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SCALE-4 Analysis of Pressurized Water Reactor Critical Configurations: Volume 4 — Three Mile Island Unit 1 Cycle 5

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Computational Physics and Engineering Division

SCALE-4 ANALYSIS OF PRESSURIZED WATER REACTOR CRITICAL CONFIGURATIONS: VOLUME 4 — THREE MILE ISLAND UNIT 1 CYCLE 5

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ABSTRACT

The requirements of ANSI/ANS-8.1 specify that calculational methods for away-from-reactor criticality safety analyses be validated against experimental measurements. If credit is to be taken for the reduced reactivity of burned or spent fuel relative to its original "fresh" composition, it is necessary to benchmark computational methods used in determining such reactivity worth against spent fuel reactivity measurements. This report summarizes a portion of the ongoing effort to benchmark away-from-reactor criticality analysis methods using relevant and well-documented critical configurations from commercial pressurized water reactors.

The analysis methodology utilized for all calculations in this report is based on the modules and data associated with the SCALE-4 code system. Isotopic densities for spent fuel assemblies in the core were calculated using the SCALE-4 SAS2H analytical sequence. The sources of data and the procedures for deriving SAS2H input parameters are described in detail. The SNIKR code family was used to extract the necessary isotopic densities from SAS2H results and to provide the data in the format required for SCALE criticality analysis modules. The CSASN analytical sequence in SCALE-4 was used to perform resonance processing of cross sections. The KENO V.a module of SCALE-4 was used to calculate the effective multiplication factor (k_{eff}) for the critical configuration. The SCALE-4 27-group burnup library containing ENDF/B-IV (actinides) and ENDF/B-V (fission products) data was used for all calculations.

This volume of the report documents a reactor critical calculation for GPU Nuclear Corporation's Three Mile Island Unit 1 (TMI-1) during hot, zero-power startup testing for the beginning of cycle 5. This unit and cycle were selected because of their relevance in spent fuel benchmark applications: (1) cycle 5 startup occurred after an especially long downtime of 6.6 years; and (2) the core consisted primarily (75%) of burned fuel, with all fresh fuel loaded on the core outer periphery. A k_{eff} value of 0.9978 ± 0.0004 was obtained using two million neutron histories in the KENO V.a model. This result is close to the known critical k_{eff} of 1.0 for the actual core and is consistent with other mixed-oxide criticality benchmarks. Thus this method is shown to be valid for spent fuel applications in burnup credit analyses.

1. INTRODUCTION

In the past, criticality analysis of pressurized-water-reactor (PWR) fuel in storage or transport has assumed that the fuel is fresh with the maximum allowable initial enrichment. This assumption has led to the design of widely spaced and/or highly poisoned storage and transport arrays. If credit is assumed for fuel burnup, more compact and economical arrays can be designed. Such reliance on the reduced reactivity of spent fuel for criticality control is referred to as "burnup credit." If burnup credit is applied in the design of a cask for use in the transport of spent light-water-reactor (LWR) fuel to a repository, a significant reduction both in the cost of transport and in the risk to the public can be realized.[1] These benefits caused the U.S. Department of Energy (DOE) to initiate a program to investigate the technical issues associated with burnup credit in spent fuel cask design. These efforts have been led by Sandia National Laboratories (SNL) and carried out as part of the Cask Systems Development Program within the Office of Civilian Radioactive Waste Management. This four-volume report documents work performed at Oak Ridge National Laboratory (ORNL) as part of a larger effort to demonstrate an acceptable approach for validating computational tools to be used in burnup credit cask design.

The computational tools of interest for burnup credit cask design are initially those currently used and accepted for spent fuel characterization (prediction of isotopics) and criticality safety (prediction of the effective multiplication factor, k_{eff}) in away-from-reactor (AFR) applications. The criticality analysis tools accepted for fresh fuel cask design have typically been validated per the requirements of the ANSI/ANS-8.1 criticality safety standard[2] (i.e., comparison against experimental data). Numerous critical experiments for fresh PWR-type fuel in storage and transport configurations exist and can be used as part of a validation data base. However, there are no critical experiments with burned PWR-type fuel in storage and transport configurations that can be directly used to extend the data base to the realm of burned fuel. Thus as part of the effort to extend the validation of existing criticality analysis tools to the domain of burned fuel, it was decided to investigate the performance of AFR analysis methods in the prediction of measured reactor critical configurations. Even though elements of a reactor critical analysis do not correspond directly to analyses of spent fuel assemblies in transportation and storage casks (e.g., elevated temperatures in reactor configurations or poison plates in cask designs), comparison against measured critical configurations can be used to validate aspects of spent fuel cask configurations which are not addressed in other experiments (i.e., fission-product interactions and the prediction of time-dependent actinide and fission-product inventories). Reactor critical configurations contain a diverse range of nuclides, including fissile and fertile actinides, fission products, and activation products. Thus nuclear reactor core criticals can be used to test an analysis methodology's ability to generate accurate burned fuel isotopics and handle the reactivity effects of complex heterogeneous systems containing burned fuel.

To date, the SCALE code system[3] developed at ORNL has been the primary computational tool used by DOE to investigate technical issues related to burnup credit.[4] SCALE is a well-established code system that has been widely used in AFR applications for spent fuel characterization via the SAS2H/ORIGEN-S analysis sequence[5] and criticality safety analyses via the CSAS/KENO V.a analysis sequence.[6] The isotopic composition of the spent fuel is derived from a SAS2H/ORIGEN-S calculation that simulates two-dimensional (2-D) effects in a one-dimensional

(1-D) model of an LWR fuel assembly. The depletion model is a spatially independent point model using cross sections and neutron flux parameters derived from the 1-D fuel assembly model. The KENO V.a Monte Carlo code[7] is used to calculate the neutron multiplication factor for complex multidimensional systems. KENO V.a has a large degree of flexibility in its geometrical modeling capabilities which enables spent fuel arrays and container geometries to be modeled in explicit detail. The SCALE-4 27-group burnup library containing ENDF/B-IV (actinides) and ENDF/B-V (fission products) data was used for all calculations.

Early efforts to analyze reactor criticals[8] using the SCALE modules concentrated on using utility-generated isotopic data although some analyses were performed using isotopics calculated with SAS2H. Based on this initial work, a consistent SCALE-based analysis methodology that simplifies both the data requirements and the calculational procedure was developed. The criteria used to select the reactor critical configurations were (1) applicability to the PWR fuel to be used in burnup credit cask design (e.g., long downtimes for decay of short-lived isotopes, large percentages of burned fuel in the configuration), the need to verify consistency in calculated results for different reactor conditions, and the need to provide a comparison with the results of ref. 5. Acceptable performance of the SCALE system in the prediction of k_{eff} will be judged relative to established SCALE performance for fresh fuel systems; if agreement is seen within the range typical for fresh fuel systems, then it will be concluded that the methodology described herein is valid in terms of its treatment of depletion and decay calculations and fission-product interactions, within the range of application defined by the reactor conditions.

The purpose of this volume is to describe the analysis of the hot, zero-power (HZP) critical configuration obtained during startup testing for Cycle 5 operation of GPU Nuclear Corporation's Three Mile Island Unit 1 (TMI-1). This particular unit and cycle were chosen because the unit had a significantly long downtime of 6.63 years prior to restart. Even though one fuel batch consisted of fresh fuel, the three remaining fuel batches had been exposed for one to three cycles prior to the extended downtime. These conditions closely represent those expected in spent fuel transportation scenarios where such fuel is expected to have been stored 5 to 10 years prior to shipment. A methodology resulting in proper characterization of in-core exposure and postexposure decay is necessary to accurately predict criticality for this configuration. Successful prediction of the critical condition may therefore be used as an indication of the validity of this methodology for spent fuel applications where long decay times are involved.

Section 2 of this volume presents an overview of the methodology employed in the reactor critical analyses. Section 3 provides the details of the analysis performed for TMI Unit 1 Cycle 5. The results and conclusions are discussed in Sect. 4.

2. OVERVIEW OF THE METHODOLOGY

The methodology applied in reactor critical analyses can be broken into five steps: (1) grouping of fuel assemblies into similar-content groups and similar-burnup subgroups; (2) calculation of burnup-dependent isotopics for each group; (3) interpolation of decay calculations from results of the previous step to obtain both individual assembly and subgroup isotopics; (4) cross-section processing based on subgroup isotopics; and (5) preparation of a KENO V.a model based on the actual core geometry, individual assembly isotopics, and subgroup-evaluated cross sections. The model developed in step 5 is used to calculate the effective multiplication factor, k_{eff}, for the reactor.

Figure 1 provides a graphical overview of these steps, showing the relationships between the data and codes used in each stage of the calculation. The first step shown in the figure represents the process of collecting assembly information from reactor documentation. Eighth-core symmetry is assumed to reduce the number of unique assembly models, such that the burnup of each assembly in an eighth-core segment represents the average burnup of all assemblies located in the corresponding symmetric position across the core. Using the reactor information, "groups" of assemblies are identified which are of cognate background (i.e., same initial loading and burn cycles). These assembly groups are then further categorized into "subgroups" consisting of assemblies within a group with similar (±2 GWd/MTU) burnups.

The second step shown in the figure involves the calculation of isotopic contents using the decay and depletion steps of the SAS2H calculational sequence of SCALE. Calculations are performed for each assembly group based on the initial fresh fuel content and operating history of the group. Output consists of calculated isotopic contents for each of a number of user-specified timesteps.

In the third step, the SNIKR code package (not a part of the SCALE system) is used to interpolate between isotopics for appropriate timesteps in order to obtain the assembly-specific isotopic contents for each assembly to be used in the KENO V.a core model. (SNIKR is a simple tool used to automate the task of extracting, interpolating, and formatting data; however, this process can be performed manually.) SNIKR is also used to calculate the isotopics for the average burnup of each assembly subgroup.

The results of step 3 are used in step 4 to create fuel-pin models based on the average composition of an assembly subgroup; the CSASN sequence in SCALE is then used to calculate the problem-dependent group-weighted cross sections for each subgroup. The SCALE WAX module is then used to combine all subgroup-based cross sections into a single working library, where cross-section identifiers are assigned such that each numeric identifier indicates both a specific isotope and the subgroup upon which it was based.

Finally, in step 5 a KENO V.a model is created based on the core geometry, again assuming eighth-core symmetry. Thus while a full-core model is prepared each eighth-core segment of the core is identical in composition to the other eighth-core segments. (A full-core model in KENO V.a is more computationally efficient than an eighth-core model with reflective boundary conditions.) Fuel assemblies are assumed to be uniform in composition (all fuel pins are comprised of the same material), and isotopics are obtained from the burnup-specific results obtained in step 3. Assembly isotopes are assigned cross-section identifiers corresponding to the appropriate subgroup-based cross sections derived in step 4. Remaining core information is obtained from the reactor documentation.

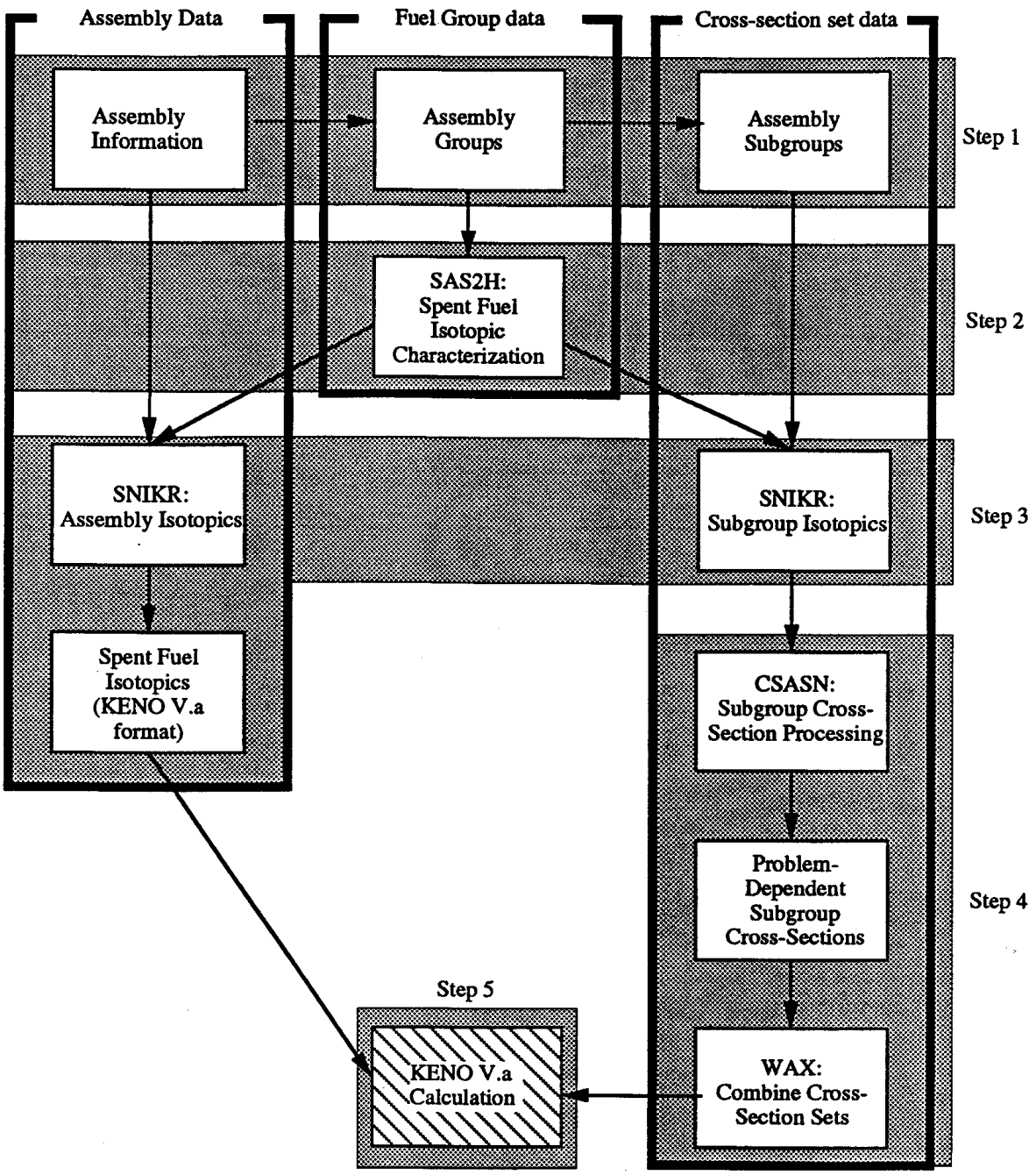


Fig. 1. Overview of the reactor critical calculation procedure.

Calculations are then performed to determine the value of k_{eff} for the reactor model, and to verify that the solution has converged.

The specifics of each of the steps described above are discussed in detail in each of the following sections.

2.1 FUEL ASSEMBLY GROUPS

To minimize the number of depletion calculations required to model the entire core, fuel assemblies are "grouped" (i.e., collected into sets that are of identical initial composition) and have been subjected to roughly the same exposure history. It is assumed that at a given level of burnup in an exposure history, all assemblies within a group will have the same isotopic content. If the isotopic content of a group is known as a function of burnup, then one can interpolate to obtain the specific isotopics for a given assembly based on the burnup of the assembly. This interpolation is discussed further in Sect. 2.3.

A minimum granularity for group partitioning is to collect fuel assemblies by reactor fuel batch. In the nomenclature generally applied by commercial LWR core designers, a fuel batch is comprised of a single enrichment fuel, all loaded at the same time, and all residing in-core for the same fuel cycles. Hence a given batch of assemblies has experienced identical operating periods, downtimes, and roughly the same exposure. This approach meets the minimum requirements for grouping. However, within a given fuel batch, additional grouping is required when significant materials (i.e., burnable poisons, control rods, or vacant positions) are found only in certain assemblies within a fuel batch.

As mentioned previously, within a fuel group it is possible to interpolate between a series of burnups to determine the isotopic concentrations corresponding to a specific burnup. Based on these isotopics, it is possible to generate a content-specific cross-section set for each assembly. However, in order to simplify cross-section processing, representative cross sections for a set of similar assemblies are desirable. Because it is felt that cross-section weighting is not strongly coupled to burnup, then for the purpose of determining microscopic cross sections for a fuel group it is possible to represent the contents of a group by an average content based on an average burnup. Unfortunately, even within a single fuel batch or group, it is possible to have a wide range of burnups. Thus it may be necessary to divide fuel groups into subgroups based on burnup such that all assemblies included in a subgroup are within a specific range of burnups; the number of subgroups will depend on the range of burnup contained in the entire group. Previous work[8] has indicated that assemblies grouped with a maximum range of no more than 2 GWd/MTU can be adequately represented by the average value of burnup within the subgroup.

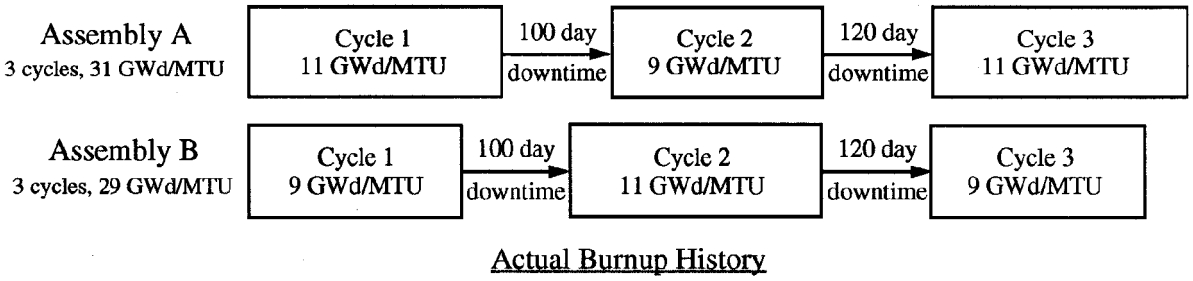
2.2 DEPLETION CALCULATIONS

Depletion calculations are performed using the SAS2H[9] sequence of the SCALE-4 code system. The SAS2H sequence invokes the ORIGEN-S[10] code to perform depletion and decay calculations, based on cross sections computed from a 1-D pin cell model, for each of any number of input specified burnup steps. At the end of each burnup step, cross sections for default and any

user-specified isotopes are reevaluated based on the new isotopic composition. The purpose of these calculations is to predict the isotopic content of each group and subgroup at the end of the final burn cycle as a function of the operating history of the constituent fuel. Thus such calculations are necessary only for fuel that has been exposed in-core prior to a critical condition. The contents of fresh fuel assemblies are already known. If one or more groups are comprised of fresh fuel at the time of the critical measurements, SAS2H calculations are not necessary for those groups; the isotopic content is based on that of the fresh fuel specifications.

Since within a fuel group it is assumed that isotopic content is a function only of burnup, it is possible to approximate the content of the fuel at a given burnup by interpolation between SAS2H/ORIGEN-S isotopics provided at each burnup step. The manner of interpolation is discussed in the following subsection. SAS2H provides the capability to obtain the isotopic composition of a fuel at specified burnup intervals given the initial composition of the fuel, clad, and moderator, design parameters of the fuel rod and lattice, and burnup/downtime history. To provide sufficient points for interpolation, the burnup history was broken into steps of less than 5 MWd/MTU. (This interval should not be confused with the 2-GWd/MTU interval used to establish assembly subgroups. The 5-GWd/MTU interval represents an interpolation range over which isotopic concentrations are assumed to vary smoothly.) The burnup history was calculated to more than 1.2 times the maximum burnup (B_{max}) in the fuel group. Note that it is generally sufficient to calculate exposures out to the maximum exposure in a fuel group, as this will bound all exposures in the group. A value of $1.2*B_{max}$ was used in this and previous burnup credit criticals to allow for the capability of modeling axial power variations, where length-averaged center-region power densities may be up to 1.2 times larger than the rod average. However, axial power variations are not included in the model presented in this report.

To make it possible to interpolate between burnup steps, a simplification must be made in the modeling of assembly burnups. It must be assumed that differences in burnup occur only in the most recent burn cycle (i.e., it is assumed that each assembly in a group experienced identical burn/downtime cycles during previous cycles), and differences in burnup between assemblies are the result of different lengths of burn in the final burn cycle. Assembly-specific burnups may then be obtained via interpolation between specific calculated states in the final burn cycle. This approach is illustrated in Fig. 2. The top portion of the picture shows the "actual" burnup histories for two hypothetical assemblies in a single fuel group. Note that in this example the number of cycles and downtimes are the same, but that the burnup in each assembly is different within each cycle. The lower portion of the figure demonstrates how the burnup of each assembly is represented in a SAS2H model, using a single calculation to represent the entire fuel group. Each cycle is broken down into multiple-burn intervals, followed by a downtime (for the first two cycles). The final cycle is calculated with sufficient burn steps to exceed the maximum burnup (31 MWd/MTU in assembly A of Fig. 2) by 20%. The isotopics are then available at fixed time intervals, from which interpolation can be performed for assembly-specific burnups. Note that the burnup in each of the first two cycles is selected to represent average cycle burnups for the group. Any downtime immediately before the reactor critical conditions was not included in the SAS2H depletion calculation, but was explicitly modeled as described in Sect. 2.3.



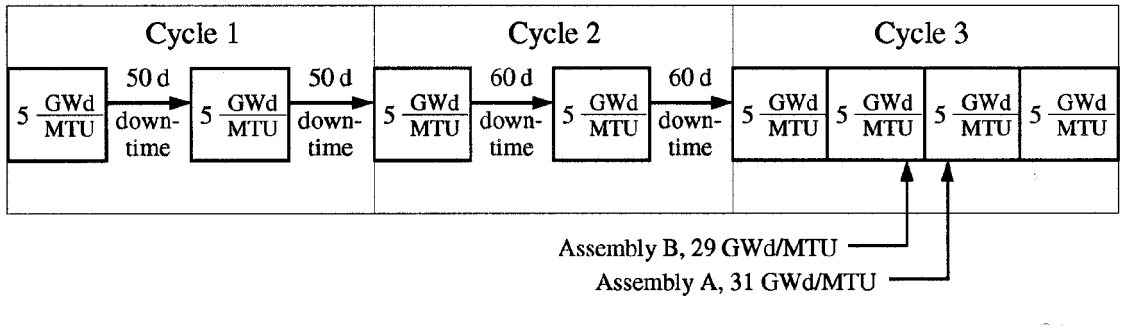


Fig. 2. SAS2H burnup model of assemblies with a fuel group.

Table 1. Nuclides updated by SAS2H

$^{234}U^{a}$	$^{243}Am^{a}$	^{94}Nb	^{132}Xe	^{145}Nd
$^{235}U^{a}$	$^{242}Cm^{a}$	$^{16}O^{b}$	$^{135}Xe^{a}$	^{147}Nd
$^{236}U^{a}$	$^{243}Cm^{a}$	^{99}Tc	^{136}Xe	^{147}Pm
$^{238}U^{a}$	$^{244}Cm^{a}$	^{101}Ru	$^{133}Cs^{a}$	^{148}Pm
$^{237}Np^{a}$	^{83}Kr	^{106}Ru	^{134}Cs	^{147}Sm
$^{238}Pu^{a}$	^{85}Kr	^{103}Rh	^{135}Cs	^{149}Sm
$^{239}Pu^{a}$	^{90}Sr	^{105}Rh	^{137}Cs	^{150}Sm
$^{240}Pu^{a}$	^{89}Y	^{105}Pd	^{136}Ba	^{151}Sm
$^{241}Pu^{a}$	^{95}Mo	^{108}Pd	^{139}La	^{152}Sm
$^{242}Pu^{a}$	^{93}Zr	^{109}Ag	^{144}Ce	^{153}Eu
$^{241}Am^{a}$	^{94}Zr	^{124}Sb	^{141}Pr	^{154}Eu
$^{242m}Am^{a}$	^{95}Zr	^{131}Xe	^{143}Pr	^{155}Eu
			^{143}Nd	^{155}Gd

[a] Automatically updated by SAS2H.
[b] Not an actinide or fission product, but present in UO_2 fuel.

As discussed earlier, group-weighted cross sections are calculated as a function of burnup within the SAS2H sequence using flux weighting performed by XSDRNPM for each specified burnup step. Cross sections are updated for a default set of isotopes built into the SAS2H sequence, plus any additional nuclides specified by the user. Table 1 shows the default set plus 44 additional actinides and fission products specified for reactor depletion cases. Also included is oxygen, which is present in significant quanties in UO_2 fuel. These nuclides represent a combination of the most important nuclides for burnup credit calculations and for reactor physics calculations. The selection of burnup credit nuclides is based on the availability of experimentally measured isotopic concentrations and on sensitivity studies performed for a large number of nuclides under various spent fuel transportation/storage conditions, as described in ref. 11. The reactor physics nuclides are additional isotopes that are not important in a transportation sense, but have been determined to be important for depletion, decay, and criticality calculations under reactor operating conditions (e.g., ^{135}Xe builds in rapidly during reactor operation, but decays away with a 9.1-h half-life, and is therefore unimportant in 5-year-cooled spent fuel). These nuclides were identified in earlier work.[12,13]

Any additional cross sections required for depletion calculations are obtained from the more than 1000 nuclides available within the ORIGEN-S 1-group LWR library and are adjusted with burnup using the ORIGEN-S spectral parameters (THERM, RES, and FAST)[10] calculated using fluxes calculated by XSDRNPM. The ORIGEN-S 1-group LWR library available in SCALE-4 has been updated to use cross sections from the SCALE-4 27-group burnup library for all 193 nuclides in that library, by extracting 1-group cross sections from the output of a low-burnup LWR-type fuel model using all burnup library nuclides as input.

Note that ORIGEN-S tracks all decay chains and does not account for the loss of volatile isotopes; however, this is not felt to have a significant effect on isotopic calculations.

