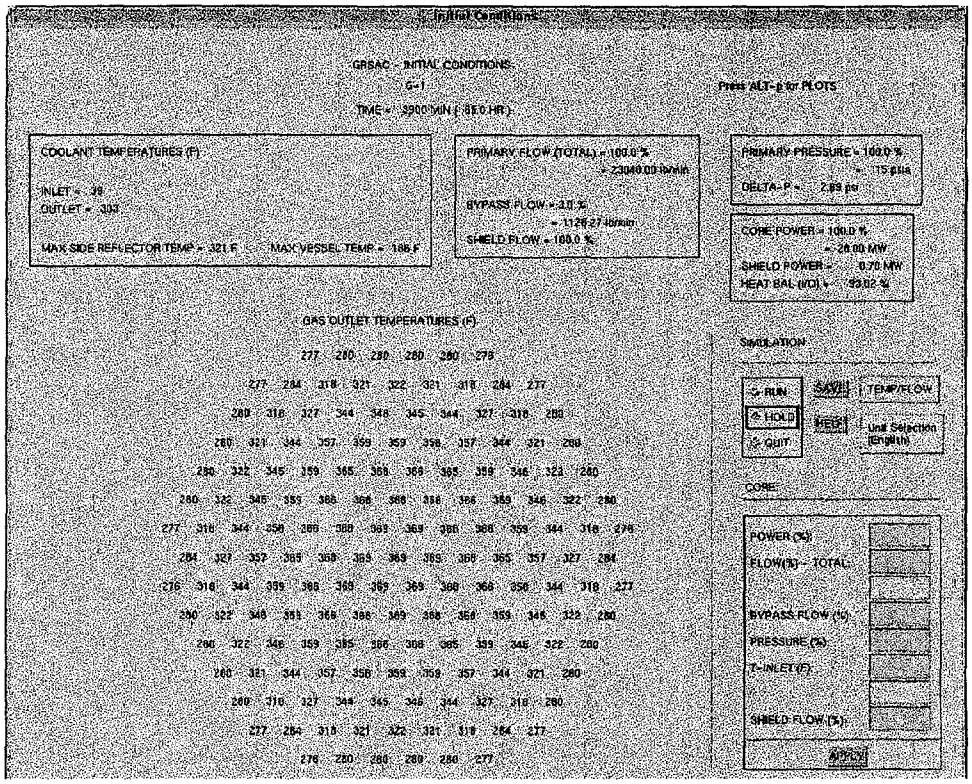

Figure 28. Initial Condition (IC) Run Screen for G1 Model, Case Study #4 (after 125h)

Step 6. Follow-up analysis:

In the initial run, it may be noted that the steady-state value of core pressure drop is about 1 psi higher than the 1.5 psi specified in the input. In the initial G1 core conditions, GRSAC calculated that a higher pressure drop was required given the initial flow and the higher temperature conditions for the G1 Default core. In subsequent initial condition runs which start at lower temperature conditions that result from the previous IC run(s), GRSAC would not have to increase the pressure drop as much, and pressure drops as low as about 1.7 psi are attainable.

Another very important input parameter not considered so far is the core's "Flow skew factor" in the Primary Cooling Design Input Screen. The outlet temperature distribution skews in gas-cooled reactors can be quite large if the central radial peaking factors are high and there are no compensating orificing capabilities to apportion more flow to the higher-power channels. The default value of skew factor is 0.5, half-way between 0.0 (all channel flows equal) and 1.0 (flows skewed to equalize all channel outlet temperatures). Varying the skew factor can also affect reflector and vessel temperatures, and may alter the heat removal via the shield cooler.

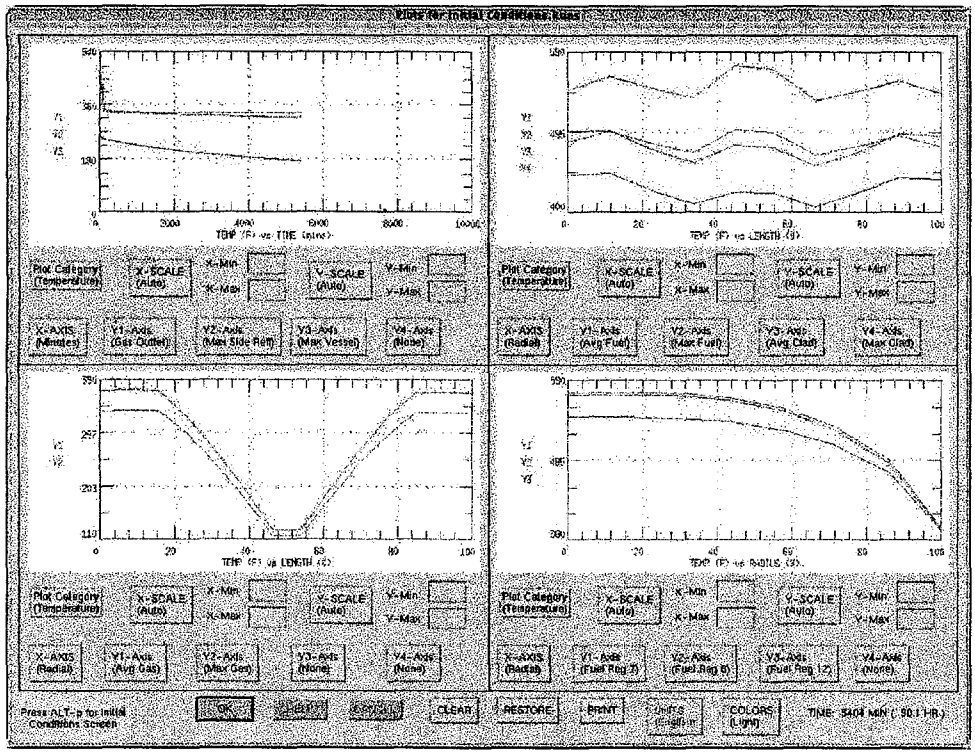

Figure 29. Typical Initial Condition (IC) Plot Screen for G1– Type Model, Case Study #4 (after 90h)

III. DETAILED DESCRIPTION AND USE OF MENUS AND INTERACTIVE SCREEN FEATURES

1. Main Menu

The first screen to appear following a normal startup of the GRSAC program is the GRSAC Main Menu (Fig. 30). GRSAC startup options and instructions are described in detail in Section V. Note that in some cases, with another large-color map program already running, there may be color allocation problems. In such cases, the user can either start GRSAC first or make the color selections manually, as described in Section V.

The main menu of the GRSAC program enables a user to access reference material, create new simulations, retrieve existing simulations or quit the program.

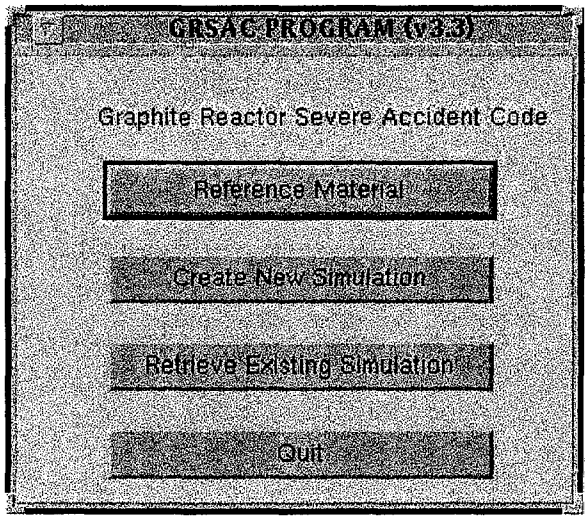

Figure 30. Main Menu

Reference Material

The GRSAC program provides updated online Reference Material. The main Reference Material menu is shown in Figure 31. Available options include Input Data Instructions, Help, Plotting, Code Descriptions and Software Requirements Documentation. To access these help areas use the mouse to click on the area of interest. Categories under the Help button are Installation, General Help and Startup. Figure 32 illustrates the Help submenu. GRSAC can be installed via floppies or a CD ROM. For information on the installation procedure, see Sect. IV or press the Installation button and then press the Floppy Disk or CD button as shown in Figure 33. The Code Descriptions submenu is illustrated in Figure 34 and includes detailed information on both the simulation and the Graphical User Interface (GUI) codes.

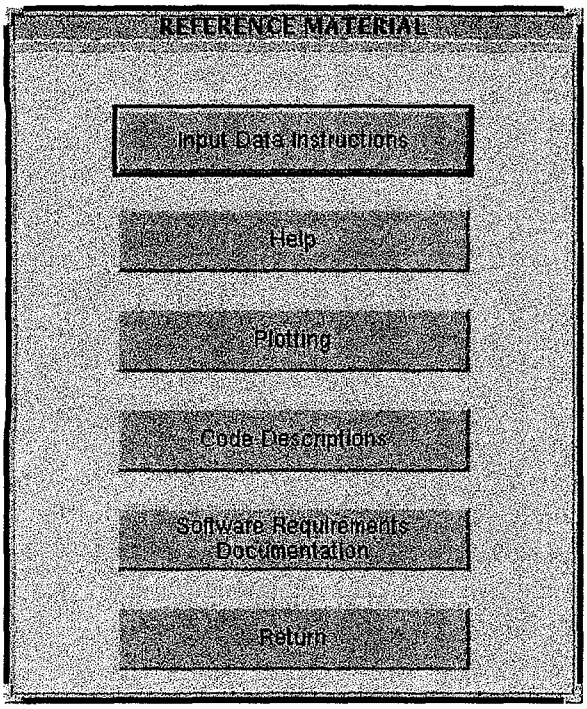

Figure 31. Reference Material Menu

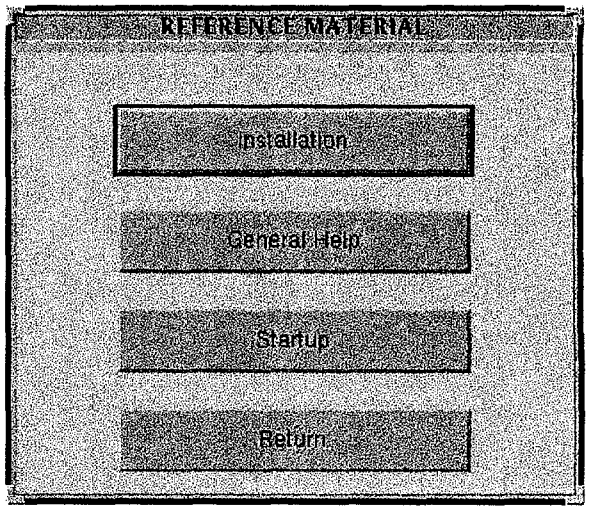

Figure 32. Help Menu

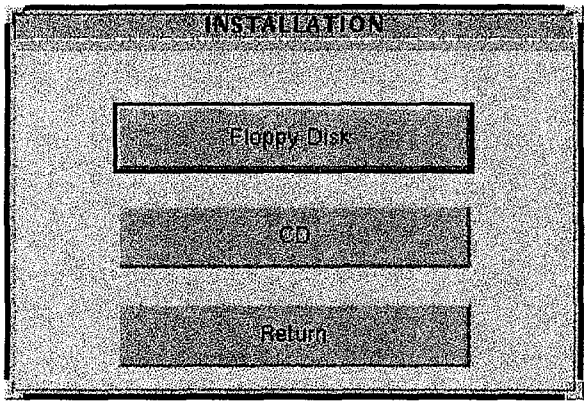

Figure 33. Installation Menu

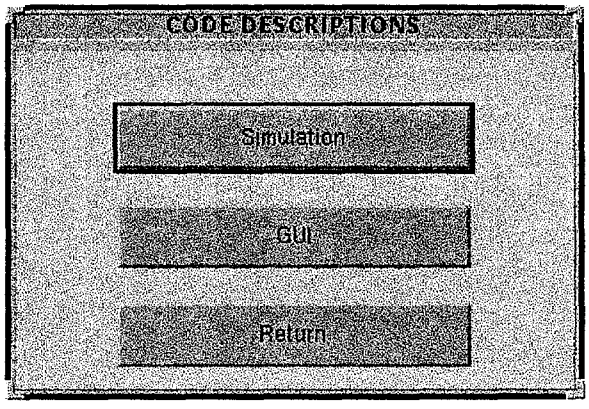

Figure 34. Code Descriptions Menu

Create New Simulation

To create a new simulation click on the Create New Simulation button on the main GRSAC menu. Available reactor types include Calder Hall, G-2/3, Windscale, Single Channel and G-1. The menu for selecting a reactor type is shown in Figure 35. To select a reactor type, use the mouse to activate the toggle button beside the needed reactor type. Toggles can be deactivated by moving the mouse cursor to an activated toggle and pressing the left mouse button. Only one reactor type can be selected. After a reactor type is selected, press the OK button to continue. Pressing the Cancel button returns to the GRSAC main menu.

After pressing the OK button on the Reactor Type selection menu, a screen for entering the Master Simulation filename is displayed. This screen is illustrated in Figure 36. It is suggested that a reactor identifier be included in the filename so that when simulation filenames are displayed it is clear which reactor the simulation models. A Description area is included in the bottom portion of the screen. This area is to be used for notes about the simulation or reactor. Entering a description is optional but inadvisable . To enter information in the Description area, move the mouse cursor to the Description input area, press the left mouse button to activate the input area and type in the information. Press the OK button to continue on to the Design Input screen. Pressing the CANCEL button returns to the GRSAC main menu.

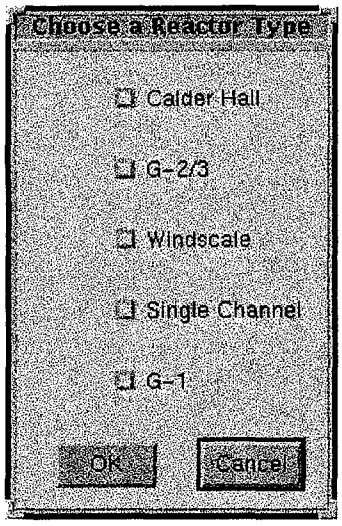

Figure 35. Create New Simulation Menu

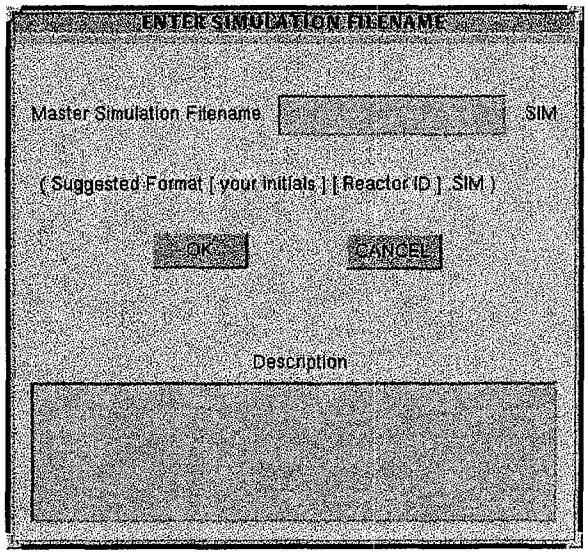

Figure 36. Simulation Filename Entry Screen

Retrieve Existing Simulation

To retrieve an existing simulation press the Retrieve Existing Simulation button on the main GRSAC menu. A file selection menu will be displayed with all the simulations previously created. A example of the file selection display for simulation files is shown in Figure 37.

For instructions on the use of the .SIM file selection menu, see the general help section (Section III.3).

Once a simulation file is selected and the OK button pressed, the Units menu is displayed as shown in Figure 38. Use the mouse to select either English or Metric units. The GRSAC program enables unit selection to be changed throughout the process of setting up and running the simulation.

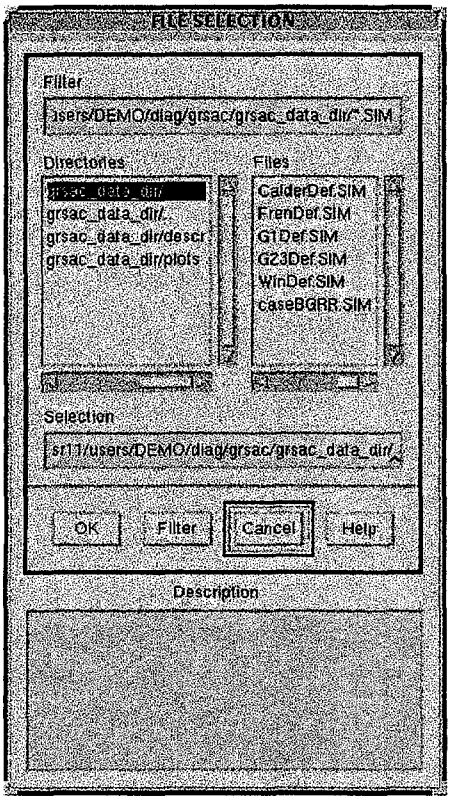

Figure 37. File Selection Screen (Applicable for IC, Accident, and Sensitivity Study)

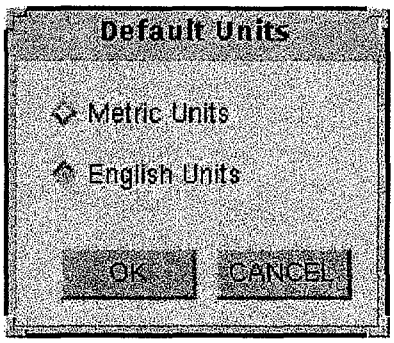

Figure 38. Choice of Units Menu

2. Simulation (Edit–Run) Selection Menu

Once a simulation file is either created or retrieved, the Simulation Selection menu is displayed. This menu is illustrated in Figure 39. Options for the Simulation Selection menu are run a simulation, run a simulation with validation, edit run programmed inputs, edit design input selection, post run plots, fission product holdup release calculations and maintenance. Pressing the CANCEL button returns to the GRSAC main menu. Following are detailed descriptions of the Simulation Selection menu options.

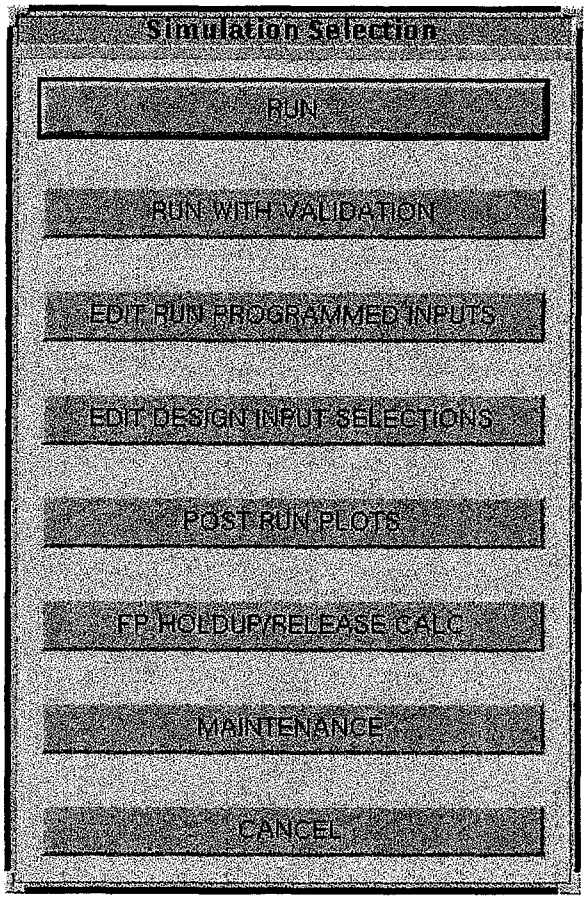

Figure 39. Simulation (Edit-Run) Selection Menu

Edit Design Input Selections

Pressing the Edit Design Input Selections button on the Simulation Selection menu displays the menu shown in Figure 40. Design inputs can be altered for the fuel element, core layout, fission product release model, nuclear design, vessel, reactor cavity, graphite properties and materials oxidation and the primary cooling system. Default values are given for each of the design input selections. If the default values have been changed for a design input selection category, the Edited toggle is activated (displayed in red) to the right of the associated design input selection button. If only the default values are being used for a given category, the Edited toggle remains inactive. To view or edit a design input category, use the mouse to press the appropriate button. Following is a detailed description of each input design screen. Pressing the DONE button returns to the GRSAC main menu. The CONTINUE button goes back to the Simulation Selection menu.

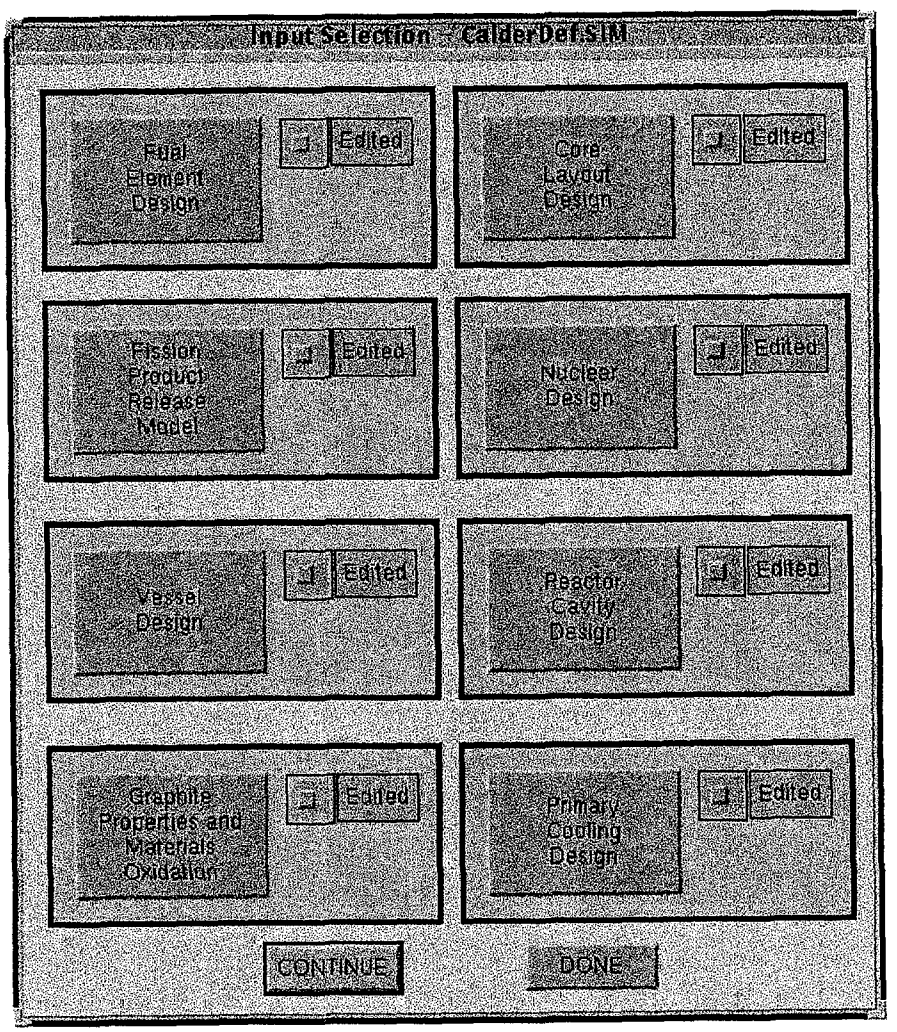

Figure 40. Edit–Design Input Selections Menu

Fuel Element Design

Pressing the Fuel Element Design button on the Edit Design Input Selection menu displays the screen shown in Figure 41.

A fuel element type is selected by pressing the button underneath the desired fuel element, displaying the appropriate defaults for that fuel element type under the DEFAULTS columns. Default values are also changed based on cladding and fuel material selections.

Clad Matl: 1=Al, 2=Mg, 3=SS:	Clad material: 1=Aluminum; 2=Magnesium; 3=Stainless steel
Fuel element diameter:	Fuel element effective diameter
Fuel rod diameter:	Fuel rod diameter
Fuel Matl: 1=U-metal, 2=UO2:	Fuel: 1=Uranium metal; 2=Uranium oxide
R-Gap multiplier:	Multiplier for clad-to-fuel gap resistance The nominal gap resistance in the model is taken from a nominal G2/3 value for "typical" gap resistance. A 0.0 value reduces the gap delta-T to zero.
Clad thickness:	Cladding thickness
Clad melting temperature:	Clad melting temperature –Note that this input can be used as an "ignition" temperature for air ingress accidents to indicate how much of the clad may have burned. The ignition temperature for Mg is in the range of 625°C for pure Mg, and most alloys reduce the ignition temperature.
Fuel melting temperature:	Fuel melting temperature - as above for the clad, the limit temperature can be used to indicate ignition during air ingress accidents. The ignition temperature for U-metal is about 600°C, and is lower for most alloys (in the 400-500°C range).

Pressing the SAVE button saves the input data and returns to the Edit Design Input Selection menu. The CANCEL button restores the previous set of saved input data and returns to the Edit Design Input Selection menu. The HELP button displays a help file for describing the input data options. The Unit Selection pulldown menu enables units to be changed to either English or Metric.

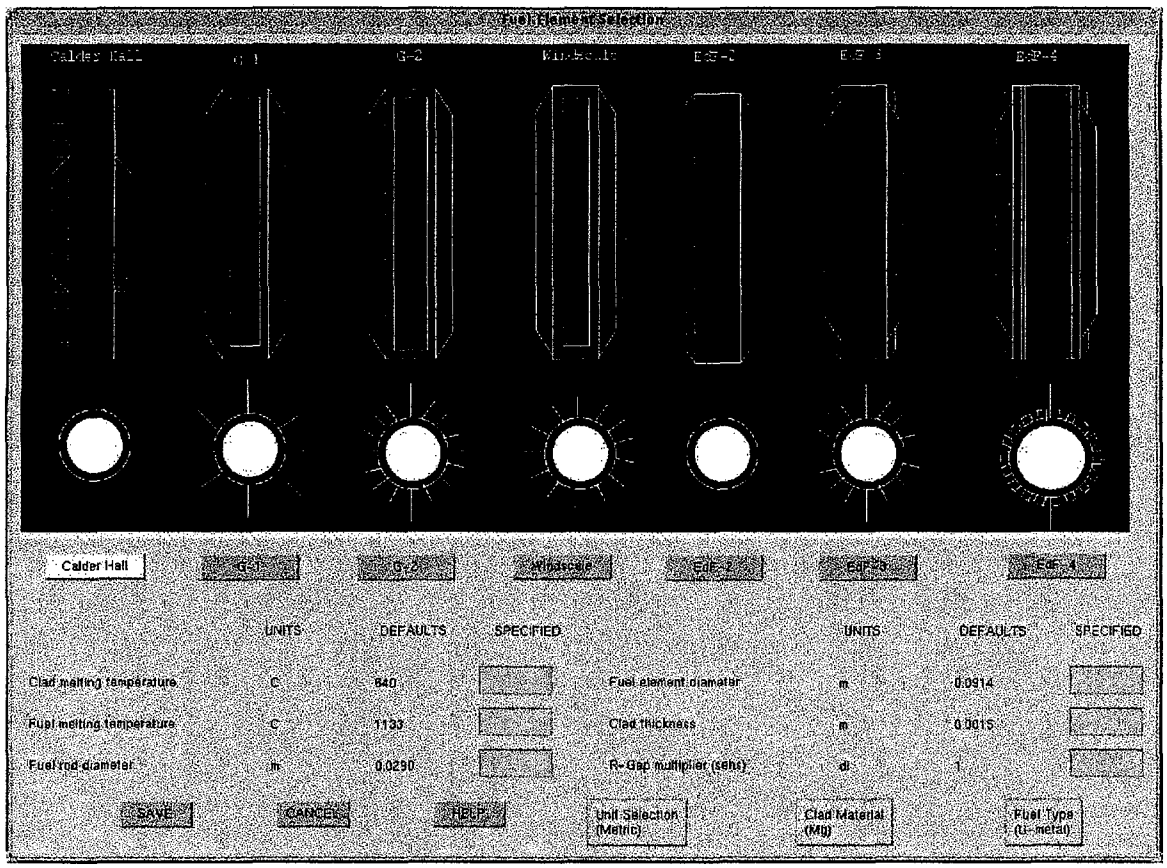

Figure 41. Fuel Element Design Input Screen

Fission Product Release Model

Pressing the Fission Product (FP) Release Model button on the Edit Design Input Selection menu displays the screen shown in Figure 42.

