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ORIGEN-ARP: AUTOMATIC RAPID PROCESS FOR SPENT FUEL DEPLETION, DECAY, AND SOURCE TERM ANALYSIS

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ABSTRACT

ORIGEN-ARP is a sequence that serves as a faster alternative to the SAS2H sequence of the SCALE system to perform point-depletion calculations with the ORIGEN-S code using problem-dependent cross sections. ARP (Automatic Rapid Processing) uses an algorithm that allows the generation of cross-section libraries for the ORIGEN-S code by interpolation over pre-generated SAS2H cross-section libraries. The interpolations are carried out on the following variables: burnup, enrichment, and water density. ORIGEN-ARP also provides an easy-to-use interface via the ORIGNARP PC input processor. ORIGNARP implements a pulldown menu system that sets up a SCALE input file to execute ARP and ORIGEN-S.

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D1.1 INTRODUCTION

The SAS2H sequence of the SCALE code system has been used worldwide for treating problems related to the characterization of spent nuclear fuel from light-water reactors and other types of reactors for disposal, storage and shipment. The calculations, in general, consist of determining the isotopic compositions of the various materials present in the problem as a function of time, which subsequently enable the determination of the heat generation and radiation source terms. In the SAS2H scheme, time-dependent material concentrations are obtained using the ORIGEN-S code based on a point-depletion calculation that utilizes problem-dependent cross-section libraries generated by functional modules in the SAS2H sequence. ORIGEN-ARP is a SCALE analytical sequence that serves as a faster alternative to the SAS2H sequence by using the automatic rapid processing (ARP) methodology for generating problem-dependent ORIGEN-S cross-section libraries. ORIGEN-ARP runs in approximately 2% of the time required by SAS2H but conserves the rigor and accuracy of the SAS2H methodology. ORIGEN-ARP has been validated extensively, as documented in Ref. 1.

ORIGEN-ARP differs from the conventional SCALE analytic sequences because it does not have a control module that reads the input and calls the functional modules. ORIGEN-ARP consists of the ORIGNARP PC input processor and the ARP and ORIGEN-S functional modules. ORIGNARP is an MS-DOS menu-driven program that creates an input file for ARP and ORIGEN-S, based on user responses and input. ORIGNARP can automatically call the SCALE driver to immediately execute ARP and ORIGEN-S on the PC, or the ARP/ORIGEN-S input file can be transferred to another computer for execution. ORIGNARP runs on MS-DOS and Windows personal computers (PCs). It provides a pull-down menu system with online help to assist the user in the setup of an ORIGEN-ARP input file. ARP employs an interpolation algorithm on burnup, enrichment, and, optionally, moderator density to rapidly generate problem-dependent ORIGEN-S cross-section libraries from specially prepared SAS2H/ORIGEN-S multiburnup libraries.

The following section describes the ORIGNARP input interface program and how to use it. Then the ARP methodology and input are discussed. The ORIGEN-ARP sample problems are presented and described in the final section.

In Appendix A the method for generating a set of ORIGEN-ARP basic cross-section libraries is presented, and the basic libraries distributed with SCALE are documented. Utility programs developed to support the ORIGEN-ARP methodology are documented in Appendix B. These utilities assist users in the production of their own ORIGEN-ARP cross-section libraries. PRISM is a utility that reads a single generic SAS2H or other type of input file and generates any number of input files for specific enrichments, densities, or other parameters. ARPLIB converts SAS2H/ORIGEN-S binary cross-section libraries into ARP basic cross-section libraries. The ORIGEN-S burnup-dependent, cross-section data can be listed with the XSECLIST utility.

D1.2 ORIGNARP INPUT PROCESSOR

ORIGEN-S is a powerful and flexible computer code for performing isotopic generation and depletion for many applications, including spent fuel characterization. ORIGEN-S computes time-dependent concentrations and source terms of a large number of isotopes, which are simultaneously generated or depleted through neutronic transmutation, fission, and radioactive decay. Input requirements include initial nuclide compositions, irradiation and/or decay history, and an appropriate cross-section library. Its design is general in nature. The number of input parameters and options can be overwhelming, which contributes not only to its flexibility, but also to its complexity. In order to provide a user-friendly interface program to a wide range of users that would be easy to learn and useful for most applications, a PC input processor named ORIGNATE was developed as part of the OFFSCALE suite of PC input processors for the SCALE-4 code system (Ref. 2).

ORIGNARP is an updated version of ORIGNATE designed to assist an ORIGEN-S user in preparing an input file for execution of fuel depletion and/or decay cases within the ORIGEN-ARP analytical sequence. ORIGNARP is designed to work with the Automatic Rapid Processing (ARP) code, which interpolates on specially prepared ORIGEN-S multiburnup binary libraries to prepare case-dependent ORIGEN-S binary libraries. The purpose of the ORIGEN-ARP sequence is to provide an updated fast and easy-to-use interface for performing spent fuel analyses on a PC or workstation.

The ORIGNARP program is written in Microsoft BASIC 7.1 (Ref. 3) and runs on an MS-DOS or Windows PC. ORIGNARP generates a SCALE input file that may be used to execute ARP and ORIGEN-S in succession. ORIGNARP features a pulldown menu system similar to the type used in many PC software products. The menu system organizes the major command categories as menu titles and pulldown commands and may be used with either a keyboard or a mouse.

When an option is selected from the menu system, a data entry screen or series of screens is displayed. Each field on a screen has a help message associated with it, which may be displayed by pressing a help key. The message gives a brief description of the input parameter and occasionally refers to a section in the SCALE manual for more detailed information. This feature minimizes the amount of time that might be used searching through the documentation when setting up an ORIGEN-S input file. Some fields have a multiple-choice menu associated with them. These menus minimize the possibility of input errors by providing a complete list of valid choices for given parameters. Depending on input options selected, the program protects other fields that are not needed for those options. ORIGNARP performs extensive error checking for each input screen and displays appropriate warning and error message boxes when applicable.

D1.2.1 INSTALLATION AND EXECUTION

ORIGNARP is installed automatically as part of the PC version of SCALE. The workstation version of SCALE includes the ORIGNARP installation files for workstation users to install it on a PC. ORIGNARP is executed by running the batch file ORIGICON.BAT. On Windows 95/98/NT systems, the user may simply double click on the ORIGEN-ARP icon that is linked to the batch file.

The easiest way to learn how to use ORIGNARP is to read through the rest of the documentation while running the program and use the options and keys as they are described. The following two sections, "Using the Menu System" and "Using the Input Screens," give an overview of how to use the program. Following these sections is a detailed description of how to use each of the menu options.

D1.2.2 USING THE MENU SYSTEM

The ORIGNARP pulldown menu system contains a menu bar across the top of the screen. Under each menu bar option there is a unique pulldown menu. The menu bar options are summarized below.

Files	Options to retrieve files, save files, execute ORIGEN-ARP, and exit the program
Initial Input	Options to input compositions and energy group edit structure
Case Types	Options to input depletion cases and decay cases
Modifying Cases	Options to insert cases and delete cases

When ORIGNARP begins, it presents the **Files** pulldown menu. The user may move across the menu bar to open the other pulldown menus by using the left and right arrow keys. Options from a pulldown menu may be accessed by using the up and down arrow keys. A description of the highlighted option will appear on the bottom line of the screen. To execute the option, simply press the <Enter> key or the highlighted letter (known as the "hot key") of the desired option.

The mouse may also be used to select an option by moving it left or right along the menu bar or up and down on a pulldown menu. To choose a pulldown menu command, simply move the mouse cursor over the desired option and click the left mouse button. Some users may prefer to "drag" the mouse (holding the left mouse button) over the menus and then release the left button when the cursor is over the desired command. One difference between the two methods of using the mouse is that dragging the mouse will cause the description of the highlighted option to be displayed on the bottom of the screen, as when using the keyboard.

Some pulldown menu commands are black with a hot key, while others are gray. The black commands are active; the gray commands are inactive and will produce no effect if selected. Commands will be activated as necessary data are entered. For example, once the Initial Input data are entered, the Case Types options are active. Most of the options will become active when ORIGNARP files are retrieved.

D1.2.3 USING THE INPUT SCREENS

Once an option is selected, an input screen or series of input screens will be displayed. The cursor will appear at the first data field on the screen that is not protected. Fields may be protected by the program, depending on the input options selected. For example, on the Compositions screen, if "Input" is "Dataset," the nuclide fields for card input are protected. To move from one field to the next, press <Enter> or <Tab>. To move backward to the previous field, press <Shift+Tab> or <Backspace>. The cursor must be at the beginning of the field for <Backspace> to move to the previous field, because within a data field it moves back one space and deletes the previous character. The user may also change fields with the arrow keys, but the movement will be somewhat erratic because the cursor skips fields if there is more than one field per screen line. <Home> moves the cursor to the beginning of the field, and <End> moves to the end of the field. The <Ins> and <Del> keys perform their normal functions for editing a field. <Ctrl+Home> moves the cursor to the first field on the screen, and <Ctrl+End> moves the cursor to the last field. <PgUp> and <PgDn> may perform the same respective functions, if they are not active functions listed on the bottom of the current input screen.

Some fields have a multiple-choice menu associated with them. Pressing <Enter> or the Space Bar at one of these fields will activate the multiple-choice menu. When this menu is displayed, all other processing and function keys are disabled until a choice is selected and the menu disappears from the screen. Pressing a letter on the keyboard will move the cursor to the next choice that begins with that letter. The up and down arrow keys, <PgUp>, <PgDn>, or the mouse may be used to make a selection. <Home> moves the cursor to

the first choice, and <End> moves the cursor to the last choice. Once the desired choice is highlighted, press <Enter> to select it and remove the menu.

Logical (YES or NO) fields use "Y" and "N" or "X" and " ". No other values will be accepted. The user may toggle between the two choices with the space bar.

Most fields have a help message associated with them. Pressing <F1> displays the message. Often the message will refer to a section of the SCALE manual for more detailed information. Press <Enter> or <Esc> to remove the message from the screen. If there is no message for a particular field and it is one of several identical fields on a screen, try moving the cursor to the first of these fields on the screen and pressing <F1>. For the Compositions screens, the help messages are only active for the first screen and the first occurrence of each field on subsequent screens.

Title and comment fields must be entered whenever they appear on an input screen. Delimiters are automatically provided by ORIGNARP and should not be input by the user.

D1.2.4 MENU SYSTEM GUIDE

The purpose of this section is to present an overview of the menu system commands. Menu bar options are presented next to square bullets; corresponding pull-down commands are listed next to round bullets. The underlined letter in commands discussed below represents the hot key for the command; these hot keys appear on the screen as bright letters, and they allow immediate access to an item by pressing the highlighted key.

▰ Files

The **Files** menu allows the user to retrieve and save files, execute ORIGEN-ARP, and exit the program.

• <u>R</u>etrieve Files

This option allows the user to retrieve random-access binary files that have been saved previously with ORIGNARP. A random-access file is saved for each pulldown menu option for which data are entered. Each ORIGNARP file for a problem has the same file name as specified by the user but a different file extension designated by ORIGNARP. A listing of these file extensions is given in Table D1.2.1. ORIGNARP presents a list of all files in the current directory that have the ".CMP" file extension (this random-access file is always required). When the user selects the desired file name, ORIGNARP loads all files with that file name and one of the extensions listed in Table D1.2.1. The program copies the files to a set of temporary files, ORIGTEMP.* (i.e., file extensions remain the same). If the user wishes to retrieve only a portion of the ORIGNARP files associated with a previously generated ORIGEN-S input file (e.g., the Compositions data), those files should be renamed or copied using the same file extensions. Four sets of sample files are provided in SCALE. These sample problems are discussed in detail in Sect. D1.4.

Table D1.2.1 ORIGNARP storage and output files

ORIGNARP file extensions	Contents
.CMP	Compositions input[a]
.DCY	Decay cases[a]
.DPL	Depletion cases[a]
.GRP	Energy group structures[a]
.INP	Card-image input file for ARP and ORIGEN-S

[a]Binary file.

- **Save Files / Input Deck**

This option saves the data entered in random-access files, which can later be retrieved by the program for modification. ORIGNARP will not save files in this option unless sufficient data have been entered to generate a meaningful ORIGEN-S input file. A random-access file will be saved for each menu option used to input data, up to a maximum of four files. ORIGNARP will prompt the user for the file name for the ORIGNARP files. In addition to the random-access files, ORIGNARP also writes a card-image SCALE input file to execute ARP and ORIGEN-S. Using this option followed by Quit allows the user to exit ORIGNARP without immediately executing the case. This option is convenient for (1) saving an input file to be transferred to another computer for execution, (2) a case that requires manual changes to the ORIGEN-S input file, or (3) later execution of a large number of cases in batch mode. Workstation users should check carefully for any MS-DOS commands following "#shell" in the SCALE input file that is created. These commands should be removed or replaced with Unix commands.

- **Save Partial Files**

This option saves ORIGNARP random-access files, regardless of the amount of data entered. It does not generate a card-image ORIGEN-S input file. This option is designed to allow the user to occasionally save input data so that they will not be lost if the program terminates abnormally. Note that if ORIGNARP does fail, the data entered still exist in the ORIGTEMP.* files. When ORIGNARP is restored, it notifies the user that it has detected these files and provides an opportunity to rename and save them.

- **Execute ORIGEN-ARP**

This option saves files as the **Save Files/Input Deck** option does. In addition, it writes an MS-DOS batch file, C:\ARP_XXX.BAT that executes ARP and ORIGEN-S immediately.

- **Quit**

This option terminates the program. If the input data have not been saved, the program will warn the user before termination. Because this option does not save files, this option may be used to cancel any changes made since the last time the files were saved.

▰ Initial Input

The **Initial Input** menu provides the user with selections to input the case-independent initial data required by ORIGEN-S.