2.3 BURNUP-DEPENDENT NUCLIDE CONCENTRATIONS

As has been indicated in previous sections, the isotopic content at the end of the final burn cycle may be determined for each assembly or fuel subgroup by interpolating between burnups for which ORIGEN-S depletion calculations have been performed, based on the final burnup of the fuel. The nuclide concentrations output at this point then represent the composition at the end of the last burnup cycle. For a criticality condition obtained later than the end of the burnup cycle, it is necessary to perform decay calculations to account for the change in composition caused by radioactive decay during the downtime prior to criticality.

The actual number densities used in the criticality calculations are derived from the SAS2H calculation for a given fuel batch using a newly developed interface module, SAS2H Nuclide Inventories for KENO Runs (SNIKR). This module was developed to enable the user to interpolate number densities from a SAS2H calculation as a function of burnup and to perform the necessary decay calculations to model cooling time for use in spent fuel critical calculations. SNIKR is not part of the SCALE system; hence, a sample driver script, sample output, and code listings are provided in Appendix B. SNIKR input is described in Sect. 3.5 of this volume.

The current version of SNIKR has been written to be executed as a sequence of computational routines. In the first phase, SNIKR1, burnup-dependent nuclide inventories are read from a dataset produced from a SAS2H calculation. SNIKR1 uses a Lagrangian interpolation scheme to calculate nuclide concentrations for a specified burnup. In the Lagrangian interpolation scheme, a polynomial of degree one less than the number of data points to be fit is used to represent the number density for each nuclide as a function of burnup. Comparisons have been made against results using nuclide concentrations calculated directly from SAS2H for a specified burnup to examine the effect of the interpolation procedure on pin-cell k_∞ (i.e., 1-D infinite-lattice calculation) values. The results of these comparisons indicated agreement to within 0.1% Δk in the k_∞ values calculated using isotopics derived from the two methods.

Upon completing interpolation, SNIKR1 sets up the input needed to decay the burnup-specific isotopics to the requested cooling time using the ORIGEN-S point-depletion code. The second phase of SNIKR executes the ORIGEN-S module in the SCALE code system. Phase three, SNIKR3, reads the number densities produced by ORIGEN-S for the requested cooling time and extracts the nuclides to be used in the depleted fuel for burnup credit criticality analysis. Number densities for these nuclides are then written to output files in SCALE standard composition input format and KENO V.a mixing table data format for use in CSASN and KENO V.a calculations, respectively. Typically, the term "SNIKR" is used to refer to the three-step sequence of calculations described above.

SNIKR extracts concentrations for the set of nuclides specified by the user. The set of nuclides selected for the reactor critical benchmark calculations consist of the 48 nuclides listed in Table 2. These nuclides are a subset of those in Table 1, with the exception of ^{103}Ru, ^{135}I, ^{148}Nd, and ^{149}Pm. The cross sections of these four nuclides are small enough or change slowly enough with burnup that omitting them from the cross-section update in SAS2H has a negligible effect and are therefore not needed in the SAS2H calculation. In addition to the 25 nuclides selected for use in

Table 2. Set of fuel nuclides used in KENO V.a calculations

$^{234}U^{a}$	$^{83}Kr^{d}$	$^{141}Pr^{b}$
$^{235}U^{a}$	$^{93}Zr^{b}$	$^{143}Nd^{a}$
$^{236}U^{a}$	$^{95}Mo^{a}$	$^{145}Nd^{a}$
$^{238}U^{a}$	$^{99}Tc^{a}$	$^{147}Nd^{c}$
$^{237}Np^{b}$	$^{101}Ru^{b}$	$^{148}Nd^{c}$
$^{238}Pu^{a}$	$^{103}Ru^{c}$	$^{147}Pm^{b}$
$^{239}Pu^{a}$	$^{103}Rh^{a}$	$^{148}Pm^{c}$
$^{240}Pu^{a}$	$^{105}Rh^{c}$	$^{149}Pm^{c}$
$^{241}Pu^{a}$	$^{105}Pd^{b}$	$^{147}Sm^{a}$
$^{242}Pu^{a}$	$^{108}Pd^{b}$	$^{149}Sm^{a}$
$^{241}Am^{a}$	$^{109}Ag^{b}$	$^{150}Sm^{a}$
$^{243}Am^{b}$	$^{135}I^{c}$	$^{151}Sm^{a}$
$^{244}Cm^{b}$	$^{131}Xe^{d}$	$^{152}Sm^{a}$
O^{a}	$^{135}Xe^{c}$	$^{153}Eu^{a}$
	$^{133}Cs^{a}$	$^{154}Eu^{b}$
	$^{134}Cs^{d}$	$^{155}Eu^{b}$
	$^{135}Cs^{a}$	$^{155}Gd^{a}$

[a] The 25 nuclides to be used in burnup credit analysis (ref. 4).
[b] Additional burnup credit nuclides from ref. 1.
[c] Additional reactor physics nuclides from Virginia Power's PDQ calculations (ref. 12).
[d] Additional reactor physics nuclides from Yankee Atomic's CASMO-3/SIMULATE-3 calculations (ref. 13).

burnup credit analysis in ref. 4, the list in Table 2 includes the other nuclides included in an earlier burnup credit feasibility study[1] together with nuclides modeled explicitly in the burnup credit work of refs. 12 and 13.

2.4 SUBGROUP CROSS-SECTION PROCESSING

The CSASN[6] sequence of the SCALE system is used to compute weighted fuel pin cross sections based on the content and geometry of a representative fuel cell. Based on a 1-D fuel cell model, CSASN invokes BONAMI-S[14] to perform resonance shielding calculations using Bondarenko factors, followed by NITAWL-II[15] calculations to perform resolved resonance range cross-section processing for any nuclides possessing resonance parameter data.

CSASN cross-section processing is applied only to subgroup-averaged nuclide concentrations. As discussed earlier in Sect. 2.1, effective microscopic cross sections are not strongly coupled to burnup; hence it is sufficient to compute cross sections for a subgroup-based average assembly, provided the range of burnups in the subgroup is not too large (subgroup "width" was addressed earlier in the discussion of the creation of subgroups). Nuclide concentrations for use in the CSASN

calculation are provided in standard composition form from the output of SNIKR subgroup calculations.

Because they represent only a small fraction of the total volume of the fuel, fission-product cross sections are essentially independent of location and need only be calculated for one subgroup. This situation is also true of many fuel-activation products; however, cross sections for seven actinides are known to have a significant burnup dependence. These isotopes, referred to as the "seven burnup-dependent actinides," are ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{239}Pu, ^{240}Pu, and ^{241}Pu. CSASN subgroup fuel-pin models include the appropriate SNIKR-computed concentrations for each of these isotopes; the remaining activation and fission products are included only in the highest burnup subgroup. The highest burnup is chosen because it will result in the lowest resonance absorption, and therefore results in a higher and therefore more conservative k_{eff}; however, the effect is extremely small (<0.1% K).

Once effective cross sections are computed for each subgroup, the SCALE utility module WAX[16] is used to combine all CSASN subgroup working libraries into a single working library for subsequent use by KENO V.a. All cross sections from the highest burn subgroup (containing all fission and activation isotopes) are copied into the combined library. For each of the remaining subgroup libraries, only the seven burnup-dependent actinides are copied. In addition, for each actinide in each subzone, the cross-section ID number is modified by prefixing the subgroup number to the cross-section ID so that the KENO V.a core model can reference the appropriate cross section for each subgroup. The cross sections with modified IDs are then copied into the combined library.

2.5 PREPARATION OF THE KENO V.a CORE MODEL

The geometry of the core model is based on the technical specifications of the core geometry available from several sources;[17-23] the detailed mechanics of the geometry model are not discussed here. Using the one-eighth core symmetry of the TMI core, it is possible to build a full-core model using a relatively small number of unique assemblies. For each assembly type, nuclide concentrations are obtained from assembly-specific SNIKR output in mixing table form; thus there is a unique mixing table for each assembly type in the model. Within each mixing table, the nuclide ID number of each of the seven burnup-dependent actinides is prefixed by the subgroup that represents the assembly type (this can be done automatically by SNIKR) so that the effective cross sections computed for the corresponding subgroup are utilized. These cross sections are located in the working library prepared as described in the previous subsection.

3. PREPARATION OF THE TMI-1 CORE MODEL

The previous section has given an overview of the technical procedure used in setting up the TMI-1 HZP critical calculation in order to provide a broad overview of the entire process before concentrating on the details. This section describes the TMI-1 beginning of cycle 5 (BOC-5) core, then details the specifics of each step used to set up a model for this core, based on the geometry, contents, and operating history of the core up to the beginning of the fifth cycle. Rather than follow the five steps used previously to outline the procedure, this section will describe each distinct aspect of the process, as illustrated by the individual boxes in Fig. 1.

Discussion of the KENO V.a criticality calculation and its results will be provided in Sect. 4 of this volume.

3.1 CORE DESCRIPTION

The TMI-1 core consists of 177 Babcock and Wilcox fuel assemblies, each comprised of a 15 × 15 lattice containing 208 fuel rods, 16 control/safety rod guide tubes, and one instrument tube. The core configuration is shown in Fig. 3, where each square represents an assembly position. At-power reactivity control is maintained using 24 full-length Ag-In-Cd control rod clusters and soluble boron. Additional shutdown margin is provided using 37 additional clusters. Eight partial-length Ag-In-Cd axial power shape rods (APSRs) are used to control the axial power distribution. Within each assembly, control rod positions are located as illustrated in Fig. 4. The positions are vacant (control rods are withdrawn) during operation.

The critical condition modeled in this report is based on HZP start-up testing for BOC-5. All core components were assumed to be at a constant temperature of 551 K, based on nominal HZP conditions. All full-length control and safety rod clusters were fully withdrawn, with APSRs at a 34.5% withdrawn position. Criticality was obtained with a soluble boron concentration of 1182 ppm. No burnable poisons were present in the core.

For BOC-5, two fuel assembly enrichments were present. Fuel batch 4B was manufactured with 2.64 wt % ^{235}U, but the remaining fuel batches (5, 6, and 7) contained 2.85 wt % ^{235}U. However, the geometries of the two designs were identical. Figure 4 illustrates this assembly configuration, showing the positions of fuel rods, control rod guide tubes, and instrument positions in each assembly. Table 3 provides a physical description of the significant aspects of the fuel design for all assemblies. Burnups for each assembly position were provided by the vendor[18] in the form of a one-eighth core symmetric region, where the burnup for each assembly position represents the average of all assemblies lying in the corresponding position in all eighth-core regions. Figure 5 shows the location, batch, and BOC-5 burnup for all assemblies in the one-eighth core. Note that the assembly numbers given in the figure were assigned for the purposes of this set of calculations and do not correspond to the vendor's numbering scheme.

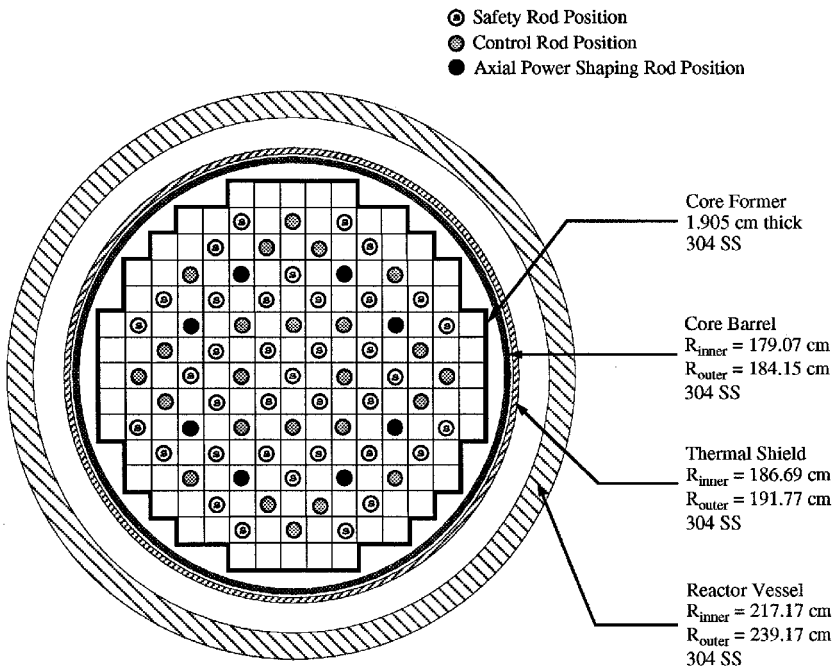


Fig. 3. TMI Unit 2 configuration.

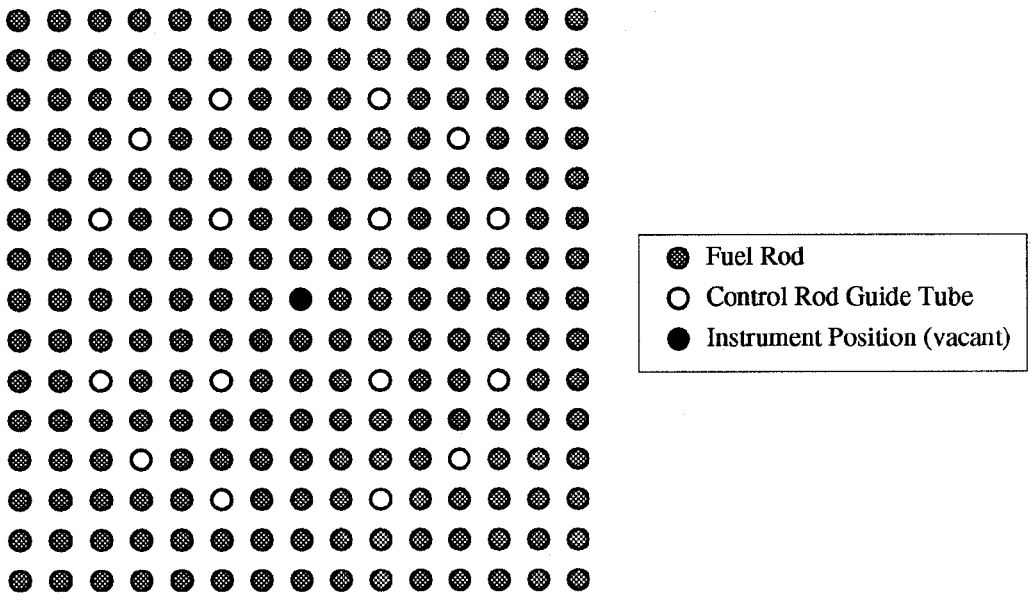


Fig. 4. TMI Unit 1 assembly geometry.

Table 3. Three Mile Island Unit 1 fuel/assembly design

Parameter	Data
Assembly data	
Number of assemblies	177
Weight of heavy metal, MTU	0.46363
Designer	Babcock & Wilcox
Lattice	15 × 15
Water temperature, K (°F)	577 (579)
Water density, g/cm^3	0.7149
Number of fuel rods	208
Number of guide tubes	16
Number of instrument tubes	1
Lattice pitch, cm (in.)	21.681 (8.536)
Fuel rod data	
Type fuel pellet	UO_2
Pellet stack density, % TD	95
Rod pitch, cm (in.)	1.44272 (0.568)
Clad OD, cm (in.)	1.09220 (0.430)
Clad ID, cm (in.)	0.95758 (0.377)
Pellet diameter, cm (in.)	0.93624 (0.3686)
Active fuel length, cm (in.)	360.17 (141.8)
Clad material	Zircaloy-4
Guide tube data	
Tube ID, cm (in.)	1.24460 (0.490)
Tube OD, cm (in.)	1.34620 (0.530)
Tube material	Zircaloy-4

1 4B 25199	2 5 18313	3 6 6683	4 4B 23926	5 6 9540	6 5 17603	7 6 9540	8 7 0
	9 6 7969	10 5 20929	11 6 5802	12 5 18740	13 6 7090	14 4B 24728	15 7 0
		16 6 7969	17 5 16615	18 6 6012	19 4B 24900	20 7 0	21 7 0
			22 5 18203	23 5 15877	24 6 9322	25 7 0	
				26 4B 21034	27 7 0	28 7 0	
					29 5 15838		

1	Assembly Reference Number
4B	Assembly Type
25199	Assembly Average Burnup (MWD/MTU)

Fig. 5. One-eighth core representation of TMI Unit 1, BOC 5.

A physical description of a partial-length control rod (i.e., APSR) is given in Fig. 6. Note that the geometry of a full-length control rod is not needed, because all full-length rods were fully withdrawn at startup and therefore need not be modeled in a criticality calculation. Axial APSR positions are specified in core reports in terms of percentage withdrawn. This value can be expressed in terms of absolute distance from the bottom of the active fuel length to the bottom of the poison region, d_{APSR}, using the following relationship:

$$d_{APSR}\ (\text{cm}) = (\%\ \text{withdrawn})(3.4925) + 19.495\ .$$

For 34.5% withdrawn, the bottom of the poison region was located at 139.99 cm above the bottom of the fuel. Thus, the bottom of the rod itself was located 136.69 cm above the bottom of the fuel. Because the rod is partially withdrawn, the water region of the rod extends above the top of the core, and the configuration of the rod above the water region is not important. APSR locations in the core are shown in Fig. 3; in the one-eighth core geometry shown in Fig. 5, the APSR control rod cluster is located in assembly 18.

3.2 SAS2H ASSEMBLY GROUPS

A "batch" of fuel assemblies is a set of identical assemblies that have been loaded into the core at the beginning of a specific fuel cycle. Assemblies of a given batch are generally relocated within the core between cycles, resulting in a more evenly distributed burnup between assemblies. Because a batch is loaded at one time and remains in the core for its lifetime, each assembly in a batch has experienced the same uptime/downtime history. Thus, a starting point for the process of collecting similar-content assemblies, or grouping, is to begin with fuel batches. As indicated in Fig. 1, assembly group information is used in preparation of SAS2H input for depletion calculations. For BOC-5, the TMI-1 core was comprised of four fuel batches. Because there were no significant geometric differences between fuel assemblies of a given batch (e.g., burnable poison rods in certain assemblies), no additional subdivision is necessary, and the four fuel batches can be used to define similar-property fuel groups. Each group can then be modeled as a single unit in a SAS2H depletion calculation over the range of burnups represented by the assemblies in the fuel group. Table 4 provides relevant information about each fuel group.

The initial isotopic content of each group was determined from the initial enrichment of the associated assembly type. The following empirical relationship was used to determine relative isotopic content:[24]

$$w_{234} = 0.007731(w_{235})^{1.0837}\ ,$$
$$w_{236} = 0.0046 w_{235}\ ,$$
$$w_{238} = 100 - w_{234} - w_{235} - w_{236}\ ,$$

where w is the weight percentage of the given isotope. Using this formulation, the fresh fuel isotopics for both enrichments were computed. The results are given in Table 5.

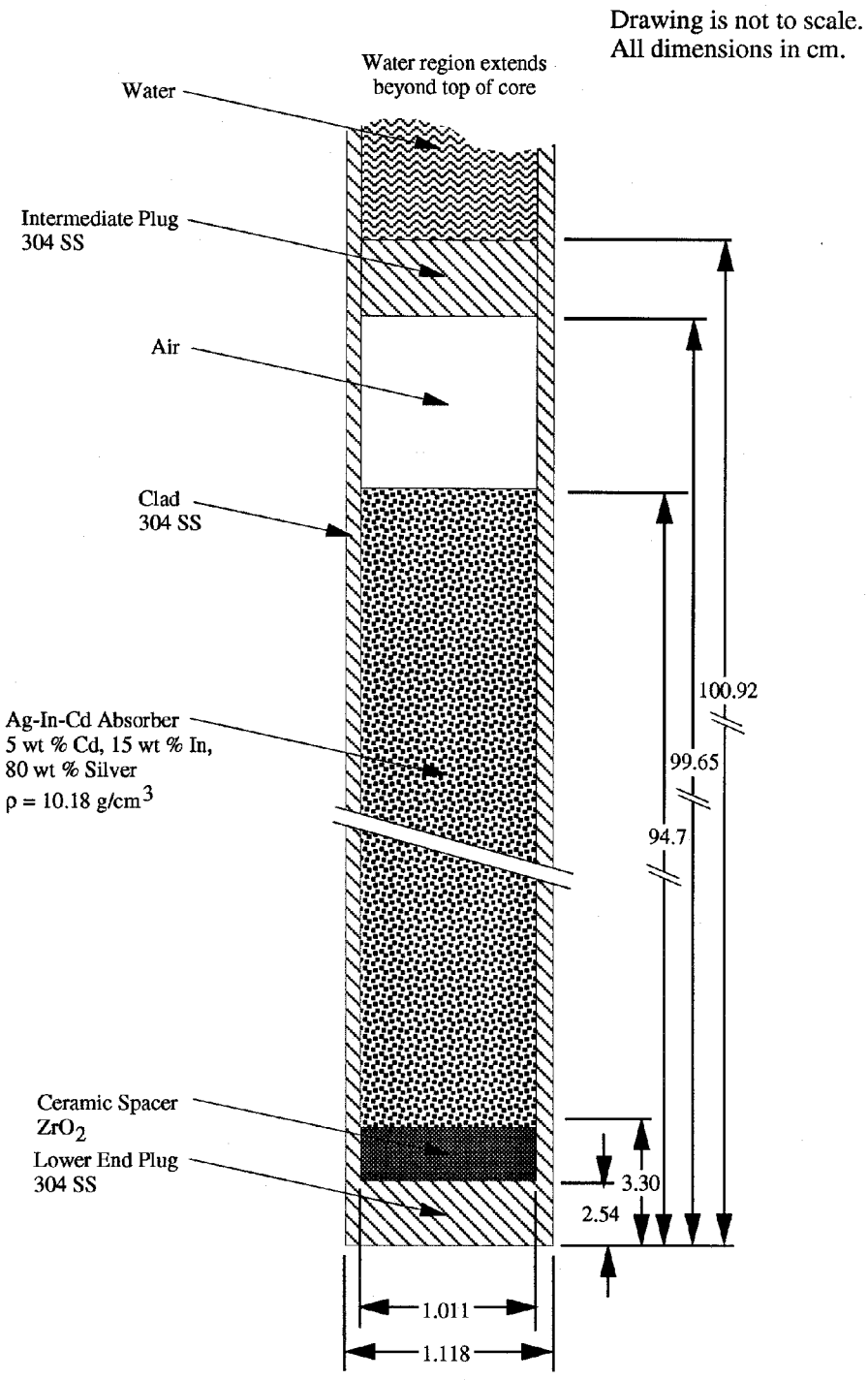


Fig. 6. Dimensions of a partial control rod (APSR).

Table 4. Assembly group data for BOC-5

Group No.	Fuel batch	Cycles in-core	Av. B/U, MWd/MTU	Max. B/U, MWd/MTU	Min. B/U, MWd/MTU	Enrichment, wt %	Av. fuel temp., K[a]	Av. clad temp., K[a]
1	4B	2,3,4	25573	28229	21034	2.64	854	621
2	5	3,4	17857	20929	15838	2.85	887	622
3	6	4	7552	9540	5802	2.85	879	619
4	7	–	0	0	0	2.85	–	–

[a]Operating temperature based on average burnup and power while in-core prior to BOC-5.

Table 5. Isotopic content of fresh fuel for 2.64 and 2.85 wt % enrichments

	Isotopic composition, wt %	
Isotope	2.64 wt % ^{235}U (Batch 4B)	2.85 wt % ^{235}U (Batches 5–7)
^{234}U	0.022	0.024
^{236}U	0.012	0.013
^{238}U	97.326	97.113

In addition to the heavy-metal fuel material description for each group, light elements are typically present in a fuel rod, primarily in the clad. Elements whose masses are typically found to be in excess of 0.5 g/kgU, plus Mn and Co, are shown in Table 6, along with their estimated masses. These masses are required by the SAS2H module of SCALE in depletion calculations. They are not used in the neutronics model, but are applied in determining the (n,γ) fraction of energy per fission.

Each SAS2H calculation also requires specification of the temperature of each material for use in cross-section Doppler broadening corrections. However, since material and, therefore, thermal properties change with exposure, and because an assembly's peak temperature is a function of its linear heat rate, the average temperature in the fuel (and to a lesser extent the average clad temperature) will change with burnup and location. Thermal data are available, giving average fuel and clad temperatures as a function of exposure and linear heat rate. To simplify the depletion analysis, it was assumed that each fuel group could be represented by a single temperature in each of the fuel, clad, and coolant regions. Based on average burnup ([total burnup]/2) and the average power generated in each fuel group, the thermal data were used to obtain a group-average operating temperature for fuel and clad materials; these data are given in Table 4. A bulk coolant temperature of 577 K was used, based on the average of inlet and outlet coolant temperatures given in thermal-hydraulic performance data.[18-20]

Table 6. Light-element masses used in SAS2H calculations

Element	Weight, g/kgU
O	135.0
Cr	5.9
Mn	0.33
Fe	12.9
Co	0.075
Ni	9.9
Zr	221.0
Nb	0.71
Sn	3.6

3.3 SIMILAR-BURNUP SUBGROUPING

Although the assemblies of a given fuel group are identical in terms of initial composition, time in core, and operating history, there is a broad range of burnups within a group. Even though effective cross sections are felt to be insensitive to minor variations in burnup, it is necessary to set a maximum range of burnup for which an average burnup is an acceptable approximation in determining cross sections. As discussed earlier, a range of no more than 2 GWd/MTU has been found to be acceptable;[25,26] this value was used in subdividing assembly groups into similar-burnup subgroups. As shown in Fig. 1, subgroup information is provided to SNIKR for subsequent use in setting up CSASN calculations. CSASN is used to compute effective cross sections for each subgroup.