Fission Product release flag	Flag to activate FP release models: Off (0); All eight FP groups calculated (1); or only groups 1 & 2 calculated (2).
Avg core burnup for FP calc	Burnup (core average) for FP calc. Each node is multiplied by axial & radial PFs to get node-specific burnup of fuel.
FP temp enhance, group R1	Bias temperature in FP release model for Group R1 (noble gasses). Bias is added to fuel temperature for use in release correlation.
FP temp enhance, group R2	Bias temperature in FP release model for Group R2 (iodine).
FP temp enhance, groups R3-8	Bias temperature in FP release model for Groups R3 - R8.

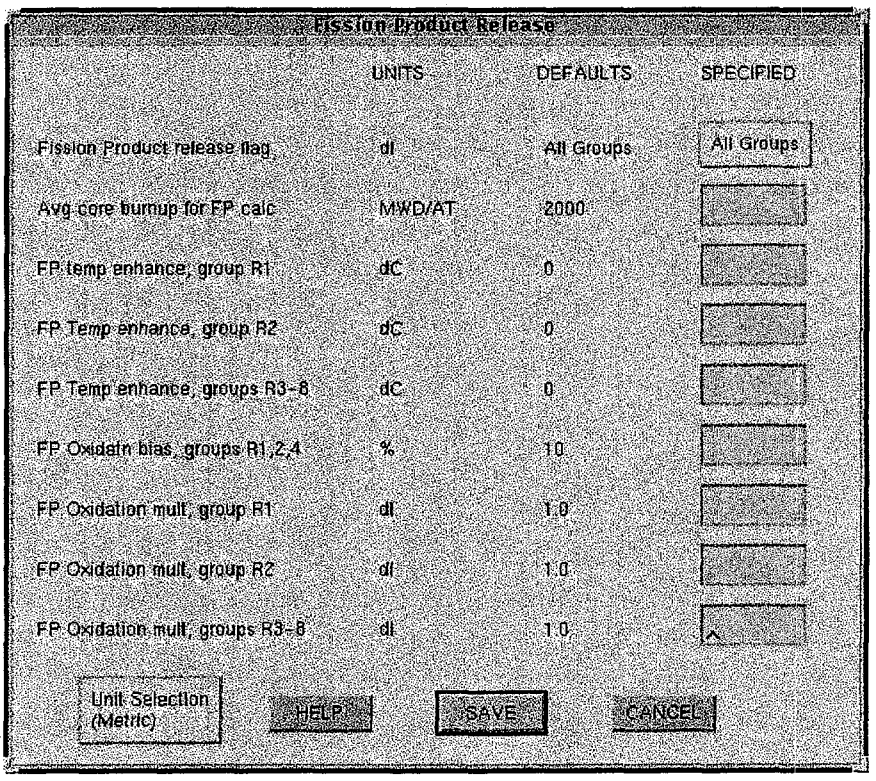

Figure 42. Fission Product Release Model Design Input Screen

FP Oxidation bias groups R1,2,4 Oxidation term bias in FP release model for Group R1 (noble gasses, 100% effect), Group 2 (Iodines, 10% effect), and Group 4 (Tellurium, 10% effect). Model predicts no FP release unless some fuel is oxidized. One exception: all noble gases are released when U-metal melting temperature is reached.

FP Oxidation mult, group R1 Oxidation term multiplier in FP release model for Group R1 (noble gasses).

FP Oxidation mult, group R2 Oxidation term multiplier in FP release model for Group R2 (iodine).

FP Oxidation mult, groups R3-8 Oxidation term multiplier in FP release model for Groups R3 - R8.

The fission product groups (R1 - R8) are as follows:

1. Noble gases
2. Halogens (Iodine)
3. Alkali metals
4. Tellurium group
5. Alkaline Earths
6. Noble metals
7. Lanthanides
8. Cerium group

Pressing the SAVE button saves the input data and returns to the Edit Design Input Selection menu. The CANCEL button restores the previous set of saved input data and returns to the Edit Design Input Selection menu. The HELP button displays a help file for describing the input data options. The Unit Selection pull down menu enables units to be changed to either English or Metric.

Vessel Design

Pressing the Vessel Design button on the Edit Design Input Selection menu displays the screen shown in Figure 43.

Outlet reflector height/length	Height of outlet reflector
Inlet reflector height/length	Height of inlet reflector
Side reflector O.D.	Outside diameter of side reflector
Vessel inside diameter:	Effective inside diameter of vessel
Vessel thickness:	Thickness of vessel
Vessel insulation thickness CH:	(C) Thickness of insulation on vessel OD
Inlet plenum height:	Height of inlet plenum
Outlet plenum height:	Height of outlet plenum
Liner/RCCS emissivity:	Emissivity of shield liner wall surface
Reflector emissivity:	Emissivity of side reflector outside surface
Vessel inside emissivity:	Emissivity of vessel inside surface
Vessel outside emissivity:	Emissivity of vessel outside surface

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(C) - Calder Hall models only

Pressing the SAVE button saves the input data and returns to the Edit Design Input Selection menu. The CANCEL button restores the previous set of saved input data and returns to the Edit Design Input Selection menu. The HELP button displays a help file for describing the input data options. The Unit Selection pulldown menu enables units to be changed to either English or Metric.

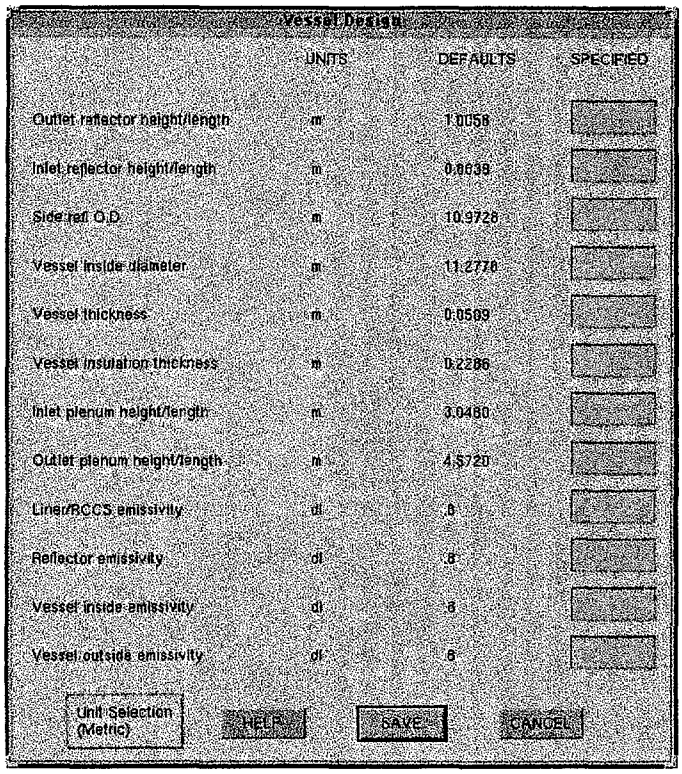

Figure 43. Vessel Design Input Screen

Graphite Properties and Materials Oxidation

Pressing the Graphite Properties and Materials Oxidation Design button on the Edit Design Input Selection menu displays the screen as shown in Figure 44.

Clad & fuel oxidation flag

The three options are: Off (ICFOX=0); ON Fuel Exp w/Clad Ox–either clad melt or oxidation exposes fuel (1); or ON Fuel Exp w/Clad Ox only–clad oxidation only exposes fuel (2). Air oxidation of cladding and fuel is calculated when this flag=1 or 2. CO_2 oxidation of exposed U-metal fuel is calculated in either case. The graphite oxidation flag must also be set. If ICFOX=1, clad failure in a node due either to overtemperature OR oxidation of 90% or more of the cladding material exposes the fuel to oxidation. If ICFOX=2, fuel is not exposed due to clad melting. Clad "melt" will cause the clad to disappear (fall out of the core) except for horizontal channels, where it continues to oxidize in that node until it burns up. Clad node failure due to oxidation is included in the tally of the "percent clad fail" output. In the case of CO_2 oxidation of U-metal fuel, if there is a subsequent depressurization and air ingress, the oxidation of graphite, cladding and fuel is modeled as with the ICFOX=1 option.

Graphite oxidation flag

The three options are: Off (IGOX=0); Reference Parms: use reference function (1); or Windscale Parms: use Windscale function (2). The graphite oxidation routine is activated when this flag IGOX is set (>0) AND the primary system coolant gas is air. If IGOX=1, the reference case oxidation parameters are used; if =2 Windscale graphite parameters are used. Sensitivity values for the two types of oxidation modes ("Zone 1 or Zone 3") can be set via sensitivity multipliers (below).

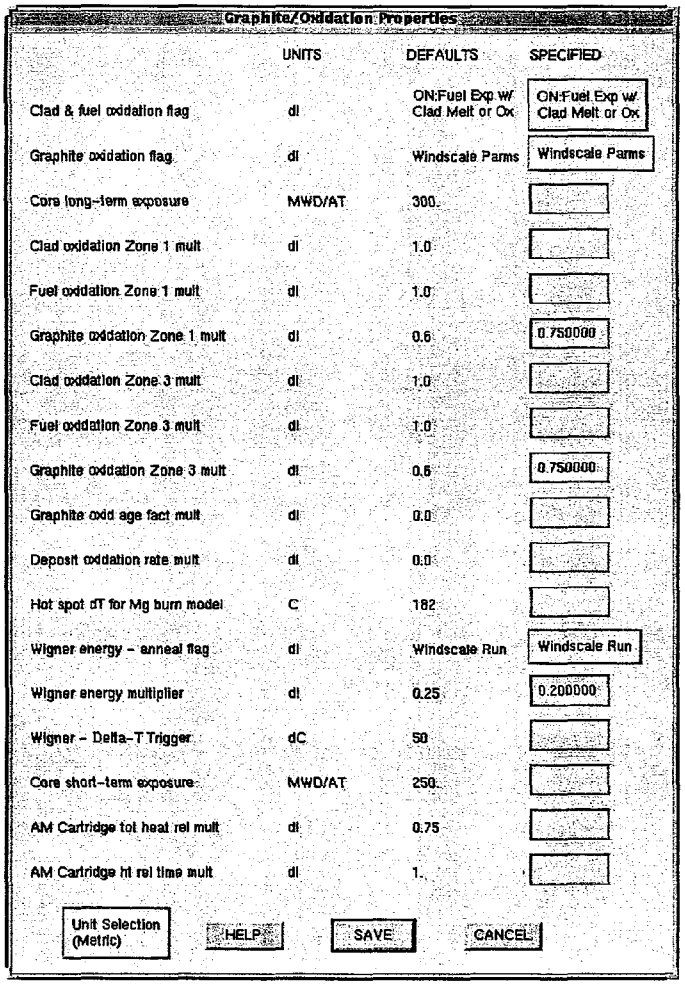

Figure 44. Graphite Properties and Materials Oxidation Design Input Screen

Core long-term exposure

Exposure values in Megawatt-days per adjacent metric ton of fuel (MWd/AT) used in calculation of Wigner energy high-temperature ("tail"), age-(exposure) dependent graphite oxidation, and for carbon deposit buildup in CO_2-cooled reactors.

Clad oxidation Zone 1 mult	Multiplier for Zone I clad oxidation rate, governed primarily by the intrinsic chemical reactivity of the clad according to the Arrhenius relationship exp(-E/RT). The reaction is assumed to occur at the exposed surface. The lesser of the two rates (Zone 1 or Zone 3) is controlling.
Fuel oxidation Zone 1 mult	Notes for clad oxidation apply here.
Graphite oxidation Zone 1 mult	Notes for clad oxidation apply here, except that in this case, rather than being a surface reaction, the reaction is assumed to occur uniformly throughout an Active Oxidation Zone (AOZ) (which is a function of temperature) near the exposed surface.
Clad oxidation Zone 3 mult	Multiplier for Zone III clad oxidation rate is governed by mass transfer to the exposed surface, where the oxidation occurs. The calculated mass transfer rate is dependent on the degree of turbulence (laminar, transition, and turbulent regimes) and the diffusion coefficient, which is proportional to the absolute temperature to the 1.8 power. The lesser of the two rates (Zone 1 or Zone 3) is controlling.
Fuel oxidation Zone 3 mult	Notes for clad oxidation apply here.
Graphite oxidation Zone 3 mult	Notes for clad oxidation apply here.
Graphite oxid age factor mult	Multiplier for age (exposure) factor in graphite oxidation model, which assumes that oxidation rate increases linearly (1.0 to 4.74) from 0 to 25,250 MWD/AT, which corresponds to 39 years at Calder Hall.
Deposit oxidation mult	Multiplier for carbon deposit oxidation rate in model for CO_2 cooled reactors.
Hot spot dT for Mg burn model	Hot spot temperature used to calculate magnesium clad burning.
Wigner energy/anneal flag	The four options are: Off (IWIG=0), Wigner On (1), Wigner and Anneal On (2), Windscale Accident (3). The Wigner energy algorithm is activated if the flag IWIG is set = 1, 2 or 3. If =1, only the Wigner energy release algorithm is activated. If the flag =2, the graphite annealing model is activated, accounting for the increased graphite thermal conductivity that accompanies annealing, in addition to the Wigner energy release model. If IWIG=3, in addition to the Wigner energy and thermal conductivity models, a

	preprogrammed power and flow sequence for the Windscale reactor accident is automatically introduced into the accident sequence for the Windscale model.
Wigner energy multiplier	Multiplier for Wigner energy correlation, which uses an approximate correlation for Wigner stored energy vs. irradiation temperature. The stored energy for the reference is for equilibrium irradiation. The upper limit stored energy (at low temperature) is 685 cal/gm, with a zero energy storage crossover at 340°C. The energy release algorithm adds a variable amount of energy per degree temperature increase, with this value decreasing with node temperature. The algorithm is implemented for all graphite in the active core, side reflector, and the nodes adjacent to the active core at the inlet and outlet.
Wigner Delta-T Trigger	Difference between annealing and irradiation temperatures for Wigner energy release start.
Core short-term exposure	Exposure values (MWd/AT) used in calculation of Wigner energy low-temperature (peak). Differs from the long-term exposure value, accounting for core annealing.
AM cartridge tot ht rel mult	(W) AM cartridge total heat release multiplier.
AM cartridge ht rel time mult	(W) AM cartridge heat release time multiplier.

(W) = Windscale model only

Core Layout Design

Pressing the Core Layout Design button on the Edit Design Input Selection menu displays the screen shown in Figure 45.

Lattice geometry	Fuel lattice geometry options: square (1) or triangular/hexagonal (2)
Core (active) diameter:	Core effective diameter
Core (active) height/length:	Active core height
No. of fuel channels:	Number of fuel channels in active core
Pitch–fuel channel spacing:	Pitch

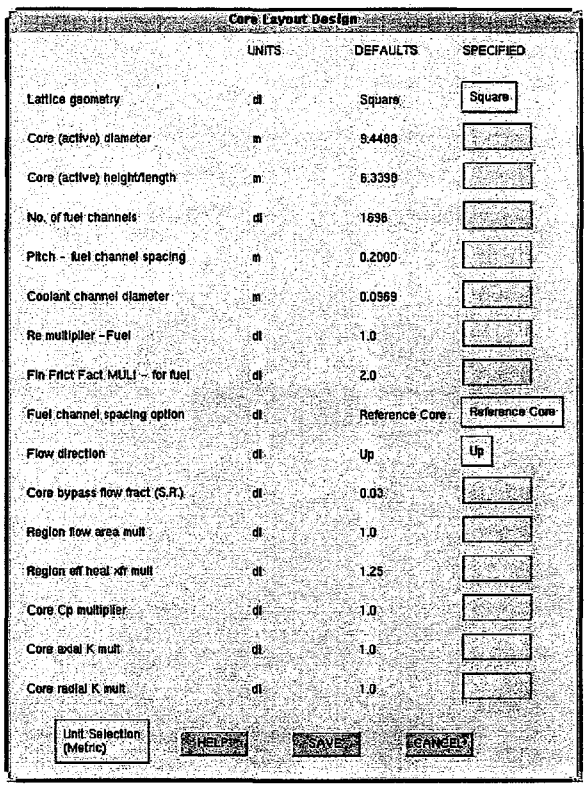

Figure 45. Core Layout Design Input Screen

Coolant channel diameter — Mean coolant channel diameter - fuel

Re multiplier–fuel: — Multiplier for fuel coolant channel Reynolds Number

Fin Frict Fact MULT - for fuel: — Multiplier for fuel channel friction factor due to fins

Fuel channel spacing option — The options are: Reference core (IFCS=1); adjust diameter (2); and adjust pitch (3). For the option flag IFCS=1, the fuel channel spacing is assumed to be the same as in the reference cores, and the total number of fuel channels is scaled according to the active core diameter input. In the "Run with Validation" program, the "actual" vs. "input" values of pitch and number of channels are displayed for this case.

For IFCS=2, the input number of channels, pitch, and lattice geometry are maintained and the active core diameter is adjusted accordingly. If the adjusted value of core diameter is less than originally specified, the additional "core volume" is added to the side reflector. If the adjusted core diameter is larger than the input value, the input value is maintained as a

"hard limit." In the "Run with Validation" program, the "actual" vs. "input" active core diameters are displayed, and an error flag is set if the "hard limit" value is exceeded.

For IFCS=3, the input number of channels, lattice geometry, and active core diameter are honored and the pitch is adjusted as required. In the "Run with Validation" program, the "actual" vs. "input" pitch values are displayed.

Flow direction:	Select upflow (1), downflow(2) or horizontal flow (3)
Core bypass flow fract (S.R.):	Core flow bypass fraction (side reflector)
Region flow area mult:	Multiplier for effective region flow area for sensitivity studies
Region eff heat xfr mult:	Multiplier for effective heat transfer coefficient times area
Core Cp multiplier:	Multiplier for core specific heat function
Core axial K mult:	Multiplier for core axial conductivity function
Core radial K mult:	Multiplier for core radial conductivity function

Pressing the SAVE button saves the input data and returns to the Edit Design Input Selection menu. The CANCEL button restores the previous set of saved input data and returns to the Edit Design Input Selection menu. The HELP button displays a help file for describing the input data options. The Unit Selection enables units to be changed to either English or Metric.

Nuclear Design

Pressing the Nuclear Design button on the Edit Design Input Selection menu displays the screen shown in Figure 46.

Core full (rated) power:	Core full (rated) power
Afterheat selector:	Six option flags are available: 1-3 are end-of-cycle (EOC) afterheat vs. time functions for various HTGR correlations; 4-6 are (sequentially) their beginning-of-cycle (BOC) counterparts. 1&4 are from the Fort St. Vrain FSAR; 2&5 are from a 1986 MHTGR "best estimate" function; and 3&6 are conservative estimates (for licensing) derived from a 1987 GA MHTGR report.

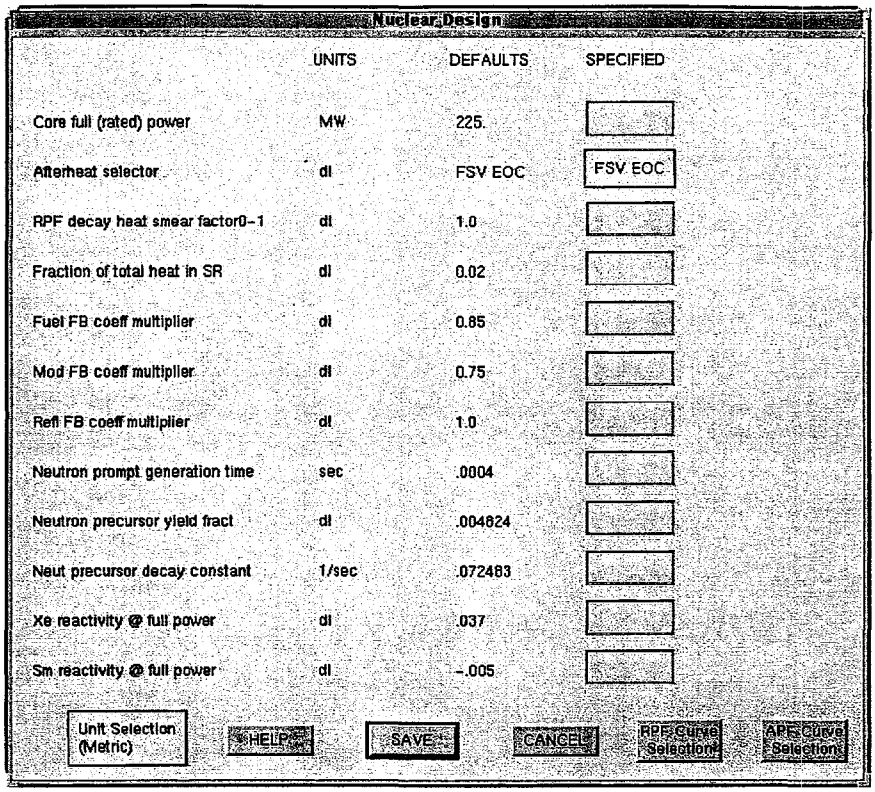

Figure 46. Nuclear Design Input Screen

RPF decay heat smear factor 0-1: Radial peaking factor "smear" (0 to 1) for Transition from at-power to shutdown: 0=maintain at-power RPFs, to 1=all RPFs=1.

Fraction of total heat in SR: Fraction of total heat generation in side reflector.

Fuel FB coeff multiplier: Multiplier for fuel temperature-reactivity coefficient (Ref.=-2.0e-5 Rho per deg. C).

Mod FB coeff multiplier: Multiplier for moderator temperature-reactivity coeff(Ref.=-4.0e-5 Rho/deg. C).

Refl FB coeff multiplier: Multiplier for side reflector temperature -reactivity coeff(Ref.~3.5e-5 Rho/deg. C).

Neutron prompt generation time: Neutron prompt generation time (lifetime).

Neutron precursor yield fract: Precursor yield fraction (Beta-Total).

Neut precursor decay constant: Precursor decay constant (Lambda-total).

Xe reactivity @ full power: Xenon reactivity at full (rated) power.

Sm reactivity @ full power: Samarium reactivity at full (rated) power.

Pressing the SAVE button saves the input data and returns to the Edit Design Input Selection menu. The CANCEL button restores the previous set of saved input data and returns to the Edit Design Input Selection menu. The HELP button displays a help file for describing the input data options. The Unit Selection pulldown menu enables units to be changed to either English or Metric.

RPF (Radial Peaking Factor) Curve Selection

The RPF Curve Selection button enables the Radial Peaking Factor Curve to be viewed and edited.

Pressing the RPF Curve Selection button on the Nuclear Design input screen displays the screen shown in Figure 47.

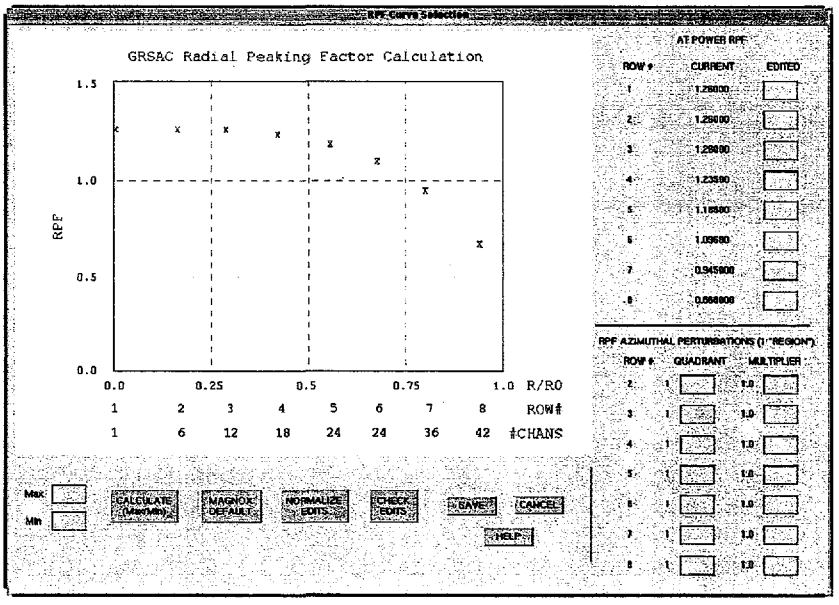

Figure 47. RPF Curve Selection Design Input Screen

The plot shows the radial peaking factor curve (RPF vs R/R0 and Row number, along with the number of channels or regions in each row or ring). The user can input at-power RPFs for any of the 8 rows.

Asymmetric azimuthal RPF perturbations ("hot channels") can be input in a fuel region in any of the rows 2-8. The quadrant (1-4) in which the perturbation is to appear and the "multiplier" are entered. The multiplier "m" sets the RPF value of the selected region to "m" times the "Row RPF" value; other region RPFs in that row are normalized to maintain the original average Row RPF.
An alternative to entering RFP values is to use the "Calculate (Max/Min)" button, which calculates a set of eight RPF values based on the max and min values entered. A pop-up window tells the status of the calculation, and the plot is updated.

"Magnox Default" button: update and plot RPFs for a Magnox default curve. Once the Row RPF values are generated, they may be edited (manually). Note that the average RPF must be maintained at 1.0 and changes are "weighted" according to the number of regions in each row. Pressing the "Normalize Edits" button normalizes the unedited RPF values displayed on the right side of the screen and updates the plot. Pressing the "Check Edits" button validates the RPF values displayed on the right portion of the screen, and the pop-up window gives the status of the calculation, and updates the plot if the sum of the RPFs is 163.0 (the number of fuel regions) +/- an acceptable error band.

Pressing the SAVE button saves the input data and returns to the Nuclear Design Input screen. Entries are not "saved" for use unless both the SAVE buttons on this screen AND the Nuclear Design Input screen are pressed. The CANCEL button restores the previous set of saved input data and returns to the Nuclear Design Input screen. The HELP button displays a help file describing the input data options.

APF (Axial Peaking Factor) Curve Selection

Pressing the APF Curve Selection button on the Nuclear Design input screen displays the screen shown in Figure 48.