• Compositions

Nuclide compositions are required input for ORIGEN-S to define the initial configuration of the system being analyzed. This option is the only active option other than Retrieve Files when the user enters the program. Select either "Cards" or "Dataset" as the source of input in the first field. If "Cards" is selected, the second field gives the user a choice of input units (choices are grams, gram-atoms, or curies). The user specifies each nuclide by element from an alphabetized menu and then type the isotope [e.g., "U(92)" and "235" for U-235 and "Xe(54)" and "135m" for Xe-135 metastable]. The program checks the isotope number to ensure it is valid for the element selected. A complete list of valid isotopes is given in Sect. F7.A. To obtain the natural abundances of an element in the ORIGEN-S light-element library (NEX1=4 in the ORIGEN-S 75$ array), input "Natl" for the isotope. If the specified nuclide appears in more than one of the ORIGEN-S master libraries (light element, actinide, or fission product), a menu is provided of the available libraries. Select a library based on the origin of the nuclide and the desired edit grouping. If only one library is valid, the program automatically fills the field with the appropriate library. Then input the concentration in the units previously selected. The concentration that is input for each nuclide determines the "basis" of the problem (e.g., fuel assembly, metric ton of uranium, etc.). Note that the problem basis is important because it determines the values of other input parameters (e.g., power for depletion cases) and the units of output parameters (e.g., nuclide concentrations or source terms).

This option displays a maximum of three screens. Each screen contains 10 nuclides, for a maximum of 30 nuclides. The <PgDn> and <PgUp> keys are used to move forward and backward, respectively, between screens. To change an element selection, simply select a new one from the multiple-choice menu. To erase an element that has been selected, press <Ctrl+E> while the cursor is on that element field.

If the user wants ORIGEN-S to read the nuclides from a dataset written by a previous ORIGEN-S job, select "Dataset" as the source of input in the first field. All nuclide fields are then blanked and protected. The second field then represents the input/output (I/O) unit number of the dataset and the position of the concentrations in the dataset. For example, "71+2" specifies I/O unit number 71 and the second position in the file. Note that ORIGEN-S prints the position in the file when it writes the data. If the user omits the position number from this field, ORIGNARP assumes that the user wants to read from the first position in the file. The user must specify the appropriate restart dataset in the script or job control language that executes the ORIGEN-S case. For example, if executing ORIGEN-S on a PC and the I/O unit number is specified as 71 in ORIGNARP, the restart dataset should be named FT71F001.

IMPORTANT NOTE: If the user reads and writes restart data in the same job, ORIGEN-S begins writing data in the file position immediately following the one from which it read. It does not search for the end of file. **If the user is reading from a position prior to the last one in the file, the data that follow may be overwritten if new restart data are saved.**

Use <F4> to cancel or <F10> to save the data and return to the main menu.

- **Neutron/Gamma Groups**

This option displays two screens, one each for the energy group structure for neutron spectra edits and gamma spectra edits. These edits are for individually selected time steps in the decay cases for which source terms are desired to perform shielding calculations. The first field on each screen gives a multiple-choice list of energy group structures corresponding to commonly used neutron or gamma cross-section libraries. The user may choose one of these or input their own group structure by selecting "Other." If the user is running only depletion cases or the user does not want these edits, the user may select "None."

If the user selects one of the standard group structures or "None," ORIGNARP protects the remaining fields on the screen and advances to the next screen. <PgUp> and <PgDn> may be used to move from one screen to the other. If the user selects "Other," specify the number of energy groups. ORIGNARP requires the user to input the maximum-energy cutoff in eV for each group, beginning with group 1 (the highest-energy group). The field following the maximum-energy cutoff for the lowest-energy group must contain the minimum-energy cutoff for that group. The remaining fields on the page remain protected. ORIGNARP verifies that the energies are entered in order from highest to lowest.

▪ *Case Types*

The **Case Types** menu provides the user with selections to enter depletion and/or decay case data. (A "case" in ORIGNARP is equivalent to a "subcase" in ORIGEN-S.) Each case is limited to ten time steps, because this is the maximum number that fit across a page of the ORIGEN-S output. Each case has a title card and a basis card. The basis card is a subtitle in the ORIGEN-S output that describes the basis for the calculations performed as determined by the concentrations input (e.g., a fuel assembly or a metric ton of uranium). All depletion cases are entered via one option, and all decay cases are entered via another option. The order in which they are entered determines the order in which they appear in the ORIGEN-S input file and is reflected by the case number that is displayed in ORIGNARP.

- **Depletion Cases**

A depletion case consists of a series of time steps where nuclear fuel is irradiated. The power at which the fuel is irradiated and the time duration are required for each time step. This option displays three screens: (1) the depletion case input, (2) the depletion case I/O options, and (3) the depletion case library specifications. The screen initially displayed is the depletion case input for a new case with a case number one greater than the last case saved. The data for a case are saved by pressing <F10> to advance to the next case, or <F9> to go back to the previous case. To avoid saving changes on the screen, press <F4> to return to the main menu system. ORIGNARP asks whether to save the changes on the screen before returning. To review existing cases, press <Ctrl+R>. This option displays a list of case numbers, types, and titles.

Each depletion case consists of a series of time steps. The beginning time, which is defaulted to zero, and the ending time for the case, are specified first. Then the power (MW/basis unit) and the cumulative time from the case beginning time are input for each time step.

IMPORTANT NOTE: The power must be consistent with the basis for the calculation (e.g., fuel assembly, MTU, etc.) in order for the calculated results to be correct.

To specify downtime during or at the end of the case, input 0 for the power. For periods greater than 100 days, a separate decay case is recommended. The time entered for the last time step must match the "ending time" field. In addition, the program checks that the cumulative time for each step is greater than the previous step. The maximum recommended increment per time step is 100 days, or 0.3 years, and the recommended minimum number of steps is three per case. If the time-step increments are larger or the number of time steps is less, ORIGNARP prints a message on the screen and automatically inserts additional steps up to the maximum of ten steps per case. The intent of this feature is to allow the user to specify only the times at which the power level changes or output is needed and let ORIGNARP determine any remaining steps needed to ensure accurate results. The user can modify the steps generated by ORIGNARP by simply editing the fields. ORIGNARP only checks the data once per edit of each case. If the user later returns to a case and edits any of the data, ORIGNARP checks the length and number of time steps again.

The option to write restart data for a time step is set by typing an "X" in the appropriate field. These data may be written for as many time steps as desired. If the Compositions input specified reading from a dataset, these data are written to the same unit, immediately following the input data read. As noted previously, **this action will result in a loss of any data following the input data in that dataset**. If the Compositions input was specified on cards, the restart data are written to I/O unit 71.

The I/O options screen is accessed by pressing <Ctrl+O>. This screen only controls the I/O options for depletion cases. This screen must be edited and saved for the first depletion case. ORIGNARP automatically displays it with a set of default values when the user presses <F10> to initially save the first case. The options stay in effect until they are changed in a subsequent case. The time units that are displayed on the depletion case input screen are selected on this screen.

The library options screen is accessed by pressing <Ctrl+L> when entering data for the first depletion case. ORIGNARP automatically displays the library options screen when the user presses <F10> to initially save the first case. The input data on this screen (fuel assembly type and enrichment) are written to the ARP input file for use by the ARP program in generating the ORIGEN-S binary depletion libraries. The fuel assembly types include 8 × 8 (for BWR fuel), 14 × 14 (for ABB Combustion Engineering-type PWR fuel with large water holes), and 15 × 15 and 17 × 17 (for Babcock & Wilcox and Westinghouse-type PWR fuel). Additional data written by ORIGNARP to the ARP input file include the average power history in MW/MTU for each depletion case. To convert the power history from MW/basis unit to MW/MTU, ORIGNARP automatically calculates the MTU per basis unit (or metric ton heavy metal for mixed-oxide fuel) in the Compositions input.

ARP produces problem-dependent ORIGEN-S cross-section libraries by reading a set of standard libraries for a fuel assembly type and interpolating on enrichment and burnup. These problem-dependent libraries are written to a file named ft33f001 for use by ORIGEN-S. The ARP program is described in detail in Sect. D1.3.

- **Decay Cases**

A decay case consists of a series of time steps where irradiated material undergoes radioactive decay. This option displays three screens: (1) the decay case input, (2) the decay case I/O options, and (3) element fractions. The screen initially displayed is the decay case input for a new case with a case number one greater than the last case saved. The <F4>, <F9>, <F10>, and <Ctrl+R> keys function the same as on the depletion case input screen.

Like a depletion case, each decay case consists of a series of time steps. The beginning time, which is defaulted to zero, and the ending time for the case are specified first. The time entered for the last time step must match the "ending time" field. In addition, the program checks that the cumulative time for each step is

greater than the previous step. The recommended maximum initial time step is 100 days, or 0.3 years, and the cumulative time for subsequent steps should be ≤3.3 times the cumulative time for the previous time step. Because the nuclides decay exponentially, this factor ensures accurate results. This rule is commonly known as the "Rule of 3s." If the time-step increments are larger, ORIGNARP prints a message on the screen and automatically inserts additional steps up to the maximum of ten steps per case. For a cumulative time of 3 raised to a power of 10 (0.3, 3, 30, 300, etc.), ORIGNARP sets the time for the next step to 10 raised to the same power of 10 (1, 10, 100, 1000, etc.). The intent of this feature is to allow the user to specify only the times at which output is needed and let ORIGNARP determine any remaining steps needed to ensure accurate results. The time steps generated by ORIGNARP may be modified by simply editing the fields. ORIGNARP only checks the data once per edit of each case. If the user later returns to a case and edits any of the data, ORIGNARP checks the length and number of time steps again.

The decay case input screen allows the user to save restart file data in the same manner as the depletion case input screen. In addition, it allows the user to request neutron and gamma source spectra output edits for any time step. These are printed by ORIGEN-S according to the energy group structures designated in the Neutron/Gamma Groups option. If "None" is selected for both group structures, requesting an edit on this screen has no effect.

The I/O options screen is accessed by pressing <Ctrl+O>. This screen only controls the I/O options for decay cases. This screen must be edited and saved for the first decay case. ORIGNARP automatically displays it with a set of default values when the user press <F10> to initially save the first case. The options stay in effect until they are changed in a subsequent case. The time units that are displayed on the decay case input screen are selected on this screen. The (α,n) source is typically UO_2, unless the user is modeling high-level waste in borosilicate glass. (See Sects. F7.2.8 and F7.2.9 for details.) ORIGEN-S allows the cutoff for the decay output edits to be in the units of the edit or % of the total. The latter is designated by typing "%" at the end of the cutoff value. In order to simplify the output edits menu, the 63 choices possible in the ORIGEN-S 65$ array (Sect. F7.6.10) have been reduced by grouping according to the three dimensions of the array. This procedure may result in more output than desired in some cases (e.g., if you wanted only grams of light elements but grams and curies of fission products). The ORIGEN-S card-image input generated by ORIGNARP has been formatted and labeled by subgroups so that an experienced ORIGEN-S user can easily modify the input by turning on or off individual edit options in the 65$ array.

The element fractions screen is an optional screen that allows the user to keep or remove all or part of a maximum of ten elements from the previous case. This option allows the user to isolate part of the problem being modeled, such as the endfittings of a fuel assembly. To access this screen, type "Y" for the element fractions' field on the decay case input screen and press <Ctrl+F>. Select whether to keep or remove the elements, then select the elements from a multiple-choice menu, and specify the fractions of each to be kept or removed.

- **Review Cases**

This option displays a list of case numbers, types, and titles for all cases that have been created. This function may also be performed by pressing <Ctrl+R> at the main menu or while using screens that require case numbers: Depletion Cases (screen 1) and Decay Cases. To remove the list from the screen, press <Enter> or <Esc>.

▰ Modifying Cases

The **Modifying Cases** menu contains options for inserting or deleting cases, so that the user can retrieve an existing set of cases and modify them to model different scenarios, such as adding or deleting a cycle from the burnup history of a fuel assembly.

● Insert Cases

This option presents a dialog box with two fields: the type of case to be inserted (depletion or decay), and where to insert it (the new case goes before the case selected). Use the <Tab> and <Shift+Tab> keys to move between the two fields and the up and down arrow keys to select the choice for each field. The mouse may also be used in the dialog box. Selecting the <Cancel> button at the bottom of the box or pressing <Esc> returns to the main menu system without inserting a case. When the user presses <Enter> or click the mouse to accept the choices made, ORIGNARP automatically adjusts the case numbers and moves directly to the depletion or decay input screen to enter the data for the new case.

● Delete Cases

This option presents a dialog box with a list of all cases. Select the case to delete by using the up and down arrow keys or the mouse. The case numbers for the remaining cases will be automatically adjusted. Selecting the <Cancel> button at the bottom of the box or pressing <Esc> returns the user to the main menu system without deleting a case.

D1.2.5 ORIGNARP PROGRAM FILES

Files included in the installation which are necessary for running the ORIGNARP program are listed in Table D1.2.2. ORIGNARP.EXE is the executable program. ORIGNARP.QSL is the ORIGNARP QuickScreen library developed with Crescent Software's QuickScreen program[4] and contains all the input screens displayed by ORIGNARP. In addition, ORIGNARP contains several routines from Crescent Software's QuickPak Professional Library.[5] The files with the ".FRM" extension contain the form definition for each of the screens in the ORIGNARP QuickScreen library. The files with the ".BSV" extension were written with Microsoft BASIC's BSAVE command[3] and contain the following data: nuclides, elements, neutron-energy-group boundaries, and gamma-energy-group boundaries.

Table D1.2.2 Files required by ORIGNARP

File name	Extension	Description
COMPNUC1	.FRM	Compositions screen No. 1 form
COMPNUC2	.FRM	Compositions screen No. 2 form
DECACAS1	.FRM	Decay case screen No. 1 form
DECACAS2	.FRM	Decay case screen No. 2 form
DECACAS3	.FRM	Decay case screen No. 3 form
DEPLCAS1	.FRM	Depletion case screen No. 1 form
DEPLCAS2	.FRM	Depletion case screen No. 2 form
DEPLCAS3	.FRM	Depletion case screen No. 3 form
G18ORIG2	.BSV	ORIGEN2 18-gamma-group structure
G18SCALE	.BSV	SCALE 18-gamma-group structure
G20	.BSV	BUGLE 20-gamma-group structure
G44	.BSV	ENDF/B-V 44-gamma-group structure
GROUP1	.FRM	Neutron-group screen form
GROUP2	.FRM	Gamma-group screen form
N218	.BSV	ENDF/B-IV 218-neutron-group structure
N22	.BSV	Straker 22-neutron-group structure
N227	.BSV	ENDF/B-V 227-neutron-group structure
N238	.BSV	ENDF/B-V 238-neutron-group structure
N27	.BSV	ENDF/B-IV 27-neutron-group structure
N47	.BSV	BUGLE 47-neutron-group structure
ORIGCOMP	.BSV	ORIGEN-S nuclides for compositions input
ORIGELEM	.BSV	ORIGEN-S elements for compositions input
ORIGNARP	.EXE	ORIGNARP executable program
ORIGNARP	.QSL	Input screen library
RENAMFIL	.FRM	Rename temporary files form
SAVEFIL	.FRM	Save files form

D1.3 ARP

D1.3.1 ARP METHODOLOGY

The main feature of the ARP methodology is that problem-dependent ORIGEN-S cross-section libraries can be obtained by interpolation. As is well known, the success of an interpolation procedure depends on the choice of independent variables pertinent to the problem under consideration and consequently on the selection of a suitable interpolation scheme that provides results within the accepted error margin. To implement the ARP methodology, cross-section changes vs several parameters were computed, and it was found that enrichment, burnup and water density were the independent variables best suited for interpolation. Therefore, cross-section libraries as a function of enrichment, burnup and water density are created using the SAS2H sequence of the SCALE system. In particular, the water density effects impact BWR systems because the axial liquid-to-steam change in these systems leads to a variation in the water density and significant cross-section changes as a function of the water density are observed. These pre-generated cross sections serve as the basic libraries from which the interpolation is performed. Significant cross-section changes, as a function of these variables, are observed. As an example, cross-section variations with burnup in a typical PWR assembly are illustrated in Fig. D1.3.1 for the ^{240}Pu isotope. This situation corresponds to a 15 × 15-type assembly with initial enrichment of 3.0 wt % of ^{235}U, water density 0.7135 g/cm^3 irradiated with a specific power of 40 MW/MTU for 1500 days.