To determine subgroups for fuel groups 1 to 3, the minimum-to-maximum burnup range for each group was simply divided into three equal-size subgroups, each with a width of one-third of the range. This division ensured that no subgroup would be greater than 2 GWd/MTU in width. Subgroups whose burnup range contained no assemblies were ignored. Table 7 shows the group breakdown, with the actual burnup limits and ranges for assemblies within each subgroup, along with the mean burnup of all assemblies in each subgroup. Note that no subgrouping was performed for fuel group 4 assemblies; these assemblies are comprised of fresh fuel, thus no subdivision was necessary.

3.4 SAS2H DEPLETION CALCULATIONS

SAS2H depletion calculations were required for fuel groups 1, 2, and 3 only, since group 4 consisted of fresh fuel at the time of startup. In the standard composition section of the SAS2H input for each fuel group, isotopic contents for the fuel were as given in Table 5, at a temperature as given in Table 4. Additionally, although not initially present in the fuel, the 44 most significant fission products were included at an atom density of 1×10^{-20} (^{135}Xe was specified with an initial

Table 7. Subgroup burnups for BOC-5

Fuel subgroup	Fuel group	Max. burnup (GWd/MTU)	Min. burnup (GWd/MTU)	Av. burnup (GWd/MTU)	Width (Max.-Min.) (GWd/MTU)	Number of assemblies
1	1	25.199	23.926	24.688	1.273	4
2	1	21.034	21.034	21.034	0	1
3	2	20.929	20.929	20.929	0	1
4	2	18.740	17.603	18.215	1.137	4
5	2	16.615	15.838	16.110	0.777	3
6	3	9.540	9.322	9.467	0.218	3
7	3	7.969	7.090	7.676	0.879	3
8	3	6.683	5.802	6.166	0.881	3
9	4	0	0	0	0	7

density of 1.2×10^{-8} atoms/b-cm, since it quickly reaches this equilibrium concentration shortly after startup), indicating to SAS2H that cross sections for these isotopes should be updated at the end of each burn cycle, in addition to the default isotopes automatically updated within SAS2H. A list of these fission products is given in Table 4. The remainder of the fuel pin cell was described as Zircaloy clad in water. Temperatures were as given in Table 5; pin and lattice geometry data were as specified in Table 3. The active fuel length was specified as 776.85 cm/MTU, based on the actual fuel length of 360.17 cm divided by the total weight of heavy metal of 0.46363 MTU; this modification gives results in units of burnup per MTU rather than burnup per assembly. Since SAS2H uses a 2-D cell model, the fuel length is arbitrary and may be used as a conversion factor.

Table 8 gives the power history data used in the three fuel group models. Note that within each group model, a constant burn time per interval was used; this constant spacing is required by SNIKR when interpolating from SAS2H/ORIGEN output. To meet this requirement, the uptime for each of reactor operating cycles 2, 3, and 4 was assumed to be 300 days, representing the average cycle length. For groups 1 and 2, cycles 2 and 3 were divided into two intervals; for all groups, cycle 4 was divided into the number of intervals required so as to exceed the maximum assembly burnup by 20%.

A copy of the SAS2H input for group 1 calculations is included in Appendix A. With the exception of the uranium isotopics and the burn steps, inputs for group 2 and group 3 calculations were identical to that of group 1.

Table 8. Fuel group burn model used in SAS2H

Fuel group	Reactor cycle	Average power (MW/MTU)	Actual uptime (d)	Actual downtime (d)	Number of intervals in cycle	Modeled burn time per interval (d)	Modeled downtime per interval (d)	Cumulative burnup (GWd/MTU)
1	2	28.383	298	56	2	150	28.192	8.516
1	3	28.383	308	42	2	150	20.457	17.032
1	4	28.383	295	0	4	150	0.0	34.064
2	3	29.614	308	42	2	150	20.454	8.884
2	4	29.614	295	0	4	150	0.0	26.653
3	4	25.342	295	0	5	100	0.0	12.671

3.5 BURNUP-DEPENDENT INTERPOLATION OF ISOTOPICS

The atom density output files from each of the previous SAS2H calculations contain isotopic concentrations for the associated fuel group at each burnup step. Using the appropriate group output, SNIKR1 was used to interpolate between burn cycles to estimate the isotopic concentration corresponding to the burnup of each assembly and subgroup in the TMI model. SNIKR1 then used these isotopics (which represented nuclide concentrations at the end of the final burn cycle) and prepared an ORIGEN decay calculation to obtain the concentration of the isotopes after the 6.625 years downtime prior to the beginning of cycle 5. After ORIGEN-S was executed, SNIKR3 read the ORIGEN-S output and prepared isotopic concentration tables in both CSAS4 standard composition format and KENO V.a mixing table format, for an input-specified set of isotopes.

The SNIKR sequence consists of three codes, described earlier in Sect. 2.3, and requires two input files. The first input file describes the calculation to be performed for a specific assembly or subgroup; the second file is the SAS2H output file containing the burn cycle isotopics for the appropriate fuel group. Although SNIKR is not part of the SCALE system, SNIKR calculations can be automated somewhat in a manner similar to SCALE calculational sequences such that the multistep calling of the individual code packages is transparent to the user. Appendix B lists a UNIX script used to create a working space, copy and/or rename all necessary input and output, and execute each module in sequence. Appendix B also includes FORTRAN listings of the SNIKR1 and SNIKR3 codes invoked by this script.

Slightly different approaches are taken between the preparation of assembly isotopics and subgroup isotopics because the results are used in different applications. The following subsections describe each of the two methods.

3.5.1 Assembly Isotopics

In the KENO V.a model of the TMI one-eighth core region, assembly isotopics calculations are used to provide the nuclide concentrations for each assembly position. The assembly isotopics are based on the average burnup for the assembly, and all fuel rods within the assembly are assumed to possess the same isotopic composition. Hence material numbers for each fuel rod in a given assembly are the same and correspond to a specific KENO V.a mixture number. This mixture is defined based on results of SNIKR calculations for the burnup of the corresponding assembly. In the TMI KENO V.a model, mixture numbers 101 through 129 correspond to SNIKR calculations for assemblies 1 through 29, respectively. Eighth-core-averaged assembly burnups are given in Table 9, along with fuel type, group, and subgroup information.

A typical SNIKR input file is shown below, based on assembly 2 data. The first line is a text description of the calculation; the second line assigns unit numbers for various files used by SNIKR. This number assignment includes the unit number of the file containing the SAS2H output file for the fuel group appropriate for this assembly. The third line specifies the total number of burn steps in the SAS2H output file (6), the burnup (MWd/MTU) for which interpolated isotopics are desired (18313), and the number of cooling time steps for which output is desired (1). The next line specifies the single cooling time at which ORIGEN-decayed isotopics are desired (i.e., 6.625 years). Next, the number of light elements (zero—not used), the KENO V.a mixture number (102), and the

Table 9. Fuel assembly data for one-eighth core geometry

Assembly No.	Assembly type	Fuel group	Subgroup	Average burnup (MWd/MTU)
1	4B	1	1	25,199
2	5	2	4	18,313
3	6	3	8	6,683
4	4B	1	1	23,926
5	6	3	6	9,540
6	5	2	4	17,603
7	6	3	6	9,540
8	7	4	9	0
9	6	3	7	7,969
10	5	2	3	20,929
11	6	3	8	5,802
12	5	2	4	18,740
13	6	3	7	7,090
14	4B	1	1	24,728
15	7	4	9	0
16	6	3	7	7,969
17	5	2	5	16,615
18	6	4	8	6,012
19	4B	1	1	24,900
20	7	4	9	0
21	7	4	9	0
22	5	2	4	18,203
23	5	2	5	15,877
24	6	3	6	9,322
25	7	4	9	0
26	4B	1	2	21,034
27	7	4	9	0
28	7	4	9	0
29	5	2	5	15,838

cross-section ID modifier (4) are specified (fuel materials in assemblies 1 through 29 were assigned mixture numbers 101 through 129, respectively). Finally, a value of -2 is a flag telling SNIKR to output isotopics for the 48 most important nuclides for burnup credit applications.

```
Batch 5 (Group 2 Subgroup 4), Assembly H9, Burnup=18313 MWd/MTU
72 70 74 71 75 73
6 18313 1
6.625
0 102  4
-2
```

The KENO V.a mixture number and the cross-section ID modifier are not essential for the calculation and are present simply to preprocess input for its use in the subsequent calculation. The mixture number simply allows SNIKR to prepare KENO V.a input with the 'mix=###' label appropriate for the mixture. The cross-section ID modifier is a number indicating the subgroup from which cross sections are to be used for certain isotopes. As discussed earlier in Sect. 2.4, subgroup-dependent cross sections are required only for the seven burnup-dependent actinides. SNIKR places the cross-section ID modifier in front of the default cross-section ID for each of these isotopes (e.g., ^{238}U, with ID number 92238, would be described as 292238 for all assemblies located in subzone 2).

The SNIKR output file consists of three sections: a summary of the input and coarsely formatted ORIGEN results; isotopic concentrations in SCALE standard composition format; and isotopic concentrations in KENO V.a mixing table format. For an assembly calculation, only the latter is of interest; this section can be edited out and placed directly into KENO V.a input to describe the isotopic composition for the burnup of a specific assembly. A sample SNIKR output, corresponding to the above sample input, is listed in Appendix B.

3.5.2 Subgroup Isotopics

Burnup-dependent cross sections were required for the seven burnup-dependent actinides. As was previously mentioned, subgroup calculations are performed to obtain the cross sections for these actinides as a function of a subgroup-averaged burnup. Subgroups are shown in Table 9 and were selected based on the burnup range criterion of 2 GWd/MTU discussed earlier. SNIKR calculations were required for subgroups 1 to 8; no calculation was required for subgroup 9 because it is comprised of fresh fuel assemblies only.

A typical SNIKR input file is shown below for a subgroup-type calculation, based on subgroup 1 data. The first four lines are used exactly as in the earlier assembly calculations. The burnup value is the average of all assembly burnups within the subgroup. Again, the number of light elements was not used, and was set to zero. The KENO V.a mixture number, which is also used as the fuel mixture number specification for the standard-composition-formatted data in CSASN calculations, was set to 1 for all subgroups. The cross-section modifier is not used and was set to 0. Finally, as before, a flag value of -2 was used to direct SNIKR to prepare formatted isotopics for the 48 most important nuclides for burnup credit applications.

```
Subgroup 1 (Group  1), Ave. Burnup=24688 MWd/MTU
72 70 74 71 75 73
8 24688 1
6.625
0   1  0
-2
```

The SNIKR output file is the same format as was produced for the assembly calculations; however, the region of output data that is of interest is the SCALE standard composition format output. A sample of the output from this calculation is also included in Appendix B.

3.6 GENERATION OF SUBGROUP CROSS SECTIONS USING CSASN

Weighted cross-section libraries are produced using the CSASN sequence of SCALE; the details of this process were described in Sect. 2.4. For each subgroup, a CSASN input deck containing subgroup-specific isotopics was created. Because the physical geometries of all fuel pins were identical, input specifications differed only in the isotopic compositions specified for each subgroup. All cases were set up to use the SCALE ENDF/B-IV and ENDF/B-V based 27-group 27BURNUPLIB cross-section library. All calculations were LATTICECELL type, with fuel in a Zircaloy clad; dimensions are specified in Table 10. A borated-water moderator was specified, with a soluble boron concentration of 1182 ppm.[21] All components were specified with a temperature of 551 K, corresponding to HZP conditions.

Isotopic concentrations for cross-section sets 1 to 8 were obtained from the earlier SNIKR subgroup calculations. Since only the seven burnup-dependent actinides were required for subgroups 2 through 8, all other actinides and fission products were deleted from the fuel mixture specifications for these cases. Subgroup 9, comprised only of fresh fuel, was specified using the fresh isotopic compositions given in Table 5. Additional materials contained in the APSRs (i.e., Ag-In-Cd poison, stainless steel 304, and ZrO_2) were added to subgroup 1. CSASN calculations were then performed, with the resulting subgroup-specific microscopic working-format cross-section library saved for each subgroup.

Sample input for subgroup 1 (containing the seven burnup-dependent actinides, remaining actinides and fission products, and APSR materials), subgroup 2 (containing the seven burnup-dependent actinides only), and subgroup 9 (containing 2.85% enriched fresh fuel actinides only) are included in Appendix C.

3.7 COMBINING SUBGROUP CROSS SECTIONS USING WAX

The WAX program[16] was used to combine the nine individual working-format libraries into a single library to be used in the KENO V.a core calculation. For cross-section set 1, corresponding to subgroup 1, WAX copied all cross sections into the combined library. For cross-section sets 2 through 8, WAX copied only the cross sections for the seven burnup-dependent actinides. For each

Table 10. Subgroups for one-eighth core assemblies

	Assembly Nos.	Burnup (MWd/MTU)		Assembly Nos.	Burnup (MWd/MTU)
Subgroup 1	1	25,199	Subgroup 2	26	21,034
	4	23,926			
	14	24,728			
	19	24,900			
Average		24,688	Average		21,034
Subgroup 3	10	20,929	Subgroup 4	2	18,313
				6	17,603
				12	18,740
				22	18,203
Average		20,929	Average		18,215
Subgroup 5	17	16,615	Subgroup 6	5	9,540
	23	15,877		7	9,540
	29	15,838		24	9,322
Average		16,110	Average		9,467
Subgroup 7	9	7,969	Subgroup 8	3	6,683
	13	7,090		11	5,802
	16	7,969		18	6,012
Average		7,676	Average		6,166
Subgroup 9	8	0			
	15	0			
	20	0			
	21	0			
	25	0			
	27	0			
	28	0			
Average		0			

of these actinides, the cross-section ID was modified by adding the subgroup/cross-section set number as a prefix, to be consistent with the numbering scheme used in the SNIKR-produced mixing-table-format isotopics for each assembly. The WAX input listing is provided in Appendix D.

3.8 PREPARATION OF A KENO V.a CORE MODEL

The KENO V.a[25] model used to determine k_{eff} for the TMI-1 BOC-5 core consists of four parts. The first section of input contains KENO V.a parameter specifications. The only significant aspect of this section is the use of 2003 generations of 1000 neutrons per generation; hence the calculation was based on two million histories (a minimum of three generations are skipped by KENO V.a). Parameter specifications are followed by mixture specifications, geometry specifications, and plotting specifications. The plotting specifications are unimportant in the criticality calculation and were simply used in debugging and verifying geometry input. The following subsections describe the details of the material and geometry specifications for this model.

3.8.1 KENO V.a Mixture Specifications

In describing the composition of a fuel assembly, it has been assumed that all fuel pins in the assembly are identical and may be represented by the assembly-averaged burnup. No attempt was made to account for burnup asymmetries within an assembly, because this information was not readily available and would have little, if any, detectable effect on the computed solution.[8,26] Thus, only a single fuel pin description is necessary to describe all fuel pins in a given assembly. In addition, in this model axial power distributions are ignored, and assemblies are represented by a model that assumes a constant (average) power distribution along the active length of the assembly. Thus the composition of fuel in an assembly is uniform and is represented by a single material specification. Based on the results of an axial end effects study,[27] this assumption has a minor effect (<0.1% $\Delta k/k$) that is probably conservative for the average burnup in this model. Because it is possible to take advantage of the one-eighth core symmetry of the TMI-1 core, only 29 assemblies are required to represent all 177 assembly positions in the core. Hence, only 29 material mixtures are necessary for the whole-core model. These come from the 29 assembly calculations performed earlier using SNIKR for mixtures 101 through 129. The portions of the SNIKR output edited for use in KENO V.a represent complete mixture specifications for each of the 29 materials.

Material specifications were also required for all remaining materials (i.e., clad, borated water, and APSR materials). Isotopic concentrations for each isotope were obtained from the output of the subgroup. Table 11 lists all materials included in the core model by mixture number.

3.8.2 KENO V.a Geometry Specifications

A fuel pin was defined for each of the 29 one-eighth core fuel assemblies based on the dimensions given in Table 3. Identical dimensions were used for all rod definitions. Fuel pins were assigned to unit numbers 101 to 129, respectively; the fuel region of each pin was linked to its corresponding material number (e.g., fuel pin 101 used material 101 for the fuel region). All pins

Table 11. Mixture numbers used in KENO V.a core model

Mixture No.	Description
2	Zircaloy clad
3	Water (1182 ppm boron)
4	Ag-In-Cd poison rod
5	Stainless steel 304 clad
6	Zirconium oxide
101–129	Fuel, assemblies 1-29

were specified with a void gap, Zircaloy clad, centered in a water cuboid. Fuel pins and enclosing cuboids were modeled as having a length equal to that of the active fuel length of the rod [i.e., rod end structure (and resultant end effects) were neglected].

Unit 201, representing a control rod guide tube, was created using the dimensions in Table 3, with water inside the tube and centered within a water cuboid. A similar structure was created as unit 200, except a 34.5% withdrawn APSR was put inside the tube using the dimensions as discussed in Sect. 3.1 and as shown in Fig. 6.

The 15 × 15 arrays were then defined for each assembly and assigned unit numbers 1 to 29. Each assembly was loaded with its corresponding fuel pin cells and water-filled control rod guide tubes, according to the assembly map shown in Fig. 4. The center instrument position was also loaded with a water-filled guide tube. Instead of vacant guide tubes, assembly 18 was loaded with the partially inserted APSR/guide tube structures in all control positions. The center instrument position was filled with a water-filled guide tube.

The core former surrounding the outermost assemblies was created as a composite of several smaller segments, comprised of four different cuboid shapes. Units 31 to 34 were used to define these shapes. Figure 7 illustrates the use of these four unit types in modeling the core former. The figure also shows assembly position numbers for the full core, based on one-eighth core symmetry and the numbering scheme shown in Fig. 5. Using these position numbers, arrays of assemblies and core former segments were used to define larger units to minimize the number of "holes" placed in the global unit. Figure 8 illustrates the clustering of assemblies used. The central array marked as unit 50 was actually the innermost component of global unit 50, which also contained the core barrel, thermal shield, and reactor vessel. All other units were placed within unit 50 using KENO V.a "holes." Note that core former components drawn in black in the figure represent individual components not included in these arrays and were entered as individual holes in the global array. Unit number assignments used in the model are given in Table 12.

This completes the geometric description of the core. As a reference, a listing of the entire KENO V.a input for the TMI-1 BOC-5 core is included in Appendix E.

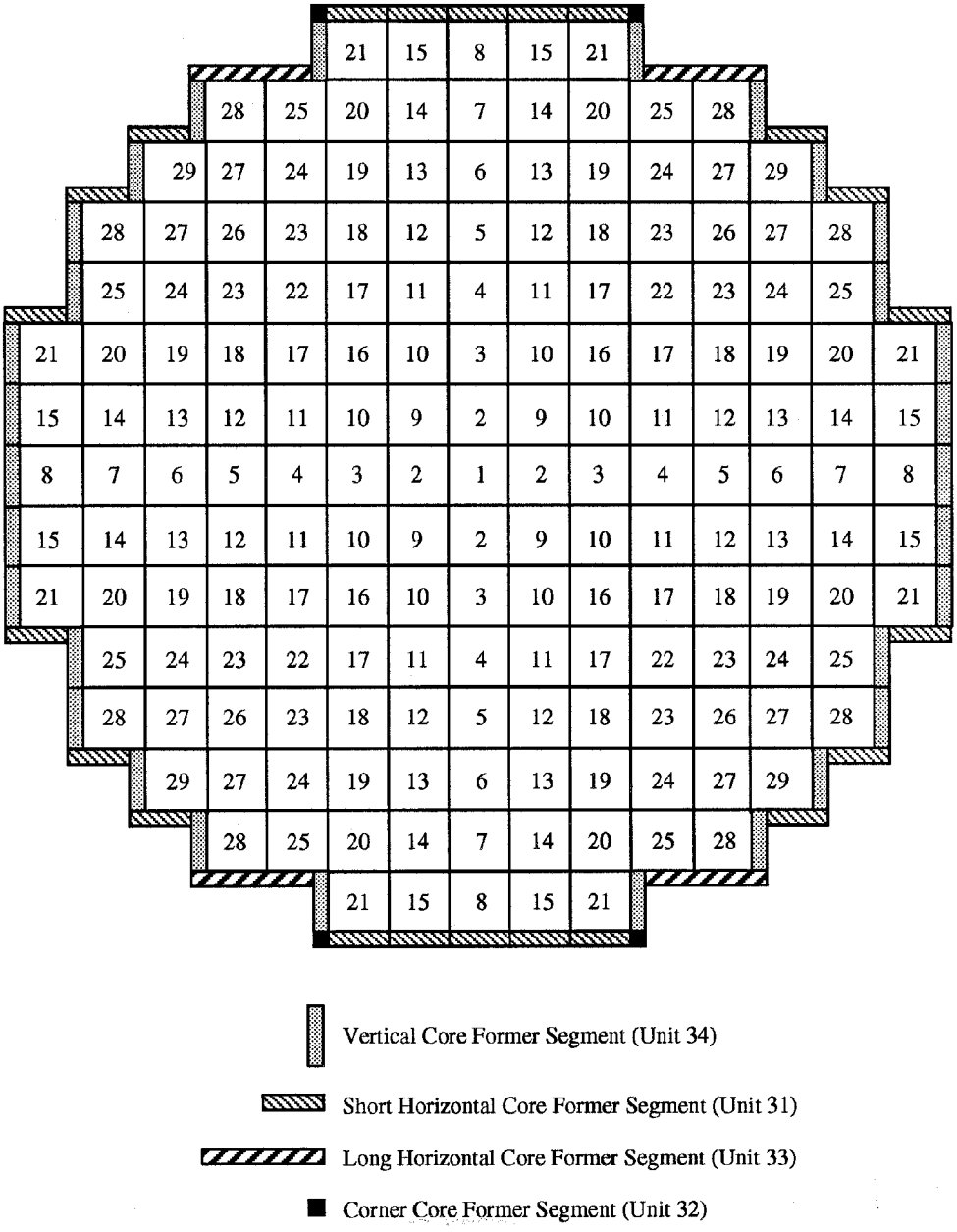


Fig. 7. Full-core assembly positions and core former configuration.

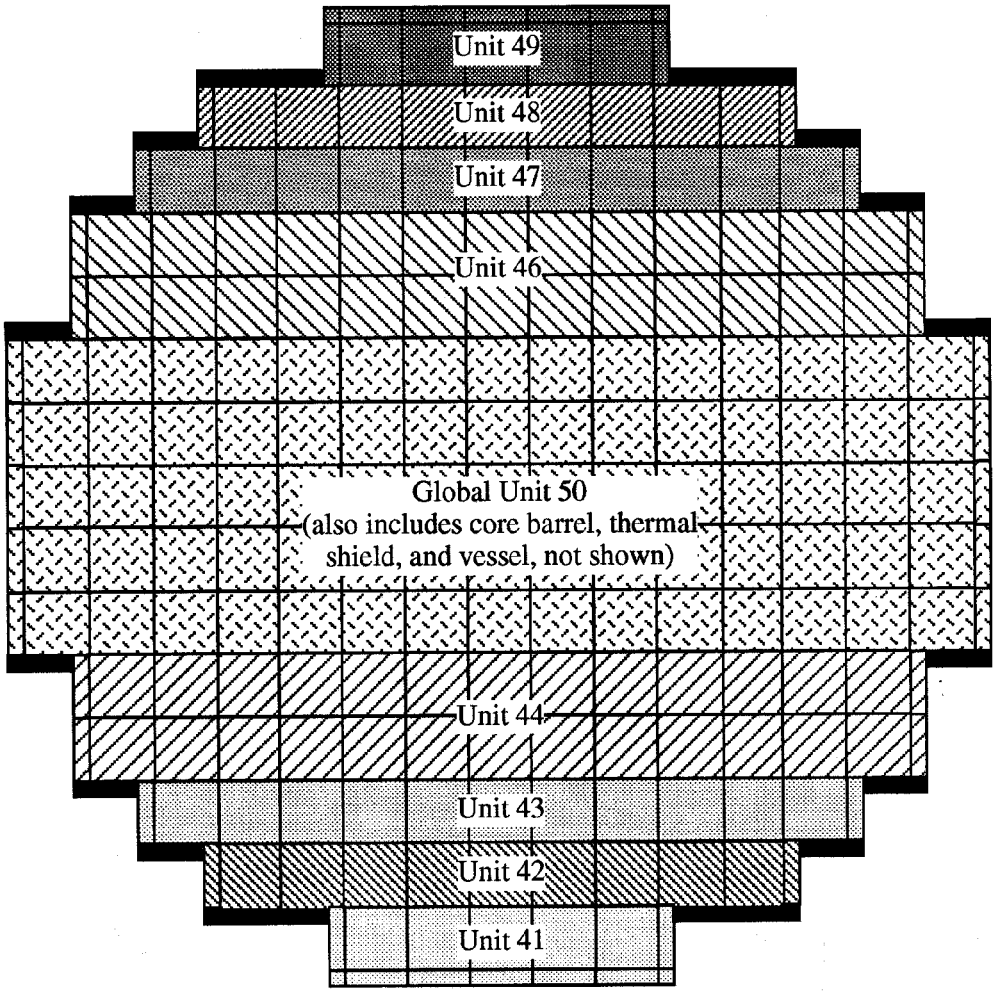


Fig. 8. Unit definitions based on assembly/core former component arrays.