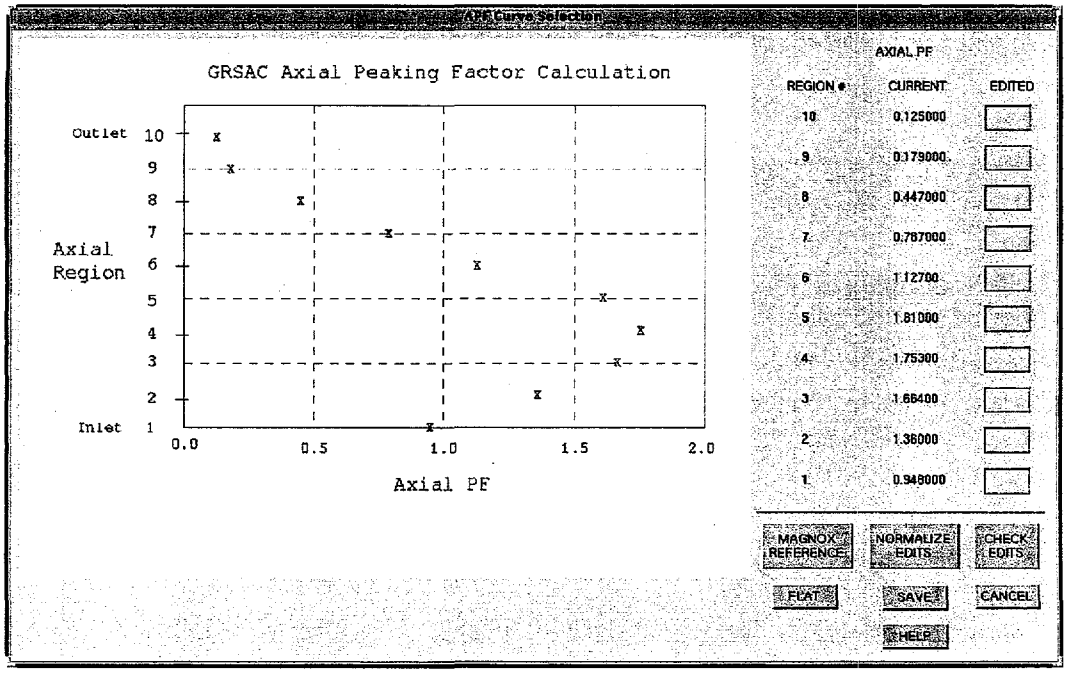

Figure 48. APF Curve Selection Design Input Screen

The plot shows the axial peaking factor curve (APF vs axial nodes). The user can input APFs for any of the 10 nodes. No changes in APFs are assumed going from at-power to shutdown conditions.

The "Magnox Default" button updates and plots APFs for a Magnox default curve, and the "Flat" button displays a flat APF curve, setting all the axial peaking factors to 1.0. Once the APF values are generated, they may be edited (manually). Note that the average APF must be maintained at 1.0; changes are weighted equally. Pressing the "Normalize Edits" button normalizes the unedited APF values displayed on the right side of the screen and updates the plot. Pressing the "Check Edits" button validates the APF values displayed on the right portion of the screen, and the pop-up window gives the status of the calculation, and updates the plot if the sum of the APFs is 10.0 (the number of axial nodes) +/- an acceptable error band.

Pressing the SAVE button saves the input data and returns to the Nuclear Design Input screen. Entries are not "saved" for use unless both the SAVE buttons on this screen AND the Nuclear Design Input screen are pressed. The CANCEL button restores the previous set of saved input data and returns to the Nuclear Design Input screen. The HELP button displays a help file for describing the input data options.

Reactor Cavity Design

Pressing the Reactor Cavity Design button on the Edit Design Input Selection menu displays the screen shown in Figure 49.

Shield cooler/PCRV HT area:	Effective heat transfer area of PCRV exposed to cavity cooling
Reactor cavity effective ID:	PCRV cavity mean inside diameter
Shield or PCRV thickness:	PCRV or shield mean thickness
T-Cav cooler water inlet:	(G2)Cavity cooler heat exchanger T-coolant in*
T-Cavity cooler water outlet:	(G2)Cavity cooler T-coolant out (initial)*
T-Cav/shield cooler gas inlet:	(P)Cavity cooler T-gas in (initial)*
T-Cav/shield cooler gas outlet:	Cavity cooler T-gas out (initial)*
Flow-Cav cooler water:	(G2)Cavity cooler coolant flow*
Flow-Cav/shield Cooler Gas:	Cavity cooler gas flow (rated)*
Air ingress Chimney flag	Flag for natural convection air ingress model (0=OFF; 1=on-activated when depressurized & coolant = air). Can be overridden by SCS (P) or blower (AC) operation.
Chimney height (air ingress)	Effective height of exhaust "chimney"for air ingress model

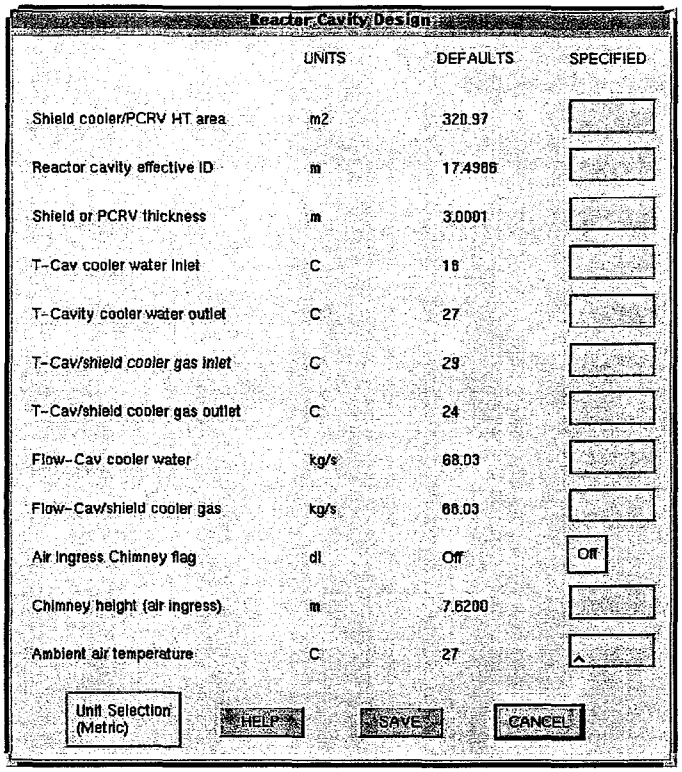

Figure 49. Reactor Cavity Design Input Screen

Ambient air temperature — Air inlet temperature for ingress model; also shield cooler air inlet temperature for non-pressurized-cavity models (Calder, AC)

* **Note**: Cavity cooler heat exchanger design based on these inputs (G2)

(G2) = For G2 reactor models only
(P) = For Pressurized reactor models only
(AC) = Air-Cooled models (Windscale, Single Channel, or G1)

Pressing the SAVE button saves the input data and returns to the Edit Design Input Selection menu. The CANCEL button restores the previous set of saved input data and returns to the Edit Design Input Selection menu. The HELP button displays a help file for describing the input data options. The Unit Selection pulldown menu enables units to be changed to either English or Metric.

Primary Cooling Design

Pressing the Primary Cooling Design button on the Edit Design Input Selection menu displays the screen shown in Figure 50.

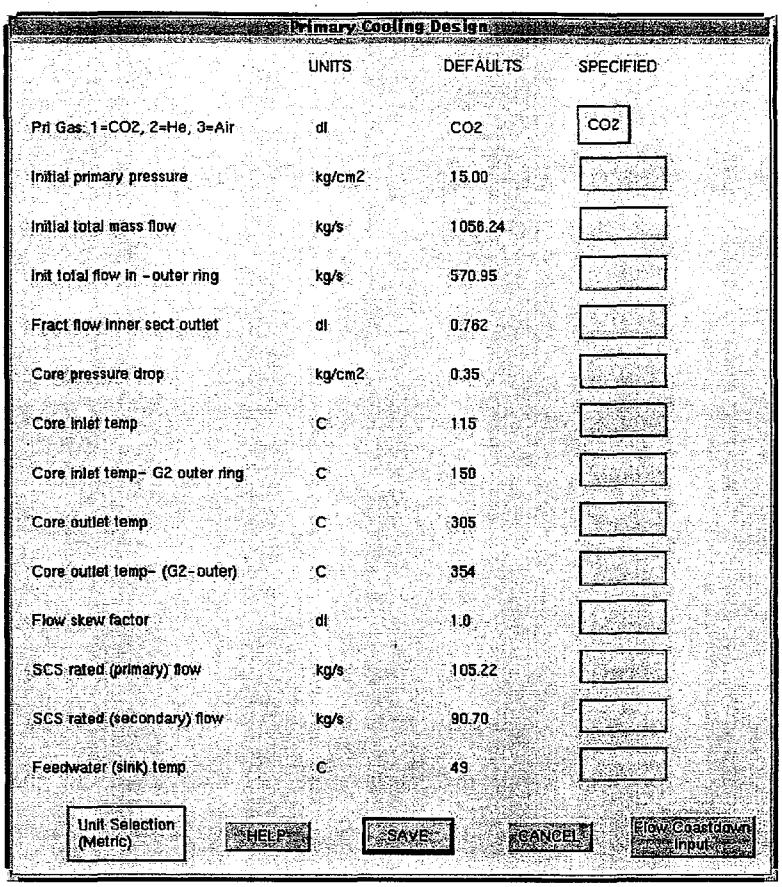

Figure 50. Primary Cooling Design Input Screen

Primary gas:	Select primary system gas: carbon dioxide(1), helium(2), or air(3)
Initial primary pressure:	Coolant pressure at core inlet (initial)
Initial total mass flow:	Total core coolant flow (initial)**
Init total flow in -outer ring:	(G2)Core inlet flow to outer ring (initial)
Fract flow inner sect outlet:	(G2)Fraction of total outlet flow - inner sect
Core pressure drop:	Core pressure drop (initial)
Core inlet temp:	Primary coolant core inlet temperature*
Core inlet temp- G2 outer ring:	(G2)Primary coolant inlet temp - outer ring
Core outlet temp:	Primary coolant core outlet temperature*
Core outlet temp-(G2 outer)	(G2) Primary coolant outlet temp-outer ring

Flow skew factor:	(0 to 1.0) 0 = all flows equal; 1 = flows throttled to give near-equal outlet temps
SCS rated (primary) flow:	Rated (shutdown) gas flow*,**
SCS rated (secondary) flow:	(P)Rated (shutdown) coolant flow*
Feedwater (sink) temp:	(P)SCS coolant inlet temperature*

* **Note:** SCS heat exchanger design based on these inputs (P)

** **Note:** The Initial total mass flow" and "SCS rated (primary) flow" can be used alternatively as "100% flow" reference values when post-LOFC flows vs. time are defined. These flow sequences can be input via the Programmed Input Screen ("SHUTDOWN COOLING (SCS)" or "CORE FLOW SEQUENCE," or via manual input from the Accident Screen. The choice of which of the two reference (100%) flows is used is made via the Programmed Input Screen flag "Core Flows = %Rated Primary [P] or SCS [S]?" For the case of air-cooled reactor models, the "SCS rated (primary) flow" is the rated flow for auxiliary (shutdown) blowers.

(G2) = For G2 models only

(P) = For pressurized reactor models only

Pressing the SAVE button saves the input data and returns to the Edit Design Input Selection menu. The CANCEL button restores the previous set of saved input data and returns to the Edit Design Input Selection menu. The HELP button displays a help file for describing the input data options. The Unit Selection pulldown menu enables units to be changed to either English or Metric.

Flow Coastdown Input

Pressing the Flow Coastdown Input button on the Primary Cooling Design input screen displays the screen shown in Figure 51.

The timing of the flow coastdowns in loss of forced convection (LOFC) accidents is crucial, especially if there is a delayed scram or ATWS (anticipated transient without scram) accompanying it. The coastdown input screen allows the user to make fine adjustments in the coastdown flow vs. time in the first 10 min. of the accident. It is assumed that this coastdown is not necessarily just a main circulator(s) rundown, but can involve emergency blowers or natural convection as well. It is also assumed that any significant long-term cooling must be supplied via turning on the shutdown cooling system (SCS) from the console (rationale: otherwise, the water in the boilers would boil away).

The default curves for Calder and G2/3 are CH-1 and G2-1. Two other defaults (each) are supplied. Changes in the 0-10 min. curve are entered as Curve Modifications, point by point. Whenever a change in the curve is made, it is entered by clicking on "APPLY", which does an error check and displays a message. Increases in flow vs. time are considered "unusual" and are noted, but allowed (it could represent activation of an emergency blower).

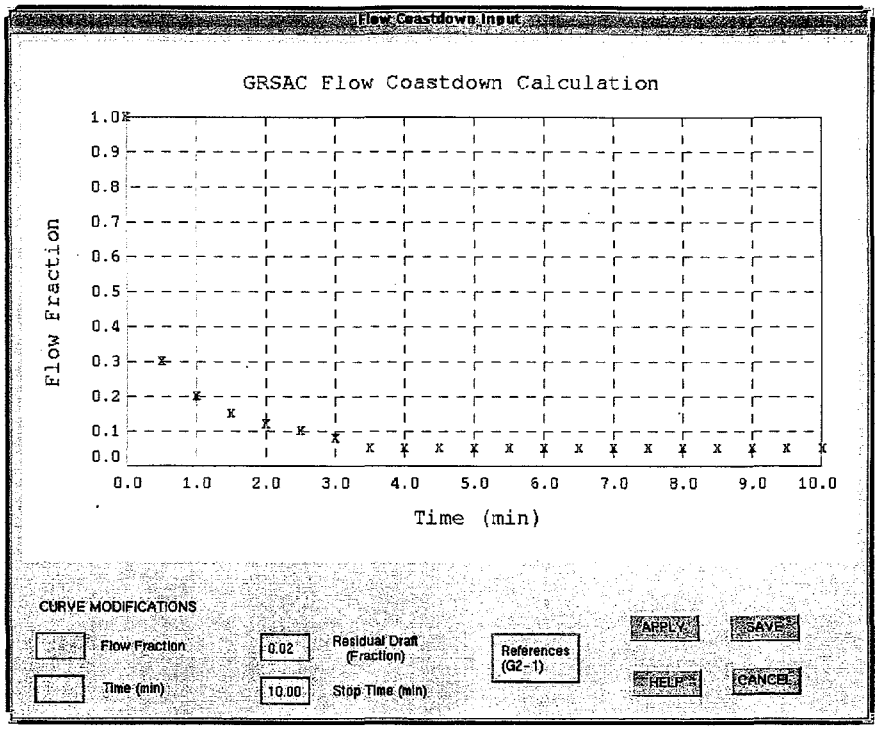

Figure 51. Flow Coastdown Input Design Screen

The "circulator stop time" (CST) and "residual draft fraction" (RDF) inputs can be used to control the flow after the coastdown. RDF has an upper limit of 0.05, and CST has a lower limit of 0.5 min.

If CST is set at > 10 min., the program reduces the flow fraction to RDF at t=20 min; otherwise it is reduced to ~0.01 at 20 min. Unless the SCS or natural convection mode is activated, the flow fraction is further reduced to ~0.005 at 60 min., and declines gradually to near zero thereafter.

Pressing the APPLY button activates the input data. Pressing the SAVE button saves the input data and returns to the Primary Cooling Design Input screen. Entries are not "saved" for use unless both the SAVE buttons on this screen AND the Primary Cooling Design Input screen are pressed. The CANCEL button restores the previous set of saved input data and returns to the Primary Cooling Design Input screen. The HELP button displays a help file for describing the input data options.

Edit Programmed Inputs

Pressing the Edit Run Programmed Inputs button on the Simulation Selection menu displays the screen shown in Figure 52.

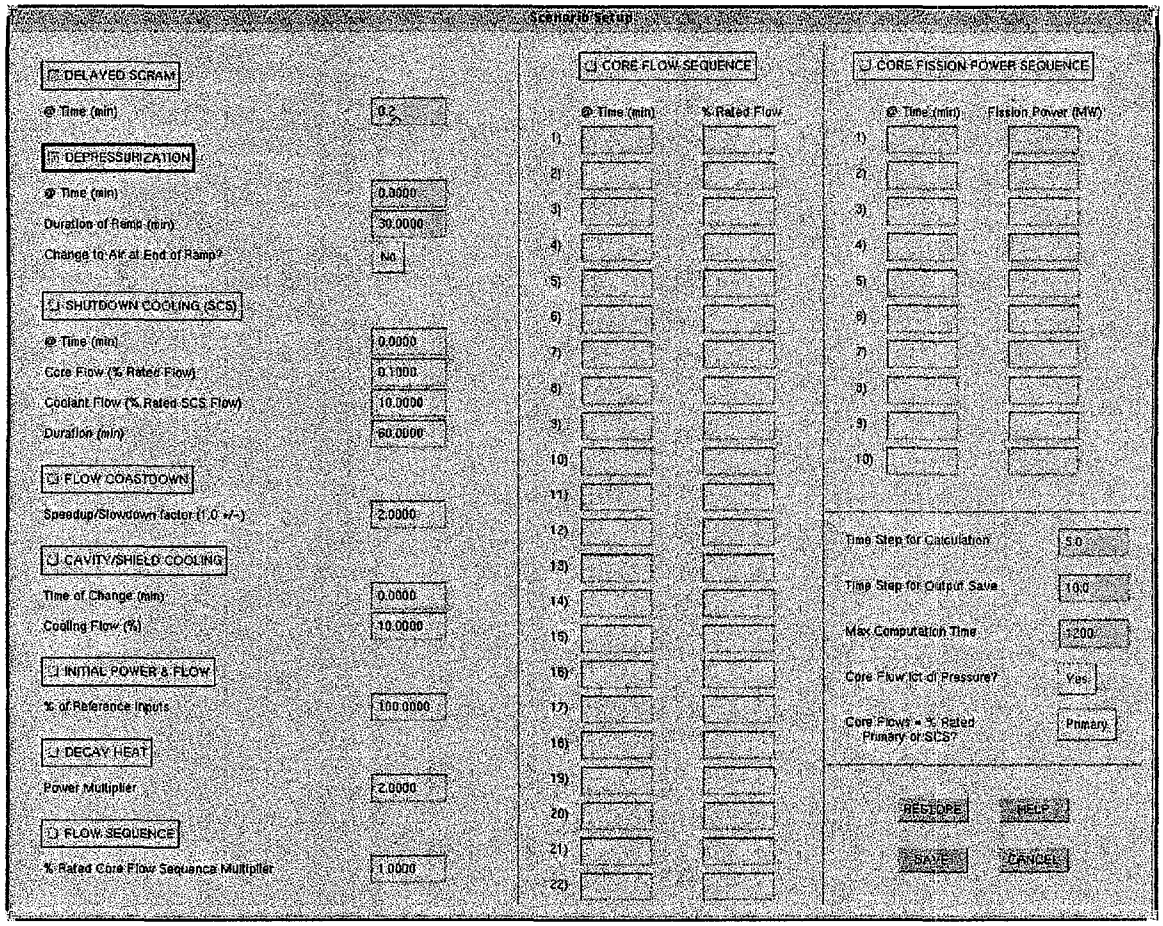

Figure 52. Edit Programmed Inputs Screen

Categories for Programmed Input Selection are Delayed Scram, Depressurization, Shutdown Cooling (SCS), Flow Coastdown, Cavity/Shield Cooling, Initial Power and Flow, Decay Heat Power Multiplier*, Flow Sequence Multiplier*, Core Flow Sequence, Core Fission Power Sequence, Computation Timing Control* (time step for calculation, time step for output save [to 'cplot' file], and maximum computation [stop] time), a flag to make (input) core flows a function of primary pressure (or not)*, and a flag to make the (input) indicated core % flows in terms of primary rated flow or SCS rated flow*. When one of the toggles is selected, the data input areas within the selected category are activated. Once these areas are activated, the user can enter data or use the default values. If the SAVE button is pressed upon leaving the Programmed Input Selection menu, all activated data fields are used as input by the simulation. If the CANCEL button is pressed, most toggled categories are unselected and not sent to the simulation*. The RESTORE button can be used to recall the last set of screen data that was SAVED for this simulation model.

** In the case of the Decay Heat Power Multiplier, the Flow Sequence Multiplier, the Computation Timing Control parameters, and the flags that select core flow options, the default values of these parameters ARE carried over to the simulation even when the SAVE button is not pressed.*

The Core Flow and Core Fission Power sequences can be used as arbitrary functions vs. time inputs. The simulation inputs are linear interpolations between the points entered. If the sequences are not completed (to the end of the run), the programmed inputs will ramp down (very slowly) towards zero. The Core Flow inputs are in % of rated flow. "Rated flow" refers either to that of the primary (main circulators) or shutdown (SCS) rating, depending on the selector flag. Flows may be assumed to be in terms of "circulator capacity" and thus derated proportionally to absolute pressure if a depressurization occurs, or not. SCS and Core Flow sequences cannot be activated at the same time. Core Fission Power Sequences are added only to afterheat power, not to fission power during an ATWS.

Since there are several core flow specification or calculation options available, it is important to understand the code's priority structure. The basic (default) flow specification is the reference case Loss Of Forced Convection (LOFC) input. That consists of the flow coastdown (as specified graphically via the Primary Cooling Design input screen), followed by a gradual decline to near zero flow. That can be overridden (after the coastdown) by the SCS "one-time" actuation OR the Core Flow Sequence on the Programmed Input screen OR the manual SCS (or blower) input on the Accident Screen. If the natural circulation calculation is activated (Reactor Cavity Design input screen - Air Ingress Chimney flag set), it will take precedence over all of the other options EXCEPT the manual input. For pressurized reactor models, air ingress and natural circulation occurs only after depressurization is complete (to atmospheric pressure) and the coolant gas has changed to air.

Many Programmed Inputs can also be used for sensitivity studies. A sensitivity study option is available as a third choice on the IC/Accident run menu. The rationale is to seek out a set of parameters within specified uncertainty bands that result in the worst (or best) case accident consequences. A set of 13 model parameters and 12 operation/run parameters is available for automatic variation (from run to run), and allows the user to select up to 10 from this set for any given study. Sensitivity studies help the analyst to recognize the accuracy limitations of the simulation, as well as to help determine the relative importance of the parameters to the outcome of the accident. The 12 operation/run parameters for sensitivity studies are selected from this screen. If a category is selected, data items in that category are displayed later as optional sensitivity parameters. If a category is not selected, the associated data items will not be available as parameter variation options during a sensitivity run.

Run with Validation

Pressing the Run with Validation button on the Simulation Selection menu runs a check on the input data entered for each category of the Design Inputs. After the data has been validated, a report is displayed explaining any inconsistencies found in the data as well as general information about the data being used in the simulation. An example of an Input Validation report display is shown in Figure 53.

Pressing the EDIT button returns to the Edit Design Input Selections screen. Pressing the RUN button continues with setting up the simulation. Please note that if problems were reported in the input data, the simulation can still be run. It is advised however that inconsistences in the data be resolved before running the simulation.

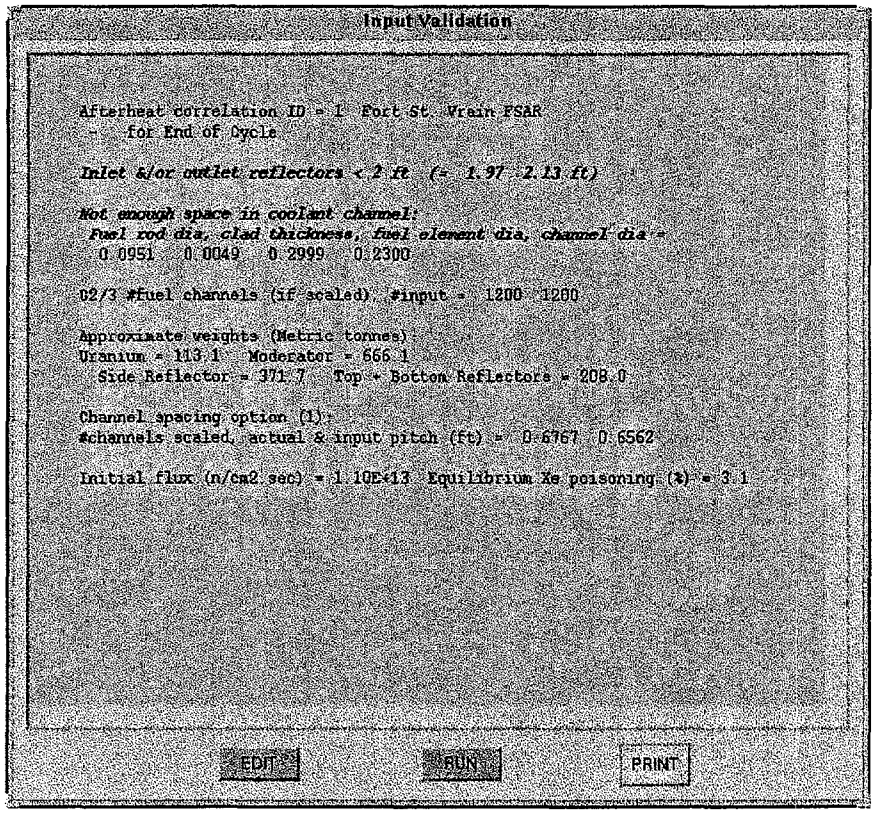

Figure 53. Run With Validation–Sample Output Screen

3. General Instructions

There are many different cases in GRSAC operations where there is a need to select files, name files, setup plots, print, etc. The procedures are essentially the same for each case, so rather than repeating the instructions for each throughout the manual, the general instructions are given here. When general instructions are needed, the reader will be referred back to this section.

File Selection

To retrieve an existing simulation, run or other file from a file selection screen (see example .SIM file, Fig. 54), highlight the file to be retrieved from the Files scrolling list area on the right side of the selection box. The filename may also be typed into the Selection input area at the end of the full directory path name. Press the OK button when the needed filename appears in the Selection area. Press the Cancel button to abort the file selection process and return to the previous menu.

The Description input area allows the user to input any type of information that needs to be stored about the selected file. The last input Description for the current file is always displayed.

The user cannot change the Filter input area, therefore pressing the Filter button does nothing.

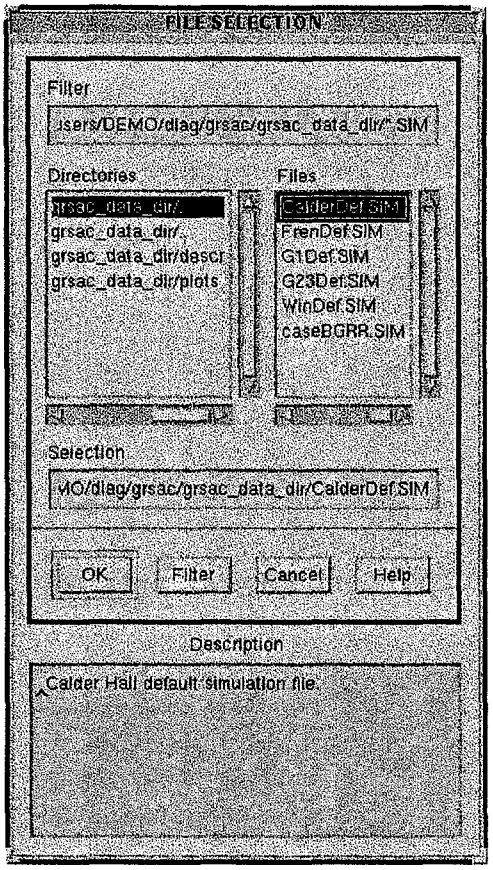

Figure 54. File Selection Screen for Simulation (SIM) Files

File Naming Convention

GRSAC files use a formatted naming convention so that all data, plot, etc. files contain the ReactorID portion of the simulation filename for which they were created. Restrictions have been put on the format and naming conventions of files so that the GRSAC program can retrieve the appropriate list of files for later selection. The simulation (.SIM) file names have the form <ReactorID.SIM>, where the ID would be some unique characteristic of the simulation. An example would be:

caseBGRR.SIM

Other types of files associated with that .SIM file must follow the given format which contains the same (case-sensitive) ReactorID name, plus a case or run ID, plus the appropriate extension that denotes what type of file it is. Examples:

caseBGRR.atws.AccPLOT	accident plot file
caseBGRR.300kgs.RUN	run file (with initial conditions)

Other file extensions include .ICPLOT (initial condition plot data), and .FPHData (fission product holdup data).