The interpolation on the burnup variable is carried out with a scheme developed by Greene,[6] which has been thoroughly tested and validated in the AMPX cross-section processing codes.[7] The interpolation scheme was developed originally for interpolation in Bondarenko factor tables. It states that for a function f(x) with known values at $x_1, x_2, \ldots x_n$, any value $f(x_q)$ can be interpolated according to

$$f(x_q) = f(x_i) + \frac{x_q^p - x_i^p}{x_{i+1}^p - x_i^p}(f(x_{i+1}) - f(x_i)) , \qquad \text{(D1.3.1)}$$

where p is a function of x and is allowed to vary linearly as

$$p(x_q) = p(x_i) + \frac{x_q - x_i}{x_{i+1} - x_i}(p(x_{i+1}) - p(x_i)) . \qquad \text{(D1.3.2)}$$

It is clear that for a constant p equal to 1, this scheme reduces to the familiar linear interpolation method. In general, however, the p values are determined from the known set $\{x_i; f(x_i)\}$ according to Eq. (D1.3.2) in such a way that the function f(x) is reproduced within the desired accuracy.

Note that the change of the effective absorption cross sections with enrichment has been found to approach a linear shape in a logarithmic-linear scale. This feature is shown in Fig. D1.3.2 for some isotopes. Therefore, logarithmic-linear interpolation is conducted for the cross section as a function of enrichment. Cross-section change with water density for some isotopes is shown in Fig. D1.3.3. Similar to enrichment, the effective absorption cross section varies linearly in a logarithmic-linear scale with the water density, and a logarithmic-linear interpolation is used.

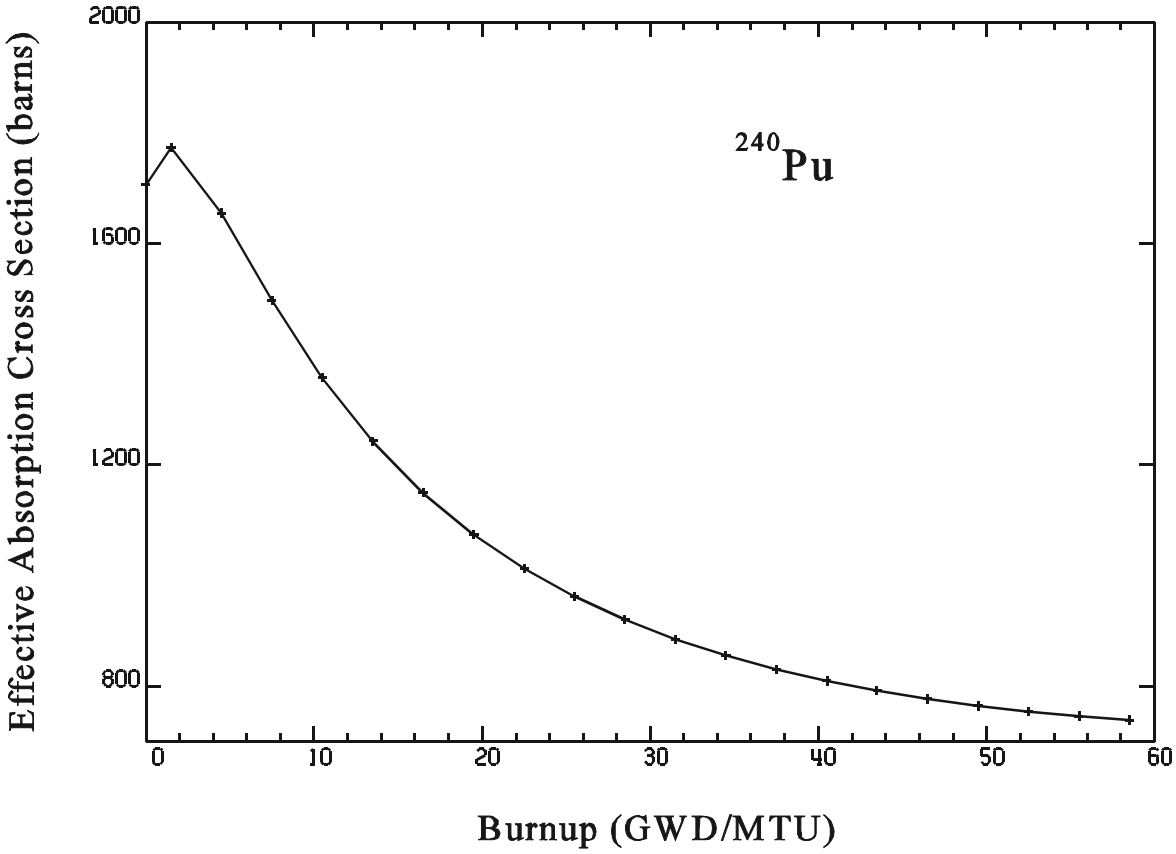

Figure D1.3.1 Effective absorption cross section as a function of burnup for the ^{240}Pu isotope

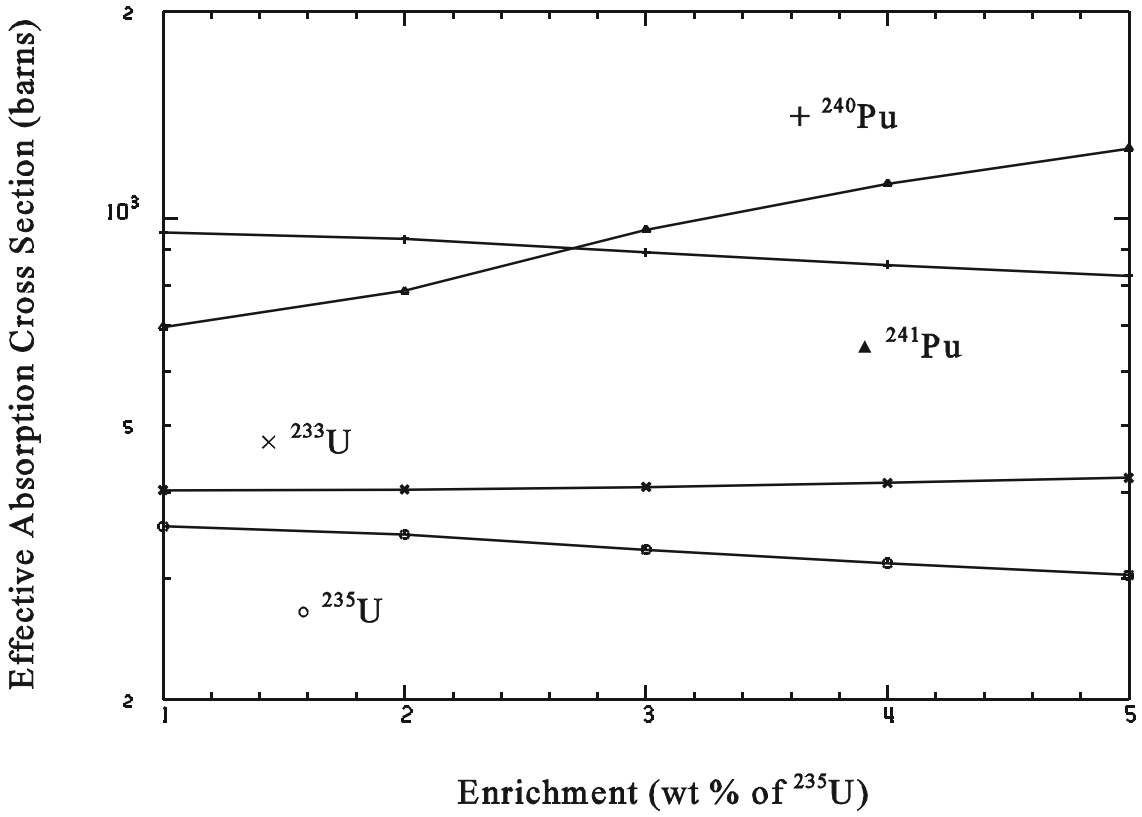

Figure D1.3.2 Effective absorption cross-section changes with enrichment

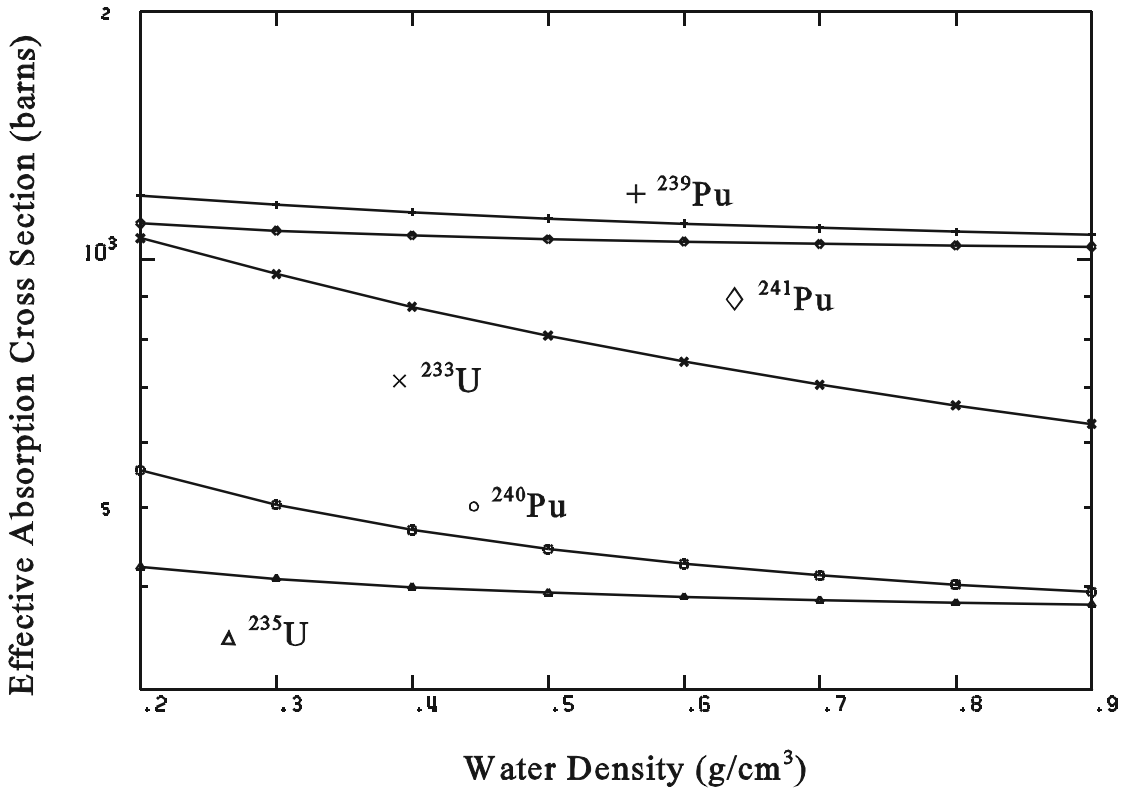

Figure D1.3.3 Effective absorption cross-section changes with water density

D1.3.2 ARP INPUT DESCRIPTION

When running ORIGEN-ARP via the ORIGNARP input processor, ORIGNARP automatically generates a SCALE input file for ARP and ORIGEN-S. Ordinarily the user will not have to be concerned about the ARP input because it is generated by the input processor. However, the input file is documented here for completeness and for the unusual situation where the user may need to set up or modify the ARP input file.

Like all other SCALE modules, the ARP input begins with either an "=" or "#," followed by the module name (e.g., =ARP) and terminates with the keyword END in the first three columns. A detailed input description is provided in Table D1.3.1. Sample input files are shown in Sect. D1.4.

In addition to the user input file, ARP also reads a file named ARPDATA.TXT. This file is stored in the same directory as the SCALE data libraries, including the ARP basic cross-section libraries (see Sect. D1.A). ARPDATA.TXT contains the input describing the pregenerated ARP libraries available for ARP to use. A detailed description of the input format for ARPDATA.TXT is listed in Table D1.3.2. A listing of the standard ARPDATA.TXT file is given in Table D1.3.3. This file may be modified or replaced by users who create their own ARP libraries using the techniques described in Sect. D1.A.2.

Table D1.3.1 ARP input description

Line No.	Parameter	Description	Comments
1	CONFIG	Fuel assembly configuration type	8x8, 14x14, 15x15, 17x17 are valid Users may add other fuel assembly types to ARPDATA.TXT for libraries they create
2	ENRT	Enrichment (wt % ^{235}U)	Must be $\geq$1.5% and $\leq$5%
3	NCY	Number of cycles	Usually the same as the number of depletion cases
4	TIRAD[a]	Fuel irradiation period (days) for each cycle	NCY entries required
5	SPF[a]	Average power for each cycle	NCY entries required
6	NLCY[a]	No. of libraries for each cycle	NCY entries required. Usually NLCY=1 for each cycle
7	RHO	Water density (g/cm^3)	One value for all cycles. Has no effect with the distributed ARP basic cross-section libraries
8	OUTLIB	Name of interpolated library output by ARP for use by ORIGEN-S	ft33f001 is used in ORIGEN-ARP

[a]May be continued on subsequent lines as needed.