Table 12. Unit numbers used in KENO V.a core model

Unit No.	Description
1-29	Fuel assemblies for positions 1 to 29, respectively
31	1.905 × 21.681 cm (horizontal) segment of core former
32	1.905 × 1.905 cm corner segment of core former
33	1.905 × 43.363 cm (horizontal) segment of core former
34	21.681 × 1.905 cm (vertical) segment of core former
41	"Bottom" of baffle + row 1 of assemblies + vertical former ends
42	Row 2 of assemblies + vertical former ends
43	Row 3 of assemblies + vertical former ends
44	Rows 4-5 of assemblies + vertical former ends
46	Rows 11-12 of assemblies + vertical former ends
47	Row 13 of assemblies + vertical former ends
48	Row 14 of assemblies + vertical former ends
49	Row 15 of assemblies + vertical former ends + "top" of former
50 (GLOBAL)	Reactor vessel + thermal shield + core barrel + rows 6–10 of assemblies + vertical former ends
101-129	Fuel rods for assemblies 1–29, respectively
200	34.5% withdrawn APSR rod inside guide tube
201	Water-filled guide tube

4. RESULTS AND CONCLUSIONS

The KENO V.a criticality calculation for the model described in this report yielded a value for k_{eff} of 0.9978 ± 0.0004, based on 2000 generations of 1000 neutrons per generation, for a total of 2×10^6 histories. The average fission group reported by SCALE, representing the average neutron energy group at which fission occurs, was calculated to be 20.7815 ± 0.0026. In terms of energy, for the 27-group burnup library, group 20 spans the energy range 0.4 to 0.8 eV. Numerical experiments with a different starting random number and different starting source shape and location indicate that this solution is well converged and adequate source sampling achieved. (See ref. 25 for what constitutes convergence.)

The base case above used P_3 scattering cross sections; however, a test using (default) P_1 scattering shows no significant change (within 0.1%) in k_{eff}. This effect is as would be anticipated, since angular fluxes throughout a reactor core would be expected to be relatively uniform except near the outer boundary of the core.

Fission densities computed by KENO V.a are shown in Fig. 9 for a one-eighth core region. These may be interpreted as relative power densities, and show the approximate shape expected for an operating PWR core, indicating no major anomalies in the core assembly model. At-power conditions would be expected to be more uniform over the inner-core regions due to xenon and temperature feedback mechanisms; however, these phenomena do not come into play under HZP conditions. Note that while k_{eff}, a total system parameter, is considered to be well converged, individual assembly fission distributions are based on substantially fewer histories, especially in outer-core regions, and therefore are subject to significantly higher uncertainties.

As described in Vols. 1 and 2 of this report,[8,26] similar reactor criticality calculations have been performed for Surry Unit 1 and Sequoyah Unit 2 PWRs. Even though each reactor model is unique in its own respect, several significant differences between TMI-1 BOC-5 and the two other criticals should be considered when comparing results. First, both Surry-1 and Sequoyah-2 cores contained burnable poison rods, but no burnable poisons were present in the TMI-1 core. Also, both Surry and Sequoyah criticals were performed with all control rods withdrawn; the TMI-1 startup critical contained partial-length control-rod clusters located near the axial midplane of the core. Additionally, as a result of the use of these partial rods for shaping axial flux profiles, TMI-1 assemblies would be expected to have a more flattened axial burnup relative to the other reactor criticals. Finally, the 6.63-year downtime of TMI-1 prior to BOC-5 startup testing is significantly longer than that of other reactor criticals; hence the time-dependent fission-product inventories are significantly different for intermediate-lived isotopes and their decay products. Surry-1 BOC calculations were performed based on a 101-d downtime; Sequoyah-2 middle-of-cycle calculations were based on a 2.7-year downtime. Figure 10 shows the relative decay of four fission products, ^{134}Cs, ^{147}Pm, ^{154}Eu, and ^{155}Eu, all with decay constants on the order of roughly 1 to 4 years, as well as the relative production of two daughter products, ^{147}Sm (from ^{147}Pm) and ^{155}Gd (from ^{155}Eu). This illustrates the difference in inventories that would be expected between the different reactor configurations. The longer downtime would also magnify error contributions in fission-product decay and daughter production isotopics, resulting in varying degrees of error in the numerical models of the physical systems.

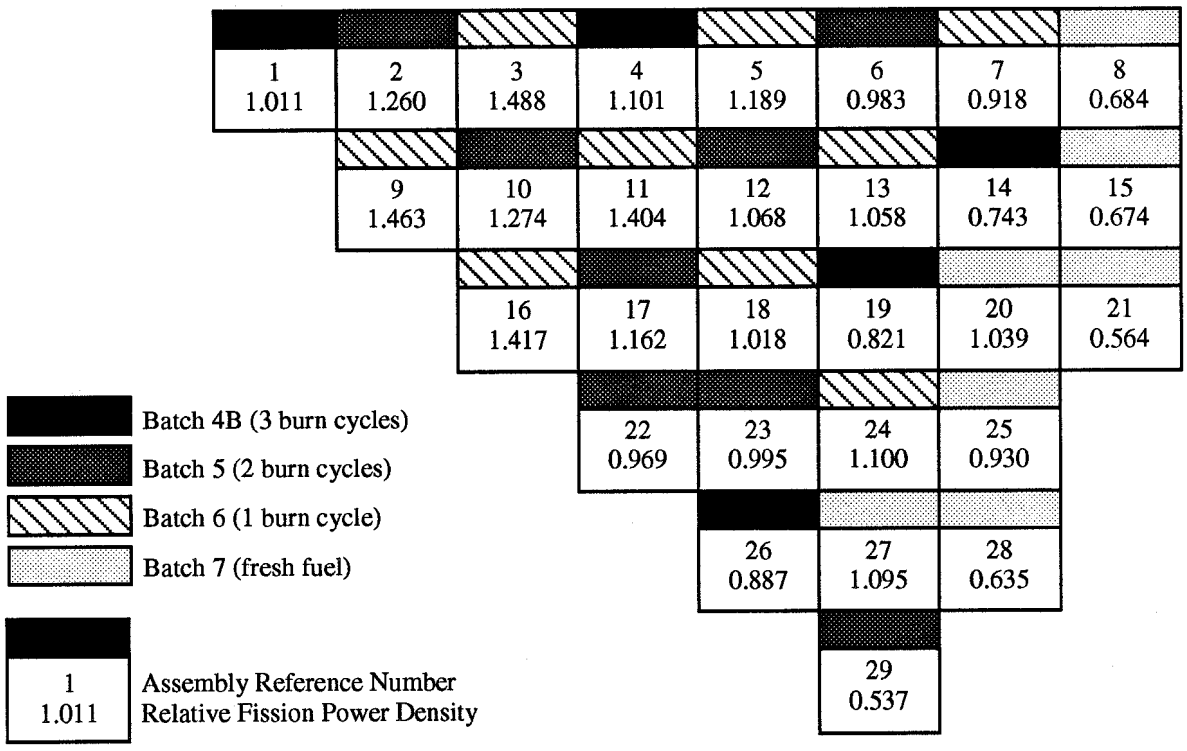


Fig. 9. KENO V.a relative fission density in TMI-1 one-eighth core.

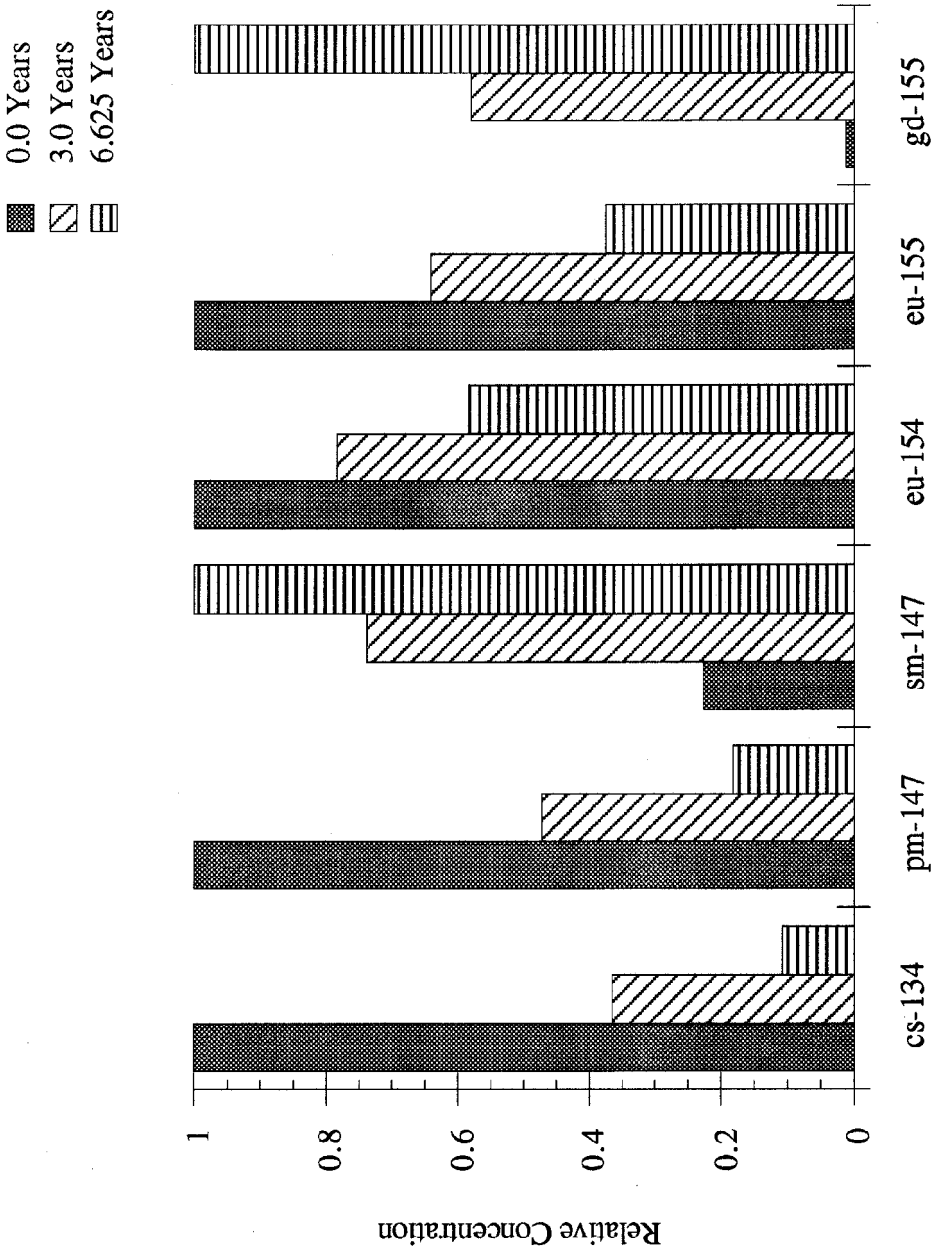


Fig. 10. Relative change in concentration for select fission products.

The results of this calculation demonstrate that even with a relatively simple core model and eighth-core and assembly-averaged exposure histories, it is possible to closely predict, in a best-estimate fashion, the critical condition after a long decay period for a lattice primarily comprised of spent fuel assemblies. Results are also consistent with SCALE validation calculations performed based on experiments using mixed-oxide fuel rods in square lattice configurations.[28] Hence, one may conclude that the methodology applied in performing this reactor critical calculation is valid for performing criticality safety analyses for systems with spent fuel.

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APPENDIX A

SAS2H CASE INPUT EXAMPLE

This appendix gives an example of the input for one of the three SAS2H cases. This input is used for zone 1 fuel.

```
=sas2     parm='halt08,skipshipdata'
TMI-1, cycles 2-4, zone 1 (4B fuel), burnup credit critical mdd 8/2/93
27burn         latticecell
'
'   mixtures of fuel-pin-unit-cell:
'
uo2  1 0.95 854 92234 0.022 92235 2.64 92236 0.012 92238 97.326  end
kr-83    1 0 1-20 854  end
kr-85    1 0 1-20 854  end
sr-90    1 0 1-20 854  end
 y-89    1 0 1-20 854  end
mo-95    1 0 1-20 854  end
zr-93    1 0 1-20 854  end
zr-94    1 0 1-20 854  end
zr-95    1 0 1-20 854  end
nb-94    1 0 1-20 854  end
tc-99    1 0 1-20 854  end
rh-103   1 0 1-20 854  end
rh-105   1 0 1-20 854  end
ru-101   1 0 1-20 854  end
ru-106   1 0 1-20 854  end
pd-105   1 0 1-20 854  end
pd-108   1 0 1-20 854  end
ag-109   1 0 1-20 854  end
sb-124   1 0 1-20 854  end
xe-131   1 0 1-20 854  end
xe-132   1 0 1-20 854  end
xe-135   1 0 1.2-8  854  end
xe-136   1 0 1-20 854  end
cs-134   1 0 1-20 854  end
cs-135   1 0 1-20 854  end
cs-137   1 0 1-20 854  end
ba-136   1 0 1-20 854  end
la-139   1 0 1-20 854  end
pr-141   1 0 1-20 854  end
pr-143   1 0 1-20 854  end
ce-144   1 0 1-20 854  end
nd-143   1 0 1-20 854  end
nd-145   1 0 1-20 854  end
pm-147   1 0 1-20 854  end
pm-148   1 0 1-20 854  end
nd-147   1 0 1-20 854  end
sm-147   1 0 1-20 854  end
sm-149   1 0 1-20 854  end
sm-150   1 0 1-20 854  end
sm-151   1 0 1-20 854  end
sm-152   1 0 1-20 854  end
gd-155   1 0 1-20 854  end
eu-153   1 0 1-20 854  end
eu-154   1 0 1-20 854  end
eu-155   1 0 1-20 854  end
zircalloy  2 1  621   end
h2o  3 den=0.7149  1  577 end
end comp
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'      fuel-pin-cell geometry:
'
squarepitch 1.44272 .936244 1  3  1.0922 2  .95758 0  end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
more data   szf=0.6  end
'
'    assembly and cycle parameters:
'
npin/assm=208 fuelnght=776.85 ncycles=8  nlib/cyc=1
```

```
printlevel=4 lightel=9  inplevel=1 ortube=0.6731 srtube=0.6223
numinstr=1  facmesh=0.65   end
'
power=28.383 burn=150.02 down=28.192   end
power=28.383 burn=150.02 down=28.192   end
power=28.383 burn=150.02 down=20.457   end
power=28.383 burn=150.02 down=20.457   end
power=28.383 burn=150.02 down=0.0      end
power=28.383 burn=150.02 down=0.0      end
power=28.383 burn=150.02 down=0.0      end
power=28.383 burn=150.02 down=0.0      end
'
  o 135  cr  5.9  mn  0.33
 fe 12.9 co 0.075 ni  9.9
  zr 221 nb  0.71 sn  3.6
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'       .....end of input.....
end
```

APPENDIX B

SNIKR EXECUTION AND OUTPUT

This appendix contains five listings:

B.1: Automated SNIKR Execution Script. A UNIX script which can be used to automate the SNIKR calling sequence and data transfer requirements.

B.2: Sample SNIKR Output - Assembly Calculation. Output listing from a SNIKR assembly calculation.

B.3: Sample SNIKR Output - Subzone Calculation. Output listing from a SNIKR subzone calculation.

B.4: SNIKR1 Source Listing. FORTRAN source listing of the file snikr1.f

B.5: SNIKR3 Source Listing. FORTRAN source listing of the file snikr3.f

B.1: Automated SNIKR Execution Script.

```
#!/bin/csh
###### shell script to execute the SNIKR sequence ######
#
# define current and new temporary working directories
#
set RTNDIR=‘pwd‘
setenv TMPDIR /var/tmp/$USER.$$
mkdir $TMPDIR
#
# set up working directory links to snikr1 and snikr3 source code
#
if (!(-e snikr1))    ln -s ~udq/snikr/snikr1  $TMPDIR/snikr1
if (!(-e snikr3))    ln -s ~udq/snikr/snikr3  $TMPDIR/snikr3
#
# copy SAS2H output (specified by user) to temp directory as input
# for snikr1.  copy snikr1 input file snikr.in to temp dir.
#
cp $1 $TMPDIR/fort.72
cp snikr.in $TMPDIR
#
# change to temp directory, execute snikr1, and save (rename) snikr1
# output.
#
cd $TMPDIR
snikr1 <snikr.in >& snikr1.msg
mv fort.70 snikr1.out
#
# execute scale (origen) using the fort.74 file written by snikr1
#
~x4s/cmds/scale4 fort.74 origen.out >& origen.msg
#
# rename the unit 71 origen output file to the form expected by snikr3.
# execute snikr3.
#
mv ft71f001 fort.71
snikr3 >& snikr3.msg
#
# assemble all output & message files and copy back to home directory
#
#echo "          ***** SNIKR1 Output *****" > output
cat fort.73 > output
#
#  Go home and clean up your room
#
cd $RTNDIR
cp $TMPDIR/output $1_snikout
rm -r $TMPDIR
```

B.2: Sample SNIKR Output - Assembly Calculation.

(Note: the shaded region below represents the section extracted from this output for use in the KENO core model.)

```
 Batch  5 (Zone 2 Sub-zone 4), Assembly H9 , Burnup=18313 MWD/MTU
    burn=     18313.
    nlitl=     1
    nfis=     -2
    mixf=    102
    idmod=     4
 92234 92235 92236 92238 93237 94238 94239 94240 94241 94242
 95241 95243 96244  8016 36083 40093 42095 43099 44101 44103
 45103 45105 46105 46108 47109 53135 54131 54135 55133 55134
 55135 59141 60143 60145 60147 60148 61147 61148 61149 62147
 62149 62150 62151 62152 63153 63154 63155 64155 99999
 1697  689  129  879    1       .00
 1697  689  129  879    2       .10
 1697  689  129  879    3       .30
 1697  689  129  879    4      1.00
 1697  689  129  879    5      2.00
 1697  689  129  879    6      4.00
 1697  689  129  879    7      6.62
    2004  2.6176E-07   81206  2.0537E-30   81207  4.3944E-22   81208  3.2037E-19
   81209  2.1940E-26   82206  2.4687E-19   82207  1.1980E-16   82208  3.7894E-13
   82209  9.2683E-23   82210  4.3437E-18   82211  3.3348E-21   82212  1.8636E-16
   82214  1.1909E-22   83208  0.0000E+00   83209  9.8431E-19       0  0.0000E+00
   83210  2.6739E-21   83211  1.9768E-22   83212  1.7677E-17   83213  2.1647E-23
   83214  8.8429E-23   84210  6.1314E-20       0  0.0000E+00   84211  2.1847E-27
   84212  9.2887E-28   84213  3.2544E-32   84214  1.2166E-29   84215  2.7405E-27
   84216  7.0553E-22   84218  1.3778E-23   85217  2.5568E-28   86218  0.0000E+00
   86219  6.0968E-24   86220  2.7054E-19   86222  2.4475E-20   87221  2.3272E-24
   87223  2.7753E-23   88222  0.0000E+00   88223  1.5210E-18   88224  1.5386E-15
   88225  1.0124E-20   88226  3.7401E-15   88228  2.1359E-21   89225  6.8391E-21
   89227  1.0563E-15   89228  2.6070E-25   90226  0.0000E+00   90227  2.4552E-18
   90228  2.9335E-13   90229  1.9686E-15   90230  9.8480E-11   90231  1.2591E-15
   90232  1.4973E-11   90233  0.0000E+00   90234  3.2834E-13   91231  8.6989E-12
   91232  0.0000E+00   91233  1.8020E-13       0  1.1071E-17   91234  4.9449E-18
   91235  0.0000E+00   92230  0.0000E+00   92231  0.0000E+00   92232  1.3818E-11
   92233  5.2648E-11   92234  4.3043E-06   92235  3.0440E-04   92236  6.5943E-05
   92237  3.6950E-13   92238  2.2236E-02   92239  0.0000E+00   92240  6.1821E-30
   92241  0.0000E+00   93235  1.9502E-15       0  0.0000E+00   93236  1.2121E-11
   93237  5.2161E-06   93238  1.4600E-15   93239  2.9981E-13       0  5.2760E-32
   93240  5.4280E-34   93241  0.0000E+00   94236  2.9258E-12   94237  4.9837E-29
   94238  9.3473E-07   94239  1.1159E-04   94240  3.0023E-05   94241  1.1988E-05
   94242  2.9296E-06   94243  2.1353E-23   94244  3.0789E-19   94245  0.0000E+00
   94246  3.0144E-29   95239  0.0000E+00   95240  0.0000E+00   95241  4.8360E-06
       0  7.8937E-09   95242  1.0184E-13   95243  3.4268E-07       0  0.0000E+00
   95244  0.0000E+00   95245  3.9942E-27   95246  7.5312E-32   96241  1.3204E-39
   96242  2.3098E-11   96243  1.1960E-09   96244  3.4098E-08   96245  1.0745E-09
   96246  7.0327E-11   96247  6.0432E-13   96248  2.4288E-14   96249  0.0000E+00
   96250  7.0690E-23   96251  0.0000E+00   97249  1.0318E-18   97250  2.0871E-31
   97251  0.0000E+00   98249  2.0758E-16   98250  1.4881E-17   98251  8.2544E-18
   98252  3.3902E-19   98253  0.0000E+00   98254  5.6487E-37   98255  0.0000E+00
   99253  0.0000E+00       0  0.0000E+00   99254  0.0000E+00   99255  0.0000E+00
   16250  0.0000E+00
isotopic results for cool step  7
origen-s cooling time (yrs)=      6.62


 for use in csas

   u-234  102  0  4.3043E-06  end
```

```
  u-235  102  0  3.0440E-04  end
  u-236  102  0  6.5943E-05  end
  u-238  102  0  2.2236E-02  end
 np-237  102  0  5.2161E-06  end
 pu-238  102  0  9.3473E-07  end
 pu-239  102  0  1.1159E-04  end
 pu-240  102  0  3.0023E-05  end
 pu-241  102  0  1.1988E-05  end
 pu-242  102  0  2.9296E-06  end
 am-241  102  0  4.8360E-06  end
 am-243  102  0  3.4268E-07  end
 cm-244  102  0  3.4098E-08  end
  o      102  0  4.6454E-02  end
 kr-83   102  0  1.8067E-06  end
 zr-93   102  0  1.6519E-05  end
 mo-95   102  0  2.6191E-05  end
 tc-99   102  0  2.5747E-05  end
 ru-101  102  0  2.3597E-05  end
 ru-103  102  0  5.5877E-25  end
 rh-103  102  0  1.5516E-05  end
 rh-105  102  0  0.0000E+00  end
 pd-105  102  0  9.9025E-06  end
 pd-108  102  0  3.0830E-06  end
 ag-109  102  0  2.0966E-06  end
  i-135  102  0  0.0000E+00  end
 xe-131  102  0  1.1761E-05  end
 xe-135  102  0  0.0000E+00  end
 cs-133  102  0  2.8329E-05  end
 cs-134  102  0  1.8521E-07  end
 cs-135  102  0  8.9558E-06  end
 pr-141  102  0  2.4948E-05  end
 nd-143  102  0  2.0684E-05  end
 nd-145  102  0  1.5502E-05  end
 nd-147  102  0  0.0000E+00  end
 nd-148  102  0  7.6169E-06  end
 pm-147  102  0  9.6606E-07  end
 pm-148  102  0  5.9421E-28  end
 pm-149  102  0  0.0000E+00  end
 sm-147  102  0  5.9377E-06  end
 sm-149  102  0  1.2173E-07  end
 sm-150  102  0  6.2795E-06  end
 sm-151  102  0  3.9482E-07  end
 sm-152  102  0  2.8038E-06  end
 eu-153  102  0  1.8347E-06  end
 eu-154  102  0  2.7233E-07  end
 eu-155  102  0  7.4319E-08  end
 gd-155  102  0  1.2530E-07  end

for use when mixing in keno

mix= 102
  492234  4.3043E-06
  492235  3.0440E-04
  492236  6.5943E-05
  492238  2.2236E-02
   93237  5.2161E-06
   94238  9.3473E-07
  494239  1.1159E-04
  494240  3.0023E-05
  494241  1.1988E-05
   94242  2.9296E-06
   95241  4.8360E-06
   95243  3.4268E-07
   96244  3.4098E-08
    8016  4.6454E-02
   36083  1.8067E-06
   40093  1.6519E-05
   42095  2.6191E-05
```

43099	2.5747E-05
44101	2.3597E-05
44103	5.5877E-25
45103	1.5516E-05
45105	0.0000E+00
46105	9.9025E-06
46108	3.0830E-06
47109	2.0966E-06
53135	0.0000E+00
54131	1.1761E-05
54135	0.0000E+00
55133	2.8329E-05
55134	1.8521E-07
55135	8.9558E-06
59141	2.4948E-05
60143	2.0684E-05
60145	1.5502E-05
60147	0.0000E+00
60148	7.6169E-06
61147	9.6606E-07
61148	5.9421E-28
61149	0.0000E+00
62147	5.9377E-06
62149	1.2173E-07
62150	6.2795E-06
62151	3.9482E-07
62152	2.8038E-06
63153	1.8347E-06
63154	2.7233E-07
63155	7.4319E-08
64155	1.2530E-07
99999	0.0000E+00

B.3: Sample SNIKR Output - Subzone Calculation.