Plots

Dynamic and post run plots are available for both Accident and IC runs. Some characteristics of plot setup, printing, saving, etc. are common to all types of plots, while unique characteristics of each exist as well. General characteristics are covered below followed by more specific details as necessary.

Plot Setup

Prior to running an Accident/Sensitivity or IC run and after selecting the "Post Run Plots" option, a plot setup screen is displayed. Pull-down menus are implemented to select plot categories, x- and y-axis variable options. Various plot category options are available, and the y-axis options change as different categories are selected. If a variable is dulled out, the option is not available in the selected category. The "None" option on the y-axis selection means that no variable will be plotted on that y-axis. If "None" is selected for all available variables on the y-axis, nothing will be drawn in that plot area.

The AUTO option on the x- or y-scale specifies that the graph will automatically rescale. If this option is selected, the x and y min/max input areas are blanked out and made inactive. If the MANUAL option for either scale is selected, a min and a max value must be entered for that scale. Otherwise, when the OK button is pressed, the scale is reset to AUTO . If a scale is set to MANUAL, the plot does not rescale, it either quits plotting (if the x-max is exceeded) or plots the point at the top of the scale (if the y-max is exceeded).

The UNITS button selector toggles between Metric and English, and the selection applies to all four plots. It also changes the units for the Initial Conditions, Accident or Sensitivity Study run screen, as well.

The PRINT menu allows a printer name and type (color or monochrome) to be chosen. It also enables the plot screen to be printed, in either color or black and white, to the selected printer. For more information on printing plots see the section on Printing below.

The COLORS menu selection toggles between a Light and Dark background color, and the selection applies to all four plots.

The CLEAR menu enables all the selections on Plots 1, 2, 3 or 4 to be cleared. Selecting All clears all selections on all 4 plots. For Initial Condition runs the CLEAR menu also enables individual selections on Plot 1 to be cleared.

The RESTORE menu enables the user to restore the last plot setup used for this type of run (IC or Accident/Sensitivity) or the last plot setup used for this type of run with the currently selected SIM file.

When satisfied with the plot setup, the OK button should be pressed to continue with the Initial Conditions or Accident/Sensitivity run or the post run plot display. Pressing the QUIT or CANCEL button returns the user to the Simulation Selection menu.

Pressing the ALT-p keys while the initial conditions or accident screen is being displayed causes the plotting screen to come to the front. Pressing the ALT-p keys while the plots are being displayed brings the initial conditions or accident screen to the front.

Saving Plot Data

After an Initial Conditions or Accident run, a file selection window is displayed for saving the generated plot data if any variables were selected to be plotted. The user has the option of saving the plot data for post run plots or pressing the CANCEL button and not saving the plot data.

To save plot data, enter a filename, using the appropriate format, in the file selection area The format for an accident plot file is <SimFileName>.<aRunID>.AccPLOT (Fig. 55). For Initial Conditions data the format is <SimFileName>.<aRunID>.ICPLOT (Fig. 56). If this format is not followed an error message dialogue window is displayed (Fig. 57) and the file is not saved. The user is returned to the file selection window to correct the problem after the error is acknowledged by pressing the OK button.

An existing plot data file can be overwritten by highlighting the file to be overwritten in the File Selection area and pressing OK. A confirmation window will be displayed to verify the action as shown in Figure 58. The user can press the Cancel button on the File Selection window at any time to bypass saving the plot data.

Printing

Plot screens can be printed, as can Reference and Help material. The print process for each is described below.

Plots

The PRINT menu allows a printer name and type to be chosen. It also enables the plot screen to be printed to the selected printer. To choose a printer name and type, select Options on the PRINT menu. Once the printer options are set, press the OK button to save them. Pressing the CANCEL button causes the options to go back to the default setting, which is a monochrome printer called the default printer name, lp. Figure 59 illustrates the Print Options window for printing plots. To print

the plot screen, select Print on the PRINT menu. If running on a SunOS 4.1.x machine the mouse pointer changes to a crossbar and the user is expected to click the mouse in the plot window to be printed. Three "beeps" will sound when the screen is grabbed for printing. If running on a Solaris 2.x machine, the root window is automatically grabbed and three consecutive beeps will be heard while the screen is being grabbed and printed. The user should wait until all three beeps have been sounded before proceeding.

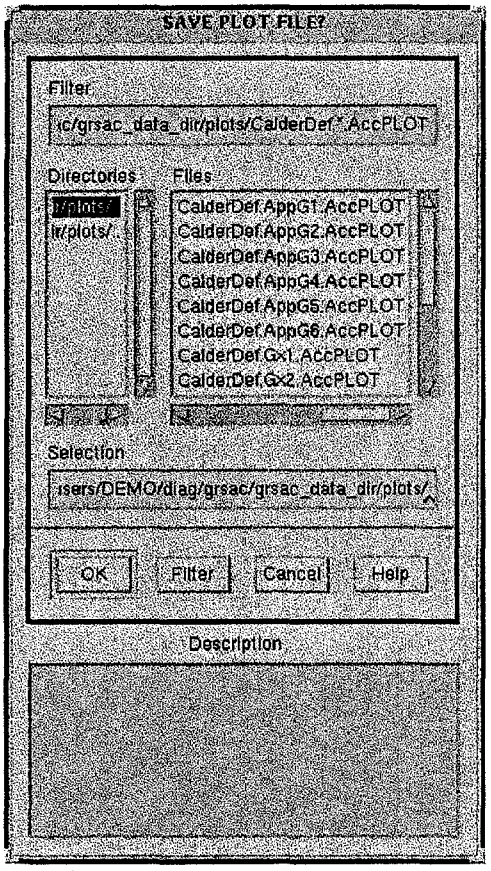

Figure 55. Screen for Saving Accident Plot Data

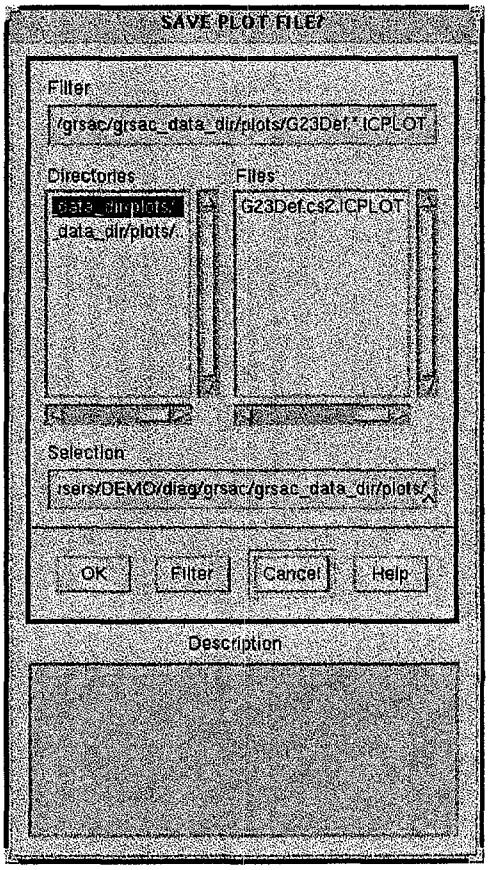

Figure 56. Screen for Saving IC Plot Data

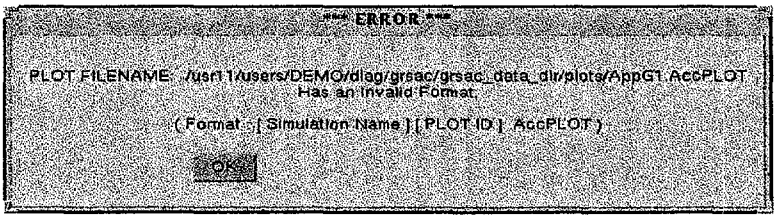

Figure 57. Error Message Display Screen

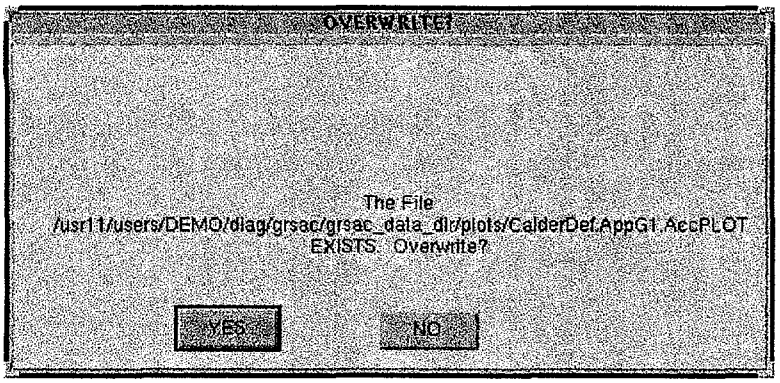

Figure 58. Confirmation Window for Overwriting Files

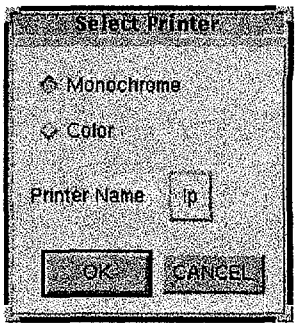

Figure 59. Plot Print Options Window

Help/Reference Files

All Help/Reference windows are equipped with a PRINT pull-down menu. The PRINT menu allows a printer name and type to be chosen. It also enables the displayed help file to be printed to the selected printer. To choose a printer name and type, select Options. on the PRINT menu. Once the printer options are set, press the OK button to save them. Pressing the CANCEL button causes the options to go back to the default setting, which is a postscript printer called the default printer name, lp. To print the help or reference file, select Print on the PRINT menu. If the postscript option is selected, the file will be printed with the same bold, italic, etc. format as is displayed. If the Raw Text option is selected, no formatting is done. Figure 60 illustrates the Print Options window for printing files.

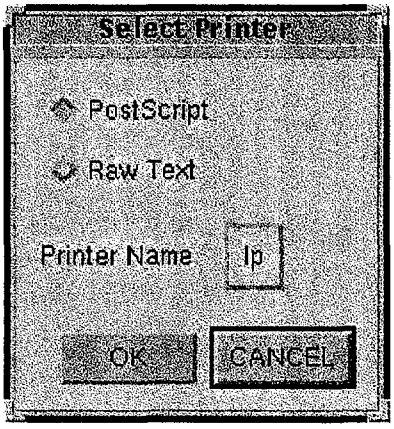

Figure 60. File Print Options Window

4. Post-Run Plots

Post-run plots can be generated for both Initial Condition and Accident runs. Plot data must be saved after a run before post-run plots can be generated for that simulation.

To generate a post-run plot press the Post Run Plot button on the Simulation Selection menu. A menu is displayed for selecting either an Initial Conditions or an Accident post-run plot. This menu is illustrated in Figure 61. Figure 62 shows a file selection screen for Accident plots generated for the simulation file G23Def.SIM, and Fig. 63 shows the corresponding screen for an IC plot. Once a plot file is selected and the OK button pressed, the appropriate plot screen is displayed. Both the Initial

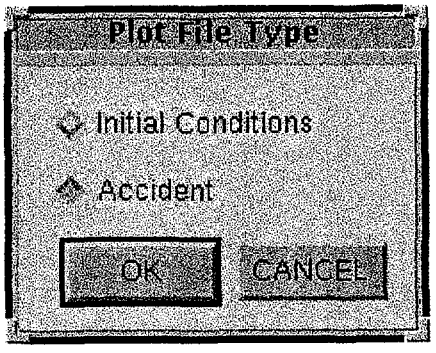

Figure 61. Post-Run Plots Selection Menu

Conditions and the Accident scenarios are described below.

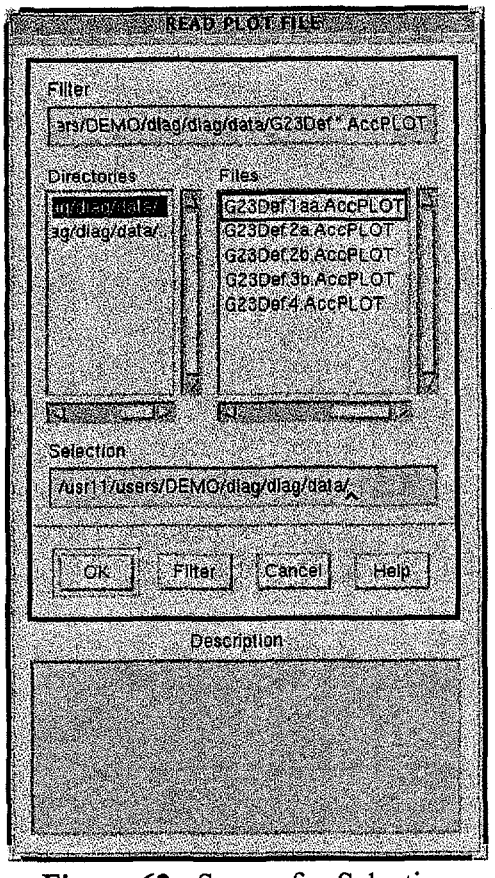

Figure 62. Screen for Selecting Accident Post-Run Plot Files

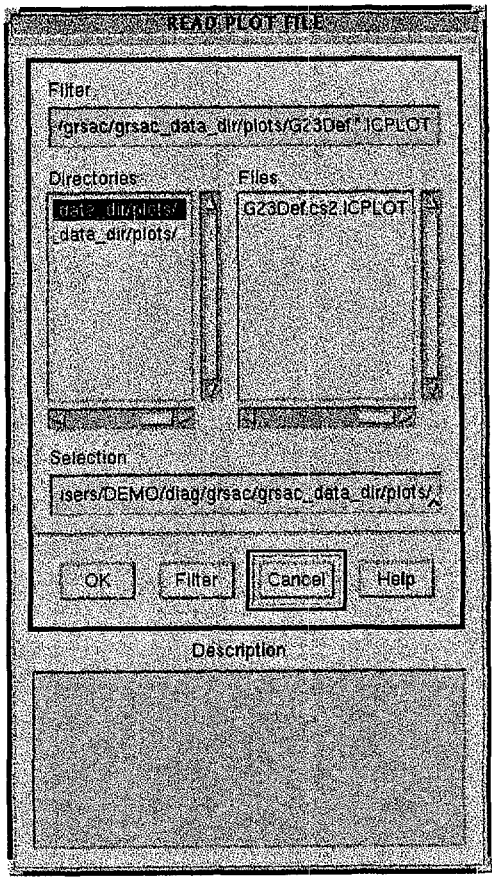

Figure 63. Screen for Selecting IC Post-Run Plot Files

Initial Conditions

Post run plots are available for Initial Condition runs (Fig. 64). Temperature variables vs. time cannot be plotted, therefore the plot options on the first (upper left) plot remain inactive during IC post run plots. Radial and axial plots are available for temperature variables on the three remaining plots for Post Run plots. The temperatures displayed are for the steady-state conditions at the time the IC plot file was saved. If a variable is dulled out, the option is not available for the selected x or y axis.

For more information on setting up the IC post run plots, see the Section on Plot Setup above.

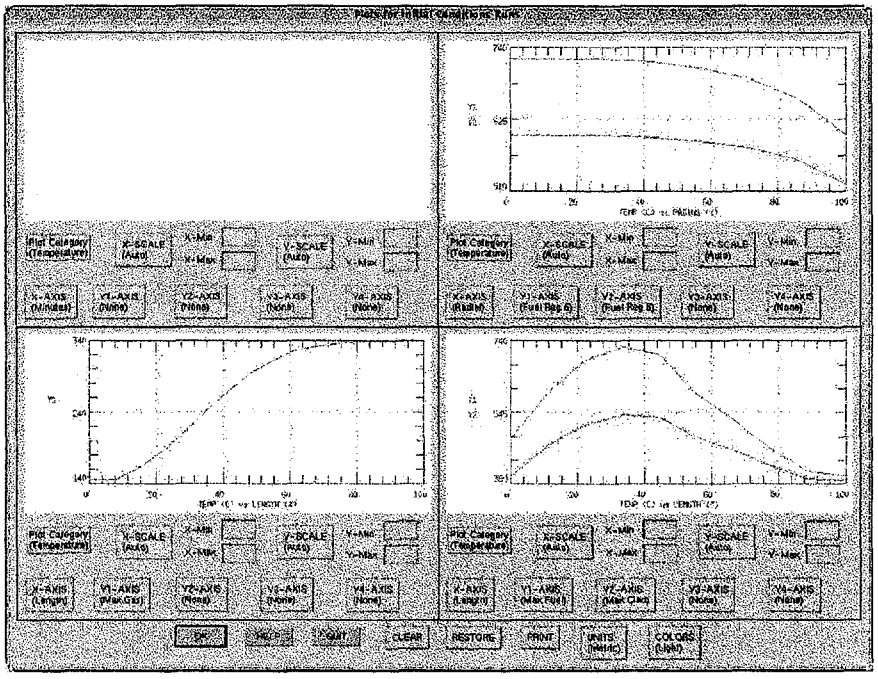

Figure 64. IC Post-Run Plot Example

Accidents

Post run plots are available for accident runs where the plot file was saved as seen in the example plot (Fig. 65). Up to four different variables can be plotted on four different plots. After selecting an accident plot file, a setup screen is displayed. Variables are divided up by category. As categories are selected, options for the y-axes change. If a variable is dulled out, the option is not available as a Post Run option. The categories that offer profile plots with y-variables vs Length or Temperature are not available as Post Run Accident Plot options.

For more information on setting up the Accident post run plots, see the Section on Plot Setup above.

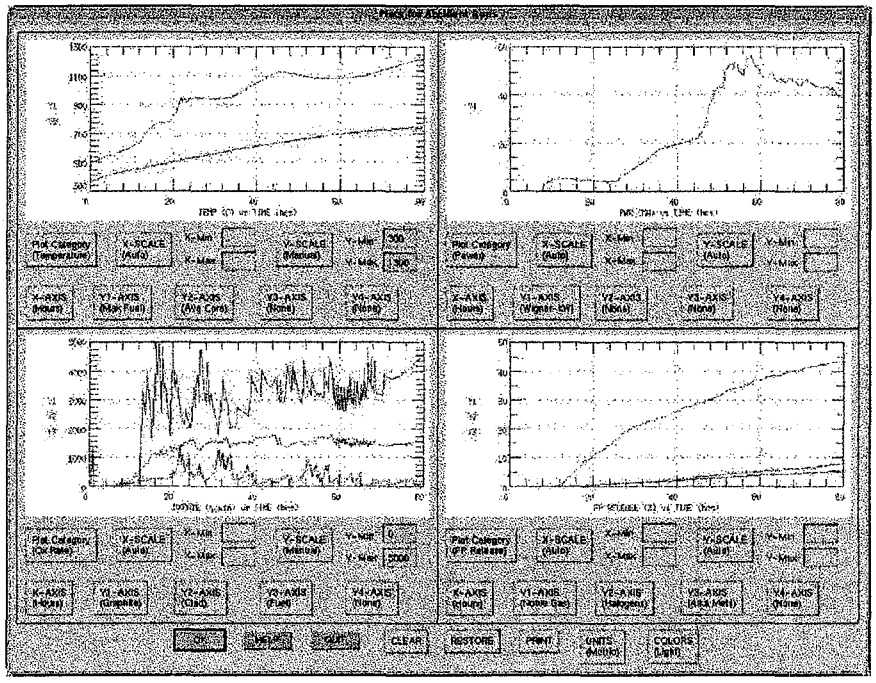

Figure 65. Accident Post-Run Plot Example

5. Fission Product Holdup/Release Calculation

The Fission Product Holdup/Release Calculation option is used to estimate holdup and release of fission products from the primary system and containment building. It uses an approximate model with only limited flexibility; however, enhancements may be included in a later (code) release.

The current GRSAC holdup/release model takes as input the % Release from fuel element values vs. time for each of the eight representative fission product groups, and calculates release rates (%) into and out of the primary system reactor vessel (RV) and containment building (CB). GRSAC calculates flow-dependent effective holdup time constants and group-dependent plateout fractions. The resultant data file of release rates (to the environment) vs. time can then be used by ORIGEN-PRO, which has been set up specially to convert this data to HASCAL-SCIPUFF input data files, taking into account the radioactive decay and transmutations occurring since the start of the accident, for calculating the atmospheric transport of the radionuclides.

To calculate fission product holdup/release data, press the FP Holdup/Release Calc button on the Simulation Selection menu (Fig. 39). The next display is a file selection menu for choosing an accident plot file that contains the simulation data to be used for the calculation. An example of the file selection menu displayed is shown in Figure 62. For detailed instructions on file selection, see Section III.3, General Instructions.

Pressing the OK button saves the required input data in the file fplot, which is used to calculate fission product holdup/release from CB. Next an input screen is displayed for entering fission product holdup/release model data. This screen is shown in Figure 66.

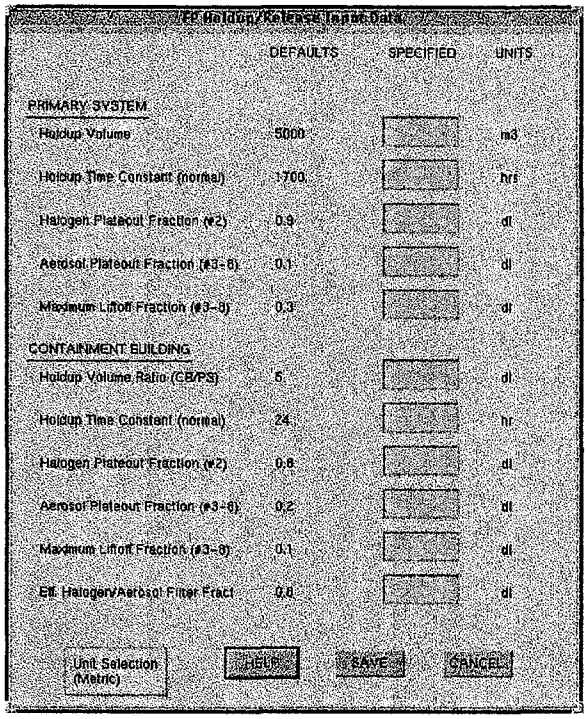

Figure 66. Fission Product Holdup/Release Calculation

The user inputs include holdup volume information and "normal" (i.e., for operational leakages) holdup times for both the primary system and the CB, and effective plateout fractions for the halogens (iodine, group 2), and the aerosols (groups 3-8), plus "upper limit" liftoff fractions for the aerosol groups. It is assumed that the plateout fraction for the noble gasses (group 1) is zero.

The holdup volume (primary system) and CB/PS volume ratio inputs are needed for calculation of the variable holdup times. Aerosol liftoff fractions are computed as a function of depressurization rate ("maximum" for depressurization occurring in 5 min or less).

Pressing the SAVE button brings up a file name selection screen (Fig. 67), and once a fission product holdup/release data file is selected and the OK button pressed, a program is called to calculate the fission product holdup/releases, and these data are written to the file. These files must end with a .FPHData extension. The "Description" input area allows the user to input any type of information that needs to be stored about the selected file. The last input Description for the current file is always displayed.

Background

Determination of the Source Term requires estimation of the fission product release from fuel into the RV gas space, followed by an estimation of the rates of leakage through the RV and CB relative to the rates of holdup by deposition on RV and CB surfaces, aerosol liftoff, and, if applicable, capture in filters located in the reactor building chimney.

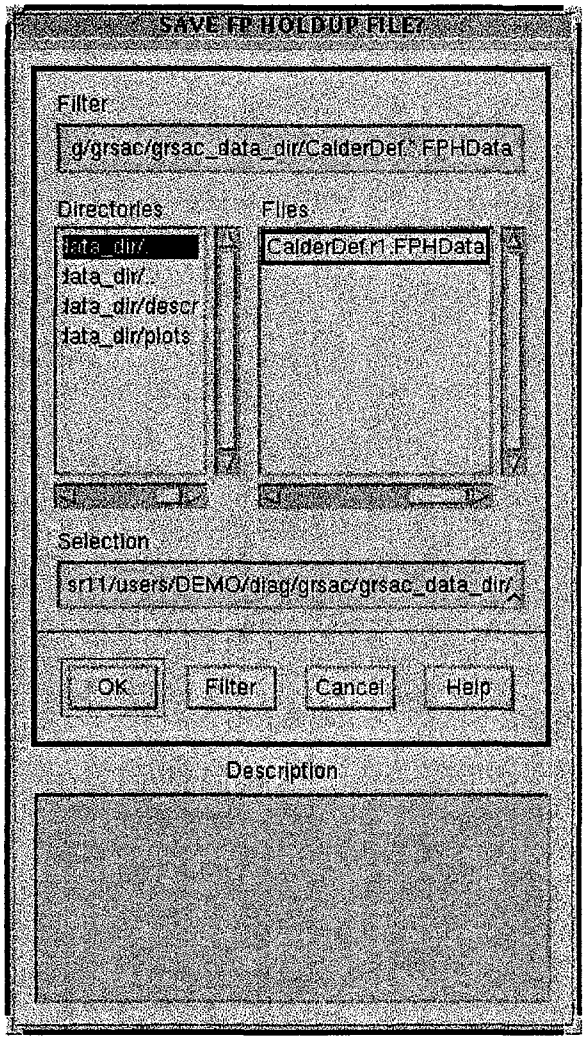

Figure 67. Fission Product Holdup/Release File Save Screen

The potential for fission product capture along the release pathway is potentially large (except for noble gases) for GCRs due to the large surface area in the core, especially due to heat transfer enhancers on the fuel elements. The degree of capture is estimated by determining the mass transport conductivity to the surface relative to the gas convection rate through the RV and CB, for each fission product group.

Group 2 (halogens) are expected to be gaseous, either methyl halide in CO_2 or molecular halogen (iodine) in air. Transport properties to the surface are determined by estimation of the laminar flow mass transfer coefficient and the geometric configuration in the fuel channel. Iodine molecules transported to the surface are assumed to remain chemisorbed throughout the sequence, unless surface temperatures are determined to exceed 800°C, at which point iodine desorption and the release of previously captured iodine to air may occur. Since most of the (cooler) surfaces where the chemi-sorbtion would occur are not expected to heat up to ~800°C, this effect is not modeled.

Fission product groups 3 to 8 are expected to condense into aerosol particles after leaving the damaged fuel element. Estimation of the degree of capture on surfaces requires assumption of aerosol properties, principally the size and the capture mechanisms. Currently, the GRSAC model default values are based on the assumption that the condensation aerosols are 0.01 microns in diameter and that Brownian motion is the principal capture mechanism. In addition, there is provision for aerosol capture on filters located in the chimney accepting flow from the reactor building.