Table D1.3.2 ARP library input data in ARPDATA.TXT

Line No.	Parameter	Description	Comments
1	CONFIGNAM	Fuel assembly configuration type (40-character maximum)	Must begin with "**!**" in column one, followed by the fuel assembly type (e.g., **!** 15x15)
2	NENRICH	Number of enrichments	Standard value = 5
	ND	Number of water densities	Standard value = 1
	NBURN	Number of burnups	Standard value = 10
3	ENR[a]	Enrichments (wt % ^{235}U) at which ARP basic libraries were generated	(NENRICH entries) Standard values are 1.5, 2.0, 3.0, 4.0, 5.0
4	DENS[a]	Water densities (g/cm^3) at which ARP basic libraries were generated	(ND entries) Standard value = 1
5	FILE[a]	Filenames of ARP basic libraries for this fuel assembly type	(NENRICH * ND entries) Increment first on density, then on enrichment. Enclose each filename in single quotes
6	BURN[a]	Burnups (MWd/MTU) at which cross-section data exist on ARP libraries	(NBURN entries) First burnup must be zero

NOTE: Repeat all of the above entries for each fuel assembly configuration type.

[a]May be continued on subsequent lines as needed.

Table D1.3.3 ARPDATA.TXT listing

```
!14x14
5  1  10
1.5 2.0 3.0 4.0 5.0
1.
's114x14' 's214x14' 's314x14' 's414x14' 's514x14'
0.0  1500.0 4500.0 7500.0 10500.0 13500.0 16500.0 31500.0
   46500.0 58500.0
!15x15
5  1  10
1.5 2.0 3.0 4.0 5.0
1.
's115x15' 's215x15' 's315x15' 's415x15' 's515x15'
0.0  1500.0 4500.0 7500.0 10500.0 13500.0 16500.0 31500.0
   46500.0 58500.0
!17x17
5  1  10
1.5 2.0 3.0 4.0 5.0
1.
's117x17' 's217x17' 's317x17' 's417x17' 's517x17'
0.0  1500.0 4500.0 7500.0 10500.0 13500.0 16500.0 31500.0
   46500.0 58500.0
!8x8
5  1  10
1.5 2.0 3.0 4.0 5.0
1.
's18x8' 's28x8' 's38x8' 's48x8' 's58x8'
0.0  1500.0 4500.0 7500.0 10500.0 13500.0 16500.0 31500.0
   46500.0 58500.0
```

D1.4 ORIGEN-ARP SAMPLE PROBLEMS

Four sample problems are presented in this section. Input listings of each problem are included in the following sections. The input files for each problem are listed in Table D1.4.1. Note there is a single "stand-alone" SCALE input file for each problem, as is usually done for other SCALE sequences. These files are located in the SCALE sample problems directory on both workstation and PC versions. In addition, there is a set of files for each sample problem that was generated with the ORIGNARP input processor. These files are installed in the sample problems directory on the PC.

Table D1.4.1 ORIGEN-ARP sample problem files

Stand-alone input files	Input files generated with input processor (PC only)	Description
ARPDEMO.INP	DEMO.ARP DEMO.CMP DEMO.DCY DEMO.DPL DEMO.GRP DEMO.INP	Simple demonstration sample problem
ARPHBROB.INP	HBROB_1.ARP HBROB_1.CMP HBROB_1.DCY HBROB_1.DPL HBROB_1.GRP HBROB_1.INP	H. B. Robinson PWR sample problem
ARPBWR.INP	BWR.ARP BWR.CMP BWR.DCY BWR.DPL BWR.GRP BWR.INP	Cooper BWR sample problem
ARPPWR.INP	PWR.ARP PWR.CMP PWR.DCY PWR.DPL PWR.GRP PWR.INP	Turkey Point PWR sample problem

D1.4.1 SIMPLE DEMONSTRATION SAMPLE PROBLEM

The first sample problem is a simple demonstration problem. This problem models the three-cycle depletion of a 3 wt % ^{235}U 17 × 17 PWR fuel assembly. The basis for this model is 1 MTU of fuel. The basic data used to generate the input file are listed in Table D1.4.2. The input file is shown in Fig. D1.4.1.

Table D1.4.2 Data for simple ORIGEN-ARP demonstration problem

Fuel loading	Burnup history data		
	Cycle No.	Power (MW/MTU)	Cumulative time (days)
Basis = 1 MTU	1	38	100
^{234}U = 0.0254 wt %		40	250
^{235}U = 3.0000 wt %		35	300
^{236}U = 0.0138 wt %		37	350
^{238}U = 96.9608 wt %		0	399
	2	35	100
		0	130
		34	300
		33	405
		0	475
	3	16	200
		15	455

```
=arp
17x17
 3.8
 3
 350
 375
 455
 38.28571
 33.98667
 15.43956
1
1
1
1
ft33f001
end
#origens
0$$  a4 33  e t
17x17 library, interpolated to 3.8 wt% -- ft33f001
3$$ 33  a3  1  0  a16 2  a33 0  e t
35$$ 0 t
56$$  6  6  a6 3  a10  0  a13 4  a15 3 a18 1 e
57** 0 a3 1.e-5 .2966102   e t
cycle 1
1 mtu
58** 38 40 40 35 37 1.e-20
60** 100 175 250 300 350 399
66$$ a1 2 a5 2 a9 2  e
73$$  922340  922350  922360  922380
74** 254 30000 138 969608
75$$  2  2  2  2  t
17x17 library, interpolated to 3.8 wt% -- ft33f001
3$$ 33  a3  2  0  a33 0  e t
35$$ 0 t
56$$  7  7  a6 3  a10  6  a15 3 a18 1 e
57** 0 a3 1.e-5 .3177966   e t
cycle 2
1 mtu
58** 35 1.e-20 34 34 33 33 1.e-20
60** 100 130 215 300 352 405 475
66$$ a1 2 a5 2 a9 2  e t
17x17 library, interpolated to 3.8 wt% -- ft33f001
3$$ 33  a3  3  0  a33 0  e t
35$$ 0 t
56$$  5  5  a6 1  a10  7  a15 3 a18 1 e
57** 0 a3 1.e-5 .3855932   e t
cycle 3
1 mtu
58** 16 16 15 15 15
60** 100 200 300 375 455
66$$ a1 2 a5 2 a9 2  e t
56$$ f0 t
end
```

Figure D1.4.1 Simple demonstration problem input listing

D1.4.2 H. B. ROBINSON UNIT 1 PWR SAMPLE PROBLEM

This problem models assembly B05, pellet sample N-9C-D from H. B. Robinson Unit 1. The assembly is a 15 × 15 PWR fuel assembly. It was used for two consecutive cycles and then discharged. Measured chemical assay data from this pellet sample have been used to benchmark SAS2H/ORIGEN-S.[8] The data used to model this problem are based on data in Ref. 8 and presented in Table D1.4.3. Note that each cycle was divided into two depletion cases. This modeling technique should increase the accuracy of the cross sections, because ARP generates a new library for each depletion case. The basis for this problem is 1 MT of UO_2, rather than U, because the assay data were reported per g of UO_2. The input file is given in Fig. D1.4.2.

Table D1.4.3 Data for H. B. Robinson Assembly B05, Pellet N-9C-D

	Burnup history data				
Fuel loading	Cycle No.	Power (MW/MTU)	Power (MW/MTUO_2)	Time (days)	Cumulative burnup (MWd/MTU)
Basis = 1 MT of UO_2	1	44.68	39.39	243.5	10,880
88.15 wt % U		0	0	40.0	
11.85 wt % O		40.25	35.48	243.5	20,680
^{234}U = 0.023 wt % U		0	0	64.0	
^{235}U = 2.561 wt % U					
^{236}U = 0.013 wt % U	2	36.61	32.27	156.0	26,390
^{238}U = 97.403 wt % U		0	0	39.0	
		33.78	29.78	156.0	31,660
	Discharge	0	0	3936	

```
#arp
15x15
 2.561
 4
 243.5
 243.5
 156
 156
 44.6852
 40.24957
 36.60806
 33.78333
1
1
1
1
1
ft33f001
end
#origens
0$$  a4 33 a11 71  e t
15x15 westinghouse pwr library -- ft33f001
3$$ 33  a3  1  0  a16 2  a33 0  e t
35$$ 0 t
56$$  4  4  a6 3  a10  0  a13 5  a15 3 a18 1 e
57** 0 a3 1.e-5 .304756   e t
cycle 1, part1 hb robinson n-9 226 cm (31.66 gwd/t)
metric ton of uo2
58** 39.39 39.39 39.39 1.e-20
60** 100 172 243.5 283.5
66$$ a1 2 a5 2 a9 2  e
73$$  922340  922350  922360  922380  80160
74** 202.74 22575.22 114.60 858607.45 118500
75$$  2  2  2  2  1  t
15x15 westinghouse pwr library -- ft33f001
3$$ 33  a3  2  0  a33 0  e t
35$$ 0 t
56$$  4  4  a6 3  a10  4  a15 3 a18 1 e
57** 0 a3 1.e-5 .304756   e t
cycle 1, part2 hb rob. n-9 (31.66 gwd/mtu)
metric ton of uo2
58** 35.48 35.48 35.48 1.e-20
60** 100 172 243.5 307.5
66$$ a1 2 a5 2 a9 2  e t
15x15 westinghouse pwr library -- ft33f001
3$$ 33  a3  3  0  a33 0  e t
35$$ 0 t
56$$  3  3  a6 3  a10  4  a15 3 a18 1 e
57** 0 a3 1.e-5 .1952441   e t
cycle 2, part1 hb rob. n-9 (31.66 gwd/mtu)
metric ton of uo2
58** 32.27 32.27 1.e-20
60** 100 156 195
66$$ a1 2 a5 2 a9 2  e t
15x15 westinghouse pwr library -- ft33f001
3$$ 33  a3  4  0  a33 0  e t
35$$ 0 t
56$$  4  4  a6 1  a10  3  a15 3 a18 1 e
57** 0 a3 1.e-5 .1952441   e t
cycle 2, part2 hb rob. n-9 (31.66 gwd/mtu)
1 mtu of fuel
58** 29.78 29.78 29.78 29.78
60** 50 100 128 156
66$$ a1 2 a5 2 a9 2  e t
54$$ a8 1  e
56$$ a2 5  a6 1  a10  4  a15 3 e
57** 0 e t
3936 day decay, hb robinson n-9 c-d, 226 cm (31.66 gwd/t)
metric ton of uo2
60** 100 300 1000 3000 3936
61** f.01
65$$
'gram-atoms   grams    curies     watts-all  watts-gamma
     3z     1  0  0        3z         3z         3z         6z
     3z     1  0  0        3z         3z         3z         6z
     3z     1  0  0        3z         3z         3z         6z   t
56$$ 0 0 a10  5  e t
56$$ f0 t
end
```

Figure D1.4.2 H. B. Robinson PWR input listing

D1.4.3 COOPER BWR SAMPLE PROBLEM

This BWR problem models assembly CZ205 from Cooper Nuclear Station. This assembly was in core for three cycles, out of core for two cycles, and in core for two more cycles. Decay heat measurements of this assembly have been used as benchmarks for SAS2H/ORIGEN-S calculations.[9] The data used in the ORIGEN-ARP model setup are given in Table D1.4.4. The two cycles out of core, cycles 4 and 5, were modeled as a decay case because of the length of time involved. Generally, any nonpower time of 100 days or greater should be modeled as a decay case rather than as a zero-power timestep in a depletion case. Light-element loadings are included in the fuel loading because they are important for decay heat and radiation source term calculations. The input file is listed in Fig. D1.4.3.

Table D1.4.4 Data for Cooper BWR assembly CZ205

	Burnup history data				
Fuel loading	Cycle No.	Power (MW/assembly)	Burnup (MWd/MTU)	Cycle length (days)	Outage length (days)
Basis = 1 assembly	1	2.427	10,298	807	59
(0.1902 MTU)	2	4.608	7,414	306	31
	3	3.464	2,987	164	35
^{234}U wt % = 0.022	4[a]	0.0	0	370	--[b]
^{235}U wt % = 2.500	5[a]	0.0	0	394	--[b]
^{236}U wt % = 0.012	6	1.118	1,864	317	48
^{238}U wt % = 97.466	7	1.520	2,781	348	--[b]
	Total		25,344	1942	
H 3.1000 kg/assembly					
B 0.0130 kg/assembly					
O 50.5000 kg/assembly					
Cr 0.4500 kg/assembly					
Mn 0.0290 kg/assembly					
Fe 1.2000 kg/assembly					
Co 0.0046 kg/assembly					
Ni 0.4500 kg/assembly					
Zr 98.2000 kg/assembly					
Sn 1.6000 kg/assembly					
Gd 0.5440 kg/assembly					

Cooling-time data	
Cooling time (days)	Measured decay heat (W)
857	324.0
871	343.5
886	331.8
892	327.5
899	311.4
946	317.1

[a]Assembly was out of core during this cycle.
[b]Not applicable.

```
=arp
8x8
 2.5
 5
 807
 306
 164
 317
 348
 12.76025
 24.22713
 18.21241
 5.878023
 7.991588
1
1
1
1
1
1
ft33f001
end
#origens
0$$  a4 33  e t
bwr 8x8 library -- ft33f001
3$$ 33  a3  1  0  a16 2  a33 0  e t
35$$ 0 t
56$$  10  10  a6 3  a10  0  a13 15  a15 3 a18 1 e
57** 0 a3 1.e-5 .415551   e t
cycle 1, cooper bwr nuclear station, assembly cz205
fuel assembly (0.1902 mtu)
58** 2.427 2.427 2.427 2.427 2.427 2.427 2.427 2.427 2.427 1.e-20
60** 100 200 300 400 500 600 700 753 807 866
66$$ a1 2 a5 2 a9 2  e
73$$  922340  922350  922360  922380  10000  50000  80000  240000
 250000  260000  270000  280000  400000  500000  640000
74** 42 4755 23 185380 3100 13 50500 450 29 1200 5 450 98200 1600 544
75$$  2  2  2  2  4  4  4  4  4  4  4  4  4  4  4  t
bwr 8x8 library -- ft33f001
3$$ 33  a3  2  0  a33 0  e t
35$$ 0 t
56$$  5  5  a6 3  a10  10  a15 3 a18 1 e
57** 0 a3 1.e-5 .1575695   e t
cycle 2, cooper bwr nuclear station, assembly cz205
fuel assembly
58** 4.608 4.608 4.608 4.608 1.e-20
60** 100 200 253 306 337
66$$ a1 2 a5 2 a9 2  e t
bwr 8x8 library -- ft33f001
3$$ 33  a3  3  0  a33 0  e t
35$$ 0 t
56$$  4  4  a6 1  a10  5  a15 3 a18 1 e
```