(Note: the shaded region below represents the section extracted from this output for use in CSASN calculations.)

```
 Subzone 1(Zone  1), Ave. Burnup=24688 MWD/MTU
    burn=     24688.
    nlitl=     1
    nfis=     -2
    mixf=      1
    idmod=     0
 92234 92235 92236 92238 93237 94238 94239 94240 94241 94242
 95241 95243 96244  8016 36083 40093 42095 43099 44101 44103
 45103 45105 46105 46108 47109 53135 54131 54135 55133 55134
 55135 59141 60143 60145 60147 60148 61147 61148 61149 62147
 62149 62150 62151 62152 63153 63154 63155 64155 99999
 1697  689  129  879    1       .00
 1697  689  129  879    2       .10
 1697  689  129  879    3       .30
 1697  689  129  879    4      1.00
 1697  689  129  879    5      2.00
 1697  689  129  879    6      4.00
 1697  689  129  879    7      6.62
    2004  6.7734E-07   81206  2.2564E-30   81207  6.4870E-22   81208  6.8767E-19
   81209  4.0295E-26   82206  3.4812E-19   82207  1.9198E-16   82208  8.3636E-13
   82209  1.7022E-22   82210  4.7721E-18   82211  4.9227E-21   82212  4.0002E-16
   82214  1.1274E-22   83208  0.0000E+00   83209  2.7535E-18       0  0.0000E+00
   83210  2.9378E-21   83211  2.9182E-22   83212  3.7944E-17   83213  3.9757E-23
   83214  8.3714E-23   84210  6.9237E-20       0  0.0000E+00   84211  3.2250E-27
   84212  1.9938E-27   84213  5.9771E-32   84214  1.1517E-29   84215  4.0455E-27
   84216  1.5144E-21   84218  1.3043E-23   85217  4.6957E-28   86218  0.0000E+00
   86219  9.0000E-24   86220  5.8070E-19   86222  2.3170E-20   87221  4.2741E-24
   87223  4.0965E-23   88222  0.0000E+00   88223  2.2452E-18   88224  3.3025E-15
   88225  1.8594E-20   88226  3.5407E-15   88228  2.7010E-21   89225  1.2561E-20
   89227  1.5591E-15   89228  3.2968E-25   90226  0.0000E+00   90227  3.6244E-18
   90228  6.2966E-13   90229  3.6155E-15   90230  8.5553E-11   90231  8.0231E-16
   90232  1.7955E-11   90233  0.0000E+00   90234  3.2707E-13   91231  1.1523E-11
   91232  0.0000E+00   91233  2.6410E-13       0  1.1028E-17   91234  4.9258E-18
   91235  0.0000E+00   92230  0.0000E+00   92231  0.0000E+00   92232  2.9442E-11
   92233  5.9192E-11   92234  3.5398E-06   92235  1.9396E-04   92236  7.3742E-05
   92237  5.4435E-13   92238  2.2150E-02   92239  0.0000E+00   92240  1.4340E-28
   92241  0.0000E+00   93235  3.8728E-15       0  0.0000E+00   93236  2.6878E-11
   93237  7.6445E-06   93238  3.1388E-15   93239  9.9217E-13       0  1.2238E-30
   93240  1.2591E-32   93241  0.0000E+00   94236  6.0627E-12   94237  8.5432E-29
   94238  2.0299E-06   94239  1.1939E-04   94240  4.2740E-05   94241  1.7661E-05
   94242  6.7702E-06   94243  3.1681E-22   94244  7.1418E-18   94245  0.0000E+00
   94246  1.2099E-27   95239  0.0000E+00   95240  0.0000E+00   95241  7.2966E-06
       0  1.6970E-08   95242  2.1893E-13   95243  1.1341E-06       0  0.0000E+00
   95244  0.0000E+00   95245  1.2640E-25   95246  3.0227E-30   96241  5.5408E-39
   96242  5.0918E-11   96243  4.3322E-09   96244  1.7108E-07   96245  6.9596E-09
   96246  7.2552E-10   96247  8.9663E-12   96248  5.5675E-13   96249  0.0000E+00
   96250  2.8372E-21   96251  0.0000E+00   97249  3.2652E-17   97250  8.4353E-27
   97251  2.8026E-45   98249  6.7390E-15   98250  6.1720E-16   98251  4.3665E-16
   98252  3.5078E-17   98253  0.0000E+00   98254  2.1287E-34   98255  0.0000E+00
   99253  0.0000E+00       0  0.0000E+00   99254  1.7326E-23   99255  2.7536E-42
   16250  0.0000E+00
isotopic results for cool step  7
origen-s cooling time (yrs)=      6.62


 for use in csas

   u-234    1  0  3.5398E-06  end
   u-235    1  0  1.9396E-04  end
```

```
  u-236    1  0  7.3742E-05  end
  u-238    1  0  2.2150E-02  end
 np-237    1  0  7.6445E-06  end
 pu-238    1  0  2.0299E-06  end
 pu-239    1  0  1.1939E-04  end
 pu-240    1  0  4.2740E-05  end
 pu-241    1  0  1.7661E-05  end
 pu-242    1  0  6.7702E-06  end
 am-241    1  0  7.2966E-06  end
 am-243    1  0  1.1341E-06  end
 cm-244    1  0  1.7108E-07  end
  o        1  0  4.6454E-02  end
 kr-83     1  0  2.1542E-06  end
 zr-93     1  0  2.1158E-05  end
 mo-95     1  0  3.3743E-05  end
 tc-99     1  0  3.3551E-05  end
 ru-101    1  0  3.1763E-05  end
 ru-103    1  0  5.8017E-25  end
 rh-103    1  0  2.0281E-05  end
 rh-105    1  0  0.0000E+00  end
 pd-105    1  0  1.5271E-05  end
 pd-108    1  0  5.3048E-06  end
 ag-109    1  0  3.3890E-06  end
  i-135    1  0  0.0000E+00  end
 xe-131    1  0  1.4856E-05  end
 xe-135    1  0  0.0000E+00  end
 cs-133    1  0  3.6801E-05  end
 cs-134    1  0  3.1880E-07  end
 cs-135    1  0  1.1736E-05  end
 pr-141    1  0  3.2960E-05  end
 nd-143    1  0  2.4846E-05  end
 nd-145    1  0  1.9841E-05  end
 nd-147    1  0  0.0000E+00  end
 nd-148    1  0  1.0206E-05  end
 pm-147    1  0  1.0230E-06  end
 pm-148    1  0  6.2838E-28  end
 pm-149    1  0  0.0000E+00  end
 sm-147    1  0  7.0185E-06  end
 sm-149    1  0  1.1882E-07  end
 sm-150    1  0  8.7331E-06  end
 sm-151    1  0  4.3137E-07  end
 sm-152    1  0  3.7387E-06  end
 eu-153    1  0  2.8292E-06  end
 eu-154    1  0  5.2182E-07  end
 eu-155    1  0  1.2753E-07  end
 gd-155    1  0  2.1492E-07  end


for use when mixing in keno

mix=   1
   92234  3.5398E-06
   92235  1.9396E-04
   92236  7.3742E-05
   92238  2.2150E-02
   93237  7.6445E-06
   94238  2.0299E-06
   94239  1.1939E-04
   94240  4.2740E-05
   94241  1.7661E-05
   94242  6.7702E-06
   95241  7.2966E-06
   95243  1.1341E-06
   96244  1.7108E-07
    8016  4.6454E-02
   36083  2.1542E-06
   40093  2.1158E-05
   42095  3.3743E-05
```

43099	3.3551E-05
44101	3.1763E-05
44103	5.8017E-25
45103	2.0281E-05
45105	0.0000E+00
46105	1.5271E-05
46108	5.3048E-06
47109	3.3890E-06
53135	0.0000E+00
54131	1.4856E-05
54135	0.0000E+00
55133	3.6801E-05
55134	3.1880E-07
55135	1.1736E-05
59141	3.2960E-05
60143	2.4846E-05
60145	1.9841E-05
60147	0.0000E+00
60148	1.0206E-05
61147	1.0230E-06
61148	6.2838E-28
61149	0.0000E+00
62147	7.0185E-06
62149	1.1882E-07
62150	8.7331E-06
62151	4.3137E-07
62152	3.7387E-06
63153	2.8292E-06
63154	5.2182E-07
63155	1.2753E-07
64155	2.1492E-07
99999	0.0000E+00

B.4: SNIKR1 Source Listing.

```
      program snikr1
c
c     new version july, 1993.
c
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
       dimension tstep(10),tcool(20),ncool(20)
      data tstep/0.1,0.3,1.0,2.0,4.0,7.0,10.,13.,16.,20./
      nstep=76
      nall=0
c
c     read all control data
c
      call rdall(tcool)
c
c  write input to nout
c
      nout=nout1
      write(nout,120)ittl
      write(nout,130)n72
      write(nout,140)nout
      write(nout,150)burn
      write(nout,160)bconv
      write(nout,170)ncyc
      write(nout,140)nors
      write(nout,180) (tcool(i), i=1,ntcool)
      write(nout,190)nlitl
  120 format(20a4)
  130 format(4x,i2)
  140 format(5x,i2)
  150 format(5x,f8.1)
  160 format(6x,f6.4)
  170 format(5x,i2)
  180 format(10(1x,f6.2))
  190 format(8x,i2)
c
c  retrieve number densities from sas2h output (n72) for burn
c
      call density
c     write(nout,110)(iddk(i),addk(i),i=1,itot)
c 110 format(4(i8,2x,1p,e10.4))
c
      call litel(0)
c
c  if the requested burnup is zero, bypass origen-s calculations.
c
      if(burn.eq.0.0) go to 1000
c
c  prepare an origen-s run to calculate decay for requested
c  cooling times
c
      call tymstp(tstep,tcool,ncool)
c
      call wrtors(tstep)
c
c  write data for transfer to step 3.
c
      call wrtall(ncool)
      go to 2000
c
c  for the special case of burn=0, prepare ice and keno input here
```

```
c  (i.e. not in step 3)
c
 1000 continue
      nout=nout3
      call rdctin1
      call clect(1)
      call wrtice
c
c  write number densities for mixing in keno to file nout3
c
      call wrtkeno
c
c  write a record for scale indicating that it abort origen step
c
      write(nors,210)
  210 format('#origens''1t''  ''5$$ 3 2t''4t''56$$ f0 5t''end')
c
c  write a record for transfer to step 3 indicating that
c  snikr3 exit immediately
c
      write(nstep) (ittl(i),i=1,20)
      n72=-1000
      write(nstep) n72,nout1,nors,n71,nice,nout3
c
 2000 stop
      end
c-----------------------------------------------------------------------
      subroutine rdall(tcool)
c
c  read all data needed for snikr1 and for snikr3.
c
c  wrtall will write this data to a temporary file (76)
c  for transfer to step 3.
c
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
       dimension tcool(20)
      character*6 ichk
      n5=5
c
c  read title card
c
      read(n5,120) ittl
c
c  read device numbers
c
      read(n5,*) n72,nout1,nors,n71,nice,nout3
      read(n5,*) ncyc,burn,ntcool
c
c  read ntcool values of tcool
c
      read(n5,*) (tcool(i), i=1,ntcool)
      read(n5,*) nlitl,mixf,idmod
c
c  read in light element data if nlitl > 0.
c
      if(nlitl.le.0) go to 1000
      read(n5,120) lttl
      read(n5,*) (idlitl(i),adlitl(i),ltyp(i), i=1,nlitl)
 1000 continue
c
c  read in criticality data if nfis .gt. 0
c
      read(n5,*) nfis
```

```
      if(nfis.gt.0) then
      ncrit=nfis
      read(n5,120) crittl
      read(n5,*) (idcrit(i), i=1,ncrit)
      endif
c
c  write input to nout
c
c     write(nout,120)ittl
c     write(nout,130)n72
c     write(nout,140)nout
c     write(nout,150)burn
c     write(nout,160)bconv
c     write(nout,170)ncyc
c     write(nout,140)nors
c     write(nout,180)cool
c     write(nout,190)nlitl
      return
  110 format(a6)
  120 format(20a4)
  130 format(4x,i2)
  140 format(5x,i2)
  150 format(5x,f8.1)
  160 format(6x,f6.4)
  170 format(5x,i2)
  180 format(8x,f6.2)
  190 format(8x,i2)
c 195 format(1x,i5,e10.4,2x,i1)
      end
c
c-----------------------------------------------------------------------
      subroutine density
c
c  get the iddk and addk arrays for the burnup times.
c  rdf72 is called and it reads the sas2h data.
c  lagint interpolates for each nuclide.
c
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
       dimension rdburn(10),a(2000),b(2000),ad(2000,10)
c
       nc=-1
       nbn=0
 1000  nc=nc+1
       nbn=nbn+1
       call rdf72(nc,ad,rdbrn)
c
c  convert rdbrn from mwd/assy to mwd/mtu
c
       rdbrn=rdbrn/bconv
       write(nout,130)rdbrn
       rdburn(nbn)=rdbrn
       if(burn.eq.0.0) go to 40
       if(nc.lt.ncyc)go to 1000
c
   40  smact0=0.
       i1=ile+1
       i2=ile+iact
       do 31 i=i1,i2
   31  smact0=smact0+ad(i,1)
       write(nout,105)smact0
  105  format('smact0=',1pe10.4)
       if(burn.eq.0.0)then
       ibn=1
```

```
       go to 1500
       end if
      if(burn.ge.rdburn(2))go to 15
      write(nout,110)
      write(nout,120)burn,rdburn(2)
      ibn=2
      go to 1500
  15  continue
      if(burn.gt.rdburn(nbn))then
      ibn=nbn
      write(nout,110)
      write(nout,140)burn,rdburn(nbn)
      go to 1500
      end if
       do 20 i=1,nbn
      bdiff=abs(rdburn(i)-burn)/burn
      if(bdiff.lt.0.01)then
      ibn=i
      go to 1500
      end if
      if(rdburn(i).gt.burn)go to 1250
      ilow=i
   20 continue
 1250 continue
      ihi=ilow+1
c
c  lagrangian interpolation
c
      do 27 i=1,itot
      do 26 j=2,nbn
   26 a(j-1)=ad(i,j)
      do 28 k=2,nbn
  28  b(k-1)=rdburn(k)
      nbint=nbn-1
      call lagint(b,a,nbint,burn,conc)
   27 addk(i)=conc
c
      return
 1500 continue
c     write(nout,160)
c     write(nout,150)(iddk(i),ad(i,ibn),i=1,itot)
      do 30 j=1,itot
   30 addk(j)=ad(j,ibn)
c     write(nout,150)(iddk(i),addk(i),i=1,itot)
      return
  110 format('$$warning --------')
  120 format('requested burnup of ',f10.3,' gwd/mtu is less than first'
     &/'cycle burnup of ',f10.3,'.  first cycle burnup has been used')
  130 format('rdbrn=',f10.3)
  140 format('requested burnup of ',f10.3,' gwd/mtu is greater than last
     &'/'cycle burnup of ',f10.3,'.   final cycle burnup has been used')
c 150 format(4(i8,2x,1p,e10.4))
c 160 format('past 1500')
      end
c-----------------------------------------------------------------------
       subroutine rdf72(nc,ad,rdburn)
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
       dimension ad(2000,10)
       character*4 itest,ttl72(20)
       nct=nc+1
       ind=3
c
c  read the following quantities from file 72 in addition to nuclide
```

```
c  id and number density
c     1) lpass, library pass no. used for origen-s case
c     2) mtime, position no. of data from unit no. 71
c     3) tw, time from start of assembly burnup, d
c     4) dum1
c     5) rdburn, accumulated burnup at tw, mwd/assembly
c     6) spwr, specific power of cycle, kw/kg u
c     7) dum3
c     8) bconv, initial metric ton u weight per assembly
c
       read(n72,100,end=2000)lpass,mtime,tw,dum1,rdburn,spwr,dum3,bconv
       if(nct.eq.1)write(nout,99)
   99  format(/,
     &/'1) lpass, library pass no. used for origen-s case',
     &/'2) mtime, position no. of data from unit no. 71',
     &/'3) tw, time from start of assembly burnup, d',
     &/'4) dum1',
     &/'5) rdburn, accumulated burnup at tw, mwd/assembly',
     &/'6) spwr, specific power of cycle, kw/kg u',
     &/'7) dum3',
     &/'8) bconv, initial metric ton u weight per assembly')
       write(nout,100) lpass,mtime,tw,dum1,rdburn,spwr,dum3,bconv
       if(lpass.eq.ncyc)ind=1
       if(lpass.ne.nc)then
       write(nout,101)nc,lpass,ncyc
  101  format('nc=',i2,' lpass=',i2,' ncyc=',i2,' mtime=',i2,' ind=',i2)
       stop 7210
       end if
       if(mtime.ne.ind)then
       write(nout,101)nc,lpass,ncyc,mtime,ind
       if(nc.eq.ncyc.and.mtime.eq.3)go to 5
       stop 7220
       end if
   5   continue
       read(n72,110) itot,ile,iact,ifp
       isum=ile+iact+ifp
       if(isum.ne.itot)stop 7230
       do 10 i=1,4
  10   read(n72,140)
       read(n72,120)(iddk(i),ad(i,nct),i=1,itot)
c      write(nout,102)nct,lpass,ncyc
c 102  format('nct=',i2,' lpass=',i2,' ncyc=',i2,'  ad array')
c      write(nout,120)(iddk(i),ad(i,nct),i=ile,ile+16)
       read(n72,125)ttl72
       write(nout,125)ttl72
c      write(nout,160)rdburn,nct
 1000  read(n72,130)itest
       if(itest.ne.'----')go to 1000
       return
 2000  continue
       write(nout,150)
       return
  100  format(2i10,6(1x,1p,e9.3))
  110  format(4i10)
  120  format(4(i8,2x,1p,e10.4))
  125  format(20a4)
  130  format(a4)
  140  format( )
  150  format('***eof error reading file 72***')
c 160  format('rdburn(f72)=',f10.3,' nct=',i2)
       end
c-----------------------------------------------------------------------
      subroutine lagint(x,y,n,xint,yout)
c
c  this subroutine performs lagrangian interpolation within a set of
c  (x,y) pairs to give the y value corresponding to xint.  the degree of
c  the interpolating polynomial is one less than the number of points
c  supplied.  taken from gerald's "applied numerical analysis" pg 181
```

```
c  parameters are:
c       x - array of values of the independent variable
c       y - array of function values corresponding to x
c       n - number of points
c    xint - the x-value for which estimate of y is desired
c    yout - the y-value returned to caller
       dimension x(10),y(10)
c
c  check for zero or near-zero number densities.
c
       nc0=0
       nm1=n-1
       do 5 i=1,n
       if(y(i).gt.1.0e-25)go to 5
       nc0=nc0+1
  5    continue
       if(nc0.lt.nm1)go to 8
       yout=0.0
       return
  8    continue
c
       yout=0.0
       do 20 i=1,n
        term=y(i)
        do 10 j=1,n
         if(i.eq.j)go to 10
         term=term*(xint-x(j))/(x(i)-x(j))
   10   continue
          yout=yout+term
   20   continue
       if(yout.le.1.0e-25)yout=0.0
        return
        end
c-----------------------------------------------------------------------
       subroutine tymstp(tstep,tcool,ncool)
        common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
        common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
        common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
        common /ident/ idlitl(40),idcrit(200),iddk(2000)
        common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
        common /title/ ittl(20),lttl(20),crittl(20)
       dimension tstep(10),tcool(20),ncool(20)
c
c  if the maximum cooling time is .le. 20 yrs. do the following:
c
c  for each requested cooling time, see if it corresponds to
c  a value in the default tstep array and if not, adjust the
c  nearest element in tstep to conform to requested time.
c
c  however, if the maximum requested cooling time is greater
c  than 20 years, we do the following:
c
c  ten new time steps are generated that are evenly spaced in
c  a logarithmic sense.  depending on the final decay time needed
c  the first few of the old time steps may be retained.
c
c  these generated time steps are now the defaults.  the
c  last one corresponds to the maximum requested one and
c  the others will be adjusted as explained above, so that
c  all the requested times are contained in tstep.
c
       if(tcool(1).lt.0.0) then
       nall=1
       tcool(1)=abs(tcool(1))
       endif
c
       if(tcool(ntcool).gt.20.0) then
       tot=tcool(ntcool)
```

```
      j=3
      if(tot.gt.5000.0) j=1
      totl=log(tot)-log(tstep(j))
      ratio=exp(totl/(10-j))
c
      do 50 i=j+1,10
      tstep(i)=ratio*tstep(i-1)
   50 continue
c
      do 60 i=j+1,10
      ts=tstep(i)
      if(ts.gt.5000.0) tstep(i)=anint(ts)
   60 continue
      endif
c
      if(nall.eq.1) go to 2000
      if(tcool(1).lt.tstep(1)) tstep(1)=tcool(1)
c
      k=0
      do 1000 j=1,ntcool
      cool=tcool(j)
c
      do 100 i=1,10
      if(cool.ne.tstep(i)) go to 100
      k=k+1
      ncool(k)=i
      go to 1000
  100 continue
c
      do 110 i=1,9
      if(tstep(i).lt.cool.and.cool.lt.tstep(i+1)) then
      icool=i
      go to 120
      endif
  110 continue
c
  120 f1=cool-tstep(icool)
      f2=tstep(icool+1)-cool
      if(f1.gt.f2) icool=icool+1
      if(j.eq.1) go to 125
      if(tcool(j-1).eq.tstep(icool)) icool=icool+1
  125 continue
c
      tstep(icool)=cool
      k=k+1
      ncool(k)=icool
 1000 continue
c
 2000 continue
c
      return
      end
c-----------------------------------------------------------------------
       subroutine litel(iflag)
c
c  this subroutine checks to see if any light elements have been
c  requested by the user; if oxygen was not explicitly requested
c  it will be added.
c
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
c
       if(nlitl.ne.0)go to 10
       nlitl=1
```

```
      idlitl(1)=8016
      ltyp(1)=1
      go to 30
   10 continue
      do 20 i=1,nlitl
      if(idlitl(i).eq.8016)go to 35
   20 continue
      nlitl=nlitl+1
      idlitl(nlitl)=8016
      ltyp(nlitl)=1
   30 continue
      if(iflag.eq.1)go to 45
      adlitl(nlitl)=2.0*smact0
      write(nout,110)adlitl(nlitl)
  110 format('adlitl(nlitl)=',1pe10.4)
   35 continue
      do 40 i=1,nlitl
      do 40 j=1,ile
      idlt=idlitl(i)*10
      if(idlt.ne.iddk(j))go to 40
      write(nout,150)iddk(j),addk(j)
      if(ltyp(i).eq.1)addk(j)=adlitl(i)
      if(ltyp(i).eq.2.and.addk(j).eq.0.)addk(j)=adlitl(i)
      if(ltyp(i).eq.3.and.addk(j).ne.0.)addk(j)=addk(j)+adlitl(i)
      write(nout,140)idlt,adlitl(i)
      write(nout,150)iddk(j),addk(j)
   40 continue
   45 continue
      do 50 i=1,nlitl
   50 if(idlitl(i).eq.8016)write(nout,120)adlitl(i)
      do 60 j=1,itot
   60 if(iddk(j).eq.80160)write(nout,130)j,iddk(j),addk(j)
      return
  120 format('adlitl for 8016= ',1pe10.4)
  130 format(i2,i10,' addk for 8016=',1pe10.4)
  140 format('litel array',2x,i6,2x,1pe10.4)
  150 format('decay array',2x,i6,2x,1pe10.4)
      end
c-----------------------------------------------------------------------
      subroutine wrtors(tstep)
c
c  aburn is the assembly burnup (mwd/assembly), n71 is the
c  file that the binary output is to be written to, tstep
c  is the array containing the decay time intervals, and
c  tburn is the total burnup (gwd/mtu)
c
c
c  this routine writes the input to the origen-s
c  decay case - ***presently in card image form to
c  unit 'nors' for input to ors, will change to write
c  binary input for driver to call origen-s
c
      common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
      common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
      common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
      common /ident/ idlitl(40),idcrit(200),iddk(2000)
      common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
      common /title/ ittl(20),lttl(20),crittl(20)
      dimension tstep(10)
c  convert burnup to gwd/mtu - tburn
      tburn=burn/1000.
c  convert burnup to mwd/assembly - aburn
      aburn=burn*bconv
        write(nors,203) n71
        write(nors,204) aburn
        write(nors,205)
      write(nors,206)itot
      write(nors,207)tburn
```

```
       write(nors,208)
       write(nors,309)(tstep(k),k=1,10)
       write(nors,211)
       write(nors,201)
       write(nors,220)(iddk(k),addk(k),k=1,itot)
       write(nors,202)
       write(nors,220)(iddk(k),addk(k),k=1,itot)
       write(nors,212)ile,iact,ifp
       write(nors,214)
       write(nors,213)
       return
  201  format('73u'/'  (3(i8,12x))')
  202  format('74u'/'  (3(10x,1p,e10.4))')
  203  format('#origens'/'0$$ a11 ',i2,' e  1t')
  204  format('decay only cases for snikr at burnup ',1p,e9.3,
     &' mwd/assembly')
  205  format('2t'/'35$$ 0 4t')
  206  format('56$$  a5 1  1 a13 ',i4,' 5 3 0 4 e 5t')
  207  format('burnup - ',1p,e9.3,' gwd/mtu')
  208  format('units - atoms/barn-cm')
  209  format('60** ',10(1x,f5.2))
  309  format('60** ', 6(1x,1p,e9.2))
  211  format('65$$ 1 a22 1 a43 1 e')
  212  format('75$$ ',i3,'r1 ',i3,'r2 ',i3,'r3'/'6t')
  213  format('56$$ f0 t'/'end')
  214  format('56$$ 0 -10 a10 0 e t')
  220  format(3(i8,2x,1p,e10.4))
       end
c-----------------------------------------------------------------------
       subroutine wrtall(ncool)
c
c   write all data that may be needed for step 3 to a temporary file
c
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
       dimension ncool(20)
c
c  we have not yet decided whether we should read in the value of nstep
c  or , rather, let it be a predetermined value (e.g. 76).
c
      nstep=76
      write(nstep) (ittl(i), i=1,20)
      write(nstep) n72,nout1,nors,n71,nice,nout3
      write(nstep) ncyc,burn,ntcool,nall
      write(nstep) (ncool(i),i=1,ntcool)
      write(nstep) nlitl,mixf,idmod,nfis
c
      if(nlitl.le.0) go to 1000
      write(nstep) (idlitl(i),adlitl(i),ltyp(i), i=1,nlitl)
 1000 continue
      if(nfis.le.0) go to 2000
      write(nstep) (idcrit(i), i=1,ncrit)
 2000 continue
      return
      end
c-----------------------------------------------------------------------
      subroutine rdctin1
c
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
```

```
      character*6 ichk
      dimension idat1(25),idat2(37),idat3(49),idat4(193)
      data idat1/92234,92235,92236,92238,94238,94239,94240,94241,
     &94242,95241,8016,42095,43099,45103,55133,55135,60143,60145,
     &62147,62149,62150,62151,62152,63153,64155/
      data idat2/92234,92235,92236,92238,93237,94238,94239,94240,94241,
     &94242,95241,95243,96244,8016,40093,42095,43099,44101,45103,46105,
     &46108,47109,55133,55135,59141,60143,60145,61147,62147,62149,
     &62150,62151,62152,63153,63154,63155,64155/
      data idat3/92234,92235,92236,92238,93237,94238,94239,94240,94241,
     &94242,95241,95243,96244,8016,36083,40093,42095,43099,
     &44101,44103,45103,45105,46105,46108,47109,53135,54131,54135,
     &55133,55134,55135,59141,60143,60145,60147,60148,61147,61148,
     &61149,62147,62149,62150,62151,62152,63153,63154,63155,64155,
     &99999/
      data idat4/ 32072,32073,32074,32076,33075,34076,34077,34078,34080,
     &34082,35079,35081,36080,36082,36083,36084,36085,36086,37085,37086,
     &37087,38086,38087,38088,38089,38090,39089,39090,39091,40090,40091,
     &40092,40093,40094,40095,40096,41093,41094,41095, 8016,42095,42096,
     &42097,42098,42099,42100,43099,44099,44100,44101,44102,44104,44105,
     &44106,46104,46105,46106,46107,46108,46110,47107,47109,47111,48108,
     &48110,48111,48112,48113,48114,      48116,49113,49115,50115,50116,
     &50117,50118,50119,50120,50122,50123,50124,50125,50126,51121,51123,
     &51124,51125,51126,52122,52123,52124,52125,52126,      52128,
     &52130,52132,53127,53129,53130,53131,54128,54129,54130,54131,54132,
     &54133,54134,54136,55133,55134,55135,55136,55137,56134,56135,56136,
     &56137,56138,56140,57139,57140,58140,58141,58142,58143,58144,59141,
     &59142,59143,60142,60143,60144,60145,60146,60150,61151,62147,62148,
     &62150,62151,62152,62153,62154,63151,63152,63156,63157,64154,64156,
     &64157,64158,64160,65159,65160,66160,66161,66162,66163,66164,67165,
     &68166,68167,44103,45103,45105,53135,54135,60147,60148,61147,61148,
     &62149,61149,63153,63154,63155,      64155,90232,91233,92233,92234,
     &92235,92236,92238,93237,94238,94239,94240,94241,94242,95241,
     &95243,96244/
      n5=5
c
c  this routine puts in placc the ids of the criticality nuclides.
c  this is normally done by rdstp3 in step 3.  it is done here
c  when burn=0.
c
c  check flag nfis to determine which fuel nuclides will be used in
c  keno calculations:
c             =0  use ttc713 intersection with sid bierman's nucs
c             =-1 use ttc713
c             =-2 use ttc713 u sid u vepco u casmo
c             =-3 use all 27burnuplib nuclides
c             =n  read in user's choice of nuclides
      if(nfis.eq.0)then
      ncrit=25
      do 10 i=1,ncrit
  10  idcrit(i)=idat1(i)
      go to 500
      end if
      if(nfis.eq.-1)then
      ncrit=37
      do 20 i=1,ncrit
  20  idcrit(i)=idat2(i)
      go to 500
      end if
      if(nfis.eq.-2)then
      ncrit=49
      do 21 i=1,ncrit
  21  idcrit(i)=idat3(i)
      go to 500
      end if
      if(nfis.eq.-3)then
      ncrit=193
      do 31 i=1,ncrit
```

```
  31  idcrit(i)=idat4(i)
      go to 500
      end if
      if(nfis.gt.0)ncrit=nfis
 500  continue
c
c  write input to nout
c
      write(nout,120)ittl
      write(nout,130)n71
      write(nout,140)nice
      write(nout,140)nout
      write(nout,150)nfis
      write(nout,160)mixf
      write(nout,145)idmod
      write(nout,170)(idcrit(i),i=1,ncrit)
  110 format(a6)
  120 format(20a4)
  130 format(4x,i2)
  140 format(5x,i2)
  145 format(6x,i2)
  150 format(8x,i3)
  160 format(5x,i4)
  170 format(10(1x,i5))
      return
      end
c-----------------------------------------------------------------------
       subroutine clect(iflag)
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
       dimension idlfp(165)
      data idlfp/ 32072,32073,32074,32076,33075,34076,34077,34078,34080,
     &34082,35079,35081,36080,36082,36083,36084,36085,36086,37085,37086,
     &37087,38086,38087,38088,38089,38090,39089,39090,39091,40090,40091,
     &40092,40093,40094,40095,40096,41093,41094,41095,42094,42095,42096,
     &42097,42098,42099,42100,43099,44099,44100,44101,44102,44104,44105,
     &44106,46104,46105,46106,46107,46108,46110,47107,47109,47111,48108,
     &48110,48111,48112,48113,48114,48115,48116,49113,49115,50115,50116,
     &50117,50118,50119,50120,50122,50123,50124,50125,50126,51121,51123,
     &51124,51125,51126,52122,52123,52124,52125,52126,52127,52128,52129,
     &52130,52132,53127,53129,53130,53131,54128,54129,54130,54131,54132,
     &54133,54134,54136,55133,55134,55135,55136,55137,56134,56135,56136,
     &56137,56138,56140,57139,57140,58140,58141,58142,58143,58144,59141,
     &59142,59143,60142,60143,60144,60145,60146,60150,61151,62147,62148,
     &62150,62151,62152,62153,62154,63151,63152,63156,63157,64154,64156,
     &64157,64158,64160,65159,65160,66160,66161,66162,66163,66164,67165,
     &68166,68167/
      nlfp=165
c
c  extract nuclides needed for criticality calculations for this
c  burnup and cooling time.  take requested light elements from
c  the light element library (1st ile entries in iddk/addk),
c  actinides from the actinide data (next iact entries in iddk/addk),
c  and fission products from the final ifp entries in iddk/addk)
c
c  nlitl will be at least 1, to account for oxygen.  the only
c  situation that will allow it to be larger than 1 is if the
c  user has chosen to input a set of isotopics different from
c  the burnup credit nuclides (ie., ttc-0713 or bierman's) and
c  has chosen to enter more light elements than just oxygen
c
c  if iflag=1 change all iddk by factor of 10 (from 72 not 71)
       if(iflag.eq.0)go to 20
       do 10 i=1,itot
```

```
   10  iddk(i)=iddk(i)/10
   20  continue
       do 40 i=1,nlitl
       do 30 j=1,ile
       if(iddk(j).ne.idlitl(i)) go to 30
       adlitl(i)=addk(j)
       go to 40
   30  continue
       write(nout,102)idlitl(i),n71
  102  format('0'/'****error, no match for light element ',i8,
     &' was found on unit ',i2)
       stop 7102
   40  continue
       nlp1=ile+1
       do 70 i=1,ncrit
        if(idcrit(i).eq.99999)go to 70
       adcrit(i)=0.0
       do 60 j=nlp1,itot
       if(iddk(j).ne.idcrit(i)) go to 60
       adcrit(i)=addk(j)
       go to 70
   60  continue
       do 65 k=1,nlitl
       if(idcrit(i).eq.idlitl(k))go to 70
   65  continue
       write(nout,103)idcrit(i),n71
  103  format('0'/'****error, no match for nuclide ',i8,
     &' was found on unit ',i2)
       stop 7103
   70  continue
c  add contribution from light element and actinide/fission product libr
       do 80 i=1,nlitl
       do 80 j=1,ncrit
       if(idcrit(j).ne.idlitl(i))go to 80
       adcrit(j)=adcrit(j)+adlitl(i)
   80  continue
c
       return
       end
c-----------------------------------------------------------------------
      subroutine wrtice
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
      dimension i2(200),i5(200),i11(201),idact(7)
      character*4 dum,t,ice,end
       data idact/92234,92235,92236,92238,94239,94240,94241/
c
      t = '  t '
      ice = '#ice'
      end = 'end '
      mix=1
c
      write(nice,110)ice
      write(nice,110)ittl
 110  format(20a4)
c
      dum = '1$$ '
      write(nice,110)dum
      ii = 0
      i4 = 10
      kopt = 4
      write(nice,120)mix,ncrit,ii,ii,ii,i4,kopt
 120  format(6i12)
      write(nice,110)t
```

```
c
      do 10 i=1,ncrit
  10  i2(i)=1
c
      dum = '2$$ '
      write(nice,110)dum
      write(nice,120)(i2(i),i=1,ncrit)
c
      if(idmod.eq.0)go to 35
      do 30 j=1,7
      do 30 i=1,ncrit
      if(idcrit(i).ne.idact(j))go to 30
      idcrit(i)=idcrit(i)+100000*idmod
      idact(j) =idact(j) +100000*idmod
  30  continue
  35  continue
c
      dum = '3$$ '
      write(nice,110)dum
      write(nice,120)(idcrit(i),i=1,ncrit)
c
      dum = '4** '
      write(nice,110)dum
      write(nice,130)(adcrit(i),i=1,ncrit)
 130  format(1p,6e12.4)
c
      i5(1)=4
      dum = '5$$ '
      write(nice,110)dum
      write(nice,120)(i5(i),i=1,mix)
      write(nice,110)t
c
      dum= '7$$ '
      write(nice,110)dum
      write(nice,140)
      write(nice,110)t
 140  format('  a8 2 e')
c
      i11(1)=1
      i11(2)=mixf
      dum = '11$$'
      write(nice,110)dum
      write(nice,120)(i11(i),i=1,mix+1)
      write(nice,110)t
      write(nice,110)end
c
      if(idmod.eq.0)go to 45
      do 40 j=1,7
      do 40 i=1,ncrit
      if(idcrit(i).ne.idact(j))go to 40
      idcrit(i)=idcrit(i)-100000*idmod
      idact(j) =idact(j) -100000*idmod
  40  continue
  45  continue
c
      return
      end
c-----------------------------------------------------------------------
      subroutine wrtkeno
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
      character*2 iname(105),ics(200)
       dimension mass(200),idact(7)
       data idact/92234,92235,92236,92238,94239,94240,94241/
      data iname/' h','he','li','be',' b',' c',' n',' o',' f','ne','na',
     & 'mg','al','si',' p',' s',
```

```
     &'cl','ar',' k','ca','sc','ti',' v','cr','mn','fe','co',
     &'ni','cu','zn','ga','ge','as','se','br','kr','rb',
     &'sr',' y','zr','nb','mo','tc','ru','rh','pd','ag','cd',
     &'in','sn','sb','te',' i','xe','cs','ba','la','ce',
     &'pr','nd','pm','sm','eu','gd','tb','dy','ho','er',
     &'tm','yb','lu','hf','ta',' w','re','os','ir','pt',
     &'au','hg','tl','pb','bi','po','at','rn','fr','ra',
     &'ac','th','pa',' u','np','pu','am','cm','bk','cf',
     &'es','fm','md','no','lr','rf','ha'/
       do 15 k=1,ncrit
       if(idcrit(k).eq.99999)go to 15
       iz=idcrit(k)/1000
       mass(k)=idcrit(k)-iz*1000
       idff=iz/100
       if(idff.gt.0)iz=iz-idff*100
       ics(k)=iname(iz)
  15   continue
       do 20 i=1,4
  20   write(nout,101)
       write(nout,202)
       write(nout,101)
       do 30 j=1,ncrit
       if(idcrit(j).eq.99999)go to 30
       if(ics(j).eq.' o')then
       write(nout,206)ics(j),mixf,adcrit(j)
       go to 30
       end if
       if(mass(j).lt.10)write(nout,203)ics(j),mass(j),mixf,adcrit(j)
       if(mass(j).ge.10.and.mass(j).lt.100)write(nout,204)ics(j),
     &mass(j),mixf,adcrit(j)
       if(mass(j).ge.100)write(nout,205)ics(j),mass(j),mixf,adcrit(j)
   30  continue
c
      if(idmod.eq.0)go to 5
      do 3 j=1,7
      do 3 i=1,ncrit
      if(idcrit(i).ne.idact(j))go to 3
      idcrit(i)=idcrit(i)+100000*idmod
      idact(j) =idact(j) +100000*idmod
    3 continue
    5 continue
c
       do 10 i=1,4
  10   write(nout,101)
       write(nout,102)
       write(nout,101)
       write(nout,104)mixf
       write(nout,103)(idcrit(j),adcrit(j),j=1,ncrit)
c
      if(idmod.eq.0)go to 25
      do 23 j=1,7
      do 23 i=1,ncrit
      if(idcrit(i).ne.idact(j))go to 23
      idcrit(i)=idcrit(i)-100000*idmod
      idact(j) =idact(j) -100000*idmod
  23  continue
  25  continue
c
       return
  101  format(a4)
  102  format(' for use when mixing in keno')
  103  format(i9,2x,1p,e10.4)
  104  format(' mix=',i4)
  202  format(' for use in csas')
  203  format(2x,a2,'-',i1,4x,i3,2x,'0',2x,1p,e10.4,'  end')
  204  format(2x,a2,'-',i2,3x,i3,2x,'0',2x,1p,e10.4,'  end')
  205  format(2x,a2,'-',i3,2x,i3,2x,'0',2x,1p,e10.4,'  end')
  206  format(2x,a2,6x,i3,2x,'0',2x,1p,e10.4,'  end')
       end
```