The output data file generated is in a form readable by ORIGEN-PRO. The output data begins when fission product release from the fuel elements begins, and continues (with hourly outputs) until the containment releases are at a low limit value (0.002%/hr) or less for all groups.

The default values in the release model apply to Magnox reactors with steel pressure vessels, the most common type. The reactor designs similar to the two newest stations in the UK, Oldbury and Wyfla, with pre-stressed concrete reactor vessels (PCRVs), would have different post-accident parameters, i.e., different release pathways from damaged fuel to the atmosphere.

Three types of accidents are considered covering a broad range of possible events:

> Accident-1: In this sequence the RV incurs slight damage at accident initiation causing a slow (viscous) blowdown. The unsealed reactor containment building (CB) remains undamaged. The release pathway proceeds from (1) damaged fuel elements, to (2) the RV gas space (a portion of the release is deposited on RV surfaces), to (3) the CB gas space (a portion being deposited on CB surfaces plus possible capture of aerosols on filters, and to (4) outside air. Item (4) is the Source Term, i.e., the timed release to air, including the chemical composition of the radioactivity.
>
> Accident-2: This set of accidents involves major damage to the RV permitting air ingress to an overheated core. The release pathway is same as for Accident-1, differing only in degree. The base case is for RV blowdown at t=0, the time of initiation. Blowdown may also occur at anytime thereafter. Blowdown time and duration is determined from data in the accident plot file.
>
> Accident-3: This sequence involves a major break in the pressure boundary outside of the reactor building, i.e., in lines leading to or from the steam generator, located outside of the CB in the steel vessel Magnox reactors. The pathway thus bypasses the reactor building. The base case is for blowdown to occur at time of accident initiation.

6. File Maintenance

Various file maintenance options are available through the GRSAC GUI. To obtain the file maintenance menu options, press the Maintenance button on the Simulation Selection menu (Fig. 39). Maintenance is available for removing simulation (.SIM) files, simulation run (.RUN) files, plot (.AccPLOT and .ICPLOT) files, and fission product holdup/release (.FPHData) files. Pressing the CANCEL button returns to the GRSAC main menu. These maintenance menu options are shown in Figure 68.

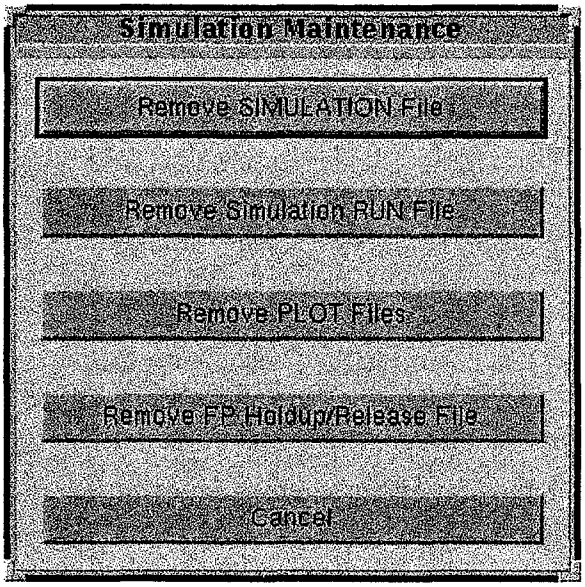

Figure 68. Maintenance–Main Menu

Remove Simulation File

To remove a simulation file and all the data files (run, plot, fission product holdup/release) associated with it press the Remove SIMULATION File button on the Maintenance submenu. The currently selected simulation file will be deleted. A confirmation window is displayed to make sure that the selected simulation file is the one to be deleted. An example of a confirmation window is shown in Figure 69. Pressing the OK button deletes the simulation file and all its associated files. Pressing the CANCEL button returns to the GRSAC main menu.

Remove Simulation Run File

To remove a simulation RUN file press the Remove Simulation RUN File button on the Maintenance submenu. A file selection window is displayed showing all the RUN files that are associated with the currently selected simulation file. Figure 70 shows an example of the file selection window

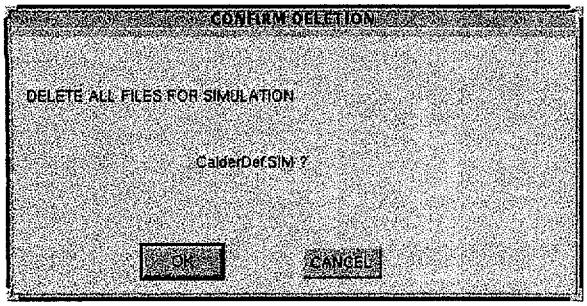

Figure 69. Screen Simulation Files–Deletion Confirmation

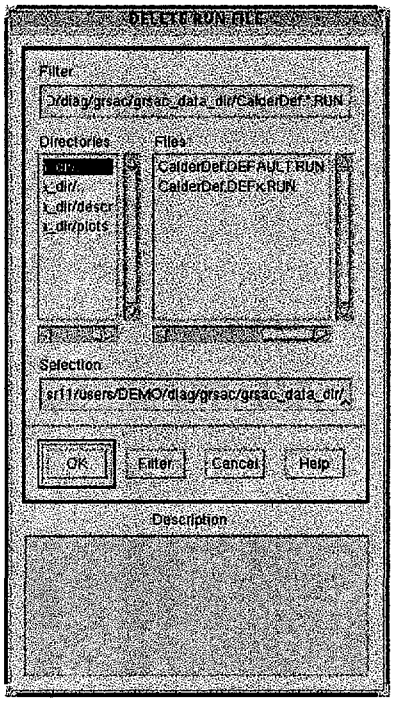

Figure 70. Typical File Selection Menu for RUN File Deletion

displayed. Select the RUN file to be deleted and press the OK button. Pressing the CANCEL button returns to the GRSAC main menu. No confirmation is asked for when deleting RUN files.

Remove Plot Files

To remove a plot file, press the Remove PLOT Files button on the Maintenance submenu. A file selection window is displayed showing all the PLOT files (both IC and accident) that are associated with the currently selected simulation file. Figure 71 shows an example of the file selection window displayed. Select the PLOT file to be deleted and press the OK button. Pressing the CANCEL button returns to the GRSAC main menu. No confirmation is asked for when deleting PLOT files.

Remove Fission Product Holdup/Release Files

To remove a fission product holdup/release data files press the Remove FP Holdup/Release File button on the Maintenance submenu. A file selection window is displayed showing all the fission product holdup/release data files that are associated with the currently selected simulation file. Figure 72 shows an example of the file selection window displayed. Select the fission product

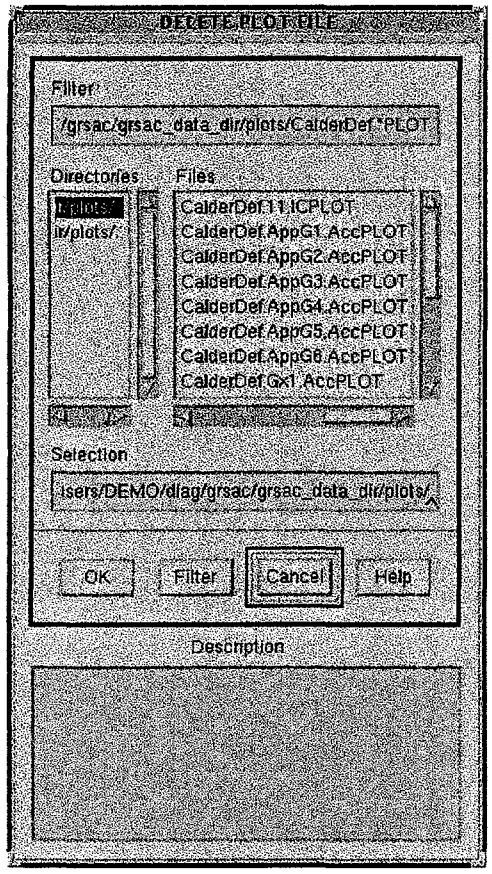

Figure 71. Typical File Selection Menu for Plot File Deletion

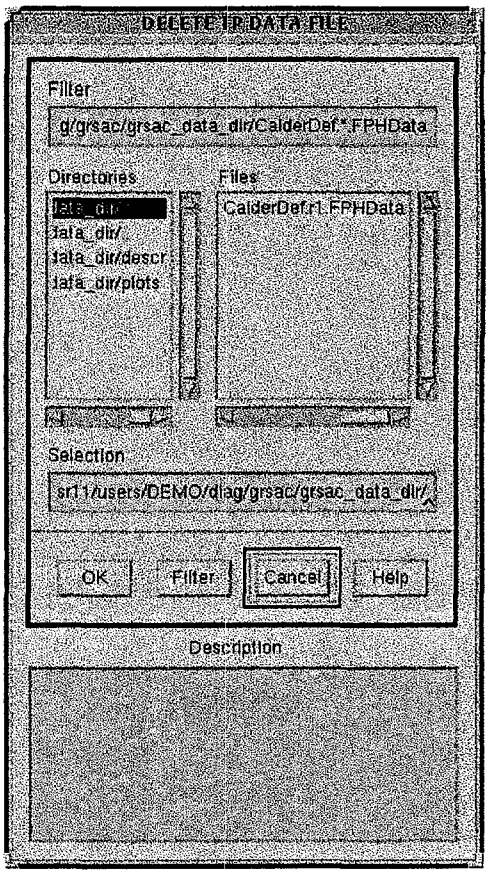

Figure 72. Typical File Selection Menu for Fission Product Holdup/Release File Deletion

holdup/release data file to be deleted and press the OK button. Pressing the CANCEL button returns to the GRSAC main menu. No confirmation is asked for when deleting fission product holdup/release data files.

7. Run Selection

Several options are available for simulation runs. These options are displayed when the RUN button is pressed on the Simulation Selection menu. A choice menu is displayed for choosing either an Initial Conditions, Accident or Sensitivity run. This menu is illustrated in Figure 73. Use the mouse to select a simulation run option. For detailed instructions on using the file selection screen, see Section III.3, General Instructions. An example of the RUN file selection window is shown in Figure 74.

Following is a detailed explanation of each simulation run option and the set up procedure for each option.

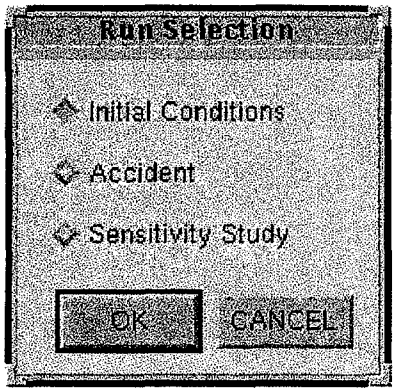

Figure 73. Run Selection Menu

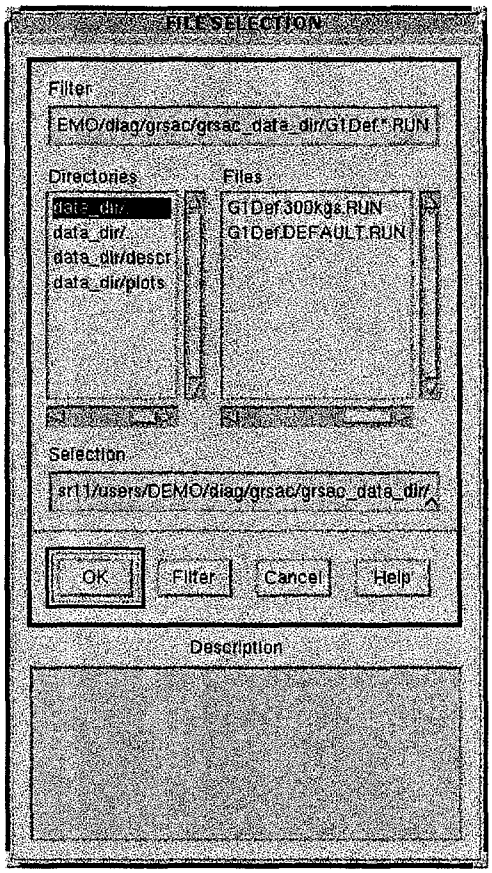

Figure 74. Typical Run Selection (applicable for IC, Accident, and Sensitivity Study)

Initial Conditions (IC) – Plots

If an Initial Condition simulation run is selected, following a .RUN file selection, a setup window for selecting dynamic plots during the Initial Condition run is displayed. For detailed instruction on setting up the IC plot screen, see Section III.3, General Instructions.

Dynamic plots during Initial Condition runs are illustrated in Fig. 75. Three different temperature variables can be plotted vs. time on the first plot. Radial and axial plots are available for temperature variables on the three remaining plots. Most plotting options can be changed during the run by selecting the appropriate variables and pressing the OK button. The exception is the first plot during Initial Condition runs. In this case, once the OK button is pressed, the buttons and menus on the first dynamic plotting screen are made inactive, i.e. the plot setup for the first plot during IC runs cannot be changed once the OK button is pressed, they can only be CLEARed.

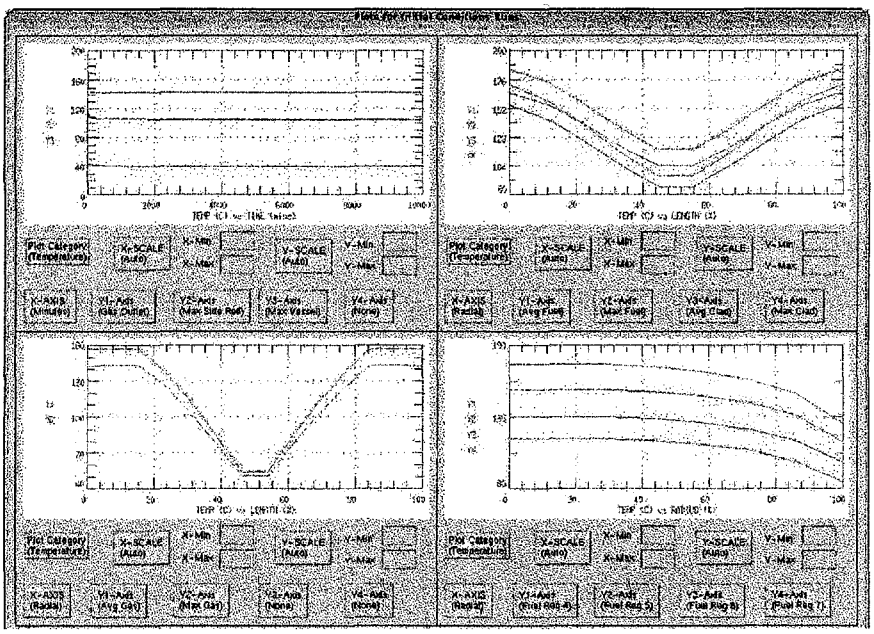

Figure 75. IC Dynamic Plot Screen

Initial Conditions (IC) – Runs

When the OK button is pressed on the dynamic plot screen for the Initial Conditions run, the Initial Conditions interactive RUN screen is displayed (Fig. 76).

The user input area is located on the far righthand side of the screen. The user can RUN, HOLD, or QUIT the simulation. The user can toggle between English and Metric units. Switching units on the IC Run Screen switches units on the dynamic plot screen as well. The remaining input areas are not activated unless the user presses the APPLY button. The HELP button activates the help window.

As the simulation runs, the output areas of the screen are updated. If the simulation is in HOLD and the APPLY button is pressed, nothing will take effect until the simulation is started again. The simulation will have reached a "good" steady-state condition when all of the displayed variables are steady [reflector temperature is usually the last to "settle"] and the "Heat balance I/O" is steady at (very close to) 100%.

The SAVE button is used to save a steady state or IC run file. The initial condition parameters are saved in the given RUN file. The RUN filename must have the format <SimulationName>.<RunID>.RUN before it will be saved. These RUN files can be used later when running an accident or sensitivity study, or another IC case. Note that the simulation must be run for at least one additional time step after saving an initial conditions file.

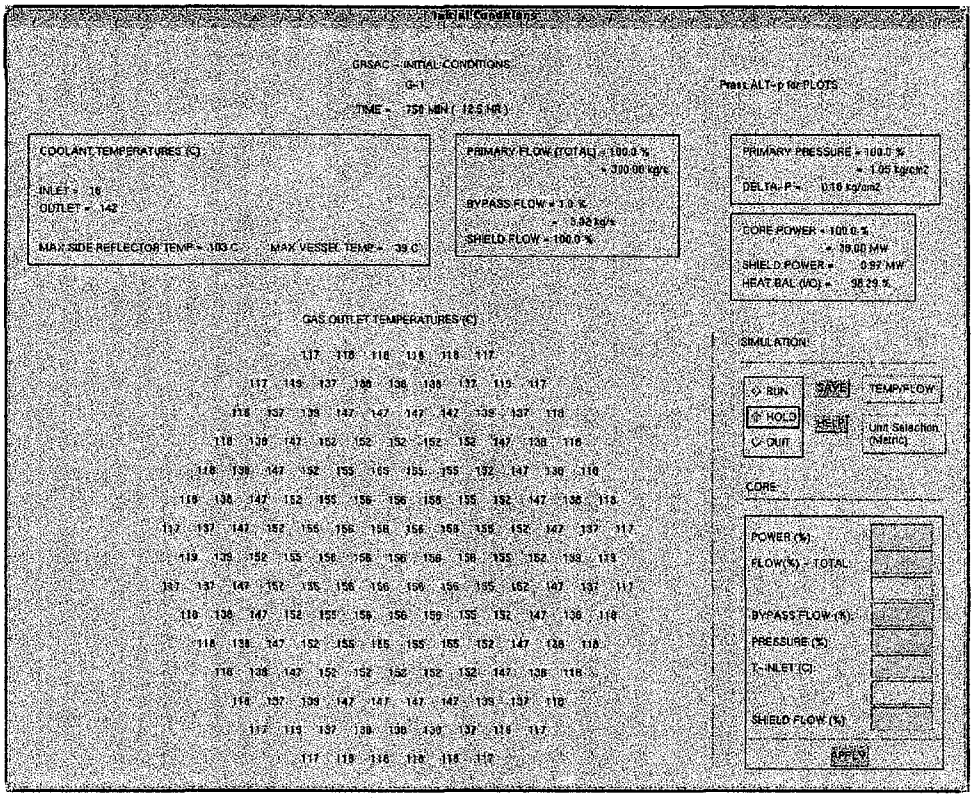

Figure 76: Initial Conditions Interactive Run Screen

The user can use the TEMP/FLOW menu to view mappings of the Core (axial regions 1-14), Peak Fuel (axial regions 3-12), and Gas Outlet Temperatures as well as the Flow, while the simulation is running.

If any on-line plots have been selected, the user can toggle back and forth between the Initial Conditions screen and the plot screen with the ALT-p keys. After the run, if plot selections were made, a file selection menu is displayed for saving the Initial Conditions plot data. This data is used in post run plots. For more information on saving plot data, see Section III.3, General Instructions. Pressing the OK button on the file selection window saves the Initial Conditions data to the specified file name and returns to the Run Selection menu. Pressing the Cancel button returns to the Run Selection menu.

Accident/Sensitivity – Plots

For either the Accident or Sensitivity simulation runs, a setup window for selecting dynamic plots during the simulation run is displayed. Up to four different variables can be plotted on four different plots. Variables are divided up by category. As categories are selected, options for the y-axes change. If a variable is dulled out, the option is not available in the selected Category. The "None" option means that no variable will be plotted. Some categories offer profile plots, with y-variables vs "Length" or "Temp." Dynamic plots for Accident/Sensitivity runs are illustrated in Figure 77.

For detailed instructions on setting up the accident plot screen, see Section III.3, General Instructions.

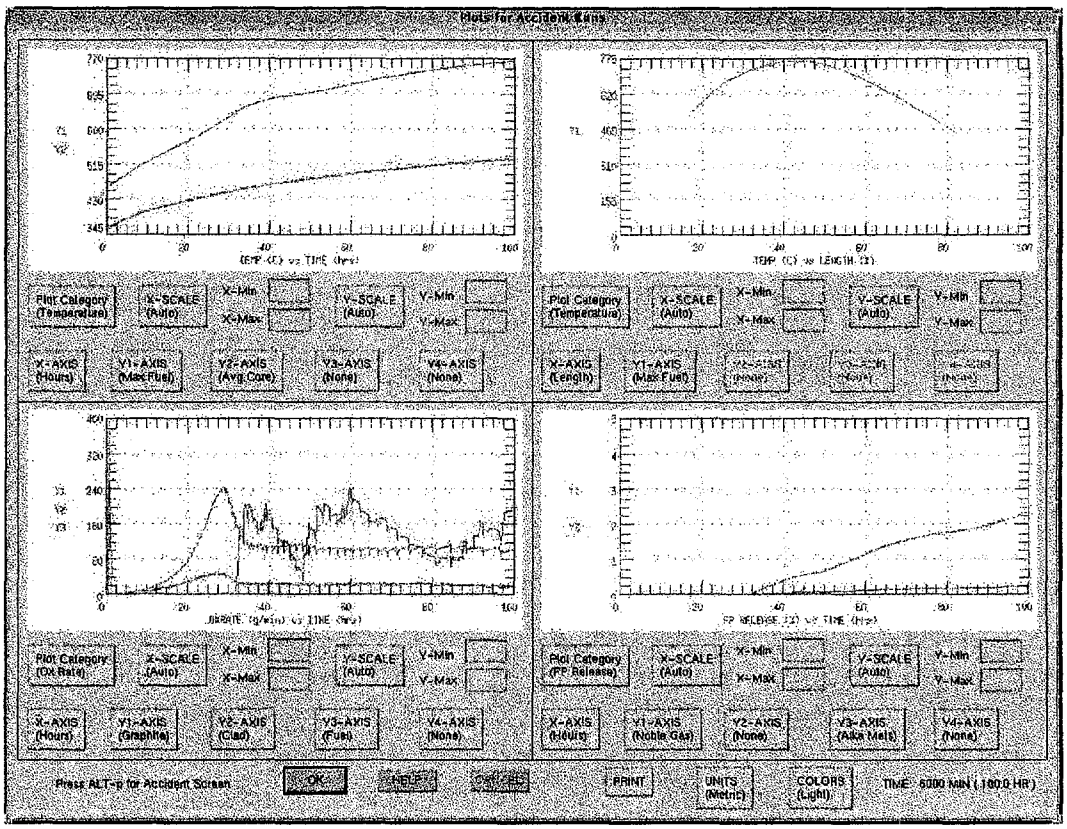

Figure 77. Accident Plot Example

Accident – Runs

When the OK button is pressed on the dynamic plot screen for the Accident run, the Accident interactive run screen is displayed. The accident screens for G2/3, Calder Hall, Single Channel, G1 and Windscale type models are illustrated in Figures 78-82, respectively. Some features are common to all screens. Located on the far righthand side of the screen is the user input area: the user can RUN or HOLD the simulation. QUIT returns to the main menu. The user can toggle between English and Metric units. Switching units on the Accident Run Screen switches units on the dynamic plot screen as well. The user can SCRAM the reactor by pressing the SCRAM button (omitted for "Single Channel"), and the HELP button pops up a help window.

For the reactor screens, the Fission Product Release button creates a pop-up window that displays the calculated % releases from 8 (or 2 or none, as selected) fission product groupings. The model

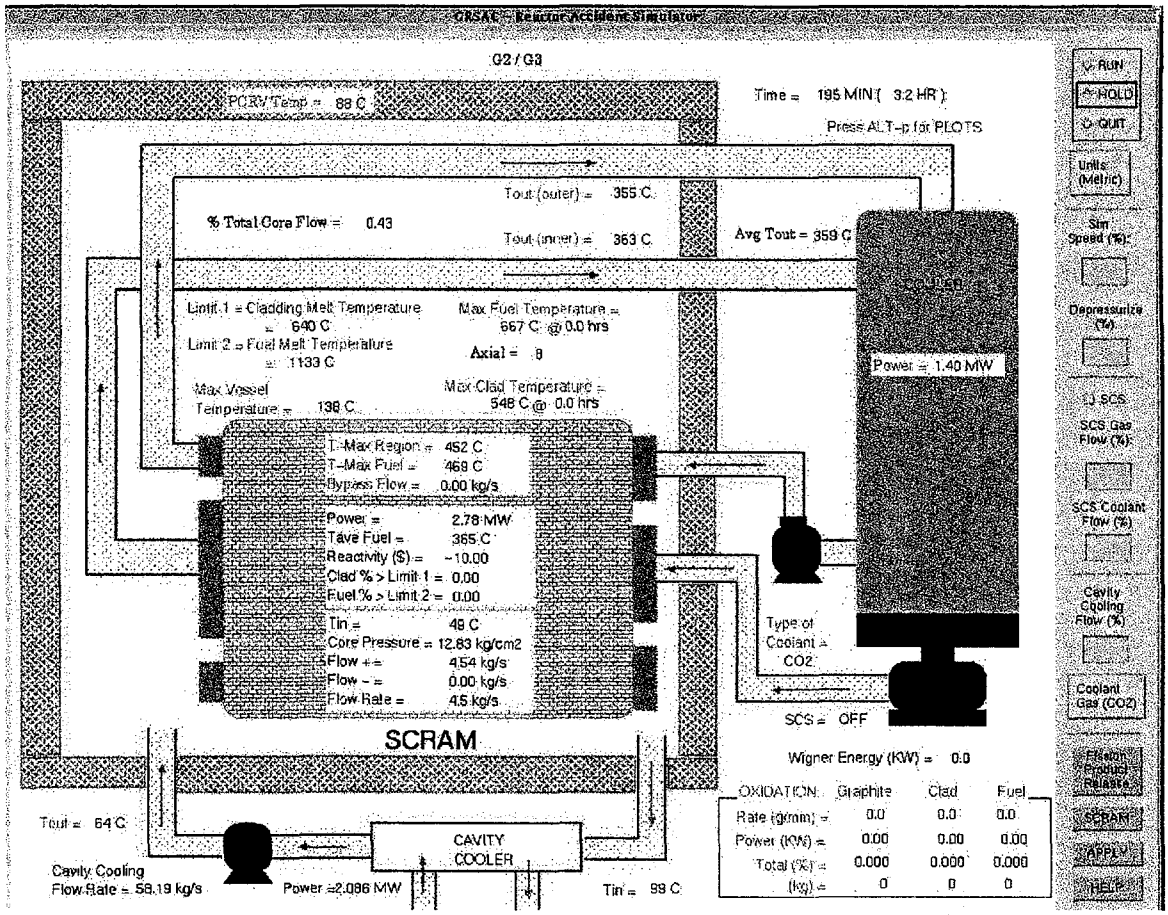

Figure 78. Accident Interactive Run Screen–G2/3 Example

for fission product release is based on data for uranium metal fuel, and are functions of irradiation, fuel oxidation, and temperature. No release is assumed until clad failure occurs. The fission product groups are as follows:

1. Noble gases
2. Halogens (Iodine)
3. Alkali metals
4. Tellurium group
5. Alkaline Earths
6. Noble metals
7. Lanthanides
8. Cerium group

Figure 83 illustrates a Windscale Accident Run screen with the pop-up Fission Product Release Window displayed.