Figure D1.4.3 Cooper BWR input listing

```
57** 0 a3 1.e-5 8.444902e-02   e t
cycle 3, cooper bwr nuclear station, assembly cz205
fuel assembly
58** 3.464 3.464 3.464 3.464
60** 50 100 132 164
66$$ a1 2 a5 2 a9 2  e t
54$$ a8 1  e
56$$ a2 3  a6 3  a10  4  a15 3 e
57** 0 e t
cycles 4&5, decay of assy cz205 in spent fuel pool
assembly cz205
60** 100 300 799
61** f.5
65$$
'gram-atoms   grams    curies     watts-all  watts-gamma
     3z     1  0  0        3z         3z         3z         6z
     3z     1  0  0        3z         3z         3z         6z
     3z     1  0  0        3z         3z         3z         6z   t
bwr 8x8 library -- ft33f001
3$$ 33  a3  4  0  a33 0  e t
35$$ 0 t
56$$  5  5  a6 3  a10  3  a15 3 a18 1 e
57** 0 a3 1.e-5 .1632338   e t
cycle 6, cooper bwr nuclear station, assembly cz205
fuel assembly
58** 1.118 1.118 1.118 1.118 1.e-20
60** 100 200 258 317 365
66$$ a1 2 a5 2 a9 2  e t
bwr 8x8 library -- ft33f001
3$$ 33  a3  5  0  a33 0  e t
35$$ 0 t
56$$  4  4  a6 1  a10  5  a15 3 a18 1 e
57** 0 a3 1.e-5 .1791967   e t
cycle 7, cooper bwr nuclear station, assembly cz205
fuel assembly
58** 1.52 1.52 1.52 1.52
60** 100 200 274 348
66$$ a1 2 a5 2 a9 2  e t
54$$ a8 1  e
56$$ a2 9  a6 1  a10  4  a15 3 e
57** 0 e t
final decay, cooper bwr assy cz205
assembly cz205
60** 50 150 400 857 871 886 892 899 946
61** f.5
65$$
'gram-atoms   grams    curies     watts-all  watts-gamma
     3z         3z         3z     1  0  0        3z         6z
     3z         3z         3z     1  0  0        3z         6z
     3z         3z         3z     1  0  0        3z         6z   t
56$$ f0 t
end
```

Figure D1.4.3 (continued)

D1.4.4 TURKEY POINT PWR SAMPLE PROBLEM

This case is a model of assembly D-15 from Turkey Point Unit 3. This assembly was loaded for three consecutive cycles and then discharged. Decay heat measurements of this assembly have also been used as a benchmark for SAS2H/ORIGEN-S.[9] The data for this assembly are presented in Table D1.4.5. Once again, the light-element loadings are included because they are important for decay heat and radiation source-term calculations. The input file is listed in Fig. D1.4.4.

Table D1.4.5 Data for Turkey Point 3 PWR assembly D-15

Fuel loading	Burnup history data				
	Cycle No.	Power (MW/assembly)	Burnup (MWd/MTU)	Cycle length (days)	Outage length (days)
Basis = 1 assembly					
(0.4561 MTU)	2	13.771	9,480	314	58
^{234}U wt % = 0.023	3	13.603	9,752	327	62
^{235}U wt % = 2.557	4	13.040	8,920	312	--
^{236}U wt % = 0.012					
^{238}U wt % = 97.408	Total		28,152	953	
O 62.000 kg/assembly					
Cr 2.700 kg/assembly					
Mn 0.150 kg/assembly					
Fe 5.900 kg/assembly					
Co 0.034 kg/assembly					
Ni 4.500 kg/assembly					
Zr 101.000 kg/assembly					
Nb 0.320 kg/assembly					
Sn 1.600 kg/assembly					

Cooling-time data	
Cooling time (days)	Measured decay heat (W)
962	1423
1144	1126
2077	625

```
=arp
15x15
 2.557
 3
 314
 327
 312
 30.19294
 29.8246
 28.59022
1
1
1
1
ft33f001
end
#origens
0$$  a4 33  e t
pwr 15x15 library -- ft33f001
3$$ 33  a3  1  27  a16 2  a33 18  e t
35$$ 0 t
56$$  5  5  a6 3  a10  0  a13 13  a15 3 a18 1 e
57** 0 a3 1.e-5 .3294858   e t
turkey point 3 cycle 2 assembly d-15
fuel assembly (0.4561 mtu)
58** 13.771 13.771 13.771 13.771 1.e-20
60** 100 200 257 314 372
66$$ a1 2 a5 2 a9 2  e
73$$  922380  922350  922340  922360  80000  240000  250000  260000
 270000  280000  400000  410000  500000
74** 444278 11662 105 55 62000 2700 150 5900 34 4500 101000 320 1600
75$$  2  2  2  2  4  4  4  4  4  4  4  4  4  t
pwr 15x15 library -- ft33f001
3$$ 33  a3  2  27  a33 18  e t
35$$ 0 t
56$$  5  5  a6 3  a10  5  a15 3 a18 1 e
57** 0 a3 1.e-5 .343127   e t
turkey point 3 cycle 3 assembly d-15
fuel assembly
58** 13.603 13.603 13.603 13.603 1.e-20
60** 100 200 263 327 389
66$$ a1 2 a5 2 a9 2  e t
pwr 15x15 library -- ft33f001
3$$ 33  a3  3  27  a33 18  e t
35$$ 0 t
56$$  4  4  a6 1  a10  5  a15 3 a18 1 e
57** 0 a3 1.e-5 .3273872   e t
turkey point 3 cycle 4 assembly d-15
fuel assembly
58** 13.04 13.04 13.04 13.04
60** 100 200 256 312
```

Figure D1.4.4 Turkey Point PWR input listing

```
66$$ a1 2 a5 2 a9 2  e t
54$$ a8 1  e
56$$ a2 5  a6 1  a10  4  a15 3 e
57** 0 e t
turkey pt assy d-15, decay: measured 625 watts @ 2077 days
assembly d-15
60** 100 300 962 1144 2077
61** f.1
65$$
'gram-atoms   grams    curies     watts-all  watts-gamma
     3z         3z         3z     1  0  0        3z         6z
     3z         3z         3z     1  0  0        3z         6z
     3z         3z         3z     1  0  0        3z         6z
81$$ 2 0 26 1  e
82$$  0  0  0  0  2
83**  1.e+7        8.e+6        6.5e+6       5.e+6        4.e+6
 3.e+6        2.5e+6       2.e+6        1.66e+6      1.33e+6
 1.e+6        8.e+5        6.e+5        4.e+5        3.e+5
 2.e+5        1.e+5        5.e+4        1.e+4
84**  2.e+7        6.434e+6     3.e+6        1.85e+6      1.4e+6
 9.e+5        4.e+5        1.e+5        1.7e+4       3.e+3
 5.5e+2       1.e+2        3.e+1        1.e+1        3.04999e+0
 1.77e+0      1.29999e+0   1.12999e+0   1.e+0        8.e-1
 4.e-1        3.25e-1      2.25e-1      9.999985e-2  5.e-2
 3.e-2        9.999998e-3  1.e-5        t
turkey pt assy d-15, decay: measured 625 watts @ 2077 days timestep 5
56$$ f0 t
end
```

Figure D1.4.4 (continued)

D1.5 REFERENCES

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2. S. M. Bowman, *OFFSCALE: A PC Input Processor for the SCALE Code System, The ORIGNATE Processor for ORIGEN-S*, NUREG/CR-6182, Vol. 2 (ORNL/TM-12263/V2), U.S. Nuclear Regulatory Commission, November 1994.

3. *Microsoft BASIC Professional Development System Version 7.1*, Microsoft Corporation, 1990.

4. *QuickScreen Version 3.0*, Crescent Software, 1989.

5. *QuickPak Professional: Advanced Programming Library for BASIC Compilers; Version 3.2*, Crescent Software, 1990.

6. N. M. Greene, "A Model for Interpolating in Bondarenko Factor Tables and Other Functions," Symposium on ENDF/B Benchmark Analysis, EPRI NP-2855, Electric Power Research Institute, February 1983.

7. N. M. Greene, W. E. Ford III, L. M. Petrie, and J. W. Arwood, *AMPX-77: A Modular Code System for Generating Coupled, Multigroup Neutron-Gamma Cross-Section Libraries from ENDF/B-IV and/or ENDF/B-V*, ORNL/CSD-283, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., October 1992.

8. O. W. Hermann, S. M. Bowman, M. C. Brady, and C. V. Parks, *Validation of the SCALE System for PWR Spent Fuel Isotopic Composition Analyses*, ORNL/TM-12667, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., March 1995.

9. O. W. Hermann et al., *Technical Support for a Proposed Decay Heat Guide Using SAS2/ORIGEN-S Data*, NUREG-CR-5625 (ORNL-6698), U.S. Nuclear Regulatory Commission, 1994.

D1.A ARP BASIC CROSS-SECTION LIBRARIES

D1.A.1 DESCRIPTION OF STANDARD ARP BASIC CROSS-SECTION LIBRARIES

The ARP program creates multiple ORIGEN-S cross-section libraries by interpolating over basic cross-section libraries pregenerated by SAS2H and processed by ARPLIB (see Sect. D1.B.2). The ARP basic cross-section libraries distributed in SCALE were generated at enrichments of 1.5, 2.0, 3.0, 4.0, and 5.0 wt % of ^{235}U and ten burnup steps from 0 to 60 GWd/MTU. To generate these basic ARP cross-section libraries, the following steps were performed for each enrichment:

1. SAS2H calculations were performed for 21 cycles with 1 library per cycle. The first cycle was extremely short (1×10^{-15} days) so that the cross-section library created in the first cycle contained fresh-fuel cross sections. The remaining cycles were 3 GWd/MTU each.

2. ARPLIB was used to reduce the number of cross-section libraries vs burnup from 21 to 10 according to the following the criteria:

   a. Fresh-fuel cross sections were retained.

   b. Minimum, maximum, and points of inflection derived from the shape of the absorption cross section with burnup for various isotopes of the library were retained.

   c. The remaining points were the ones that best represent the burnup-dependent ^{240}Pu absorption cross sections. The ^{240}Pu absorption cross section was used as the criterion because it changes more significantly with burnup than that of any other major actinide.

See Table D1.A.1 for a listing of the burnup associated with each library. The libraries used were the first seven (0, 1.5, 4.5, 7.5, 10.5, 13.5, 16.5 GWd/MTU), the 12th (31.5 GWd/MTU), the 17th (46.5 GWd/MTU), and the 21st (58.5 Gwd/MTU). Basic ARP cross-section libraries were generated for fuel assembly designs 8 × 8 (General Electric BWR), 14 × 14 (ABB Combustion Engineering PWR), 15 × 15 (Westinghouse PWR), and 17 × 17 (Westinghouse PWR). The SAS2H input files used to generate the libraries for the enrichment of 3.0 wt % ^{235}U are shown in Figs. D1.A.1 through D1.A.4, respectively. The design data for the 14 × 14 and 15 × 15 PWR assemblies can be found in Ref. 8. The operational conditions assumed for the fuel and moderator temperatures and the moderator water density for each assembly are displayed in Table D1.A.2. The remaining libraries for 1.5, 2.0, 4.0, and 5.0 wt % of ^{235}U were created using a SAS2H input similar to that shown in these tables. For a given ^{235}U enrichment, the uranium isotope weight percentages were calculated according to the following expressions:

$$^{234}\text{U (wt \%)} = 0.0089 \times {}^{235}\text{U (wt \%)}$$

$$^{236}\text{U (wt \%)} = 0.0046 \times {}^{235}\text{U (wt \%)}$$

$$^{238}\text{U (wt \%)} = 100 - ({}^{234}\text{U (wt \%)} + {}^{235}\text{U (wt \%)} + {}^{236}\text{U (wt \%)})$$

Table D1.A.1 Twenty-one burnup positions of the SAS2H-generated libraries

Position	Burnup (MWd/MTU)
1	0[a]
2	1500[a]
3	4500[a]
4	7500[a]
5	10500[a]
6	13500[a]
7	16500[a]
8	19500
9	22500
10	25500
11	28500
12	31500[a]
13	34500
14	37500
15	40500
16	43500
17	46500[a]
18	49500
19	52500
20	55500
21	58500[a]

[a]These values represent the 10 burnup positions in the ARP basic cross-section library.

```
=sas2h     parm='halt21,skipshipdata'
 8x8 BWR Assembly
' Fuel enrichment 3.0 wt % of u-235, Fuel Temperature 840 k
' Moderator Temperature 558 K, Moderator Density 0.4323 g/cc
'
'  Twenty-one cycles and one library per cycle including fresh fuel
'  Cross section.
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'   mixtures of fuel-pin-unit-cell:
'
27burnuplib    latticecell
uo2  1  den=9.871 1 840
 92234 0.0267 92235 3.0 92236 0.0138 92238 96.9595 end
'hot-den=10.96(the theor.-den)*0.94(%-td)*(.416/.425)**2 cold/hot diam
co-59  3 0 1-20 558  end
zr-94  1 0 1-20 840  end
tc-99  1 0 1-20 840  end
ru-106 1 0 1-20 840  end
rh-103 1 0 1-20 840  end
rh-105 1 0 1-20 840  end
xe-131 1 0 1-20 840  end
cs-134 1 0 1-20 840  end
ce-144 1 0 1-20 840  end
pr-143 1 0 1-20 840  end
nd-143 1 0 1-20 840  end
nd-145 1 0 1-20 840  end
nd-147 1 0 1-20 840  end
pm-147 1 0 1-20 840  end
sm-149 1 0 1-20 840  end
sm-151 1 0 1-20 840  end
sm-152 1 0 1-20 840  end
eu-153 1 0 1-20 840  end
eu-154 1 0 1-20 840  end
eu-155 1 0 1-20 840  end
' Change needed for ENDF/B-V
' zircalloy  2 1  620   end
zirc2  2 1  620   end
h2o  3 den=0.4323  1  558 end
'
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'   mixtures of larger-unit-cell:
'
uo2  9  den=9.871 1 840
 92234 0.0267 92235 3.0 92236 0.0138 92238 96.9595 end
arbm-gdburn  9.871 7 0 1 1
           64154  2.18  64155 14.80  64156 20.47
           64157 15.65  64158 24.84  64160 21.86
            8016 150.0  9  0.040  840  end
'                ....above is 4.0 wt % gadolinium (as gd2-ox3) in the
'                    burnable poison pins of bwr assembly....
' Change needed for ENDF/B-V
' zircalloy  10  1  588 end
zirc2  10  1  588 end
```