B.5: SNIKR3 Source Listing.

```
      program snikr3
c
c  new version, july, 1993.
c
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
       dimension tym(20),ncool(20)
c
c  read material to be transferred from step 1.
c
      call rdstp3(ncool)
c
      if(n72.eq.-1000) go to 2000
c
      if(nall.eq.1) then
      ntcool=11
      do 10 k=1,11
      ncool(k)=k-1
   10 continue
      endif
c
c  loop through designated cooling times
c
      do 1000 i=1,ntcool
      npos=ncool(i)+1
      call rdf71(npos,tym)
      rewind n71
      call clect(0)
c
      write(nout,107)npos
      write(nout,108)tym(npos)
      write(nice,107)npos
      write(nice,108)tym(npos)
c
      call wrtice
c
c  use mixed cross sections written on unit nice in keno calc
c
  107 format('isotopic results for cool step ',i2)
  108 format('origen-s cooling time (yrs)=',f10.2)
c
      call wrtkeno
 1000 continue
c
 2000 continue
c
      stop
      end
c---------------------------------------------------------------------
      subroutine rdstp3(ncool)
c
c  this module reads the data that were written to a temporary file
c  (nstep) in step 1 and that may be needed in step 3.
c
c  having read the data being passed from step 1, this routine then
c  determines the criticality nuclide id numbers.  it may read them
c  from nstep or it may choose one of the sets in the data statements.
c
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
```

```
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
      character*6 ichk
      dimension ncool(20)
      dimension idat1(25),idat2(37),idat3(49),idat4(193)
      data idat1/92234,92235,92236,92238,94238,94239,94240,94241,
     &94242,95241,8016,42095,43099,45103,55133,55135,60143,60145,
     &62147,62149,62150,62151,62152,63153,64155/
      data idat2/92234,92235,92236,92238,93237,94238,94239,94240,94241,
     &94242,95241,95243,96244,8016,40093,42095,43099,44101,45103,46105,
     &46108,47109,55133,55135,59141,60143,60145,61147,62147,62149,
     &62150,62151,62152,63153,63154,63155,64155/
      data idat3/92234,92235,92236,92238,93237,94238,94239,94240,94241,
     &94242,95241,95243,96244,8016,36083,40093,42095,43099,
     &44101,44103,45103,45105,46105,46108,47109,53135,54131,54135,
     &55133,55134,55135,59141,60143,60145,60147,60148,61147,61148,
     &61149,62147,62149,62150,62151,62152,63153,63154,63155,64155,
     &99999/
      data idat4/ 32072,32073,32074,32076,33075,34076,34077,34078,34080,
     &34082,35079,35081,36080,36082,36083,36084,36085,36086,37085,37086,
     &37087,38086,38087,38088,38089,38090,39089,39090,39091,40090,40091,
     &40092,40093,40094,40095,40096,41093,41094,41095, 8016,42095,42096,
     &42097,42098,42099,42100,43099,44099,44100,44101,44102,44104,44105,
     &44106,46104,46105,46106,46107,46108,46110,47107,47109,47111,48108,
     &48110,48111,48112,48113,48114,      48116,49113,49115,50115,50116,
     &50117,50118,50119,50120,50122,50123,50124,50125,50126,51121,51123,
     &51124,51125,51126,52122,52123,52124,52125,52126,      52128,
     &52130,52132,53127,53129,53130,53131,54128,54129,54130,54131,54132,
     &54133,54134,54136,55133,55134,55135,55136,55137,56134,56135,56136,
     &56137,56138,56140,57139,57140,58140,58141,58142,58143,58144,59141,
     &59142,59143,60142,60143,60144,60145,60146,60150,61151,62147,62148,
     &62150,62151,62152,62153,62154,63151,63152,63156,63157,64154,64156,
     &64157,64158,64160,65159,65160,66160,66161,66162,66163,66164,67165,
     &68166,68167,44103,45103,45105,53135,54135,60147,60148,61147,61148,
     &62149,61149,63153,63154,63155,      64155,90232,91233,92233,92234,
     &92235,92236,92238,93237,94238,94239,94240,94241,94242,95241,
     &95243,96244/
      n5=5
      nstep=76
c
c  read data from step 1.
c
      read(nstep) (ittl(i), i=1,20)
      read(nstep) n72,nout1,nors,n71,nice,nout3
      if(n72.eq.-1000) return
      read(nstep) ncyc,burn,ntcool,nall
      read(nstep) (ncool(i),i=1,ntcool)
      read(nstep) nlitl,mixf,idmod,nfis
      nout=nout3
c
c  at this point nlitl will be at least one.
c
      read(nstep) (idlitl(i),adlitl(i),ltyp(i), i=1,nlitl)
c
c  check flag nfis to determine which fuel nuclides will be used in
c  keno calculations:
c             =0  use ttc713 intersection with sid bierman's nucs
c             =-1 use ttc713
c             =-2 use ttc713 u sid u vepco u casmo
c             =-3 use all 27burnuplib nuclides
c             =n  read in user's choice of nuclides (from step 1)
c
      if(nfis.eq.0)then
      ncrit=25
      do 10 i=1,ncrit
  10  idcrit(i)=idat1(i)
      go to 500
```

```
      end if
      if(nfis.eq.-1)then
      ncrit=37
      do 20 i=1,ncrit
   20 idcrit(i)=idat2(i)
      go to 500
      end if
      if(nfis.eq.-2)then
      ncrit=49
      do 21 i=1,ncrit
   21 idcrit(i)=idat3(i)
      go to 500
      end if
      if(nfis.eq.-3)then
      ncrit=193
      do 31 i=1,ncrit
   31 idcrit(i)=idat4(i)
      go to 500
      end if
      if(nfis.gt.0)ncrit=nfis
  500 continue
      if(nfis.le.0)go to 1000
      read(nstep) (idcrit(i), i=1,nfis)
 1000 continue
c
c  write input to nout
c
      write(nout,120)ittl
      write(nout,130)burn
      write(nout,140)nlitl
      write(nout,150)nfis
      write(nout,160)mixf
      write(nout,165)idmod
      write(nout,170)(idcrit(i),i=1,ncrit)
  110 format(a6)
  120 format(20a4)
  130 format(4x,'burn= ',f10.0)
  140 format(4x,'nlitl= ',i5)
  150 format(4x,'nfis= ',i5)
  160 format(4x,'mixf= ',i5)
  165 format(4x,'idmod= ',i5)
  170 format(10(1x,i5))
      return
      end
c-----------------------------------------------------------------------
      subroutine rdf71(npos,tym)
c
c  this routine reads atom densities from the binary output
c  file on unit 'n71' written from origen-s for the decay time
c  corresponding to the position, npos(equal to ncool+1), where
c  ncool is returned from subroutine tymstp), and at the
c  requested burnup, burn.
c
      common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
      common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
      common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
      common /ident/ idlitl(40),idcrit(210),iddk(2000)
      common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
      common /title/ ittl(20),lttl(20),crittl(20)
      dimension tym(20)
c
c  iddk and addk are arrays containing the id's and number densities for
c  all nuclides used in the origen-s decay
c  case.  in this routine they are used to retrieve data from unit n71
c  before it is condensed into the adcrit array which will contain number
c  densities corresponding to the id's given in idcrit.  idcrit contains
c  ids for the nuclides to be used in the criticality analysis.  the
c  densities stored in adcrit are burnup dependent.
```

```
c
c  files needed in this subroutine should be opened by the main program
c
  10   read(n71,end=100)itot,ile,iact,ifp,nd1,nd2,nstep,
     &n1,n2,n3,n4,n5,n6,n7,n8,n9,n10,n11,n12,n13,n14,n15,
     &n16,n17,n18,n19,n20,n21,n22,n23,r1,r2,r3,r4,tym(npos)
       write(nout,102)itot,ile,iact,ifp,nstep,tym(npos)
       if(nstep.eq.npos) then
         read(n71,end=100) (iddk(i),i=1,itot),(addk(i),i=1,itot)
         do 15 i=1,itot
c
c  added the following single line to eliminate double entry problem
c  caused by metastable isotopes (e.g., gd-155m) when dividing by
c  ten.  mdd 8/27/93 (as per smb change in old version of snikr3 6/16/93)
         if(mod(iddk(i),10).gt.0) iddk(i) = 0
c
  15     iddk(i)=iddk(i)/10
         ia1=ile+1
         ia2=ile+iact
         write(nout,103)(iddk(i),addk(i),i=ia1,ia2)
         go to 20
       endif
       read(n71,end=100)idumy
       go to 10
 100   write(nout,101)n71
 101   format('0'/'****error reading unit ',i2)
       stop 7101
  20   continue
  102  format(5(1x,i4),f10.2)
  103  format(4(i8,2x,1p,e10.4))
       return
       end
c-----------------------------------------------------------------------
       subroutine clect(iflag)
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
       dimension idlfp(165)
      data idlfp/ 32072,32073,32074,32076,33075,34076,34077,34078,34080,
     &34082,35079,35081,36080,36082,36083,36084,36085,36086,37085,37086,
     &37087,38086,38087,38088,38089,38090,39089,39090,39091,40090,40091,
     &40092,40093,40094,40095,40096,41093,41094,41095,42094,42095,42096,
     &42097,42098,42099,42100,43099,44099,44100,44101,44102,44104,44105,
     &44106,46104,46105,46106,46107,46108,46110,47107,47109,47111,48108,
     &48110,48111,48112,48113,48114,48601,48116,49113,49115,50115,50116,
     &50117,50118,50119,50120,50122,50123,50124,50125,50126,51121,51123,
     &51124,51125,51126,52122,52123,52124,52125,52126,52601,52128,52611,
     &52130,52132,53127,53129,53130,53131,54128,54129,54130,54131,54132,
     &54133,54134,54136,55133,55134,55135,55136,55137,56134,56135,56136,
     &56137,56138,56140,57139,57140,58140,58141,58142,58143,58144,59141,
     &59142,59143,60142,60143,60144,60145,60146,60150,61151,62147,62148,
     &62150,62151,62152,62153,62154,63151,63152,63156,63157,64154,64156,
     &64157,64158,64160,65159,65160,66160,66161,66162,66163,66164,67165,
     &68166,68167/
      nlfp=165
c
c  extract nuclides needed for criticality calculations for this
c  burnup and cooling time.  take requested light elements from
c  the light element library (1st ile entries in iddk/addk),
c  actinides from the actinide data (next iact entries in iddk/addk),
c  and fission products from the final ifp entries in iddk/addk)
c
c  nlitl will be at least 1, to account for oxygen.  the only
c  situation that will allow it to be larger than 1 is if the
c  user has chosen to input a set of isotopics different from
```

```
c  the burnup credit nuclides (ie., ttc-0713 or bierman's) and
c  has chosen to enter more light elements than just oxygen
c
c  if iflag=1 change all iddk by factor of 10 (from 72 not 71)
c
       if(iflag.eq.0)go to 20
       do 10 i=1,itot
   10  iddk(i)=iddk(i)/10
   20  continue
       do 40 i=1,nlitl
       do 30 j=1,ile
       if(iddk(j).ne.idlitl(i)) go to 30
       adlitl(i)=addk(j)
       go to 40
   30  continue
       write(nout,102)idlitl(i),n71
  102  format('0'/'****error, no match for light element ',i8,
     &' was found on unit ',i2)
       stop 7102
   40  continue
       nlp1=ile+1
       do 70 i=1,ncrit
        if(idcrit(i).eq.99999)go to 70
       adcrit(i)=0.0
       do 60 j=nlp1,itot
       if(iddk(j).ne.idcrit(i)) go to 60
       adcrit(i)=addk(j)
       go to 70
   60  continue
       do 65 k=1,nlitl
       if(idcrit(i).eq.idlitl(k))go to 70
   65  continue
       write(nout,103)idcrit(i),n71
  103  format('0'/'****error, no match for nuclide ',i8,
     &' was found on unit ',i2)
       stop 7103
   70  continue
c  add contribution from light element and actinide/fission product libr
       do 80 i=1,nlitl
       do 80 j=1,ncrit
       if(idcrit(j).ne.idlitl(i))go to 80
       adcrit(j)=adcrit(j)+adlitl(i)
   80  continue
c
       return
       end
c-----------------------------------------------------------------------
      subroutine wrtice
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
       common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20),lttl(20),crittl(20)
      dimension i2(200),i5(200),i11(201),idact(7)
      character*4 dum,t,ice,end
       data idact/92234,92235,92236,92238,94239,94240,94241/
c
      t = '  t '
      ice = '#ice'
      end = 'end '
      mix=1
c
      write(nice,110)ice
      write(nice,110)ittl
 110  format(20a4)
c
      dum = '1$$ '
```

```
      write(nice,110)dum
      ii = 0
      i4 = 10
      kopt = 4
      write(nice,120)mix,ncrit,ii,ii,ii,i4,kopt
 120  format(6i12)
      write(nice,110)t
c
      do 10 i=1,ncrit
  10  i2(i)=1
c
      dum = '2$$ '
      write(nice,110)dum
      write(nice,120)(i2(i),i=1,ncrit)
c
      if(idmod.eq.0)go to 35
      do 30 j=1,7
      do 30 i=1,ncrit
      if(idcrit(i).ne.idact(j))go to 30
      idcrit(i)=idcrit(i)+100000*idmod
      idact(j) =idact(j) +100000*idmod
  30  continue
  35  continue
c
      dum = '3$$ '
      write(nice,110)dum
      write(nice,120)(idcrit(i),i=1,ncrit)
c
      dum = '4** '
      write(nice,110)dum
      write(nice,130)(adcrit(i),i=1,ncrit)
 130  format(1p,6e12.4)
c
      i5(1)=4
      dum = '5$$ '
      write(nice,110)dum
      write(nice,120)(i5(i),i=1,mix)
      write(nice,110)t
c
      dum= '7$$ '
      write(nice,110)dum
      write(nice,140)
      write(nice,110)t
 140  format('  a8 2 e')
c
      i11(1)=1
      i11(2)=mixf
      dum = '11$$'
      write(nice,110)dum
      write(nice,120)(i11(i),i=1,mix+1)
      write(nice,110)t
      write(nice,110)end
c
      if(idmod.eq.0)go to 45
      do 40 j=1,7
      do 40 i=1,ncrit
      if(idcrit(i).ne.idact(j))go to 40
      idcrit(i)=idcrit(i)-100000*idmod
      idact(j) =idact(j) -100000*idmod
  40  continue
  45  continue
c
      return
      end
c-----------------------------------------------------------------------
      subroutine wrtkeno
       common /const/ bconv,burn,cool,mixf,idmod,smact0,ntcool,nall
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc,nfis
```

```
      common /untnos/ n72,nout,nout1,nout3,n71,nors,nice,nstep
      common /ident/ idlitl(40),idcrit(210),iddk(2000)
      common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
      common /title/ ittl(20),lttl(20),crittl(20)
     character*2 iname(105),ics(200)
      dimension mass(200),idact(7)
      data idact/92234,92235,92236,92238,94239,94240,94241/
     data iname/' h','he','li','be',' b',' c',' n',' o',' f','ne','na',
    & 'mg','al','si',' p',' s',
    &'cl','ar',' k','ca','sc','ti',' v','cr','mn','fe','co',
    &'ni','cu','zn','ga','ge','as','se','br','kr','rb',
    &'sr',' y','zr','nb','mo','tc','ru','rh','pd','ag','cd',
    &'in','sn','sb','te',' i','xe','cs','ba','la','ce',
    &'pr','nd','pm','sm','eu','gd','tb','dy','ho','er',
    &'tm','yb','lu','hf','ta',' w','re','os','ir','pt',
    &'au','hg','tl','pb','bi','po','at','rn','fr','ra',
    &'ac','th','pa',' u','np','pu','am','cm','bk','cf',
    &'es','fm','md','no','lr','rf','ha'/
      do 15 k=1,ncrit
      if(idcrit(k).eq.99999)go to 15
      iz=idcrit(k)/1000
      mass(k)=idcrit(k)-iz*1000
      idff=iz/100
      if(idff.gt.0)iz=iz-idff*100
      ics(k)=iname(iz)
 15   continue
      do 20 i=1,4
 20   write(nout,101)
      write(nout,202)
      write(nout,101)
      do 30 j=1,ncrit
      if(idcrit(j).eq.99999)go to 30
      if(ics(j).eq.' o')then
      write(nout,206)ics(j),mixf,adcrit(j)
      go to 30
      end if
      if(mass(j).lt.10)write(nout,203)ics(j),mass(j),mixf,adcrit(j)
      if(mass(j).ge.10.and.mass(j).lt.100)write(nout,204)ics(j),
    &mass(j),mixf,adcrit(j)
      if(mass(j).ge.100)write(nout,205)ics(j),mass(j),mixf,adcrit(j)
 30   continue
c
      if(idmod.eq.0)go to 5
      do 3 j=1,7
      do 3 i=1,ncrit
      if(idcrit(i).ne.idact(j))go to 3
      idcrit(i)=idcrit(i)+100000*idmod
      idact(j) =idact(j) +100000*idmod
  3   continue
  5   continue
c
      do 10 i=1,4
 10   write(nout,101)
      write(nout,102)
      write(nout,101)
      write(nout,104)mixf
      write(nout,103)(idcrit(j),adcrit(j),j=1,ncrit)
c
      if(idmod.eq.0)go to 25
      do 23 j=1,7
      do 23 i=1,ncrit
      if(idcrit(i).ne.idact(j))go to 23
      idcrit(i)=idcrit(i)-100000*idmod
      idact(j) =idact(j) -100000*idmod
 23   continue
 25   continue
c
      return
```

```
101  format(a4)
102  format(' for use when mixing in keno')
103  format(i9,2x,1p,e10.4)
104  format(' mix=',i4)
202  format(' for use in csas')
203  format(2x,a2,'-',i1,4x,i3,2x,'0',2x,1p,e10.4,'  end')
204  format(2x,a2,'-',i2,3x,i3,2x,'0',2x,1p,e10.4,'  end')
205  format(2x,a2,'-',i3,2x,i3,2x,'0',2x,1p,e10.4,'  end')
206  format(2x,a2,6x,i3,2x,'0',2x,1p,e10.4,'  end')
     end
```