The remaining input areas are not activated unless the user presses the APPLY button. If an input area is not active, it is because programmed inputs are being used to control that input variable. Since some inputs and outputs apply in only certain cases, we use the following keys to make the distinctions:

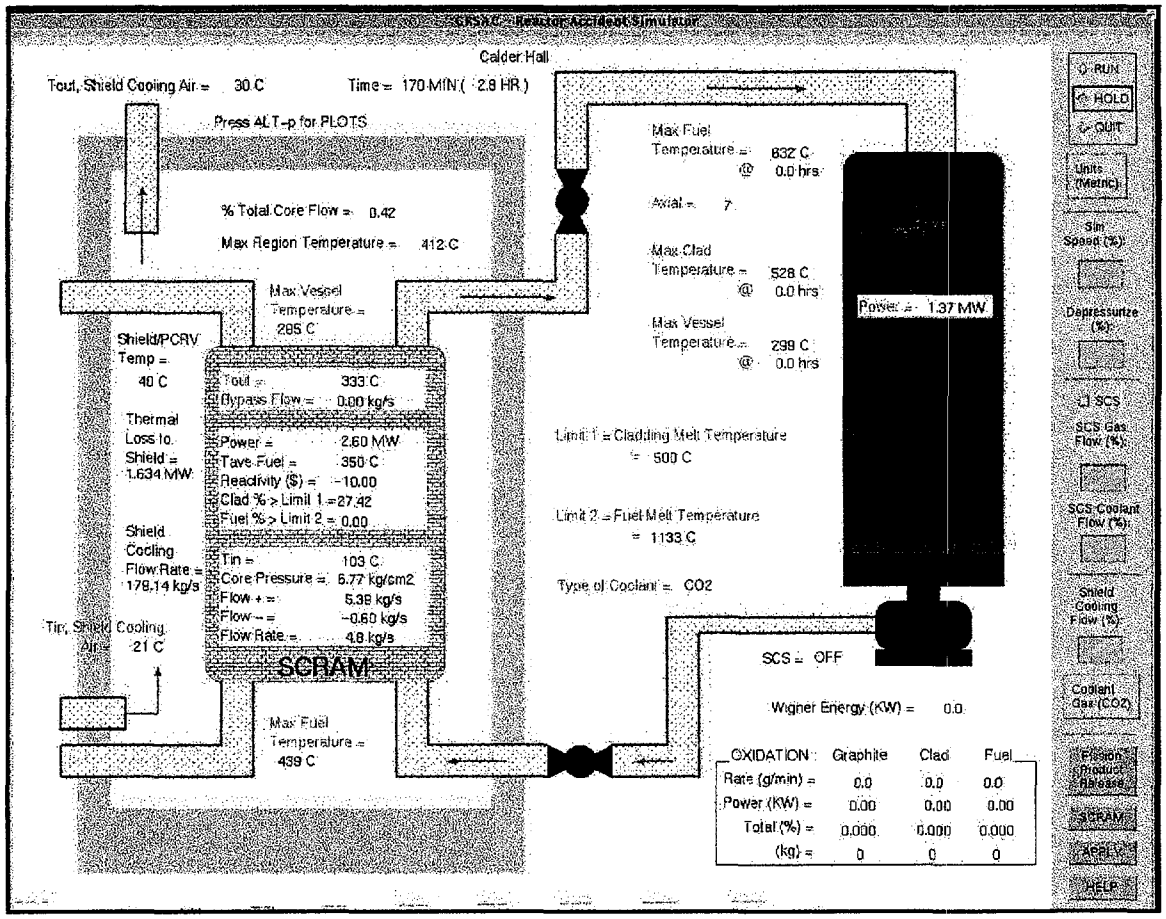

Figure 79. Accident Interactive Run Screen – Calder Hall Example

(P) = Pressurized reactor models (G2 and Calder Hall)
(AC) = Air-Cooled reactor models (Windscale, Single Channel, and G1)

Simulation speed (%) may be reduced below 100%.

(P) The primary system may be depressurized by entering (%) numbers between 100 (rated pressure) and 0 (atmospheric pressure). Pressures can only be decreased.

(P) The Shutdown Cooling System (SCS) may be activated manually by clicking on the SCS button. % of rated flows for the primary system gas and water coolant can be entered for reduced/degraded flow conditions. The entry for gas flow is in terms of either %rated primary flow (default) or % rated SCS flow, depending on the flag set in the Programmed Input Screen.

(AC) The manual Blower control is via the Blower button and the Air Flow (% Rated) entry. The entry for gas flow is in terms of either % rated primary flow (default) or % rated SCS flow, depending on the flag set in the Programmed Input Screen.

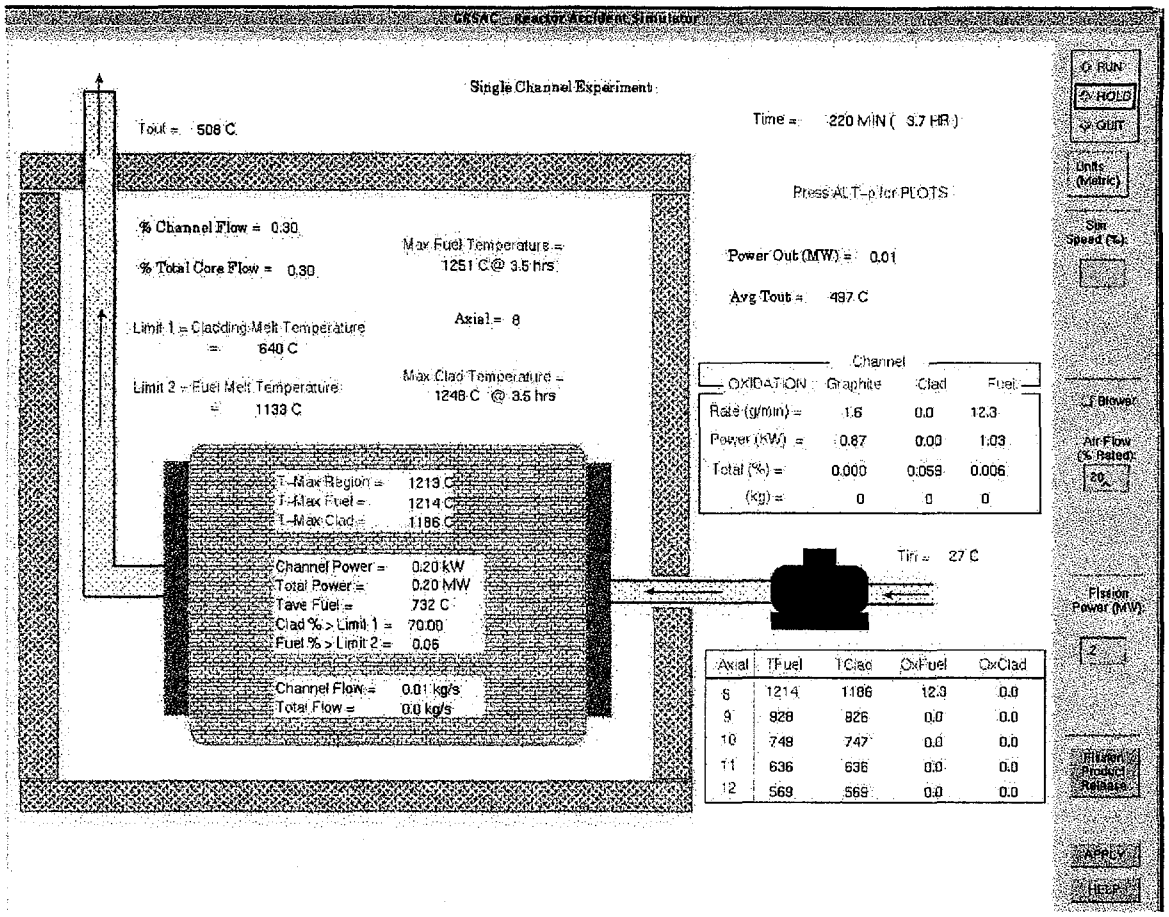

Figure 80. Accident Interactive Run Screen–Single Channel Experiment Example

(AC) The Fission Power (MW) allows addition of arbitrary total core power input. It is added to the afterheat, and only applies after SCRAM.

Shield cooling flow (%) of rated flow refers to the air flow specified in the "Reactor Cavity Design" input screen.

(P) The primary coolant gas type (CO_2, He, or Air) may be selected. The change is assumed to be instantaneous.

As the simulation runs, the output areas of the screen are updated. If the simulation is in HOLD and the APPLY button is pressed, nothing will take effect until the simulation is started again.

When in the accident or sensitivity study mode, the user can toggle back and forth between the screens using the ALT-p keys.

In the left-hand (output) portion of the screen, some entries may need clarification:
(P) Power (out) in the SCS icon refers to the power (MW) removed by the SCS when it is operating. The power shown when the SCS is not operating is derived from the core flow and temperature rise, whether via a programmed LOFC or natural convection (air) flow.

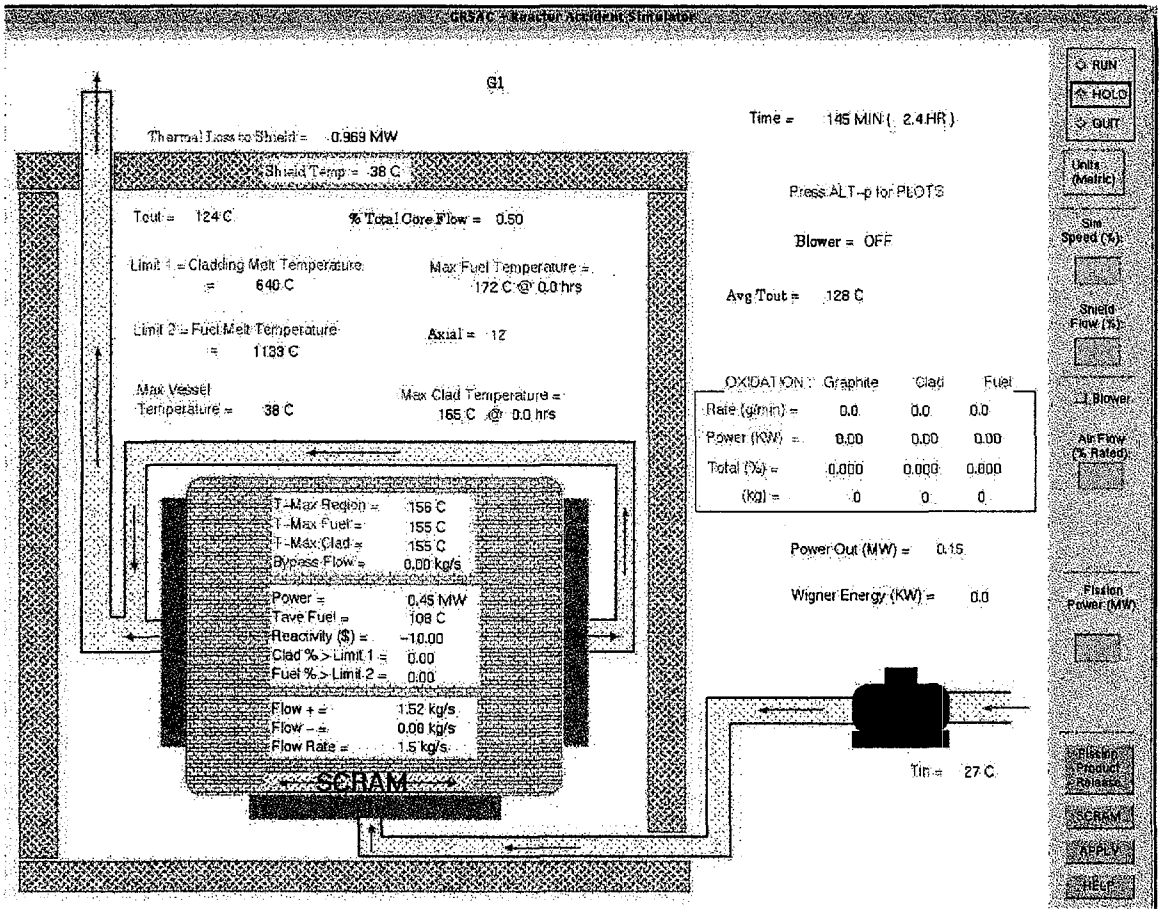

Figure 81. Accident Interactive Run Screen – G1 Example

(AC) Power out is derived from the core flow and temperature rise, whether via a programmed LOFC, blower input, or natural convection (air) flow.

The values for Flow + and - in the core icon refer to the sums of the total regions flows in the normal (+) and the reverse (-) directions. The Flow Rate value (just below) refers to the net flow in.

If on-line plots have been selected, after the run a file selection menu is displayed for the option of saving either the Accident or Sensitivity Study (final run) plot data.

The plot data file is used both for post run plots and for calculating fission product holdup/releases. An example of the file selection window displayed for saving Accident and Sensitivity Study plot data is shown in Figure 55. Plot data files for Accident and Sensitivity Study runs must end in AccPLOT. Pressing the OK button on the file selection window saves the Accident or Sensitivity

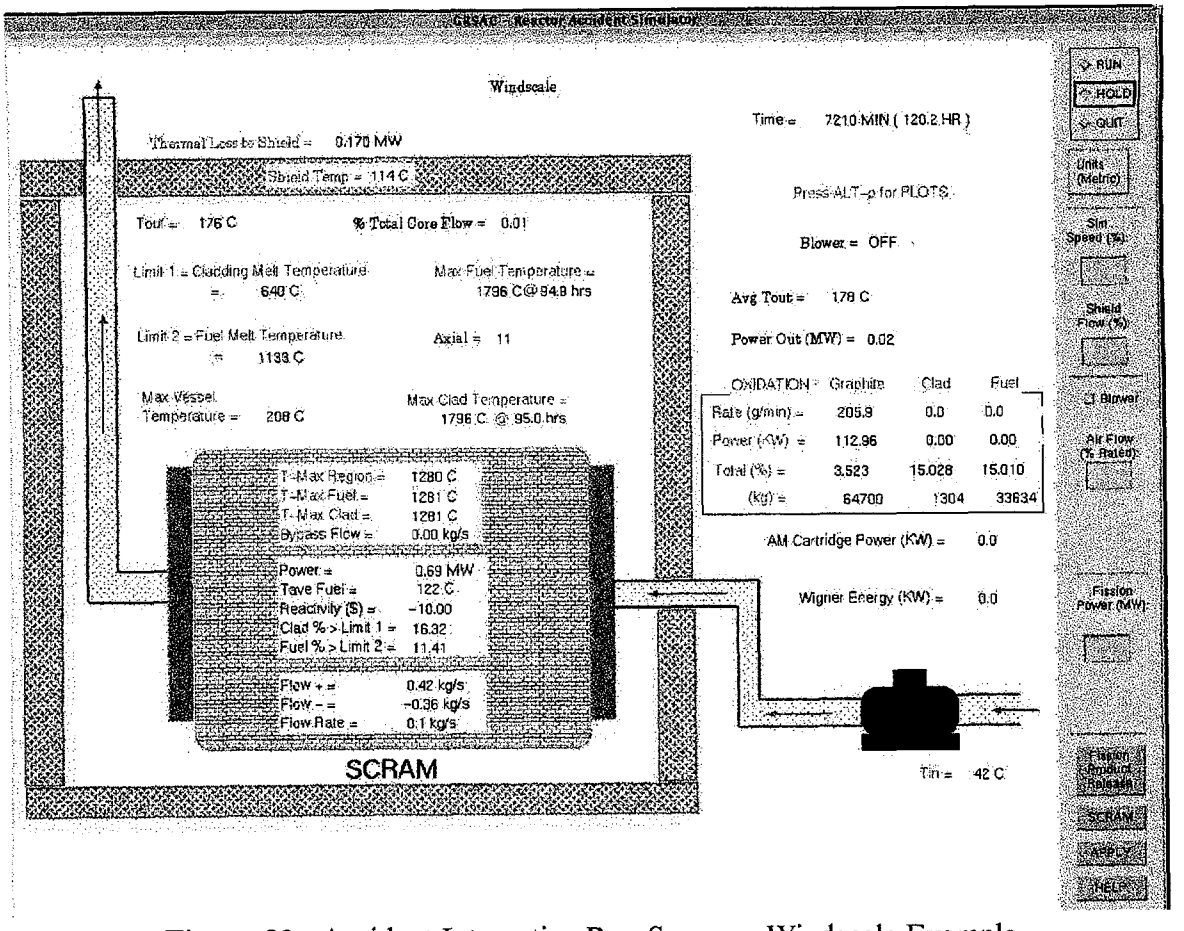

Figure 82. Accident Interactive Run Screen – Windscale Example

Study data with the specified file name and returns to the GRSAC main menu. Pressing the Cancel button returns to the GRSAC main menu.

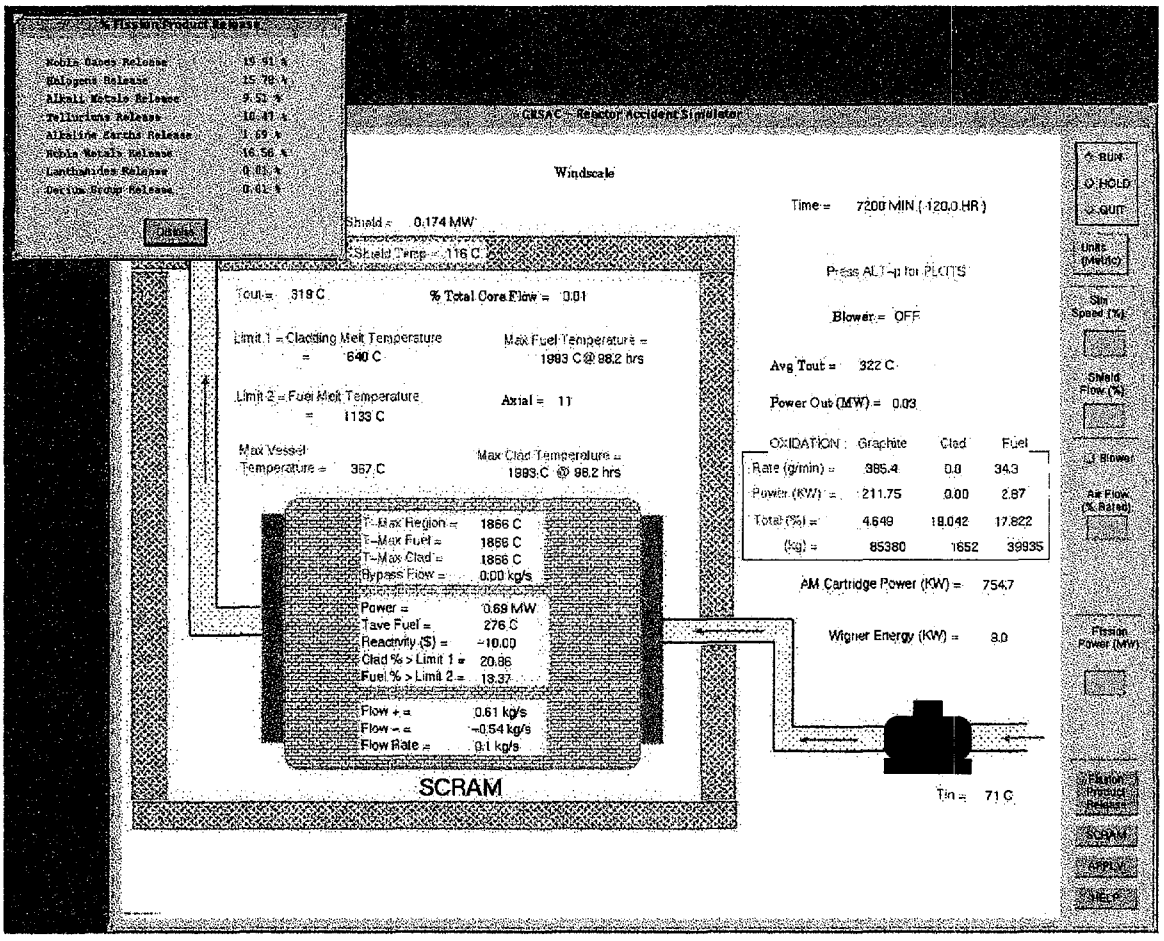

Figure 83. Accident Interactive Run Screen–Windscale Example Showing Fission Product Release Pop-up Screen

Sensitivity Study–Design Inputs

When the OK button is pressed on the dynamic plot screen for the Sensitivity Study run, the display for selecting Design Input parameters for the Sensitivity Study is displayed. This input screen is shown in Figure 84 .

The sensitivity study option facilitates investigations of the effects of changes in model and operational uncertainties on the outcome of selected accident scenarios. Sensitivity parameters can be selected from this screen (design inputs) and/or from a second screen (operational inputs) that appears after the "reference run" is completed.

A maximum of 10 sensitivity parameters can be selected. The current number of parameters selected is displayed below the objective function.

Categories for Design Input Selection are Core Layout Design, Fuel Element Design, Nuclear Design, and Graphite Properties & Materials Oxidation. When one of these toggles is selected, the data input area for that selection is activated. Once these areas are activated, the user can enter data or accept the default values. Each variable is displayed with a nominal or reference value and a

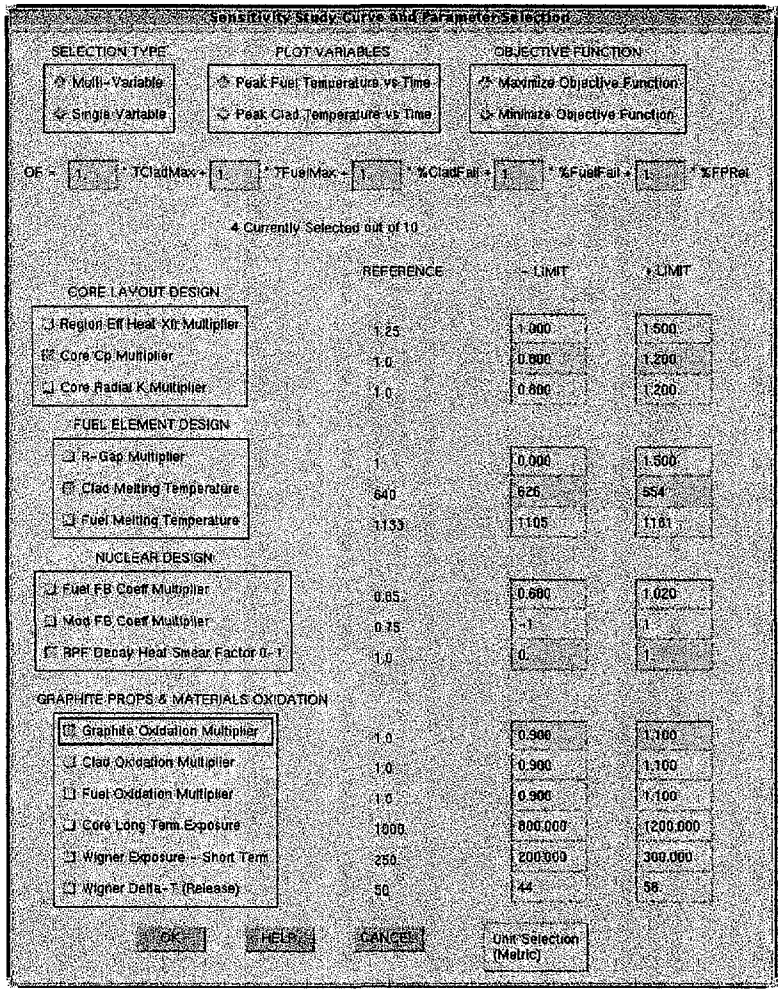

Figure 84. Sensitivity Study Curve and Parameter Selection (Design) Screen. (Note: A Reference Case Accident Run Follows.)

default "uncertainty range." The nominal values are those specified via the design parameter selection setup. The +/- uncertainty ranges for the selected variables may be changed manually. Some design input variable changes affect the initial conditions (Region Eff Heat Xfr Mult and Core Radial K Mult), so the accident runs for these variations would be "approximate." Two Nuclear variables are for ATWS runs only–Fuel FB Coeff Multiplier and Mod FB Coeff Multiplier. In the Graphite/Materials category, the Graphite, Clad, and Fuel oxidation multipliers are always 1.0 as a reference. They are used to multiply BOTH the Zone 1 and Zone 3 multipliers specified in the Design Input screen.

The user also has the option of selecting the Plot Variable to be displayed on the sensitivity screen and the objective function to be used during the sensitivity calculations. The user can choose from two plots, Peak Fuel Temperature vs Time or Peak Clad Temperature vs Time. In addition, the user can change unit selection (Metric/English).

The user selects five weighting coefficients to be used in the "objective function" (O.F.). The O.F. is what is to be maximized or minimized by a gradient search technique. Parameters included in the O.F. are T-max-fuel, T-max-clad, %fuel failure, %clad failure, and %FPRel (% Fission Product Release, which is a sum of releases in all 8 chemical groupings). The total O.F. needs to have a non-zero value (to guide the search process), so something in addition to the failure numbers must be included (e.g., non-zero temperature multipliers) in case no clad or fuel failures or fission product releases occur. The O.F. vs. time will also be plotted (along with the reference case) as each run progresses.

A "single-variable" sensitivity option is also available. That one parameter can be selected from either the Design or Operational Input screen. The program runs the reference case plus 4 additional cases by varying the selected parameter more or less uniformly within the uncertainty band.

If the CANCEL button is pressed, all selected categories are reset and the sensitivity run is canceled and the GRSAC main menu is displayed. If the RUN button is pressed, the sensitivity study continues with the running of the reference case.

Sensitivity Study–Operational Inputs

After the reference run has completed and the Quit button activated on the Accident screen, the screen for selecting Operational parameters for the Sensitivity Study is displayed (Fig. 85).

This display provides options for selecting operational inputs to be added to the sensitivity list. The list from which these selections can be made is determined by entries that have been made (in advance) in the "Programmed Run Inputs." The "reference case run" values in the sensitivity study are determined from these values as well as from the reference case design input values.

The user selects the operating condition variables to be included in the sensitivity study (the total number, design plus operating, is limited to 10).

The nominal values for the operating conditions are those specified by the "Programmed Input" selections. The +/- limits can be changed manually once the category has been selected. The categories available are: Delayed Scram, Depressurization (@ Time, Duration of Ramp, Change to Air at End of Ramp?), Shutdown Cooling -SCS (@ Time, Gas Flow, Coolant Flow), Flow Coastdown Cavity/Shield Cooling (Time of Change, Cooling Flow), Initial Power and Flow multiplier, Decay Heat Power multiplier, and Flow Sequence multiplier (which is a multiplier for all the flow values entered in the Flow Sequence listing.

The CANCEL button returns to the GRSAC main menu. The OK button continues with the sensitivity runs.