Figure D1.A.1 SAS2H input used to generate 21 BWR 8 × 8 cross-section libraries

```
'                ....above is zircalloy casing around assembly
b-10    11 0 7.15-6  552  end
2o          11 0.669  552 end
'                 ....above is channel moderator at higher density
end comp
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'      fuel-pin-cell geometry:
'
squarepitch   1.6256 1.0795  1 3  1.25222  2  end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'    assembly and cycle parameters:
'
npin/assm=63  fuelnght=1993.26  ncycles=21  nlib/cyc=1
printlevel=4  lightel=10  inplevel=2  numzones=6   end
9 0.53975 2 0.62611 3 0.91715 500 3.6398 10 3.8103 11 4.3261
'           ..these mixtures & radii place gadolinium pin at center
'             of 1/4 of assembly fuel, casing & channel mod.
power=40    burn=1.0e-15 down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=1500.0   end
  h 16.4 b 0.068
  o 265  cr  2.4  mn  0.15
  fe 6.6 co 0.024 ni  2.4
  zr 516 sn  8.7
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
end
```

Figure D1.A.1 (continued)

```
=sas2h     parm='halt21,skipshipdata'
 14x14 PWR Assembly CE
' Fuel enrichment 3.0 wt % of u-235, Fuel Temperature  873 K
' Moderator Temperature 570 K, Moderator Density 0.7332 g/cc
'
'   Twenty-one cycles and one library per cycle including fresh fuel
'   cross section.
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'   mixtures of fuel-pin-unit-cell:
'
27burnuplib    latticecell
uo2  1 den=10.045  1  873
   92234 0.0267 92235 3.0 92236 0.0138 92238 96.9595 end
c    1 den=1.8-4  1  873  end
n    1 den=2.3-4  1  873  end
co-59  3 0 1-20 570  end
zr-94  1 0 1-20 873  end
mo-94  1 0 1-20 873  end
nb-95  1 0 1-20 873  end
mo-95  1 0 1-20 873  end
tc-99  1 0 1-20 873  end
rh-103 1 0 1-20 873  end
rh-105 1 0 1-20 873  end
ru-106 1 0 1-20 873  end
sn-126 1 0 1-20 873  end
xe-131 1 0 1-20 873  end
cs-134 1 0 1-20 873  end
cs-135 1 0 1-20 873  end
cs-137 1 0 1-20 873  end
pr-143 1 0 1-20 873  end
nd-143 1 0 1-20 873  end
ce-144 1 0 1-20 873  end
nd-144 1 0 1-20 873  end
nd-145 1 0 1-20 873  end
nd-146 1 0 1-20 873  end
nd-147 1 0 1-20 873  end
pm-147 1 0 1-20 873  end
sm-147 1 0 1-20 873  end
nd-148 1 0 1-20 873  end
pm-148 1 0 1-20 873  end
sm-148 1 0 1-20 873  end
pm-149 1 0 1-20 873  end
sm-149 1 0 1-20 873  end
nd-150 1 0 1-20 873  end
sm-150 1 0 1-20 873  end
sm-151 1 0 1-20 873  end
eu-151 1 0 1-20 873  end
sm-152 1 0 1-20 873  end
eu-153 1 0 1-20 873  end
eu-154 1 0 1-20 873  end
gd-154 1 0 1-20 873  end
eu-155 1 0 1-20 873  end
gd-155 1 0 1-20 873  end
gd-157 1 0 1-20 873  end
gd-158 1 0 1-20 873  end
gd-160 1 0 1-20 873  end
```

Figure D1.A.2 SAS2H input used to generate 21 PWR 14 × 14 cross-section libraries

```
'   need the following to use endf/b5 library:
'   from st5:  (2nd line same as def. of zircalloy in sect. m8, scale-4.1)
zircalloy  2 1  620   end
' zirc2  2 1  620   end
h2o  3 den=0.7332  1  570 end
arbm-bormod  0.7332 1 1 0 0 5000 100 3 330.8e-6  570  end
'
'  331 ppm boron (wt) in moderator
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
end comp
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'      fuel-pin-cell geometry:
'
squarepitch   1.4732  0.9563 1  3  1.1176  2  0.9855   0  end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'    assembly and cycle parameters:
'
npin/assm=176 fuelnght=787.52 ncycles=21  nlib/cyc=1
printlevel=4 lightel=9  inplevel=2 numztotal=5   end
3  1.314  2  1.416  3  1.662  500  5.203  3  5.243
power=40.0 burn=1.0e-15  down=0.0    end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=0.0  end
power=40.0 burn=75.0   down=1500.0  end
  o 119  cr  5.2  mn  0.29
  fe 11. co 0.066 ni  8.7
  zr 195 nb  0.63 sn  3.2
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
end
```

Figure D1.A.2 (continued)

```
=sas2h    parm='halt21,skipshipdata'
 15x15 PWR Assembly Whestinghouse
' Fuel enrichment 3.0 wt % of u-235, Fuel Temperature 923 K
' Moderator Temperature 579 K, Moderator density 0.7135 g/cc
'
'   Twenty-one cycles and one library per cycle including fresh fuel
'   cross section.
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'   mixtures of fuel-pin-unit-cell:
'
27burnuplib    latticecell
uo2  1 den=9.944 1  923
          92234 0.0267 92235 3.0 92236 0.0138 92238 96.9595 end
co-59  3 0 1-20 579  end
zr-94  1 0 1-20 923  end
mo-94  1 0 1-20 923  end
nb-95  1 0 1-20 923  end
mo-95  1 0 1-20 923  end
tc-99  1 0 1-20 923  end
rh-103 1 0 1-20 923  end
rh-105 1 0 1-20 923  end
ru-106 1 0 1-20 923  end
xe-131 1 0 1-20 923  end
cs-134 1 0 1-20 923  end
cs-135 1 0 1-20 923  end
cs-137 1 0 1-20 923  end
pr-143 1 0 1-20 923  end
nd-143 1 0 1-20 923  end
ce-144 1 0 1-20 923  end
nd-145 1 0 1-20 923  end
nd-146 1 0 1-20 923  end
nd-147 1 0 1-20 923  end
pm-147 1 0 1-20 923  end
sm-147 1 0 1-20 923  end
nd-148 1 0 1-20 923  end
pm-149 1 0 1-20 923  end
sm-149 1 0 1-20 923  end
sm-150 1 0 1-20 923  end
sm-151 1 0 1-20 923  end
eu-151 1 0 1-20 923  end
sm-152 1 0 1-20 923  end
eu-153 1 0 1-20 923  end
eu-154 1 0 1-20 923  end
gd-154 1 0 1-20 923  end
eu-155 1 0 1-20 923  end
gd-155 1 0 1-20 923  end
gd-157 1 0 1-20 923  end
gd-158 1 0 1-20 923  end
gd-160 1 0 1-20 923  end
'   need the following to use endf/b5 library:
'   from st5:  (2nd line same as def. of zircalloy in sect. m8, scale-4.1)
' zirc2  2 1  595   end
zircalloy  2 1  595   end
h2o  3 den=0.7135  1  579 end
```

Figure D1.A.3 SAS2H input used to generate 21 PWR 15 × 15 cross-section libraries

```
arbm-bormod  0.7135 1 1 0 0 5000 100 3 652.5e-6  579  end
'
'
end comp
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'      fuel-pin-cell geometry:
'
squarepitch   1.4300  0.9294 1  3  1.0719  2  0.9484   0  end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'    assembly and cycle parameters:
'
npin/assm=204 fuelnght=824.34 ncycles=21  nlib/cyc=1
printlevel=5 lightel=9  inplevel=2 numztotal=4  end
'  the 10 larger unit cell zones follow for 2 passes bp, 2 passes h2o :
3  0.65024 2  0.69342 3  0.80680 500  2.64088
'
power=40   burn=1.0e-15 down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=0.0    end
power=40   burn=75.0  down=1500.0    end
  o 119  cr  5.2  mn  0.29
  fe 11. co 0.066 ni  8.7
  zr 195 nb  0.63 sn  3.2
end
```

Figure D1.A.3 (continued)

```
=sas2h    parm='halt21,skipshipdata'
 17x17 PWR Assembly Whestinghouse
' Fuel enrichment 3.0 wt of u-235, Fuel Temperature 811 K
' Moderator Temperature 570, Moderator Density 0.7295 g/cc

'   Twenty-one cycles and one library per cycle including fresh fuel
'   cross section.
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'   mixtures of fuel-pin-unit-cell:
'
27burnuplib    latticecell
uo2  1 0.945 811 92234 0.0267 92235 3.0 92236 0.0138 92238 96.9595 end
co-59  3 0 1-20 570  end
zr-94  1 0 1-20 811  end
mo-94  1 0 1-20 811  end
nb-95  1 0 1-20 811  end
mo-95  1 0 1-20 811  end
tc-99  1 0 1-20 811  end
ru-106 1 0 1-20 811  end
rh-103 1 0 1-20 811  end
rh-105 1 0 1-20 811  end
xe-131 1 0 1-20 811  end
cs-134 1 0 1-20 811  end
cs-135 1 0 1-20 811  end
cs-137 1 0 1-20 811  end
ce-144 1 0 1-20 811  end
pr-143 1 0 1-20 811  end
nd-143 1 0 1-20 811  end
nd-145 1 0 1-20 811  end
nd-146 1 0 1-20 811  end
nd-147 1 0 1-20 811  end
pm-147 1 0 1-20 811  end
sm-147 1 0 1-20 811  end
nd-148 1 0 1-20 811  end
pm-149 1 0 1-20 811  end
sm-149 1 0 1-20 811  end
sm-150 1 0 1-20 811  end
sm-151 1 0 1-20 811  end
eu-151 1 0 1-20 811  end
sm-152 1 0 1-20 811  end
eu-153 1 0 1-20 811  end
eu-154 1 0 1-20 811  end
gd-154 1 0 1-20 811  end
eu-155 1 0 1-20 811  end
gd-155 1 0 1-20 811  end
gd-157 1 0 1-20 811  end
gd-158 1 0 1-20 811  end
gd-160 1 0 1-20 811  end
' Change needed for running sas2h with ENDF/B-V library
' zircalloy  2 1  620   end
zirc2  2 1  620   end
'           40000 97.91 26000 0.5 50116 0.86 50120 0.73 2 1 620 end
h2o  3 den=0.7295  1  570 end
arbm-bormod  0.7295 1 1 0 0 5000 100 3 550.0e-6  570  end
```

Figure D1.A.4 SAS2H input used to generate 21 PWR 17 × 17 cross-section libraries

```
'
'  550 ppm boron (wt) in moderator
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
end comp
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'      fuel-pin-cell geometry:
'
squarepitch   1.25984 0.81915 1 3 0.94966 2 0.83566 0  end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'    assembly and cycle parameters:
'
npin/assm=264 fuelnght=787.28 ncycles=21  nlib/cyc=1
printlevel=4 lightel=9  inplevel=1 ortube=0.61214 srtube=0.5715
numinstr=1  end
power=40  burn=1.0e-15 down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=0.0   end
power=40  burn=75.0  down=1500.0   end
  o 135  cr  5.9  mn  0.33
  fe 13. co 0.075 ni  9.9
  zr 221 nb  0.71 sn  3.6
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
end
```

Figure D1.A.4 (continued)

Table D1.A.2 Operational conditions used in creating ARP basic cross-section libraries

Assembly type	Fuel temperature (K)	Moderator temperature (K)	Density of moderator (g/cc)
BWR 8 × 8	840	558	0.4323
PWR 14 × 14	873	570	0.7332
PWR 15 × 15	923	579	0.7135
PWR 17 × 17	811	570	0.7295

Various utility programs (Sect. D1.B) have been developed to automate the procedure to create basic ARP cross-section libraries. The generation of the ARP basic libraries is performed only once for each fuel assembly type and enrichment. The procedure for generating the ARP basic libraries is discussed in the following section.

D1.A.2 HOW TO GENERATE ARP BASIC CROSS-SECTION LIBRARIES

To generate the basic ARP cross-section libraries for a particular LWR fuel assembly type, one needs to follow the steps outlined below. Note that extension beyond 5 wt % enrichment has not been investigated at ORNL. Likewise, extension to non-LWR fuel has not been investigated. **Such applications of the ARP methodology should be tested carefully and validated.**

Construct SAS2H input with the descriptions (pin cell description such as dimensions, concentrations, etc.) of the reactor assembly under consideration for five enrichments. The recommended enrichments are 1.5, 2.0, 3.0, 4.0 and 5.0 wt % of ^{235}U. For a BWR assembly, in addition to enrichment and burnup, one has also to consider the water density variation for each enrichment. The recommended water density values for BWRs are: 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 g/cm^3. No water density variation has been used at ORNL for PWRs.

For each enrichment and water-density combination, perform a SAS2H calculation with 21 cycles and 1 library per cycle. The cross-section libraries created in this step must contain fresh-fuel cross sections for the first cycle. From studies performed with PWR and BWR assemblies, it is recommended that a specific power of 40 MW/MTU and a total irradiation period of 1500 days be applied for a total burnup of 60,000 MWd/MTU. To obtain the 21 burnup-dependent cross-section libraries, use one burnup step of 1×10^{-15} days and 20 burnup steps of 3000 MWd/MTU. With the exception of the first library in the zero-burnup position, the remaining 20 libraries correspond to a burnup position at the midpoint of each burnup step. The burnup positions are listed in Table D1.A.1.