APPENDIX C

SCALE CSASN-SEQUENCE INPUT LISTINGS

This appendix contains three listings:

C.1: TMISUBZ1 Listing. Input listing for a CSASN case used to compute AMPX working format microscopic cross-sections for subzone 1 fuel, including all 48 actinides and fission products plus APSR materials.

C.2: TMISUBZ2 Listing. Input listing for a CSASN case used to compute AMPX working format microscopic cross-sections for subzone 2 fuel, including only the seven most important actinides in the fuel mixture.

C.3: TMISUBZ9 Listing. Input listing for a CSASN case used to compute AMPX working format microscopic cross-sections for subzone 9 fuel, including only the four uranium isotopes present in fresh fuel.

C.1: TMISUBZ1 Listing

```
=csasn
Subzone 1(Zone  1), Ave. Burnup=24688 MWD/MTU
27burnup  latticecell
   u-234    1  0  3.5398E-06  551  end
   u-235    1  0  1.9396E-04  551  end
   u-236    1  0  7.3742E-05  551  end
   u-238    1  0  2.2150E-02  551  end
  np-237    1  0  7.6445E-06  551  end
  pu-238    1  0  2.0299E-06  551  end
  pu-239    1  0  1.1939E-04  551  end
  pu-240    1  0  4.2740E-05  551  end
  pu-241    1  0  1.7661E-05  551  end
  pu-242    1  0  6.7702E-06  551  end
  am-241    1  0  7.2966E-06  551  end
  am-243    1  0  1.1341E-06  551  end
  cm-244    1  0  1.7108E-07  551  end
   o        1  0  4.6454E-02  551  end
  kr-83     1  0  2.1542E-06  551  end
  zr-93     1  0  2.1158E-05  551  end
  mo-95     1  0  3.3743E-05  551  end
  tc-99     1  0  3.3551E-05  551  end
  ru-101    1  0  3.1763E-05  551  end
  ru-103    1  0  5.8017E-25  551  end
  rh-103    1  0  2.0281E-05  551  end
  rh-105    1  0  0.0000E+00  551  end
  pd-105    1  0  1.5271E-05  551  end
  pd-108    1  0  5.3048E-06  551  end
  ag-109    1  0  3.3890E-06  551  end
   i-135    1  0  0.0000E+00  551  end
  xe-131    1  0  1.4856E-05  551  end
  xe-135    1  0  0.0000E+00  551  end
  cs-133    1  0  3.6801E-05  551  end
  cs-134    1  0  3.1880E-07  551  end
  cs-135    1  0  1.1736E-05  551  end
  pr-141    1  0  3.2960E-05  551  end
  nd-143    1  0  2.4846E-05  551  end
  nd-145    1  0  1.9841E-05  551  end
  nd-147    1  0  0.0000E+00  551  end
  nd-148    1  0  1.0206E-05  551  end
  pm-147    1  0  1.0230E-06  551  end
  pm-148    1  0  6.2838E-28  551  end
  pm-149    1  0  0.0000E+00  551  end
  sm-147    1  0  7.0185E-06  551  end
  sm-149    1  0  1.1882E-07  551  end
  sm-150    1  0  8.7331E-06  551  end
  sm-151    1  0  4.3137E-07  551  end
  sm-152    1  0  3.7387E-06  551  end
  eu-153    1  0  2.8292E-06  551  end
  eu-154    1  0  5.2182E-07  551  end
  eu-155    1  0  1.2753E-07  551  end
  gd-155    1  0  2.1492E-07  551  end
zircalloy  2 1  551  end
h2o  3 den=0.7700  1  551 end
boron 3 den=0.7700  1182.0E-6  551 end
ag-107          4  den=10.18 .5184 551 end
ag-109          4  den=10.181 .4816 551 end
in-113          4  den=10.18 0.043 551 end
in-115          4  den=10.18 0.957 551 end
cd              4  den=10.18 1.0 551 end
ss304           5  1.0 551 end
arbmzro2 5.5899 2  0 1 0  40000 1 8016 2 6  1.0 551 end
end comp
squarepitch 1.44272 .936244 1  3  1.0922 2  .95758 0  end
end
```

C.2: TMISUBZ2 Listing

```
=csasn
Subzone 2(Zone  1), Ave. Burnup=21034 MWD/MTU
27burnup  latticecell
   u-234    1  0  3.7539E-06  551  end
   u-235    1  0  2.3563E-04  551  end
   u-236    1  0  6.7794E-05  551  end
   u-238    1  0  2.2227E-02  551  end
  pu-239    1  0  1.1468E-04  551  end
  pu-240    1  0  3.6105E-05  551  end
  pu-241    1  0  1.4586E-05  551  end
   o        1  0  4.6454E-02  551  end
zircalloy  2 1  551   end
h2o  3 den=0.7700  1  551 end
boron 3 den=0.7700  1182.0E-6  551 end
end comp
squarepitch 1.44272 .936244 1  3  1.0922 2  .95758 0  end
end
```

C.3: TMISUBZ9 Listing

```
=csasn
Subzone 9(Zone  4), Ave. Burnup=0 MWD/MTU
27burnup  latticecell
   u-234    1  0  5.6679E-06  551  end
   u-235    1  0  6.7019E-04  551  end
   u-236    1  0  3.0441E-05  551  end
   u-238    1  0  2.2548E-02  551  end
   o        1  0  4.6454E-02  551  end
zircalloy  2 1  551   end
h2o  3 den=0.7700  1  551 end
boron 3 den=0.7700  1182.0E-6  551 end
end comp
squarepitch 1.44272 .936244 1  3  1.0922 2  .95758 0  end
end
```

APPENDIX D

WAX INPUT LISTING

This appendix lists the input used in the WAX calculation used to create a single working library for KENO.

```
=wax
'write final library to unit 4 / biggest input lib is on unit 31
0$$ 4 31
'input xsec's from 10 libs
1$$  9    t
'input xsec's for fuel subzone 1.  this contains all fission prods
2$$ 31 0 t
'input xsec's for fuel subzone 2
2$$ 32 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 292234 292235 292236 292238 294239 294240 294241 t
'input xsec's for fuel subzone 3
2$$ 33 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 392234 392235 392236 392238 394239 394240 394241 t
'input xsec's for fuel subzone 4
2$$ 34 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 492234 492235 492236 492238 494239 494240 494241 t
'input xsec's for fuel subzone 5
2$$ 35 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 592234 592235 592236 592238 594239 594240 594241 t
'input xsec's for fuel subzone 6
2$$ 36 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 692234 692235 692236 692238 694239 694240 694241 t
'input xsec's for fuel subzone 7
2$$ 37 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 792234 792235 792236 792238 794239 794240 794241 t
'input xsec's for fuel subzone 8
2$$ 38 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 892234 892235 892236 892238 894239 894240 894241 t
'input xsec's for fuel subzone 9. this subzone contains fresh fuel only.
2$$ 39 4 t
3$$   92234   92235   92236   92238
4$$  992234  992235  992236  992238 t
end
```