Sensitivity Study–Run Screen

After the RUN button is pressed on the Operational Parameter Selection screen, the Sensitivity Study Run Screen is displayed. An example of a Sensitivity Run screen is illustrated in Figure 86. When the sensitivity runs are started, the user can watch the progress via the two plots (selected variable

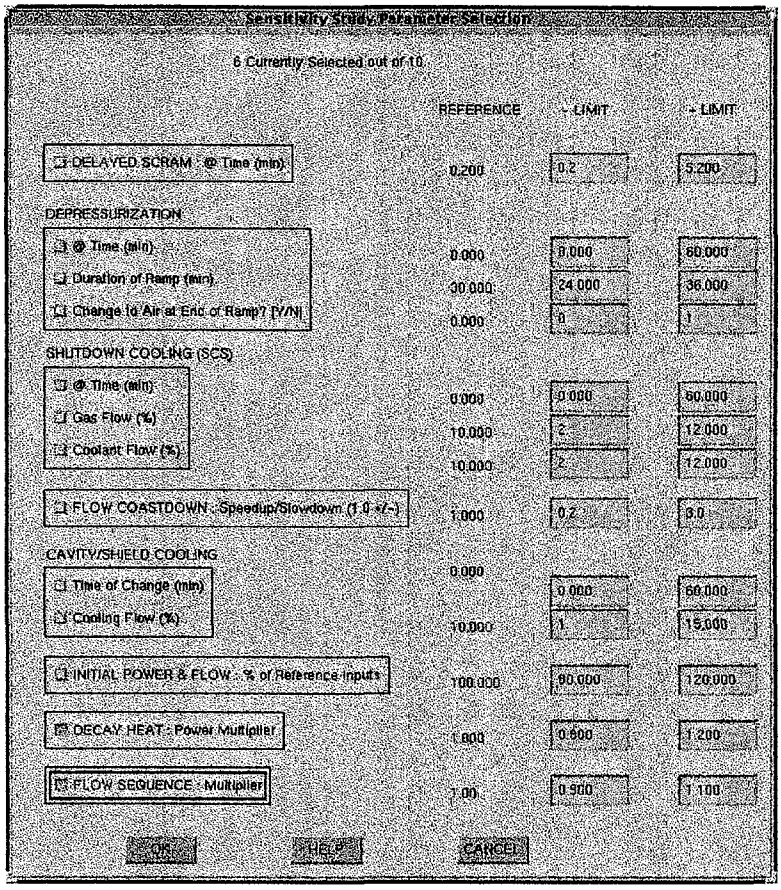

Figure 85. Sensitivity Study Parameter Selection (Operational)

and O.F. vs. time) and the running tally of the current and "best" cases to date (per the O.F.) and the corresponding peak fuel/clad temperatures and %fuel/clad failures. The current values used in all of the selected sensitivity variables are displayed. In future implementations, the user may also manually vary the parameter sensitivity ranges during the runs using the APPLY button. The APPLY button is inactive until the implementation of this feature. To determine the relative effects on the O.F. due to changes in each of the parameters, the sensitivity terms d(O.F.)/d(Param) are calculated and are available via a report generator.

The HOLD button pauses the simulation. The STOP button stops the sensitivity run (never to be restarted). The RETURN button returns the user to the main menu. After all sensitivity runs are completed, a report on the results can be viewed (and printed) via the REPORT GENERATOR. A PRINT button allows for printouts of this screen. Figure 87 illustrates an example of a generated report during a Sensitivity Study run.

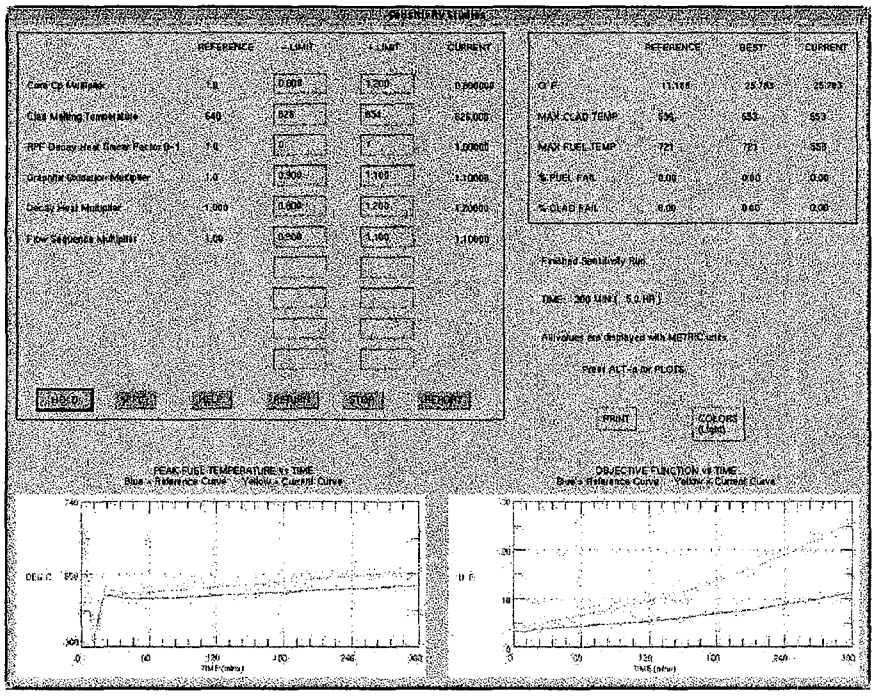

Figure 86. Sensitivity Study Run Screen

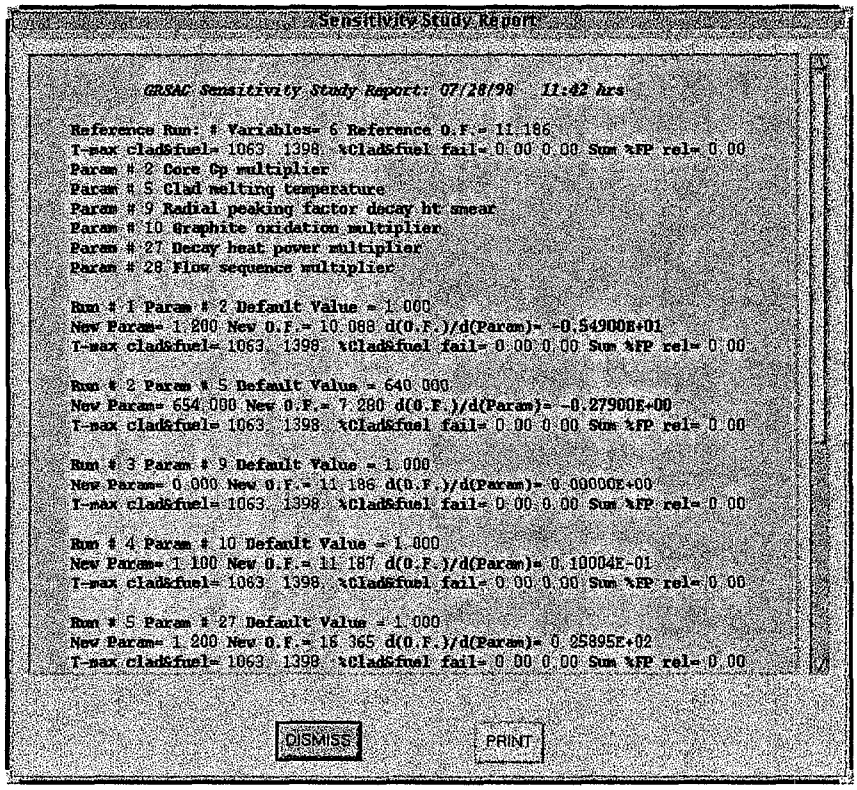

Figure 87. Sensitivity Study Report–Example

IV. GRSAC Installation

The GRSAC software runs on SUN OS 4.x and Solaris and is distributed on both cd-rom and floppies. Installation programs exist for each media and both are described below.

CDROM

The generic cdrom installation program, install.cd, has four options on the main menu (Figure 88). The INSTALL GRSAC option begins the installation of the Graphite Reactor Severe Accident Code. The INSTALL ORIGEN-Pro option initiates the installation of the Origen-Pro neutronics code. The INSTALL APROS GUI option begins the installation of the interface for APROS reactor simulations. The Help button displays help information and the Quit button quits the installation program.

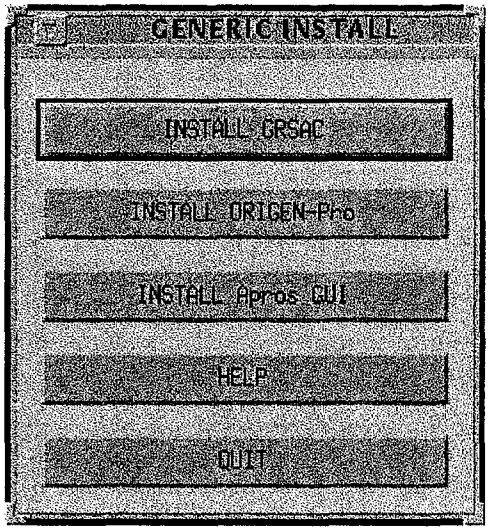

Figure 88. Generic Installation Menu (CDROM)

Overview

This installation program enables the user to install the software packages that are distributed on the enclosed cdrom.

To run the generic cdrom install program type

/cd_directory/install.cd

where cd_directory is the name of the cdrom mount point for your system.

***** IMPORTANT *** Please NOTE:**

1) The installation program assumes that the cdrom is already mounted.

2) The installation program assumes a default mount point of /cdrom. If this assumption is incorrect for your system, set the environment variable CD_MOUNT_PT to reflect the appropriate mount point BEFORE running the installation program. Make sure that you are setting the variable in the same window from which you are running install.cd or set it in such a way that the variable will be seen from the installation program. For example, to set the environment variable before running the installation program, type

    setenv CD_MOUNT_PT /cd_directory

    where cd_directory is the name of the cdrom mount point for your system.

3) For the installation of GRSAC, the software is installed in the directories specified during the installation process for GRSAC_BASE_DIR, GRSAC_DATA_DIR and GRSAC_SIM_DIR .

4) The GRSAC software requires that three directories be created and defined, GRSAC_BASE_DIR, GRSAC_DATA_DIR and GRSC_SIM_DIR. The GRSAC Base Directory is defined by the environment variable GRSAC_BASE_DIR. This directory contains basic files used by the Human-Machine Interface (HMI). The GRSAC_BASE_DIR is a directory that can be shared by all users and does not need to be duplicated in each individual's GRSAC home area. The directory defined by the environment variable GRSAC_DATA_DIR contains data files used by the HMI. The directory defined by the environment variable GRSAC_SIM_DIR contains simulation files used by both the HMI and the simulation. Unlike the base directory structure, EACH user will need their OWN copy of the data and simulation directories. The user will need to have write access to these areas.

Steps for Installing the GRSAC Server Files

The following Section describes how to install the GRSAC software on a server in a multi-user environment. These instructions are also sufficient for installing the software in a single user environment.

STEP 1:

Mount the cdrom.

STEP 2:

The installation program assumes the cdrom mount point /cdrom . If your mount point has a different name, set the environment variable CD_MOUNT_PT as follows

setenv CD_MOUNT_PT /some_directory

This should be done in the cmdtool window from which you are going to run install.cd and BEFORE you start the installation process.

STEP 3:

To the installation program, type

install.cd

and select GRSAC as the software to be installed.

STEP 4:

Follow the installation program instructions to set the required environment variables GRSAC_BASE_DIR, GRSAC_DATA_DIR and GRSAC_SIM_DIR . A window is displayed, as shown in Figure 89, asking for verification of the definition of GRSAC_BASE_DIR. If the displayed definition is correct, press the YES button, if it needs to be reset press the NO button. Pressing the YES button continues on with the installation process. Pressing the NO button displays a file selection window as shown in Figure 90 for setting GRSAC_BASE_DIR. A path selection window will be displayed for defining each of the three options. Choosing the option directory_name/. under the Directories section moves back one directory. The area titled Selection shows the current directory selection. To select these directories, click on the directory to be used from the "Directories" scrolling list area on the left side of the selection box. Press the OK button when the needed directory name appears in the "Selection" area. The user may also type the full directory path in the "Selection" area and then press the OK button. Press the Cancel button to abort the directory selection process and return to the main menu. Please note that these directories MUST EXIST prior to the installation process.

The installation program automatically updates the users .cshrc file with the directories selected during the installation process for GRSAC_BASE_DIR,GRSAC_DATA_DIR and GRSAC_SIM_DIR and sets their path and resource directory appropriately. If the installation is for a single user environment, this process is sufficient. If the installation is for a multi-user environment, please refer to the Section below on the GRSAC Start Up Script.

After installing GRSAC, you must log off and then log back on so that your environment is setup correctly before running the program. If the start up script provided with the distribution is used, it is not necessary to restart your login session.

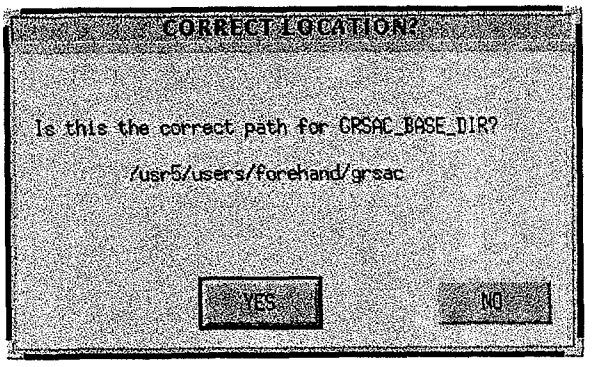

Figure 89. Path Confirmation Screen

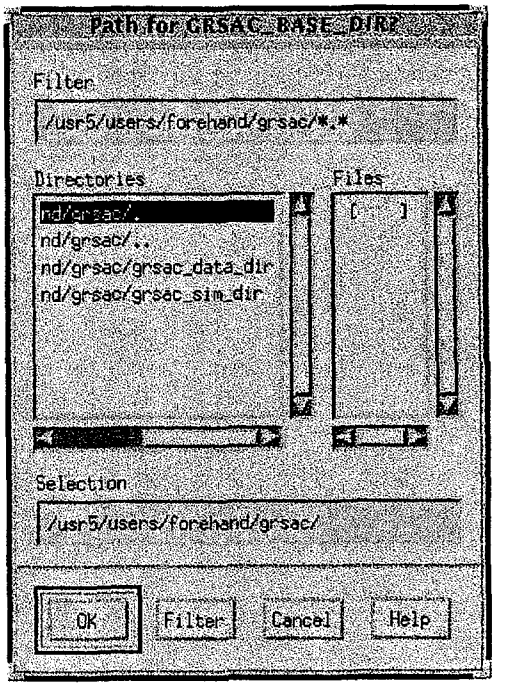

Figure 90. Path Selection Screen

FLOPPY DISKS

The generic installation program using floppies has four options

1)	INSTALL SunOS	- begin installation on a machine running SUN OS 4.x
1)	INSTALL Solaris	- begin installation on a machine running Solaris 2.x
2)	Help	- display help information
3)	Quit	- quit the installation program

This installation program enables you to install GRSAC and/or OrigenPro software. GRSAC is distributed on floppies, and OrigenPro is distributed on 8mm tape.

Overview

To run the generic install program type

genInstall

Please NOTE:

1) The compressed tar files extracted from the installation floppies will be put in the directory from which you run genInstall.
2) There is no "&" after the genInstall command ("&" would make genInstall run in the background). Running the installation program in the background causes problems with the interaction required with the cpio and bar commands, so do not run the installation program in the background (followed by an "&").

*** For SOLARIS installations ONLY: read 3) and 4) ***

3) While using cpio, the system may pop up an "Unlabeled Floppy" window. If so, just press the Cancel button and continue with the installation process.

4) The installation program assumes floppy device /vol/dev/aliases/floppy0. If your floppy drive has a different name, set the environment variable FLOPPY_DEVICE_NAME as follows

setenv FLOPPY_DEVICE_NAME your_floppy_device_name

This should be done in the cmdtool window from which you are going to run genInstall and BEFORE you start the installation process.

5) When cpio prompts you for device/filename to continue, respond with

/vol/dev/rdiskette0/unlabeled

if you are using floppy0, (or /vol/dev/rdiskette1/unlabeled for floppy1, etc.).

Steps for Installing the GRSAC Server Files

The following section describes how to install the GRSAC software on a server in a multi-user environment. These instructions are also sufficient for installing the software in a single user environment.

The GRSAC software requires that three directories be created and defined, GRSAC_BASE_DIR, GRSAC_DATA_DIR and GRSAC_SIM_DIR. The GRSAC Base Directory is defined by the environment variable GRSAC_BASE_DIR. This directory contains basic files used by the HMI. The GRSAC_BASE_DIR is a directory that can be shared by all users and does not need to be duplicated in each individual's GRSAC home area. The directory defined by the environment variable GRSAC_DATA_DIR contains data files used by the HMI. The directory defined by the environment variable GRSAC_SIM_DIR contains simulation files used by both the HMI and the simulation.

Unlike the base directory structure, EACH user will need their OWN copy of the data and simulation directories. The user needs to have write access to these areas.

STEP 1:

Place the installation floppy labeled "Volume 1" in the floppy drive.

STEP 2:

Start the installation program genInstall. The main menu for genInstall is shown in Figure 91.

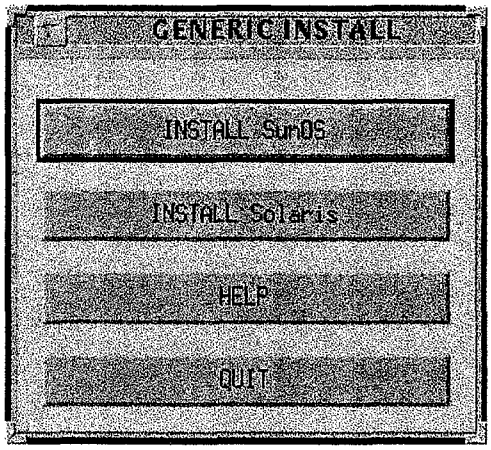

Figure 91. Generic Installation Main Menu (floppies)

STEP 3:

Choose the installation platform ("Install SunOS" for machines running SUN OS 4.x or "INSTALL Solaris" for machines running Solaris 2.x). Press the OK button. The selection window shown in Figure 92 will be displayed. Pressing the CANCEL button returns to the main menu.

STEP 4:

Select GRSAC as the software to be installed, and then press the OK button.

STEP 5:

A window will be displayed requesting that the user insert the floppy as shown in Figure 93. The user is also informed where the tar files will be extracted. Press the CONTINUE button to proceed with the installation. Press the QUIT button to end the installation process. If the CONTINUE button is pressed, the "working" window shown in Figure 94 is displayed.

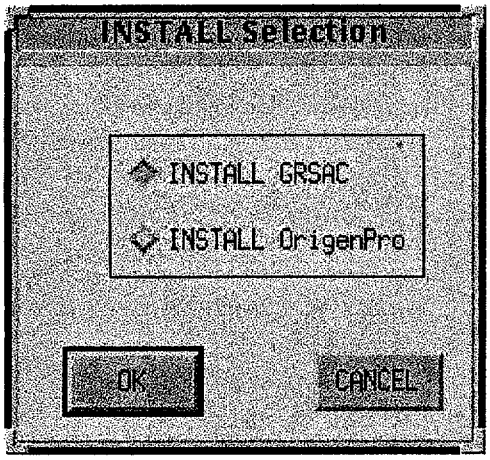

Figure 92. Generic Installation Program Selection Menu (floppies)

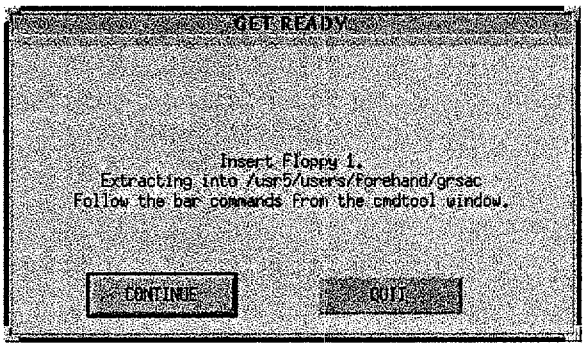

Figure 93. Floppy Insertion Prompt

Follow the installation progress from the cmdtool window from which the installation program was started. Interact with the program as requested from this window (i.e. insert next floppy and press Return, ...).

Figure 94. "Working" Window Display

STEP 6:

Once the tar files are extracted, the user is prompted to set the environment GRSAC_BASE_DIR, GRSAC_DATA_DIR and GRSAC_SIM_DIR . A window is displayed, as shown in Figure 89, asking for verification of the definition of GRSAC_BASE_DIR. If the displayed definition is correct, press the YES button, if it needs to be reset press the NO button. Pressing the YES button continues on with the installation process. Pressing the NO button displays a selection window as shown in Figure 90 for setting GRSAC_BASE_DIR. This is the directory where the distribution was installed. Either highlight the correct directory on the left side of the file selection window (labeled "Directories") so that it appears in the "Selection" area or type the full directory path in the "Selection" area. Press the OK button to continue, or press the Cancel button to end the installation process.

STEP 7:

Continue the process described in Step 6 for setting the environment variables GRSAC_DATA_DIR and GRSAC_SIM_DIR .

STEP 8: Finishing up

The installation program automatically updates your .cshrc file with the directories selected during the installation process for GRSAC_BASE_DIR, GRSAC_DATA_DIR and GRSAC_SIM_DIR .

Installing the User Files

Provided in the distribution is a Start Up Script for automating the installation and start up process for the GRSAC software. The script, startGrsac, is located in the directory $GRSAC_BASE_DIR/Startup.

For ease of use, it is best if the System Administrator edits this script to define the environment specific for their site. Otherwise the users will have to override the defaults on the command line each time they start the script.

System Requirements for Each User

Each user of the GRSAC software will need to have their own copy of the simulation and data directories. To avoid numerous changes to the startup script, each user should name these directories grsac_sim_dir and grsac_data_dir, respectively.

When using GRSAC in a multi-user environment, it is best if each user maintains a common directory structure so that the use of automation and generalization in the start up script may be increased. Otherwise, each user will have to have their own customized start up script. Following are some suggestions for setting up the GRSAC users' directory structure. Each user could have the directory ${HOME}/grsac with the subdirectories ${HOME}/grsac/grsac_data_dir and ${HOME}/grsac/grsac_sim_dir. Or the System Administrator could designate a disk partition for the software (/apps/users for example) and have an area on that partition for each user. For example, the disk area could have the directory /apps/users/${LOGNAME}/grsac with the subdirectories /apps/users/${LOGNAME}/grsac/grsac_data_dir and apps/users/${LOGNAME}/grsac/grsac _sim_dir for each user of the GRSAC software, where LOGNAME represents the login name of each user of the GRSAC software.

Automatic Installation

If the distributed Startup script is used, user's files are automatically updated when new versions are installed. For more information on this process, see the Section on Automatic Updates.

Manually Installing the User Files

If for some reason the System Administrator chooses not to use the start up script, following are the instructions for manually copying and maintaining the GRSAC users' area.

Environment Variables

Before running the GRSAC software, there are several environment variables that need to be set for each user.

1) setenv GRSAC_BASE_DIR /some_full_directory_path

GRSAC_BASE_DIR is the directory where the tar file grsacbase.tar was installed on the server (see your System Administrator for more details). For example, our base directory is /usr11/users/DEMO/grsac.

2) setenv GRSAC_DATA_DIR /some_full_directory_path

GRSAC_DATA_DIR is the directory where the GRSAC data files were installed for the user. Each user must have their own data directory and it must be writeable by the user. For example, our data directory is /usr11/users/DEMO/ball/grsac/grsac_data_dir .

3) setenv GRSAC_SIM_DIR /some_full_directory_path

GRSAC_SIM_DIR is the directory where the GRSAC simulation files were installed. Each user must have their own simulation directory and it must be writeable by the user. For example, our simulation directory is /usr11/users/DEMO/ball/grsac/grsac_sim_dir .

Each user must also add the GRSAC_BASE_DIR to their path.

4) set path=($path $GRSAC_BASE_DIR)

The environment variable XAPPLRESDIR must also be set (or appended) as follows.

5) setenv XAPPLRESDIR $GRSAC_BASE_DIR/res

If this environment variable is not set you will notice funny looking colors and label names.

Each user should make sure the appropriate values corresponding to statements 1)-5) above are in their .cshrc file, or use the start up script provided with the distribution. For more information on the start up script, read the Installing the User Files Section above.

Installation of GRSAC_DATA_DIR

To install the distributed GRSAC data directory into a users area, the server's data area must be copied into EACH users area. For example,

```
cd $GRSAC_DATA_DIR
cp -r $GRSAC_BASE_DIR/grsac_data_dir .
```

goes to the USERS GRSAC data area and copies the distributed data directory from the servers area to the users area.

Installation of GRSAC_SIM_DIR

To install the distributed GRSAC simulation directory into a users area, the server's simulation area must be copied into EACH users area. For example,

```
cd $GRSAC_SIM_DIR
cp -r $GRSAC_BASE_DIR/grsac_data_dir .
```

goes to the USERS GRSAC simulation area and copies the distributed simulation directory from the servers area to the users area.

Installation Steps for Origen-Pro

See the Origen-Pro Users Manual for instructions on installing the Origen-Pro software package

Installation Steps for the APROS GUI

Not available on all distributions. If available, instructions on the installation are included separately in the distribution package.

If additional help is needed on the installation process, contact Delphy Nypaver at (423) 574-2969.

V. GRSAC PROGRAM STARTUP

The GRSAC software can be started via a distributed startup script or manually. It is highly recommended that the script be used in a multi-user environment. Both processes are described below.

Startup Script

When using GRSAC in a multi-user environment, it is best if each user maintains a common directory structure so that the use of automation and generalization in the start up script may be increased. Otherwise, each user will have to have their own customized start up script. For suggestions on setting up the GRSAC multi-user environment, see the section on Installing Users Files.

Required Edits to the Start Up Script

Lines 5, 6 and 7 of the script need to be changed to the appropriate GRSAC server directories (where the software was installed).

Line 22 needs to be changed to reflect the generic automated directory structure (described in System Requirements for Each User) used for the users of the GRSAC software.

Line 68 may be edited to include or exclude certain options in the program (tty output, sound, etc.). For more information on start up options, see the section on Manual Start Up below.

Overriding the Start Up Script Defaults

Users can also override certain start up defaults on the command line. The first argument on the command line is GRSAC_BASE_DIR. The script then assumes that the GRSAC server simulation and data directories are $GRSAC_BASE_DIR/grsac_sim_dir and $GRSAC_BASE_DIR/grsac_data_dir respectively.

The second argument on the command line is the user's GRSAC directory. The script then assumes that this directory has the subdirectories grsac_sim_dir and grsac_data_dir and defines them as GRSAC_SIM_DIR and GRSAC_DATA_DIR respectively.

For example, the command

/apps/grsac/Startup/startGrsac /apps/grsac /home/mygrsac

starts the GRSAC software defining GRSAC_BASE_DIR to /apps/grsac, GRSAC_SIM_DIR to /home/mygrsac/grsac_sim_dir, and GRSAC_DATA_DIR to /home/mygrsac/grsac_data_dir .

Automatic Updates

Once a user's GRSAC area is set up, the Start Up Script checks to see if a new version has been installed on the server since the last time it was started. If a new version has been installed, the script notifies the user as shown in Figure 95. If the CONTINUE button is press, the script automatically copies over the needed files into the user's area from the server and displays the "working" window shown in Figure 96. If the QUIT button is pressed the GRSAC program is halted.

Please note that this is only possible if the start up script is used to start the GRSAC software. Otherwise updates will have to be manually copied into each user's area, as described below.

Also note that any distributed data files that have been edited will be overwritten. For this reason, it is best to use the distributed data files as a reference and create your own simulation data files rather than modify the distributed reference files.