A single SAS2H input file can be constructed with generic flags substituted for the parameters that vary from case-to-case (i.e., enrichment and water density). This single SAS2H input file can be processed through the PRISM utility (see Sect. D1.B.1) to generate specific SAS2H input files for each enrichment/density combination. A generic SAS2H example input file for a BWR 7 × 7 fuel assembly is shown in Fig. D1.A.5. The generic flags are highlighted in bold type. A PRISM example input file is listed in Fig. D1.A.6 that generates 40 specific SAS2H input files from the generic file in Fig. D1.A.5. The specific SAS2H input file created by PRISM for 3.0 wt % ^{235}U and 0.5 g/cc water density is shown in Fig. D1.A.7.

```
=sas2     parm='halt21,skipshipdata'
sas2 cooper bwr 7x7, enr wt% u-235, ddd g/cc h2o density
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'   mixtures of fuel-pin-unit-cell:
'
44group    latticecell
uo2  1 den=10.32   1  840
 92234 u234wt% 92235 enr 92236 u236wt% 92238 u238wt%x end
co-59  3 0 1-20 558  end
zr-94  1 0 1-20 840  end
nb-95  1 0 1-20 840  end
mo-95  1 0 1-20 840  end
tc-99  1 0 1-20 840  end
rh-103 1 0 1-20 840  end
rh-105 1 0 1-20 840  end
ru-106 1 0 1-20 840  end
sn-126 1 0 1-20 840  end
xe-131 1 0 1-20 840  end
cs-134 1 0 1-20 840  end
cs-135 1 0 1-20 840  end
cs-137 1 0 1-20 840  end
pr-143 1 0 1-20 840  end
nd-143 1 0 1-20 840  end
ce-144 1 0 1-20 840  end
nd-144 1 0 1-20 840  end
nd-145 1 0 1-20 840  end
nd-146 1 0 1-20 840  end
nd-147 1 0 1-20 840  end
pm-147 1 0 1-20 840  end
sm-147 1 0 1-20 840  end
nd-148 1 0 1-20 840  end
pm-148 1 0 1-20 840  end
pm-148 1 0 1-20 840  end
pm-149 1 0 1-20 840  end
sm-149 1 0 1-20 840  end
nd-150 1 0 1-20 840  end
sm-150 1 0 1-20 840  end
sm-151 1 0 1-20 840  end
eu-151 1 0 1-20 840  end
sm-152 1 0 1-20 840  end
eu-153 1 0 1-20 840  end
eu-154 1 0 1-20 840  end
eu-155 1 0 1-20 840  end
zircalloy  2 1  620   end
h2o  3 den=ddd   1  558 end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'   mixtures of larger-unit-cell:
'
uo2  5 den=10.32   1  840
 92234 u234wt% 92235 enr 92236 u236wt% 92238 u238wt%x end
arbm-gdburn  10.32    7 0 1 1
           64154  2.18  64155 14.80  64156 20.47
           64157 15.65  64158 24.84  64160 21.86
            8016 150.0  5   0.034   840  end
'                ....above is 3.4 wt % gadolinium (as gd2-ox3) in the
```

Figure D1.A.5 SAS2H generic input example for the generation of ARP basic cross-section libraries

```
'                    burnable poison pins of bwr assembly....
n          6  0  1-5 840  end
zircalloy  7  1  558 end
'                ....above is zircalloy casing around assembly
h2o       11  den=0.7627   1    552  end

'                ....above is channel moderator at higher density
end comp
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -


'      fuel-pin-cell geometry:
'
squarepitch   1.875   1.212   1 3  1.430   2  1.242   0  end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'    assembly and cycle parameters:
'
npin/assm=49  fuelngth=1944.52  ncycles=21  nlib/cyc=1
printlevel=4  lightel=8  inplevel=2  numzones=7   end
5  0.606   6  0.621   2  0.715   3  1.058
 500 3.311   7 3.412  11  3.845
power=40    burn=1.0e-15 down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=1500.0   end
       h   14.5     o  236      cr  2.1
       mn  0.13    fe  5.8      ni 2.1
       zr  455     sn  7.7
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
end
=shell
mv ft33f001  $RTNDIR/bwr7x7_enr_ddd.lib
end
```

Figure D1.A.5 (continued)

```
=shell
cp $RTNDIR/cooper_bwr.inp .
end
=prism
cooper_bwr.inp
bwr7x7_enr_ddd.inp
5 40
enr
1.5 2.0 3.0 4.0 5.0
1.5 2.0 3.0 4.0 5.0
1.5 2.0 3.0 4.0 5.0
1.5 2.0 3.0 4.0 5.0
1.5 2.0 3.0 4.0 5.0
1.5 2.0 3.0 4.0 5.0
1.5 2.0 3.0 4.0 5.0
1.5 2.0 3.0 4.0 5.0
u234wt%
0.01335 0.01780 0.02670 0.03560 0.04450
0.01335 0.01780 0.02670 0.03560 0.04450
0.01335 0.01780 0.02670 0.03560 0.04450
0.01335 0.01780 0.02670 0.03560 0.04450
0.01335 0.01780 0.02670 0.03560 0.04450
0.01335 0.01780 0.02670 0.03560 0.04450
0.01335 0.01780 0.02670 0.03560 0.04450
0.01335 0.01780 0.02670 0.03560 0.04450
u236wt%
0.00690 0.00920 0.01380 0.01840 0.02300
0.00690 0.00920 0.01380 0.01840 0.02300
0.00690 0.00920 0.01380 0.01840 0.02300
0.00690 0.00920 0.01380 0.01840 0.02300
0.00690 0.00920 0.01380 0.01840 0.02300
0.00690 0.00920 0.01380 0.01840 0.02300
0.00690 0.00920 0.01380 0.01840 0.02300
0.00690 0.00920 0.01380 0.01840 0.02300
u238wt%x
98.47975 97.97300 96.95950 95.94600 94.93250
98.47975 97.97300 96.95950 95.94600 94.93250
98.47975 97.97300 96.95950 95.94600 94.93250
98.47975 97.97300 96.95950 95.94600 94.93250
98.47975 97.97300 96.95950 95.94600 94.93250
98.47975 97.97300 96.95950 95.94600 94.93250
98.47975 97.97300 96.95950 95.94600 94.93250
98.47975 97.97300 96.95950 95.94600 94.93250
ddd
0.2 0.2 0.2 0.2 0.2
0.3 0.3 0.3 0.3 0.3
0.4 0.4 0.4 0.4 0.4
0.5 0.5 0.5 0.5 0.5
0.6 0.6 0.6 0.6 0.6
0.7 0.7 0.7 0.7 0.7
0.8 0.8 0.8 0.8 0.8
0.9 0.9 0.9 0.9 0.9
end
=shell
cp bwr7x7*.inp $RTNDIR
end
```

Figure D1.A.6 PRISM input example to generate specific SAS2H input files for the generation of ARP basic cross-section libraries

```
=sas2     parm='halt21,skipshipdata'
sas2 cooper bwr 7x7, 3.0 wt% u-235, 0.5 g/cc h2o density
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'   mixtures of fuel-pin-unit-cell:
'
44group    latticecell
uo2  1 den=10.32   1  840
 92234 0.02670 92235 3.0 92236 0.01380 92238 96.95950 end
co-59  3 0 1-20 558  end
zr-94  1 0 1-20 840  end
nb-95  1 0 1-20 840  end
mo-95  1 0 1-20 840  end
tc-99  1 0 1-20 840  end
rh-103 1 0 1-20 840  end
rh-105 1 0 1-20 840  end
ru-106 1 0 1-20 840  end
sn-126 1 0 1-20 840  end
xe-131 1 0 1-20 840  end
cs-134 1 0 1-20 840  end
cs-135 1 0 1-20 840  end
cs-137 1 0 1-20 840  end
pr-143 1 0 1-20 840  end
nd-143 1 0 1-20 840  end
ce-144 1 0 1-20 840  end
nd-144 1 0 1-20 840  end
nd-145 1 0 1-20 840  end
nd-146 1 0 1-20 840  end
nd-147 1 0 1-20 840  end
pm-147 1 0 1-20 840  end
sm-147 1 0 1-20 840  end
nd-148 1 0 1-20 840  end
pm-148 1 0 1-20 840  end
pm-148 1 0 1-20 840  end
pm-149 1 0 1-20 840  end
sm-149 1 0 1-20 840  end
nd-150 1 0 1-20 840  end
sm-150 1 0 1-20 840  end
sm-151 1 0 1-20 840  end
eu-151 1 0 1-20 840  end
sm-152 1 0 1-20 840  end
eu-153 1 0 1-20 840  end
eu-154 1 0 1-20 840  end
eu-155 1 0 1-20 840  end
zircalloy  2 1  620   end
h2o  3 den=0.5   1  558 end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'   mixtures of larger-unit-cell:
'
uo2  5 den=10.32   1  840
 92234 0.02670 92235 3.0 92236 0.01380 92238 96.95950 end
arbm-gdburn  10.32    7 0 1 1
           64154  2.18  64155 14.80  64156 20.47
           64157 15.65  64158 24.84  64160 21.86
            8016 150.0  5   0.034   840  end
'                ....above is 3.4 wt % gadolinium (as gd2-ox3) in the
'                    burnable poison pins of bwr assembly....
n          6  0  1-5 840  end
zircalloy  7  1  558 end
'                ....above is zircalloy casing around assembly
```

Figure D1.A.7 SAS2H specific input created by PRISM for 3.0 wt % ^{235}U and 0.5 g/cc water density

```
h2o       11  den=0.7627   1    552  end
'                ....above is channel moderator at higher density
end comp
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

'      fuel-pin-cell geometry:
'
squarepitch   1.875   1.212   1 3  1.430   2  1.242   0  end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'    assembly and cycle parameters:
'
npin/assm=49  fuelngth=1944.52  ncycles=21  nlib/cyc=1
printlevel=4  lightel=8  inplevel=2  numzones=7   end
5  0.606   6  0.621   2  0.715   3  1.058
 500 3.311   7 3.412  11  3.845
power=40    burn=1.0e-15 down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=0.0   end
power=40    burn=75.0    down=1500.0   end
       h   14.5     o  236      cr  2.1
       mn  0.13    fe  5.8      ni 2.1
       zr  455     sn  7.7
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
end
=shell
mv ft33f001    $RTNDIR/bwr7x7_3.0_0.5.lib
end
```

Figure D1.A.7 (continued)

Reduce the 21-burnup SAS2H/ORIGEN-S libraries to 10-burnup ARP basic cross-section libraries using ARPLIB following these criteria:

a. retain the fresh-fuel cross sections;

b. retain the minimum, maximum, and inflection points derived from the shape of the absorption cross sections with burnup for various isotopes of the library; and

c. select points that best represent the burnup-dependent ^{240}Pu absorption cross sections.

The ten burnup positions resulting from the application of steps a, b and c to LWR fuel are: 0, 1500, 4500, 7500, 10500, 13500, 16500, 31500, 46500, and 58500 MWd/MTU for PWR and BWR systems. They are indicated in Table D1.A.1 with the superscript letter *a*. The procedure for reducing the burnups is performed with the utility ARPLIB (see Sect. D1.B.2). An example ARPLIB input file to reduce the SAS2H/ORIGEN-S BWR 7 × 7 libraries to ARP basic cross-section libraries for the 40 enrichment/density combinations is presented in Fig. D1.A.8.

Finally ARPDATA.TXT must be modified to include the data for the new ARP basic cross-section libraries. An example of the modified ARPDATA.TXT file containing the standard ARP libraries and the new ARP BWR 7 × 7 libraries is given in Fig. D1.A.9.

Note that the procedure for generating ARP basic libraries is performed only once for each fuel assembly type and enrichment. **Users should not use these cross-section libraries for fuel assembly configurations other than the ones for which they were generated.**

```
=shell
cp $RTNDIR/bwr7x7*.lib .
end
=arplib
bwr7x7_1.5_0.2.lib
b1_7x7_2
bwr7x7_2.0_0.2.lib
b2_7x7_2
bwr7x7_3.0_0.2.lib
b3_7x7_2
bwr7x7_4.0_0.2.lib
b4_7x7_2
bwr7x7_5.0_0.2.lib
b5_7x7_2
bwr7x7_1.5_0.3.lib
b1_7x7_3
bwr7x7_2.0_0.3.lib
b2_7x7_3
bwr7x7_3.0_0.3.lib
b3_7x7_3
bwr7x7_4.0_0.3.lib
b4_7x7_3
bwr7x7_5.0_0.3.lib
b5_7x7_3
bwr7x7_1.5_0.4.lib
b1_7x7_4
bwr7x7_2.0_0.4.lib
b2_7x7_4
bwr7x7_3.0_0.4.lib
b3_7x7_4
bwr7x7_4.0_0.4.lib
b4_7x7_4
bwr7x7_5.0_0.4.lib
b5_7x7_4
bwr7x7_1.5_0.5.lib
b1_7x7_5
bwr7x7_2.0_0.5.lib
b2_7x7_5
bwr7x7_3.0_0.5.lib
b3_7x7_5
bwr7x7_4.0_0.5.lib
b4_7x7_5
bwr7x7_5.0_0.5.lib
b5_7x7_5
bwr7x7_1.5_0.6.lib
b1_7x7_6
bwr7x7_2.0_0.6.lib
b2_7x7_6
bwr7x7_3.0_0.6.lib
b3_7x7_6
bwr7x7_4.0_0.6.lib
b4_7x7_6
bwr7x7_5.0_0.6.lib
b5_7x7_6
bwr7x7_1.5_0.7.lib
b1_7x7_7
```

Figure D1.A.8 ARPLIB example input to reduce SAS2H/ORIGEN-S libraries to ARP basic cross-section libraries

```
bwr7x7_2.0_0.7.lib
b2_7x7_7
bwr7x7_3.0_0.7.lib
b3_7x7_7
bwr7x7_4.0_0.7.lib
b4_7x7_7
bwr7x7_5.0_0.7.lib
b5_7x7_7
bwr7x7_1.5_0.8.lib
b1_7x7_8
bwr7x7_2.0_0.8.lib
b2_7x7_8
bwr7x7_3.0_0.8.lib
b3_7x7_8
bwr7x7_4.0_0.8.lib
b4_7x7_8
bwr7x7_5.0_0.8.lib
b5_7x7_8
bwr7x7_1.5_0.9.lib
b1_7x7_9
bwr7x7_2.0_0.9.lib
b2_7x7_9
bwr7x7_3.0_0.9.lib
b3_7x7_9
bwr7x7_4.0_0.9.lib
b4_7x7_9
bwr7x7_5.0_0.9.lib
b5_7x7_9
end
=shell
cp b?_7x7? $RTNDIR
end
```