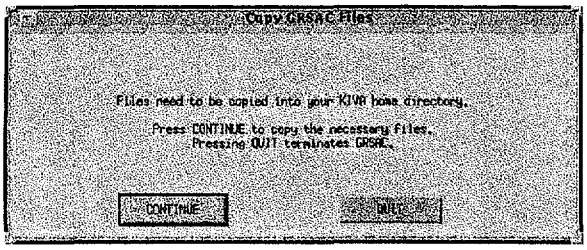

Figure 95. New Version Notification Screen

Figure 96. "Working" Windows Display

VI. RUNNING GRSAC

Using the Start Up Script

To run GRSAC using the Start Up Script, startGrsac, provided in the distribution, type

$GRSAC_BASE_DIR/Startup/startGrsac

For more information on the start up script, see the section on Installing the Users' Files above.

Manual Start Up

To manually start the GRSAC program, type

grsac_hmi &

To run the GRSAC program without tty simulation output, type

grsac_hmi -o &

To run the GRSAC program with sound effects, type

grsac_hmi -s &

or

grsac_hmi -o -s &

Another option is to display the Fortran simulation input flags as numbers instead of descriptive text or menus. This option is provided mainly for flexibility in developing and testing new options in the simulation before adding them to the GUI. To use this option, type

grsac_hmi -txt &

If the grsac_hmi program cannot be found, make sure that GRSAC_BASE_DIR is included in the path and that the variable is defined properly.

Color Allocation

If programs that use a large colormap (such as Netscape) are running when GRSAC is started, normal color allocation may not be possible for the interface. If the interface cannot allocate certain colors, a window is displayed that signals a color allocation problem (Figure 97). Users can either choose the system default colors or their own colors. If the user presses the "System Defaults"

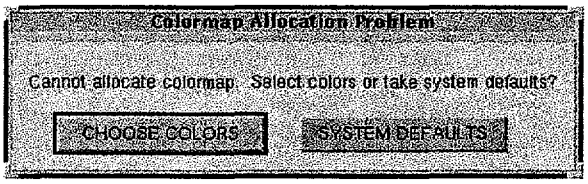

Figure 97. Color Allocation Problem Warning

button, the program replaces colors that cannot be allocated with a color that it thinks is close to the original color. The system, however, does not always choose the best color for some selections.

Users can choose their own color selections by pressing the "Choose Colors" button. In this case, a color pallet is displayed as shown in Figure 98. The number of colors displayed on the pallet can vary based upon the number of available colors left for system allocation. The user is told what the color is going to be used for (background, plots or image), the name of the color the system cannot allocate and the total number of color selections needed for the background, plots or image. The system default color is also displayed. If the system choice is close enough to the unallocated color, press the "System Choice" button. To select a different color, use the mouse to click on the colored square in the pallet that represents the desired color. Once a color is selected with the mouse, the colored square selected is displayed in the "Own Choice" area of the pallet as illustrated in Figure

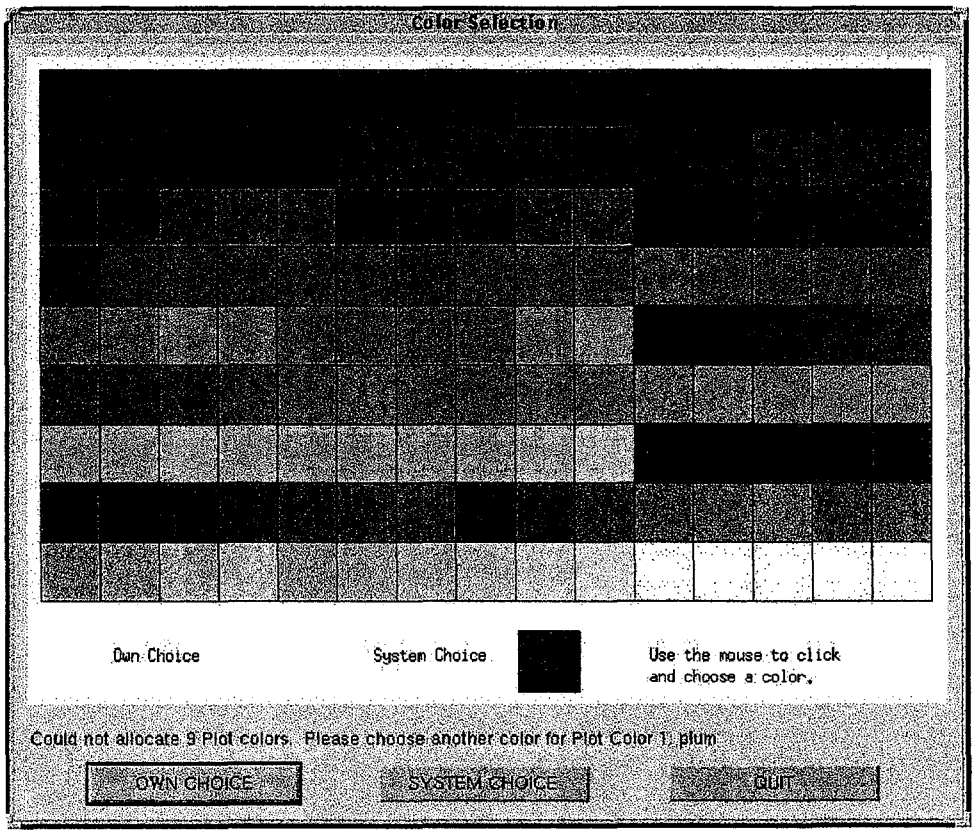

Figure 98. Color Selection Pallet

98. The user can continue to change color selections using the mouse. When the appropriate color is displayed in the "Own Choice" area, press the "Own Choice" button to allocate the color.

This color selection process continues until the system has resolved all the unallocated colors for the background, plots and reactor images. To abort the process and stop the GRSAC program, press the QUIT button at anytime during color selection. Otherwise, after the colors have been selected and the menus built, the main GRSAC installation menu will be displayed as shown in Figure 88.

To avoid the color allocation problems, start GRSAC before any program that uses large colormaps.

Running GRSAC and Origen-Pro

If users are going to access and use both the Origen-Pro and the GRSAC software packages, make sure that the res subdirectory for both packages is included in the definition of XAPPLRESDIR. The file needed by the GRSAC software is XApplication1 and for the Origen-Pro software it is XApplication2.

Also note that Origen-Pro needs the environment variable for the user's GRSAC_DATA_DIR defined as it is for the GRSAC software.

Making the FORTRAN Simulation

To make (compile) the Fortran simulation go to the $GRSAC_BASE_DIR/f77 directory and type

```
make -f diag.make
```

then copy the diag executable to the GRSAC_SIM_DIR directory.

Initial Setup Overview

Following is an overview of the files that were changed by the GRSAC Installation program. Below is an example which shows a segment of our .cshrc file that contains lines added by the installation program.

```
setenv GRSAC_BASE_DIR   /apps/grsac
setenv GRSAC_DATA_DIR   /home/ball/grsac/grsac_data_dir
setenv GRSAC_SIM_DIR    /home/ball/grsac/grsac_sim_dir

set path=($path $GRSAC_BASE_DIR)

setenv XAPPLRESDIR      /apps/grsac/res
```

********** NOTE **********

To get rid of the numerous warnings displayed when grsac_hmi is started, append the file $GRSAC_BASE_DIR/Xm/lib/XKeysymDB to the end of the file $OPENWINHOME/lib/XKeysymDB.

For a look at what's new in latest version of the GRSAC code and how to use and access these features press the GENERAL HELP button from the HELP option of the REFERENCE MATERIAL menu.

If additional help is needed on the installation process, contact Delphy Nypaver at (423) 574-2969.

APPENDIX

Appendix A

GRSAC (Graphite Reactor Severe Accident Code) Program Descriptions

GRSAC's MAIN program is a modified version of MORECA for generic gas reactor designs. It controls most of the action between subroutines, and does some variable initialization and calculations. Most of the initialization is done in other subroutines, primarily INIT, but also in FLOW, TIN, RCCSSC, PRESS, CFLOW, and CONVEC. MAIN contains the main loop which controls the progression of the simulation through the time steps. It also computes the 3-D core (solid) node temperatures. The temperature-dependent conductance between blocks is obtained from calls to functions RADK and AXIK, with effective conductance between individual blocks computed in subroutine ALGEN. If the option to consider thermal annealing of the graphtie core is selected, conductances are calculated in subroutine ANNEAL. For each element (node), the neighboring node identifiers are obtained from subroutine SUBS. Variable node physical properties and are called from subroutine TPROP. Inlet temperature, flow, pressure, and afterheat information is obtained via calls to TIN, FLOW, PRESS, and POW, respectively. Heat sinks via cavity or shield cooling is calculated in subroutine RCCSSC. For ATWS runs, power is calculated from POWX. Calls to subroutines GROX (for graphite, clad, and fuel oxidation) and WIGEN (for Wigner energy release) are also made in MAIN. AM cartridge oxidation (for Windscale) is calculated in subroutine AMCART. Fission product release from uranium metal fuel is calculated in subroutine FISS. Subroutines CFLOG1 and SUMWG1, corresponding in function to CFLOW and SUMW, were added to accommodate the peculiar features of the G1 reactor, where the flow enters at mid-core and exits both ends. The MAIN program provides the output data for the initial condition file, and generates steady state profile data for channel clad, fuel, and coolant gas temperatures. Detailed and summary outputs are generated via calls to subroutine OUTNOS.

GRSAC Program Subroutines:

Subroutine ALGEN generates the average of the diffusivity ratios for core nodes neighboring the selected (i,j) node.

Subroutine AMCART computes the oxidation rate (power) for Windscale accident scenarios.

Subroutine ANNEAL computes core graphite thermal conductance accounting for annealing (optional).

Subroutine ANHTTR is like ANNEAL but with parameters set for HTTR graphite.

Function AXIK computes core node axial conductance as a function of temperature and material.

Subroutine BOTTEM is used to calculate heat transfer in the lower plenum region, including radiant heat transfer from the core support blocks to the floor and side walls. Node temperature averaging to obtain an effective temperature for radiant heat transfer is done on the basis of its 4th power. A

simple model (with fixed h) is used for convection heat transfer. Vessel wall temperature updates are done via Euler approximations.

Subroutine CAVHE models the cavity cooling heat exchanger for the G2/3 reactor design. See the notes on SECHE for modeling details.

Subroutine CFLOG1 computes the core flows for the G1 reactor model, in which the coolant enters the core in the middle and exits both ends. Details of the general methods are described in the CFLOW writeup.

Subroutine CFLOW computes the flows in each of the 163 representative fuel element regions individually. The flow effective resistance for an element is computed using a weighted average. Core bypass flow is also computed based on the input value of initial bypass flow fractions and thereafter assuming fixed orifice characteristics. Flow resistances are based on viscosity calculated at the mean channel temperature, and account for laminar, turbulent, and transition flow regions. Buoyancy forces allow for flow in some elements to be reversed while other are downward, with or without forced circulation. Channel orientation can be selected via an input flag. An iterative scheme is used to determine a net plenum-to-plenum pressure difference which satisfies the net total flow (input) requirement to within specified (input) error bounds.

Subroutine CONVEC computes the convection heat transfer in each of the fuel elements in the core, accounting for variations in both flow regime and direction. An average reflector (or heated bypass) flow is used. Average plenum temperatures are calculated assuming well-mixed flow-weighted averages of all contributing inputs. Approximate heat capacities of the core support posts are included in the lower plenum mixed-mean temperature calculation. Reflector to vessel nodes heat transfer is also calculated. The inlet plenum inlet temperature is dependent on a computed temperature rise across the circulator and heat transfer in the (upflow) channels adjacent to the core barrel. Calls to the subrutines for cavity shield cooling system performance (RCCSSC), and upper and lower plenum heat transfer (TOPTEM and BOTTEM) are made from CONVEC.

Subroutine DGAS calculates primary coolant gas properties and coefficients for the three gas type options (carbon dioxide, helium, and air).

Subroutine FISS calculates the fission product releases from uranium metal fuel. The fission products are represented by eight chemical groupings, similar to, but differing slightly from, the NRC and MELCOR groups.

Subroutine FLOW calculates the total primary system flow. It uses a flow vs. time schedule (via a data statement for X [time, min] and Y [flow, lb/min]), via the flow coastdown input (accessed via the design input screen) for accident calculations, and via interactive input from the workstation while in the initial condition mode.

Subroutine HTRAD calculates reactor vessel to vessel cooling system (VCS) heat transfer for the HTTR, in conjunction with subroutine RCPFIX.

Subroutine GROX calculates graphite oxidation in the active core and the inlet and outlet reflectors (but not side reflectors), and clad and fuel oxidation during air ingress accidents (when the appropriate enabling flags are set).

Subroutine INIT is called by MAIN to input the bulk of the initial condition data and perform initialization calculations.

Subroutine OUTNOS provides the output for a variety of options at specified intervals, including some post-processing to obtain variables that are needed only for display. OUTNOS provides the interface to the interactive workstation programs. Variables are passed via arrays REMI (inputs from the workstation display) and REMO (outputs to the workstation).

Function POW calculates the afterheat, fraction of initial power, using either the MHTGR PSID correlation, the MHTGR "best estimate" (HTGR-86-109) or the Fort St. Vrain FSAR correlation. There is also an option to use Beginning-Of-Cycle or End-Of-Cycle (BOC/EOC) variations on the three basic choices. When the ATWS option is chosen, power is computed in subroutine POWX.

Subroutine POWX calculates reactivity and power during LOFC accidents for the ATWS option. Reactivity is calculated by using nuclear importance weighting from 3-D temperatures (fuel, moderator, and inner and outer reflectors). Xenon and samarium poisoning is included. Point neutron kinetics use a prompt-jump approximation with one delayed-neutron group (verified vs 6-group for slow LOFC transients). Point kinetics are not invoked when the neutron power is small vs afterheat and the reactor is sufficiently subcritical. Because thermohydraulic (TH) responses are much slower than neutronics, shorter time steps are used to solve for fission power. The TH time step is reduced whenever neutronics are calculated. ATWS capability is limited to slow reactivity transients characteristic of LOFC/ATWS events. The fuel (vs moderator) temperature is calculated via a quasi-steady state relationship from the total fuel element (bulk) temperature. Provisions are made via DATA statement changes to insert reactivity ramps at preset times during the run.

Subroutine PRESS provides a simplified primary system constant-inventory pressure calculation based on a detailed averaging of gas volume temperatures in the reactor vessel but only a cursory approximation in the steam generator. Programmed depressurization can be introduced, where the pressure is ramped downward at a specified rate. Full depressurization is assumed to occur if the relief valve limit is reached. If depressurization is to an intermediate pressure, it is computed subsequently based on constant inventory at the end point; otherwise, it stays at atmospheric. Approximations to the heat sink average gas volume temperature are computed in PRESS.

Subroutine QSET sets the QR array (radial peaking factors - RPFs) to the at-power or afterheat values per flag IPORS. The RPF values can be "smeared" (representing the fact that unlike fission heating, gamma heating (which dominates upon shutdown) is smeared out over a wider region of

the core. Using the RPFSM input parameter, the RPFs can all be set to 1.0 (RPFSM=1 - "total smear") or 0.0 (no smear - the at-power RPFs are maintained) or anywhere in between. Axial PFs are assumed to stay constant upon shutdown.

Function RADK computes core node radial conductance as a function of temperature and material.

Subroutine RCCSSC models the shield cooler for the Calder Hall reactor type and the cavity cooler for the G2/3 reactor types, and provides heat loss terms for the vessel node temperature calculations in CONVEC, TOPTEM, and BOTTEM.

Subroutine RCPFIX, in conjunction with HTRAD, calculates HTTR reactor vessel to VCS heat transfer for assumed fixed-temperature VCS cooling panels.

Subroutine SECHE is used to calculate the performance of the shutdown cooling system (SCS), which would consist of auxiliary circulators driving the primary coolant to a "shutdown" (single phase water coolant) steam generator. It makes use of the analytical steady-state solution for single-phase counterflow heat exchanger behavior given both hot and cold side inlet temperatures and flow. The variable gas and coolant water properties are accounted for. SECHE takes advantage of the fact that the response time of SCS heat exchange is much shorter than that of the core it is cooling, especially during low-flow "shutdown" conditions.

Subroutine SUBS provides the array indices (subscripts) for neighboring nodes of the reference (i,j) node.

Subroutine SUMW is used to sum the individual fuel element flows as computed in CFLOW for each iteration in the solution for plenum-to-plenum pressure drop.

Subroutine SUMWG1 is like SUMW, but accommodates flow summation chores for CFLOG1, the G1 reactor model.

Subroutine TIN is used to calculate the reactor inlet temperature. The temperature is either read from a schedule of X [time, min] and Y [temp, F] input via data statements, or if the SCS operating flag [ICORC] is set=1, then the reactor inlet temperature (or SCS gas outlet temperature) is calculated using subroutine SECHE. Inlet temperatures can also be input from the workstation interface when in the core map mode.

Subroutine TOPTEM is used to calculate heat transfer in the upper plenum region, including radiant heat transfer from the core plenum element blocks to the top and sidewall vessel nodes. Node temperature averaging to obtain an effective ring temperature for radiant heat transfer is done on the basis of its 4th power. A simple model (with fixed h) is used for convection heat transfer. Vessel wall temperature updates are done via Euler approximations.

Subroutine TPROP calculates the temperature-dependent diffusivity for the core nodes, and accounts for the geometry andcomposition differences according to node position.

Subroutine WIGEN calculates the Wigner energy release rate due to the annealing of irradiated graphite.

Other Programs: Other Fortran "support" programs used in GRSAC that are not part of the simulation itself are "GRCHK" - which does off-line validity checks of the model inputs upon request ("RUN WITH VALIDATION"); DJRPFC and DJAPFC, which support the automatic generation and checking of radial and axial (respectively) power peaking factors; and GRSENS, which controls the sensitivity-optimization option with automatic report generation. Program FPREL is called by the GUI to read fission product release (from fuel) data vs. time in the file "fplot" and calculates holdup and plateout in the primary system and containment building. Data generated for ORIGEN-PRO (and HASCAL) are stored in the file "frplot."

Appendix B

Plotting Help File

1. Output file "cplot" description – for GRSAC accident simulations

Selected parameter values are written to the file every "DTP" minutes, where the value of DTP may be selected in the Programmed Input Screen. The "cplot" file is used with the sensitivity program, and can be used with off-line plotting packages (e.g. LOTUS). The file cplot is located in the directory defined by the environment variable GRSAC_SIM_DIR.

CPLOT FORMAT

	Variable Definition	Units	Format
	TIME		
1.	Time	hr	f9.3
	TEMPERATURE		
2.	Max Fuel	F	f7.0
3.	Avg Fuel	F	f7.0
4.	Max Clad	F	f7.0
5.	Avg Clad	F	f7.0
6.	Max Core Region	F	f7.0
7.	Avg Core Region	F	f7.0
8.	Max Vessel	F	f7.0
9.	Inlet Plenum	F	f7.0
10.	Outlet Plenum	F	f7.0
	PRESSURE & FLOW		
11.	Primary Pressure	psia	f7.0
12.	Primary Flow	lb/sec	f7.2
	POWER		
13.	Reactor (nuclear)	MW	f7.2
14.	Primary System	MW	f7.2
15.	Cavity/Shield	MW	f7.2
16.	Graphite Oxidation	kW	f9.1
17.	Clad Oxidation	kW	f9.1

18.	Fuel Oxidation	kW	f9.1
19.	Wigner release rate	kW	f9.1

Variable Definition		Units	Format
	PERCENTAGES		
20.	Clad Fail (> Tmax)	%	f7.2
21.	Fuel Fail (> Tmax)	%	f7.2
22.	Graphite Oxidized	%	f7.2
23.	Clad Oxidized	%	f7.2
24.	Fuel Oxidized	%	f7.2
	OXIDATION RATES		
25.	Graphite	gm/min	f9.1
26.	Clad	gm/min	f9.1
27.	Fuel	gm/min	f9.1
	OXIDATION WEIGHTS		
28.	Graphite	kg	f9.1
29.	Clad	kg	f9.1
30.	Fuel	kg	f9.1
	OTHERS		
31.	Objective function	dl	f11.3
32.	AM cartridge power	kw	f8.2
33-40.	Fiss product rel	%	8f7.2

* NOTE: For all sensitivity study cases, the plot interval is set at 10 min; TFMC is set to the maximum value of peak fuel temperature within that 10-min. interval; TCMC likewise for clad temperature; & OBJF = Objective Function, which is calculated every 10 min.

2. Output file "ssplot.dat" description – for GRSAC initial condition runs

Selected parameter values are written to the file ssplot.dat every 10 min for use by the on-line plot routine. The output (in metric units) can be compared with available data and calculations for MAGNOX reactor steady state operation. The file ssplot.dat is located in the directory defined by the environment variable GRSAC_SIM_DIR. Arrays are printed in the order inlet to outlet (14 or 10 axial regions), and inner to outer rings (8).

	VARIABLE DEFINITION	Format
1.	Reactor power (fission + afterheat) (MW)	f7.1
2.	Primary loop flow (kg/s)	f7.1
3.	Primary loop pressure (kg/cm2)	f7.2
4.	Inlet plenum temperature (C)	f7.1
5.	Outlet plenum temperature (C)	F7.1
6.	Region outlet temps for each row (ring) (C)	14(8f6.0)
7.	Clad temps for each row (ring) (C)	10(8f6.0)
8.	Fuel temps for each row (ring) (C)	10(8f6.0)
9.	Clad average temps for each axial region (C)	10f6.0
10.	Col# & Clad temps for column with T-max clad (C)	I5, 10f6.0
11.	Col# & fuel temps for column with T-max fuel (C)	I5, 10f6.0
12.	Col# & T-gas outs from col. with T-max gas (C)	I5, 14f6.0

Appendix C

Windscale Model

1. Reference case Windscale model features

The Reference case Windscale model has several modifications to facilitate the modeling of Windscale reactor behavior in general and the October 1957 accident at unit 1 in particular. The Windscale data set specifies air as the coolant, atmospheric pressure, horizontal flow, and aluminum cladding.

The shifting of the peak power (for the annealing heatup accident case) to the inlet end of the core is done by using the axial peaking factor curve input. The RPF and APF curves for normal operation, which determine the afterheat power distribution, are built in as data statements.

Specific models are included for the LiMg target absorber elements, with a time-at-temperature failure algorithm and a timed (4-hr reference case) release of oxidation energy. The clad oxidation properties of Al are assumed to equal those of magnesium, but with a protective coating to prevent oxidation before the melting temperature is reached. The LiMg elements (in out-of-pile tests) had significant failures when the aluminum clad temperature reached ~440 C (which is lower than the normal failure temperature for aluminum) due to a chemical reaction between the clad and target.

An annealing model for graphite node thermal conductivity has been included as a GRSAC option. The model was developed and used for the MHTGR in the ORNL MORECA code (GRSAC's predecessor). It was incorporated because of the large (up to a factor of ~40) increases in graphite conductivity that can occur upon annealing, and hence may be crucial in the predictions of Windscale annealing transients. In the MHTGR core, irradiation temperatures were in the range of 500 C, with the effective start of annealing at ~1000 C, and with full annealing occurring at ~1300 C. Data presented by Nightingale[1] indicate that for the early Hanford (and Windscale) graphites with very low irradiation temperatures, the annealing effectively starts at much lower temperature. Per a recommendation from Jim Davidson (LANL), data derived for CSF graphite from the Nightingale reference were used to approximate Windscale graphite. They were incorporated into the MORECA hysteresis model for both the radial and axial conductivities as functions of temperature. An approximate model was added to GRSAC for the heat transfer resistance due to the gaps between elements. This model accounts for radiant heat transfer and conduction through the gas in the gap. The original MORECA model was altered to account for the very low temperature conditions (with air as the coolant) seen in Windscale.

The inclusion of the annealing and gap models in the calculation is an option selectable (Design Inputs, Graphite Properties category) via the Wigner energy model flag (1 = Wigner energy only, while 2 = Wigner energy and thermal conductivity annealing with gap resistance models [both].

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[1]Nightingale, R. E., *Nuclear Graphite*, Academic Press, New York (1962).

0 = omit Wigner and annealing). The Wigner flag values of 1 or 2 are the reference or default cases for Windscale transients, where power and flow inputs are entirely "manual," i.e., are input either as a preprogrammed input or changed during the run via the interactive accident screen.

Setting the flag = 3 enables a preprogrammed approximation of the October 1957 accident sequence, as described below.

2. Special case Windscale GRSAC setup to model the accident sequence

An additional Windscale option has been added to GRSAC which introduces programmed core power and primary cooling flow sequences vs. time that correspond roughly to those for the October 1957 accident scenario. This option is activated by setting the Wigner energy model flag = 3. For this option, the thermal conductivity annealing and gap resistance models apply.

The sequence begins with an arbitrary 12-hour cooldown period just prior to the time all the blowers were cut off (Monday, October 7, 1415 h). The purpose of this cooldown period is to make the initial core temperatures correspond approximately to those reported. The first of the two nuclear heatups began later that day (1925 h) and continued to early the next morning. Our best estimate for shutdown is October 8, 0225 h. The second nuclear heatup was assumed to be on October 8, from 1105 h to 1925 h. In the reference case sequence, the fission power (added to the afterheat) was assumed to be 1.8 MW during each of the heatup powers. It is also assumed that ambient heat losses (via the "shield cooler" model) are minimal, and the flow is set to 1% for the reference case. This gives an air mass flow of about 1 kg/s and a nominal heat loss of about 100 kW. The accident sequence begins (T = 0) at 0215 hrs on Monday, October 7. The sequence for the fission power heating periods (with the total power equal to the afterheat power plus 1.8 MW, revised downward to 1 MW) is shown in the following table:

Fission Heating Sequence

Heating Period	Start/Stop Times	
	Calendar	Simulation
1	10/7 1925 h to 10/8 0225 h	17.2 h to 24.2 h
2	10/8 1105 h to 10/8 1925 h	34.3 h to 42.7 h

The reference case primary coolant air flows for the accident sequence are shown in the next table. Note that the cooling flow for the first 12 hours is arbitrary - enough to cool the core down to the reported temperatures. In the next period, the fans are off, and the chimney hatch is open, which inhibits tendencies for core drafts which increases (assumed linear ramp) over the next 55 hours during the core heatup.

Core Cooling Air Flow Sequence

Event	Start Times Calendar	Simulation	Duration (h)	Flow (Kg/s)
Cooldown	10/7 0215 h	0.0 h	12	120
No fans on	10/7 1415 h	12.0 h	54.8	0.01 ->0.05
Closed hatch	10/9 2100 h	66.8 h	1.25	0.3
Damper openings: ("Sealed-off flow" = 0.3 kg/s assumed after each event)				
#1	10/9 2215 h	0.0 h	0.5	7.5
#2	10/10 0000 h	12.0 h	0.17	7.5
#3	10/10 0215 h	72.0 h	0.21	7.5
#4	10/10 0510 h	74.9 h	0.5	7.5
#5	10/10 1200 h	81.8 h	0.25	7.5
#6	10/10 1330 h	83.3 h	0.08	7.5
Cooldown	10/10 1430 h	84.3 h	19.5	120
Sealed off	10/11 1000 h	103.8	16.2	0.1

End of run: 10/12 0215 h 120.0 h (5 days)

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