Figure D1.A.8 (continued)

```
!14x14
5  1  10
1.5 2.0 3.0 4.0 5.0
1.
’s114x14’ ’s214x14’ ’s314x14’ ’s414x14’ ’s514x14’
0.0  1500.0 4500.0 7500.0 10500.0 13500.0 16500.0 31500.0
   46500.0 58500.0
!15x15
5  1  10
1.5 2.0 3.0 4.0 5.0
1.
’s115x15’ ’s215x15’ ’s315x15’ ’s415x15’ ’s515x15’
0.0  1500.0 4500.0 7500.0 10500.0 13500.0 16500.0 31500.0
   46500.0 58500.0
!17x17
5  1  10
1.5 2.0 3.0 4.0 5.0
1.
’s117x17’ ’s217x17’ ’s317x17’ ’s417x17’ ’s517x17’
0.0  1500.0 4500.0 7500.0 10500.0 13500.0 16500.0 31500.0
   46500.0 58500.0
!8x8
5  1  10
1.5 2.0 3.0 4.0 5.0
1.
’s18x8’ ’s28x8’ ’s38x8’ ’s48x8’ ’s58x8’
0.0  1500.0 4500.0 7500.0 10500.0 13500.0 16500.0 31500.0
   46500.0 58500.0
!bwr7x7
5  8  10
1.5 2.0 3.0 4.0 5.0
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
’b1_7x7_2’ ’b1_7x7_3’ ’b1_7x7_4’ ’b1_7x7_5’
’b1_7x7_6’ ’b1_7x7_7’ ’b1_7x7_8’ ’b1_7x7_9’
’b2_7x7_2’ ’b2_7x7_3’ ’b2_7x7_4’ ’b2_7x7_5’
’b2_7x7_6’ ’b2_7x7_7’ ’b2_7x7_8’ ’b2_7x7_9’
’b3_7x7_2’ ’b3_7x7_3’ ’b3_7x7_4’ ’b3_7x7_5’
’b3_7x7_6’ ’b3_7x7_7’ ’b3_7x7_8’ ’b3_7x7_9’
’b4_7x7_2’ ’b4_7x7_3’ ’b4_7x7_4’ ’b4_7x7_5’
’b4_7x7_6’ ’b4_7x7_7’ ’b4_7x7_8’ ’b4_7x7_9’
’b5_7x7_2’ ’b5_7x7_3’ ’b5_7x7_4’ ’b5_7x7_5’
’b5_7x7_6’ ’b5_7x7_7’ ’b5_7x7_8’ ’b5_7x7_9’
0.0  1500.0 4500.0 7500.0 10500.0 13500.0 16500.0 31500.0
   46500.0 58500.0
```

Figure D1.A.9 Modified ARPDATA.TXT example

D1.B ARP UTILITY PROGRAMS

D1.B.1 PRISM

PRISM is a utility that reads a single input template file containing generic parameter flags and replaces them with specific values designated by the user to generate any number of files containing desired combinations of specific parameter values. PRISM was developed to provide an easy mechanism to convert a generic SAS2H input file for a particular fuel assembly design into a large number of SAS2H input files containing combinations of specific fuel enrichment and moderator densities and/or other parameters for generating ARP basic cross-section libraries. However, the program was designed in a general manner so PRISM can be used to generate multiple files from any generic template file.

The input description for PRISM is presented in Table D1.B.1. The input format is free form. The user input includes the name of the template file to be read; the pattern for the name of the output files to be generated, using the generic parameter flags; the number of generic parameter flags; the number of files to be generated; each generic parameter flag and the specific values to be substituted in each output file.

The template file is the generic SAS2H or other input file containing the generic parameter flags. PRISM creates copies of the template file and substitutes specific values for the generic flags. Note that the character length of each specific value must be the same as that of the associated generic flag.

An example using PRISM to generate 40 SAS2H BWR input files for combinations of five fuel enrichments and eight water densities has been presented previously in Figs. D1.A.5–7. A simple example is presented here of a generic CSAS1X input file for a PWR fuel pin cell with specific values of ^{235}U wt %, ^{238}U wt %, and water density. The user input to PRISM is shown in Fig. D1.B.1. The generic CSAS1X template file is shown in Fig. D1.B.2. The first file generated by PRISM in this example would be named "pwr_1.50_0.2.inp." It would contain values of 1.50, 98.50, and 0.2 for the ^{235}U wt %, ^{238}U wt %, and density, respectively. The 40th and last input file would be named "pwr_5.00_0.9.inp" and would contain values of 5.00, 95.00, and 0.9, respectively.

Table D1.B.1 PRISM input description

Line No.	Parameter	Description	Comments
1	TEMPLATE	Template file name	80 characters maximum
2	OUT_TEMPLATE	Pattern for output file names	80 characters maximum Must contain enough generic parameter names to create unique filename for each output file
3	NUMPARMS	Number of generic parameter types	
	NUMFILES	Number of output files to be generated	
	NOTE: Repeat the following data for each generic parameter type (i.e., a total of NUMPARMS times).		
4	PARAM_NAME	Generic parameter name as it appears in template file	80 characters maximum
5[a]	PARAMETERS	Specific values of generic parameter for each output file	NUMFILES entries required. Length of value must be same as length of PARAM_NAME

[a]May be continued on subsequent lines as needed.

```
=prism
prism_template.inp
pwr_u235_ddd.inp
3 40
u235
1.50 2.00 3.00 4.00 5.00
1.50 2.00 3.00 4.00 5.00
1.50 2.00 3.00 4.00 5.00
1.50 2.00 3.00 4.00 5.00
1.50 2.00 3.00 4.00 5.00
1.50 2.00 3.00 4.00 5.00
1.50 2.00 3.00 4.00 5.00
1.50 2.00 3.00 4.00 5.00
u_238
98.50 98.00 97.00 96.00 95.00
98.50 98.00 97.00 96.00 95.00
98.50 98.00 97.00 96.00 95.00
98.50 98.00 97.00 96.00 95.00
98.50 98.00 97.00 96.00 95.00
98.50 98.00 97.00 96.00 95.00
98.50 98.00 97.00 96.00 95.00
98.50 98.00 97.00 96.00 95.00
ddd
0.2 0.2 0.2 0.2 0.2
0.3 0.3 0.3 0.3 0.3
0.4 0.4 0.4 0.4 0.4
0.5 0.5 0.5 0.5 0.5
0.6 0.6 0.6 0.6 0.6
0.7 0.7 0.7 0.7 0.7
0.8 0.8 0.8 0.8 0.8
0.9 0.9 0.9 0.9 0.9
end
```

Figure D1.B.1 PRISM input example

```
#csas1x
pwr fuel pin cell
44group     latticecell
uo2   1 0.95 293 92235 u235 92238 u_238  end
zirc2 2 1  end
h2o   3 den=ddd 1 293  end
end comp
squarepitch  1.25 0.8 1 3 0.95 2 0.84 0  end
end
```

Figure D1.B.2 Generic template example for PRISM

D1.B.2 ARPLIB

ARPLIB is a utility program specifically designed to read a SAS2H/ORIGEN-S multiburnup binary cross-section library and copy the cross-section data from only the desired burnup positions to create an ARP basic cross-section library. The default behavior of ARPLIB is to read a 21-burnup SAS2H/ORIGEN-S library and reduce it to a 10-burnup ARP basic cross-section library. The ten default burnup positions in the library are 1, 2, 3, 4, 5, 6, 7, 12, 17, and 21 (see Table D1.A.1).

The input for ARPLIB is described in Table D1.B.2. The input format is free form. The use of the first input parameter depends upon whether the user wants to select the ten default burnup positions from the SAS2H/ORIGEN-S multiburnup library. If the default positions are desired, the first parameter is the total number of multiburnup library files to be converted (NUMLIBS). If the user wants to override the defaults, the first input parameter should be any negative integer. If a negative integer is used, it should be followed by the number of burnup positions in each SAS2H/ORIGEN-S multiburnup library (NL), flags for each burnup position (IN(I), I=1, NL), and the total number of multiburnup libraries to be converted (NUMLIBS). The final portion of the input file in all cases is the filename of each SAS2H/ORIGEN-S multiburnup library, followed by the filename of the reduced ORIGEN-ARP basic cross-section library to be created from it.

The input to ARPLIB has been demonstrated previously in Fig. D1.A.8. An input example for saving nondefault burnup positions is given in Fig. D1.B.3. Note that the first burnup position is always saved, regardless of the input value for IN(1). The cross sections in the first burnup position are assumed to be the fresh fuel cross sections.

Table D1.B.2 ARPLIB input description

Parameter	Description	Comments
NUMLIBS	Number of SAS2H/ORIGEN-S multi-burnup library files (>0) or flag to read following optional data (<0)	NUMLIBS <0 if number of burnups and/or burnup positions to keep differ from default[a]
	NOTE: The following data are read only if NUMLIBS <0.	
NL	Number of burnup positions on each multiburnup library	Input if NUMLIBS <0 Default = 21.
IN	Flag for each burnup position to keep or remove cross sections[a]	Input if NUMLIBS <0 NL entries required = 0 Remove cross sections > 0 Keep cross sections
NUMLIBS	Number of SAS2H/ORIGEN-S multi-burnup library files	Input if NUMLIBS <0
	NOTE: End of optional input for NUMLIBS <0.	
	NOTE: The following entries are entered in pairs NUMLIB times.	
FILENAME	Input SAS2H/ORIGEN-S multiburnup library filename	80 characters maximum
FILENAME2	Output ORIGEN-ARP basic cross-section library filename	80 characters maximum

[a]Default is to keep cross sections from the following ten burnup positions of a 21-burnup cross-section library: 1, 2, 3, 4, 5, 6. 7, 12, 17, 21. The first burnup position (i.e., fresh fuel) is always kept, regardless of user input.

```
=arplib
-1
21
1 1 1 0 1 1 0 1 1 1 0 0 1 0 1 0 0 0 0 0 1
4
bwr2.0_0.3.lib
bwr6x6_2wt_3
bwr2.0_0.4.lib
bwr6x6_2wt_4
bwr2.0_0.7.lib
bwr6x6_2wt_7
bwr2.0_0.8.lib
bwr6x6_2wt_8
end
```

Figure D1.B.3 ARPLIB input example

D1.B.3 XSECLIST

The XSECLIST program is intended to provide an interpreted listing of any ORIGEN-ARP or SAS2H/ORIGEN-S multiburnup cross-section library. This utility program allows users to list the absorption and/or fission cross sections of any or all nuclides in the library as a function of burnup. The absorption cross sections are given for light elements, actinides, and fission products. At the present time there are 689 light-element nuclides, 129 actinides, and 879 fission products, totaling 1697 nuclides. Some of the light-element isotopes present may also appear as fission products; therefore, a few isotopes may be listed twice, but the cross-section values for each listing may be different. Fission cross sections may be listed for any or all actinides with nonzero values.

ORIGEN-S cross sections are normalized to thermal flux, rather than the more conventional method of applying total flux. Either thermal flux or specific power may be input to irradiation cases.

The nuclide ID numbers used in library data have the form IZ*10000+IA*10+IS,

where

IZ = the atomic number;
IA = the atomic weight;
IS = 0, for ground state;
IS = 1, for metastable state.

The XSECLIST input is described in Table D1.B.3. The input format is free form. The user specifies the SAS2H/ORIGEN-S or ORIGEN-ARP multiburnup library filename, the number of burnup positions in the library, and the burnup (GWd/MTU) corresponding to each burnup position. The user then indicates whether the cross-section data listings are for absorption, fission, or both; and whether the listings are for all nuclides or only certain specified ones.

An example input file for XSECLIST is shown in Fig. D1.B.4. This example contains two cases. The first case lists both absorption and fission cross sections for ^{240}Pu in the ORIGEN-ARP 5 wt % enriched PWR 14 × 14 basic cross-section library. The output listing for this case is displayed in Fig. D1.B.5. The second case lists the fission cross sections for all nuclides in the ORIGEN-ARP 1.5 wt % enriched PWR 14 × 14 basic cross-section library. The output from this case is not presented here because of its size.

Table D1.B.3 XSECLIST input description

Line No.	Parameter	Description	Comments
1	FILENAME	SAS2H/ORIGEN-S or ORIGEN-ARP multiburnup library filename	30-character maximum
2	NL	Number of burnup positions in library	
3[a]	BURN	Burnup (GWd/MTU) of each burnup position in library	NL entries required
4	CHARD	Cross-section data to be printed	a = absorption f = fission b = both
5	CHARL	List entire library (all nuclides)	y = yes n = no
	NOTE: The following optional data are entered only if CHARL = n.		
6	MT	Number of nuclides for which cross-section listings are desired	
7[a]	MTRD	Nuclide IDs[b]	MT entries required

[a]Input may be continued on subsequent lines as needed.
[b]Nuclide ID = Atomic No. * 10000 + Atomic wt * 10 + IS, where IS = 0 for ground state and 1 for metastable state.

```
=xseclist
s514x14
10
0.0 1.5 4.5 7.5 10.5 13.5 16.5 31.5
46.5  58.5
b
n
1
942400
end
=xseclist
s114x14
10
0.0 1.5 4.5 7.5 10.5 13.5 16.5 31.5
46.5  58.5
f
y
end
```

Figure D1.B.4 XSECLIST input example

```
****** absorption cross sections ******

----------- light elements -----------
------- end of light elements --------

------------- actinides --------------

material= 942400 (pu240 )
    burnup            xsec
  0.00000E+00       1.80359E+03
  1.50000E+00       1.86136E+03
  4.50000E+00       1.74640E+03
  7.50000E+00       1.58809E+03
  1.05000E+01       1.43944E+03
  1.35000E+01       1.31221E+03
  1.65000E+01       1.20584E+03
  3.15000E+01       8.78435E+02
  4.65000E+01       7.20012E+02
  5.85000E+01       6.49990E+02
--------- end of actinides -----------

--------- fission products ----------
------ end of fission products -------

***** end of absorption cross sections ****


****** fission cross sections ******

material= 942400 (pu240 )
    burnup            xsec
  0.00000E+00       4.80163E+00
  1.50000E+00       5.05037E+00
  4.50000E+00       5.18527E+00
  7.50000E+00       5.26234E+00
  1.05000E+01       5.30021E+00
  1.35000E+01       5.30902E+00
  1.65000E+01       5.29514E+00
  3.15000E+01       5.01853E+00
  4.65000E+01       4.60936E+00
  5.85000E+01       4.32095E+00

***** end of fission cross sections *****
```

Figure D1.B.5 XSECLIST listing of ^{240}Pu data