APPENDIX E

KENO V.a INPUT LISTING

This appendix lists the input used in the KENO V.a k_{eff} calculation for the TMI Unit 1 Core at BOC-5 under HZP conditions.

```
=kenov
TMI Unit 1, Cycle 5, BOC, HZP, ARO, 1/8 core symmetry
'
' *** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***
' *** *                                                                         * ***
' *** *            Full core KENO V.a reactor configuration                     * ***
' *** *              for TMI Unit-1 BOC-5, HZP conditions                       * ***
' *** *                        1 plane model                                    * ***
' *** *                                                                         * ***
' *** *                              by                                         * ***
' *** *                         Mark D. DeHart                                  * ***
' *** *                 Oak Ridge National Laboratory                           * ***
' *** *                                                                         * ***
' *** *                         August 1993                                     * ***
' *** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * ***
'
read parm
run=yes plt=yes nub=yes fdn=yes tme=240.0 gen=1003 npg=1000
wrs=34 res=50
lib=4 nb8=2400 nl8=880 end parm
read mixt
sct=2
mix=101
'Batch 4B (Zone 1 Sub-zone 1), Assembly H8 , Burnup=25199 MWD/MTU
    92234  3.5219E-06
    92235  1.9062E-04
    92236  7.4198E-05
    92238  2.2143E-02
    93237  7.7749E-06
    94238  2.0951E-06
    94239  1.1971E-04
    94240  4.3292E-05
    94241  1.7913E-05
    94242  6.9845E-06
    95241  7.4040E-06
    95243  1.1868E-06
    96244  1.8217E-07
     8016  4.6454E-02
    36083  2.1719E-06
    40093  2.1403E-05
    42095  3.4139E-05
    43099  3.3953E-05
    44101  3.2191E-05
    44103  5.8298E-25
    45103  2.0514E-05
    45105  0.0000E+00
    46105  1.5550E-05
    46108  5.4215E-06
    47109  3.4528E-06
    53135  0.0000E+00
    54131  1.5008E-05
    54135  0.0000E+00
    55133  3.7236E-05
    55134  3.2658E-07
    55135  1.1891E-05
    59141  3.3382E-05
    60143  2.5057E-05
    60145  2.0066E-05
    60147  0.0000E+00
    60148  1.0343E-05
    61147  1.0269E-06
    61148  6.3103E-28
    61149  0.0000E+00
    62147  7.0677E-06
    62149  1.1900E-07
    62150  8.8669E-06
    62151  4.3417E-07
    62152  3.7844E-06
```

```
    63153  2.8805E-06
    63154  5.3582E-07
    63155  1.3064E-07
    64155  2.2016E-07
mix=102
'Batch  5 (Zone 2 Sub-zone 4), Assembly H9 , Burnup=18313 MWD/MTU
   492234  4.3043E-06
   492235  3.0440E-04
   492236  6.5943E-05
   492238  2.2236E-02
    93237  5.2161E-06
    94238  9.3473E-07
   494239  1.1159E-04
   494240  3.0023E-05
   494241  1.1988E-05
    94242  2.9296E-06
    95241  4.8360E-06
    95243  3.4268E-07
    96244  3.4098E-08
     8016  4.6454E-02
    36083  1.8067E-06
    40093  1.6519E-05
    42095  2.6191E-05
    43099  2.5747E-05
    44101  2.3597E-05
    44103  5.5877E-25
    45103  1.5516E-05
    45105  0.0000E+00
    46105  9.9025E-06
    46108  3.0830E-06
    47109  2.0966E-06
    53135  0.0000E+00
    54131  1.1761E-05
    54135  0.0000E+00
    55133  2.8329E-05
    55134  1.8521E-07
    55135  8.9558E-06
    59141  2.4948E-05
    60143  2.0684E-05
    60145  1.5502E-05
    60147  0.0000E+00
    60148  7.6169E-06
    61147  9.6606E-07
    61148  5.9421E-28
    61149  0.0000E+00
    62147  5.9377E-06
    62149  1.2173E-07
    62150  6.2795E-06
    62151  3.9482E-07
    62152  2.8038E-06
    63153  1.8347E-06
    63154  2.7233E-07
    63155  7.4319E-08
    64155  1.2530E-07
mix=103
'Batch  6 (Zone 3 Sub-zone 8), Assembly H10, Burnup= 6683 MWD/MTU
   892234  5.1368E-06
   892235  5.0602E-04
   892236  3.2194E-05
   892238  2.2441E-02
    93237  1.2979E-06
    94238  7.9321E-08
   894239  6.5339E-05
   894240  7.9780E-06
   894241  1.9053E-06
    94242  1.4377E-07
    95241  7.3797E-07
    95243  5.2456E-09
```

```
     96244  1.6331E-10
      8016  4.6454E-02
     36083  7.8706E-07
     40093  6.5330E-06
     42095  1.0222E-05
     43099  9.9976E-06
     44101  8.6071E-06
     44103  3.9041E-25
     45103  5.7569E-06
     45105  0.0000E+00
     46105  2.6895E-06
     46108  5.9830E-07
     47109  4.3415E-07
     53135  0.0000E+00
     54131  4.7032E-06
     54135  0.0000E+00
     55133  1.0974E-05
     55134  2.6988E-08
     55135  3.6328E-06
     59141  9.3939E-06
     60143  8.9193E-06
     60145  6.1422E-06
     60147  0.0000E+00
     60148  2.8072E-06
     61147  5.1914E-07
     61148  2.8756E-28
     61149  0.0000E+00
     62147  2.7293E-06
     62149  9.4849E-08
     62150  2.0317E-06
     62151  2.6678E-07
     62152  9.6003E-07
     63153  4.3927E-07
     63154  3.0961E-08
     63155  2.0080E-08
     64155  3.3914E-08
mix=104
'Batch 4B (Zone 1 Sub-zone 1), Assembly H11, Burnup=23926 MWD/MTU
     92234  3.5809E-06
     92235  2.0171E-04
     92236  7.2671E-05
     92238  2.2165E-02
     93237  7.3487E-06
     94238  1.8858E-06
     94239  1.1860E-04
     94240  4.1469E-05
     94241  1.7080E-05
     94242  6.2947E-06
     95241  7.0489E-06
     95243  1.0199E-06
     96244  1.4780E-07
      8016  4.6454E-02
     36083  2.1132E-06
     40093  2.0601E-05
     42095  3.2840E-05
     43099  3.2635E-05
     44101  3.0794E-05
     44103  5.7359E-25
     45103  1.9748E-05
     45105  0.0000E+00
     46105  1.4644E-05
     46108  5.0437E-06
     47109  3.2452E-06
     53135  0.0000E+00
     54131  1.4508E-05
     54135  0.0000E+00
     55133  3.5810E-05
     55134  3.0144E-07
```

```
     55135  1.1385E-05
     59141  3.2002E-05
     60143  2.4358E-05
     60145  1.9327E-05
     60147  0.0000E+00
     60148  9.8956E-06
     61147  1.0137E-06
     61148  6.2209E-28
     61149  0.0000E+00
     62147  6.9034E-06
     62149  1.1840E-07
     62150  8.4303E-06
     62151  4.2499E-07
     62152  3.6345E-06
     63153  2.7132E-06
     63154  4.9058E-07
     63155  1.2061E-07
     64155  2.0328E-07
mix=105
'Batch  6 (Zone 3 Sub-zone 6), Assembly H12, Burnup= 9540 MWD/MTU
   692234  4.9208E-06
   692235  4.4833E-04
   692236  4.2181E-05
   692238  2.2393E-02
    93237  2.1162E-06
    94238  1.8762E-07
   694239  8.1972E-05
   694240  1.3274E-05
   694241  3.9711E-06
    94242  4.4897E-07
    95241  1.5598E-06
    95243  2.4750E-08
    96244  1.1336E-09
     8016  4.6454E-02
    36083  1.0743E-06
    40093  9.1241E-06
    42095  1.4336E-05
    43099  1.4090E-05
    44101  1.2295E-05
    44103  4.1867E-25
    45103  8.2426E-06
    45105  0.0000E+00
    46105  4.2259E-06
    46108  1.0621E-06
    47109  7.6709E-07
    53135  0.0000E+00
    54131  6.5803E-06
    54135  0.0000E+00
    55133  1.5459E-05
    55134  5.4013E-08
    55135  5.1889E-06
    59141  1.3296E-05
    60143  1.2217E-05
    60145  8.5796E-06
    60147  0.0000E+00
    60148  3.9935E-06
    61147  6.6689E-07
    61148  3.8440E-28
    61149  0.0000E+00
    62147  3.6780E-06
    62149  1.0140E-07
    62150  3.0383E-06
    62151  3.0499E-07
    62152  1.4349E-06
    63153  7.2089E-07
    63154  6.6692E-08
    63155  2.9464E-08
    64155  4.9775E-08
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mix=106
'Batch  5 (Zone 2 Sub-zone 4), Assembly H13, Burnup=17603 MWD/MTU
   492234  4.3512E-06
   492235  3.1444E-04
   492236  6.4362E-05
   492238  2.2249E-02
    93237  4.9434E-06
    94238  8.4781E-07
   494239  1.1002E-04
   494240  2.8697E-05
   494241  1.1341E-05
    94242  2.6398E-06
    95241  4.5653E-06
    95243  2.9520E-07
    96244  2.7977E-08
     8016  4.6454E-02
    36083  1.7552E-06
    40093  1.5949E-05
    42095  2.5273E-05
    43099  2.4828E-05
    44101  2.2685E-05
    44103  5.5285E-25
    45103  1.4958E-05
    45105  0.0000E+00
    46105  9.3941E-06
    46108  2.8898E-06
    47109  1.9770E-06
    53135  0.0000E+00
    54131  1.1376E-05
    54135  0.0000E+00
    55133  2.7324E-05
    55134  1.7218E-07
    55135  8.6161E-06
    59141  2.4023E-05
    60143  2.0080E-05
    60145  1.4971E-05
    60147  0.0000E+00
    60148  7.3249E-06
    61147  9.4956E-07
    61148  5.8295E-28
    61149  0.0000E+00
    62147  5.7866E-06
    62149  1.2097E-07
    62150  6.0009E-06
    62151  3.8808E-07
    62152  2.6982E-06
    63153  1.7346E-06
    63154  2.5047E-07
    63155  6.9630E-08
    64155  1.1740E-07
mix=107
'Batch  6 (Zone 3 Sub-zone 6), Assembly H14, Burnup= 9540 MWD/MTU
   692234  4.9208E-06
   692235  4.4833E-04
   692236  4.2181E-05
   692238  2.2393E-02
    93237  2.1162E-06
    94238  1.8762E-07
   694239  8.1972E-05
   694240  1.3274E-05
   694241  3.9711E-06
    94242  4.4897E-07
    95241  1.5598E-06
    95243  2.4750E-08
    96244  1.1336E-09
     8016  4.6454E-02
    36083  1.0743E-06
    40093  9.1241E-06
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     42095  1.4336E-05
     43099  1.4090E-05
     44101  1.2295E-05
     44103  4.1867E-25
     45103  8.2426E-06
     45105  0.0000E+00
     46105  4.2259E-06
     46108  1.0621E-06
     47109  7.6709E-07
     53135  0.0000E+00
     54131  6.5803E-06
     54135  0.0000E+00
     55133  1.5459E-05
     55134  5.4013E-08
     55135  5.1889E-06
     59141  1.3296E-05
     60143  1.2217E-05
     60145  8.5796E-06
     60147  0.0000E+00
     60148  3.9935E-06
     61147  6.6689E-07
     61148  3.8440E-28
     61149  0.0000E+00
     62147  3.6780E-06
     62149  1.0140E-07
     62150  3.0383E-06
     62151  3.0499E-07
     62152  1.4349E-06
     63153  7.2089E-07
     63154  6.6692E-08
     63155  2.9464E-08
     64155  4.9775E-08
mix=108
'Batch 7 (Zone 4 Sub-zone 9), Assembly H15, Burnup=0 MWD/MTU
   992234  5.6679E-06
   992235  6.7019E-04
   992236  3.0441E-06
   992238  2.2548E-02
     8016  4.6454E-02
mix=109
'Batch  6 (Zone 3 Sub-zone 7), Assembly K9 , Burnup= 7969 MWD/MTU
   792234  5.0387E-06
   792235  4.7927E-04
   792236  3.6847E-05
   792238  2.2419E-02
    93237  1.6508E-06
    94238  1.2111E-07
   794239  7.3411E-05
   794240  1.0315E-05
   794241  2.7696E-06
    94242  2.5485E-07
    95241  1.0796E-06
    95243  1.1413E-08
    96244  4.2523E-10
     8016  4.6454E-02
    36083  9.1964E-07
    40093  7.7125E-06
    42095  1.2092E-05
    43099  1.1854E-05
    44101  1.0268E-05
    44103  4.0399E-25
    45103  6.8811E-06
    45105  0.0000E+00
    46105  3.3579E-06
    46108  7.9396E-07
    47109  5.7604E-07
    53135  0.0000E+00
    54131  5.5596E-06
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     54135  0.0000E+00
     55133  1.3009E-05
     55134  3.8126E-08
     55135  4.3341E-06
     59141  1.1158E-05
     60143  1.0439E-05
     60145  7.2521E-06
     60147  0.0000E+00
     60148  3.3422E-06
     61147  5.9017E-07
     61148  3.3402E-28
     61149  0.0000E+00
     62147  3.1707E-06
     62149  9.8015E-08
     62150  2.4790E-06
     62151  2.8511E-07
     62152  1.1748E-06
     63153  5.5975E-07
     63154  4.5199E-08
     63155  2.4099E-08
     64155  4.0708E-08
mix=110
'Batch  5 (Zone 2 Sub-zone 3), Assembly K10, Burnup=20929 MWD/MTU
   392234  4.1364E-06
   392235  2.6965E-04
   392236  7.1296E-05
   392238  2.2187E-02
    93237  6.2389E-06
    94238  1.2977E-06
   394239  1.1650E-04
   394240  3.4792E-05
   394241  1.4303E-05
    94242  4.1246E-06
    95241  5.8139E-06
    95243  5.6068E-07
    96244  6.5837E-08
     8016  4.6454E-02
    36083  1.9855E-06
    40093  1.8579E-05
    42095  2.9509E-05
    43099  2.9079E-05
    44101  2.6950E-05
    44103  5.7563E-25
    45103  1.7516E-05
    45105  0.0000E+00
    46105  1.1837E-05
    46108  3.8345E-06
    47109  2.5499E-06
    53135  0.0000E+00
    54131  1.3126E-05
    54135  0.0000E+00
    55133  3.1960E-05
    55134  2.3607E-07
    55135  1.0203E-05
    59141  2.8335E-05
    60143  2.2784E-05
    60145  1.7415E-05
    60147  0.0000E+00
    60148  8.6901E-06
    61147  1.0166E-06
    61148  6.2885E-28
    61149  0.0000E+00
    62147  6.4531E-06
    62149  1.2403E-07
    62150  7.3091E-06
    62151  4.1869E-07
    62152  3.1848E-06
    63153  2.2133E-06
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    63154  3.5983E-07
    63155  9.3204E-08
    64155  1.5713E-07
mix=111
'Batch  6 (Zone 3 Sub-zone 8), Assembly K11, Burnup= 5802 MWD/MTU
   892234  5.2049E-06
   892235  5.2514E-04
   892236  2.8848E-05
   892238  2.2455E-02
    93237  1.0723E-06
    94238  5.6652E-08
   894239  5.9168E-05
   894240  6.4462E-06
   894241  1.3894E-06
    94242  8.9587E-08
    95241  5.3580E-07
    95243  2.7747E-09
    96244  7.5534E-11
     8016  4.6454E-02
    36083  6.9297E-07
    40093  5.7114E-06
    42095  8.9226E-06
    43099  8.7126E-06
    44101  7.4687E-06
    44103  3.7883E-25
    45103  4.9832E-06
    45105  0.0000E+00
    46105  2.2550E-06
    46108  4.7735E-07
    47109  3.4547E-07
    53135  0.0000E+00
    54131  4.1059E-06
    54135  0.0000E+00
    55133  9.5642E-06
    55134  2.0375E-08
    55135  3.1520E-06
    59141  8.1770E-06
    60143  7.8437E-06
    60145  5.3690E-06
    60147  0.0000E+00
    60148  2.4396E-06
    61147  4.6579E-07
    61148  2.5286E-28
    61149  0.0000E+00
    62147  2.4124E-06
    62149  9.2457E-08
    62150  1.7313E-06
    62151  2.5218E-07
    62152  8.1307E-07
    63153  3.6305E-07
    63154  2.2885E-08
    63155  1.7465E-08
    64155  2.9493E-08
mix=112
'Batch  5 (Zone 2 Sub-zone 4), Assembly K12, Burnup=18740 MWD/MTU
   492234  4.2764E-06
   492235  2.9849E-04
   492236  6.6868E-05
   492238  2.2228E-02
    93237  5.3813E-06
    94238  9.8938E-07
   494239  1.1248E-04
   494240  3.0815E-05
   494241  1.2374E-05
    94242  3.1112E-06
    95241  4.9978E-06
    95243  3.7354E-07
    96244  3.8242E-08
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     8016  4.6454E-02
    36083  1.8371E-06
    40093  1.6859E-05
    42095  2.6739E-05
    43099  2.6297E-05
    44101  2.4146E-05
    44103  5.6207E-25
    45103  1.5849E-05
    45105  0.0000E+00
    46105  1.0211E-05
    46108  3.2014E-06
    47109  2.1693E-06
    53135  0.0000E+00
    54131  1.1989E-05
    54135  0.0000E+00
    55133  2.8929E-05
    55134  1.9320E-07
    55135  9.1598E-06
    59141  2.5504E-05
    60143  2.1040E-05
    60145  1.5819E-05
    60147  0.0000E+00
    60148  7.7923E-06
    61147  9.7540E-07
    61148  6.0060E-28
    61149  0.0000E+00
    62147  6.0262E-06
    62149  1.2216E-07
    62150  6.4473E-06
    62151  3.9881E-07
    62152  2.8669E-06
    63153  1.8955E-06
    63154  2.8588E-07
    63155  7.7231E-08
    64155  1.3021E-07
mix=113
'Batch  6 (Zone 3 Sub-zone 7), Assembly K13, Burnup= 7090 MWD/MTU
   792234  5.1056E-06
   792235  4.9741E-04
   792236  3.3696E-05
   792238  2.2434E-02
    93237  1.4067E-06
    94238  9.1387E-08
   794239  6.8008E-05
   794240  8.7066E-06
   794241  2.1655E-06
    94242  1.7461E-07
    95241  8.4046E-07
    95243  6.8259E-09
    96244  2.2507E-10
     8016  4.6454E-02
    36083  8.2963E-07
    40093  6.9088E-06
    42095  1.0817E-05
    43099  1.0587E-05
    44101  9.1328E-06
    44103  3.9500E-25
    45103  6.1135E-06
    45105  0.0000E+00
    46105  2.8967E-06
    46108  6.5783E-07
    47109  4.7753E-07
    53135  0.0000E+00
    54131  4.9763E-06
    54135  0.0000E+00
    55133  1.1621E-05
    55134  3.0326E-08
    55135  3.8548E-06
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     59141  9.9539E-06
     60143  9.4066E-06
     60145  6.4959E-06
     60147  0.0000E+00
     60148  2.9767E-06
     61147  5.4248E-07
     61148  3.0280E-28
     61149  0.0000E+00
     62147  2.8717E-06
     62149  9.5891E-08
     62150  2.1722E-06
     62151  2.7288E-07
     62152  1.0281E-06
     63153  4.7624E-07
     63154  3.5148E-08
     63155  2.1322E-08
     64155  3.6014E-08
mix=114
'Batch 4B (Zone 1 Sub-zone 1), Assembly K14, Burnup=24728 MWD/MTU
     92234  3.5377E-06
     92235  1.9356E-04
     92236  7.3797E-05
     92238  2.2149E-02
     93237  7.6600E-06
     94238  2.0376E-06
     94239  1.1943E-04
     94240  4.2805E-05
     94241  1.7691E-05
     94242  6.7955E-06
     95241  7.3095E-06
     95243  1.1403E-06
     96244  1.7237E-07
      8016  4.6454E-02
     36083  2.1563E-06
     40093  2.1187E-05
     42095  3.3789E-05
     43099  3.3599E-05
     44101  3.1814E-05
     44103  5.8048E-25
     45103  2.0309E-05
     45105  0.0000E+00
     46105  1.5304E-05
     46108  5.3186E-06
     47109  3.3966E-06
     53135  0.0000E+00
     54131  1.4874E-05
     54135  0.0000E+00
     55133  3.6853E-05
     55134  3.1973E-07
     55135  1.1754E-05
     59141  3.3010E-05
     60143  2.4871E-05
     60145  1.9868E-05
     60147  0.0000E+00
     60148  1.0222E-05
     61147  1.0235E-06
     61148  6.2871E-28
     61149  0.0000E+00
     62147  7.0243E-06
     62149  1.1885E-07
     62150  8.7490E-06
     62151  4.3170E-07
     62152  3.7442E-06
     63153  2.8353E-06
     63154  5.2348E-07
     63155  1.2790E-07
     64155  2.1554E-07
mix=115
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'Batch 7 (Zone 4 Sub-zone 9), Assembly K15, Burnup=0 MWD/MTU
   992234  5.6679E-06
   992235  6.7019E-04
   992236  3.0441E-06
   992238  2.2548E-02
     8016  4.6454E-02
mix=116
'Batch  6 (Zone 3 Sub-zone 7), Assembly L10, Burnup= 7969 MWD/MTU
   792234  5.0387E-06
   792235  4.7927E-04
   792236  3.6847E-05
   792238  2.2419E-02
    93237  1.6508E-06
    94238  1.2111E-07
   794239  7.3411E-05
   794240  1.0315E-05
   794241  2.7696E-06
    94242  2.5485E-07
    95241  1.0796E-06
    95243  1.1413E-08
    96244  4.2523E-10
     8016  4.6454E-02
    36083  9.1964E-07
    40093  7.7125E-06
    42095  1.2092E-05
    43099  1.1854E-05
    44101  1.0268E-05
    44103  4.0399E-25
    45103  6.8811E-06
    45105  0.0000E+00
    46105  3.3579E-06
    46108  7.9396E-07
    47109  5.7604E-07
    53135  0.0000E+00
    54131  5.5596E-06
    54135  0.0000E+00
    55133  1.3009E-05
    55134  3.8126E-08
    55135  4.3341E-06
    59141  1.1158E-05
    60143  1.0439E-05
    60145  7.2521E-06
    60147  0.0000E+00
    60148  3.3422E-06
    61147  5.9017E-07
    61148  3.3402E-28
    61149  0.0000E+00
    62147  3.1707E-06
    62149  9.8015E-08
    62150  2.4790E-06
    62151  2.8511E-07
    62152  1.1748E-06
    63153  5.5975E-07
    63154  4.5199E-08
    63155  2.4099E-08
    64155  4.0708E-08
mix=117
'Batch  5 (Zone 2 Sub-zone 5), Assembly L11, Burnup=16615 MWD/MTU
   592234  4.4175E-06
   592235  3.2885E-04
   592236  6.2068E-05
   592238  2.2268E-02
    93237  4.5683E-06
    94238  7.3499E-07
   594239  1.0762E-04
   594240  2.6832E-05
   594241  1.0431E-05
    94242  2.2621E-06
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     95241  4.1866E-06
     95243  2.3680E-07
     96244  2.0906E-08
      8016  4.6454E-02
     36083  1.6812E-06
     40093  1.5148E-05
     42095  2.3984E-05
     43099  2.3538E-05
     44101  2.1414E-05
     44103  5.4383E-25
     45103  1.4170E-05
     45105  0.0000E+00
     46105  8.6991E-06
     46108  2.6291E-06
     47109  1.8133E-06
     53135  0.0000E+00
     54131  1.0829E-05
     54135  0.0000E+00
     55133  2.5914E-05
     55134  1.5467E-07
     55135  8.1422E-06
     59141  2.2728E-05
     60143  1.9217E-05
     60145  1.4224E-05
     60147  0.0000E+00
     60148  6.9181E-06
     61147  9.2457E-07
     61148  5.6591E-28
     61149  0.0000E+00
     62147  5.5679E-06
     62149  1.1981E-07
     62150  5.6148E-06
     62151  3.7856E-07
     62152  2.5497E-06
     63153  1.5973E-06
     63154  2.2147E-07
     63155  6.3425E-08
     64155  1.0694E-07
mix=118
'Batch 6 (Zone 4 Sub-zone 8), Assembly L12, Burnup= 6012 MWD/MTU
    892234  5.1886E-06
    892235  5.2052E-04
    892236  2.9657E-05
    892238  2.2452E-02
     93237  1.1248E-06
     94238  6.1642E-08
    894239  6.0689E-05
    894240  6.8050E-06
    894241  1.5062E-06
     94242  1.0102E-07
     95241  5.8144E-07
     95243  3.2592E-09
     96244  9.1860E-11
      8016  4.6454E-02
     36083  7.1564E-07
     40093  5.9083E-06
     42095  9.2337E-06
     43099  9.0199E-06
     44101  7.7401E-06
     44103  3.8185E-25
     45103  5.1678E-06
     45105  0.0000E+00
     46105  2.3568E-06
     46108  5.0518E-07
     47109  3.6593E-07
     53135  0.0000E+00
     54131  4.2491E-06
     54135  0.0000E+00
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    55133  9.9015E-06
    55134  2.1874E-08
    55135  3.2666E-06
    59141  8.4677E-06
    60143  8.1027E-06
    60145  5.5543E-06
    60147  0.0000E+00
    60148  2.5273E-06
    61147  4.7887E-07
    61148  2.6134E-28
    61149  0.0000E+00
    62147  2.4891E-06
    62149  9.3043E-08
    62150  1.8024E-06
    62151  2.5585E-07
    62152  8.4802E-07
    63153  3.8074E-07
    63154  2.4689E-08
    63155  1.8081E-08
    64155  3.0534E-08
mix=119
'Batch 4B (Zone 1 Sub-zone 1), Assembly L13, Burnup=24900 MWD/MTU
    92234  3.5219E-06
    92235  1.9062E-04
    92236  7.4198E-05
    92238  2.2143E-02
    93237  7.7749E-06
    94238  2.0951E-06
    94239  1.1971E-04
    94240  4.3292E-05
    94241  1.7913E-05
    94242  6.9845E-06
    95241  7.4040E-06
    95243  1.1868E-06
    96244  1.8217E-07
     8016  4.6454E-02
    36083  2.1719E-06
    40093  2.1403E-05
    42095  3.4139E-05
    43099  3.3953E-05
    44101  3.2191E-05
    44103  5.8298E-25
    45103  2.0514E-05
    45105  0.0000E+00
    46105  1.5550E-05
    46108  5.4215E-06
    47109  3.4528E-06
    53135  0.0000E+00
    54131  1.5008E-05
    54135  0.0000E+00
    55133  3.7236E-05
    55134  3.2658E-07
    55135  1.1891E-05
    59141  3.3382E-05
    60143  2.5057E-05
    60145  2.0066E-05
    60147  0.0000E+00
    60148  1.0343E-05
    61147  1.0269E-06
    61148  6.3103E-28
    61149  0.0000E+00
    62147  7.0677E-06
    62149  1.1900E-07
    62150  8.8669E-06
    62151  4.3417E-07
    62152  3.7844E-06
    63153  2.8805E-06
    63154  5.3582E-07
```

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    63155  1.3064E-07
    64155  2.2016E-07
mix=120
'Batch 7 (Zone 4 Sub-zone 9), Assembly L14, Burnup=0 MWD/MTU
   992234  5.6679E-06
   992235  6.7019E-04
   992236  3.0441E-06
   992238  2.2548E-02
     8016  4.6454E-02
mix=121
'Batch 7 (Zone 4 Sub-zone 9), Assembly L15, Burnup=0 MWD/MTU
   992234  5.6679E-06
   992235  6.7019E-04
   992236  3.0441E-06
   992238  2.2548E-02
     8016  4.6454E-02
mix=122
'Batch  5 (Zone 2 Sub-zone 4), Assembly M11, Burnup=18203 MWD/MTU
   492234  4.3115E-06
   492235  3.0594E-04
   492236  6.5702E-05
   492238  2.2238E-02
    93237  5.1737E-06
    94238  9.2094E-07
   494239  1.1135E-04
   494240  2.9818E-05
   494241  1.1888E-05
    94242  2.8837E-06
    95241  4.7940E-06
    95243  3.3501E-07
    96244  3.3088E-08
     8016  4.6454E-02
    36083  1.7988E-06
    40093  1.6431E-05
    42095  2.6049E-05
    43099  2.5606E-05
    44101  2.3456E-05
    44103  5.5788E-25
    45103  1.5430E-05
    45105  0.0000E+00
    46105  9.8232E-06
    46108  3.0528E-06
    47109  2.0780E-06
    53135  0.0000E+00
    54131  1.1701E-05
    54135  0.0000E+00
    55133  2.8174E-05
    55134  1.8317E-07
    55135  8.9032E-06
    59141  2.4806E-05
    60143  2.0592E-05
    60145  1.5421E-05
    60147  0.0000E+00
    60148  7.5716E-06
    61147  9.6358E-07
    61148  5.9252E-28
    61149  0.0000E+00
    62147  5.9145E-06
    62149  1.2162E-07
    62150  6.2363E-06
    62151  3.9378E-07
    62152  2.7875E-06
    63153  1.8191E-06
    63154  2.6888E-07
    63155  7.3580E-08
    64155  1.2406E-07
mix=123
'Batch  5 (Zone 2 Sub-zone 5), Assembly M12, Burnup=15877 MWD/MTU
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   592234  4.4678E-06
   592235  3.3995E-04
   592236  6.0281E-05
   592238  2.2281E-02
    93237  4.2921E-06
    94238  6.5682E-07
   594239  1.0568E-04
   594240  2.5427E-05
   594241  9.7459E-06
    94242  1.9997E-06
    95241  3.9030E-06
    95243  1.9868E-07
    96244  1.6594E-08
     8016  4.6454E-02
    36083  1.6243E-06
    40093  1.4542E-05
    42095  2.3012E-05
    43099  2.2565E-05
    44101  2.0464E-05
    44103  5.3668E-25
    45103  1.3575E-05
    45105  0.0000E+00
    46105  8.1897E-06
    46108  2.4406E-06
    47109  1.6932E-06
    53135  0.0000E+00
    54131  1.0414E-05
    54135  0.0000E+00
    55133  2.4850E-05
    55134  1.4207E-07
    55135  7.7873E-06
    59141  2.1758E-05
    60143  1.8554E-05
    60145  1.3659E-05
    60147  0.0000E+00
    60148  6.6140E-06
    61147  9.0437E-07
    61148  5.5213E-28
    61149  0.0000E+00
    62147  5.3979E-06
    62149  1.1887E-07
    62150  5.3280E-06
    62151  3.7135E-07
    62152  2.4376E-06
    63153  1.4968E-06
    63154  2.0093E-07
    63155  5.9029E-08
    64155  9.9527E-08
mix=124
'Batch  6 (Zone 3 Sub-zone 6), Assembly M13, Burnup= 9322 MWD/MTU
   692234  4.9370E-06
   692235  4.5252E-04
   692236  4.1463E-05
   692238  2.2396E-02
    93237  2.0496E-06
    94238  1.7731E-07
   694239  8.0862E-05
   694240  1.2858E-05
   694241  3.7964E-06
    94242  4.1793E-07
    95241  1.4896E-06
    95243  2.2433E-08
    96244  9.9984E-10
     8016  4.6454E-02
    36083  1.0532E-06
    40093  8.9301E-06
    42095  1.4027E-05
    43099  1.3782E-05
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    44101  1.2014E-05
    44103  4.1669E-25
    45103  8.0546E-06
    45105  0.0000E+00
    46105  4.1022E-06
    46108  1.0230E-06
    47109  7.3950E-07
    53135  0.0000E+00
    54131  6.4404E-06
    54135  0.0000E+00
    55133  1.5121E-05
    55134  5.1663E-08
    55135  5.0704E-06
    59141  1.3000E-05
    60143  1.1975E-05
    60145  8.3972E-06
    60147  0.0000E+00
    60148  3.9033E-06
    61147  6.5686E-07
    61148  3.7781E-28
    61149  0.0000E+00
    62147  3.6096E-06
    62149  1.0096E-07
    62150  2.9599E-06
    62151  3.0233E-07
    62152  1.3990E-06
    63153  6.9765E-07
    63154  6.3433E-08
    63155  2.8684E-08
    64155  4.8457E-08
mix=125
'Batch 7 (Zone 4 Sub-zone 9), Assembly M14, Burnup=0 MWD/MTU
   992234  5.6679E-06
   992235  6.7019E-04
   992236  3.0441E-06
   992238  2.2548E-02
     8016  4.6454E-02
mix=126
'Batch 4B (Zone 1 Sub-zone 2), Assembly N12, Burnup=21034 MWD/MTU
   292234  3.7539E-06
   292235  2.3563E-04
   292236  6.7794E-05
   292238  2.2227E-02
    93237  6.1577E-06
    94238  1.3573E-06
   294239  1.1468E-04
   294240  3.6105E-05
   294241  1.4586E-05
    94242  4.5273E-06
    95241  5.9828E-06
    95243  6.3192E-07
    96244  7.6921E-08
     8016  4.6454E-02
    36083  1.9339E-06
    40093  1.8302E-05
    42095  2.9122E-05
    43099  2.8865E-05
    44101  2.6872E-05
    44103  5.4906E-25
    45103  1.7519E-05
    45105  0.0000E+00
    46105  1.2183E-05
    46108  4.0390E-06
    47109  2.6737E-06
    53135  0.0000E+00
    54131  1.3029E-05
    54135  0.0000E+00
    55133  3.1720E-05
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     55134  2.3556E-07
     55135  9.9571E-06
     59141  2.8105E-05
     60143  2.2234E-05
     60145  1.7198E-05
     60147  0.0000E+00
     60148  8.6416E-06
     61147  9.7114E-07
     61148  5.9302E-28
     61149  0.0000E+00
     62147  6.3861E-06
     62149  1.1644E-07
     62150  7.2242E-06
     62151  3.9888E-07
     62152  3.2039E-06
     63153  2.2502E-06
     63154  3.7204E-07
     63155  9.4689E-08
     64155  1.5960E-07
mix=127
'Batch 7 (Zone 4 Sub-zone 9), Assembly N13, Burnup=0 MWD/MTU
   992234  5.6679E-06
   992235  6.7019E-04
   992236  3.0441E-06
   992238  2.2548E-02
     8016  4.6454E-02
mix=128
'Batch 7 (Zone 4 Sub-zone 9), Assembly N14, Burnup=0 MWD/MTU
   992234  5.6679E-06
   992235  6.7019E-04
   992236  3.0441E-06
   992238  2.2548E-02
     8016  4.6454E-02
mix=129
'Batch  5 (Zone 2 Sub-zone 5), Assembly O13, Burnup=15838 MWD/MTU
   592234  4.4705E-06
   592235  3.4055E-04
   592236  6.0184E-05
   592238  2.2282E-02
    93237  4.2776E-06
    94238  6.5284E-07
   594239  1.0558E-04
   594240  2.5352E-05
   594241  9.7096E-06
    94242  1.9863E-06
    95241  3.8880E-06
    95243  1.9679E-07
    96244  1.6388E-08
     8016  4.6454E-02
    36083  1.6212E-06
    40093  1.4510E-05
    42095  2.2960E-05
    43099  2.2514E-05
    44101  2.0414E-05
    44103  5.3627E-25
    45103  1.3543E-05
    45105  0.0000E+00
    46105  8.1630E-06
    46108  2.4308E-06
    47109  1.6870E-06
    53135  0.0000E+00
    54131  1.0391E-05
    54135  0.0000E+00
    55133  2.4793E-05
    55134  1.4142E-07
    55135  7.7685E-06
    59141  2.1706E-05
    60143  1.8518E-05
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    60145  1.3629E-05
    60147  0.0000E+00
    60148  6.5979E-06
    61147  9.0328E-07
    61148  5.5139E-28
    61149  0.0000E+00
    62147  5.3888E-06
    62149  1.1882E-07
    62150  5.3129E-06
    62151  3.7096E-07
    62152  2.4316E-06
    63153  1.4915E-06
    63154  1.9987E-07
    63155  5.8804E-08
    64155  9.9147E-08
mix=2
'zircaloy
   40302   4.25156E-02
mix=3
'borated water
   308016  2.48763E-02
     1001  4.97526E-02
     5010  9.68023E-06
     5011  3.92988E-05
mix=4
'Ag/Cd/In absorber rod
    47107  2.97279E-02
   447109  2.71133E-02
    49113  2.33484E-03
    49115  5.10593E-02
    48000  5.45296E-02
mix=5
'SS304
    24304  1.74286E-02
    25055  1.73633E-03
    26304  5.93579E-02
    28304  7.72074E-03
mix=6
'zirconium oxide (ZrO2)
    40000  2.73217E-02
    608016 5.46433E-02
mix=7
'50% Borated Water, 50% SS304
    705010 5.00926E-06
    705011 2.03361E-05
    701001 2.57456E-02
    708016 1.28728E-02
    724304 8.71429E-03
    725055 8.68166E-04
    726304 2.96790E-02
    728304 3.86037E-03
end mixt

read geom
'*****************************************************************************
'  Unit number designations:
'
'      1 - 29  Fuel assemblies for positions 1 - 29
'          31  1.905 x 21.68144 (horizontal) segment of core baffle
'          32  1.905 x 1.905 corner segment of core baffle
'          33  1.905 x 43.36288 long (horizontal) segment of core baffle
'          34  21.68144 x 1.905 (vertical) segment of core baffle
'          41  "Bottom" of baffle + row 1 of assemblies w/ vertical baffle ends
'          42  Row 2 of assemblies w/ vertical baffle ends
'          43  Row 3 of assemblies w/ vertical baffle ends
'          44  Rows 4-5 of assemblies w/ vertical baffle ends
'          46  Rows 11-12 of assemblies w/ vertical baffle ends
'          47  Row 13 of assemblies w/ vertical baffle ends
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'          48  Row 14 of assemblies w/ vertical baffle ends
'          49  Row 15 of assemblies w/ vertical baffle ends + "top" of baffle
'          50  Reactor vessel and all internals (global)
'   101 - 129  Fuel rods for assemblies positions 1 - 29
'         200  APSR rod inside guide tube
'         201  Water filled guide tube
'
'*******************************************************************************
'define the 29 different fuel pin types.
unit 101
cylinder  0101  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 102
cylinder  0102  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 103
cylinder  0103  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 104
cylinder  0104  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 105
cylinder  0105  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 106
cylinder  0106  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 107
cylinder  0107  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 108
cylinder  0108  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 109
cylinder  0109  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 110
cylinder  0110  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 111
cylinder  0111  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 112
cylinder  0112  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
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cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 113
cylinder  0113  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 114
cylinder  0114  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 115
cylinder  0115  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 116
cylinder  0116  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 117
cylinder  0117  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 118
cylinder  0118  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 119
cylinder  0119  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 120
cylinder  0120  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 121
cylinder  0121  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 122
cylinder  0122  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 123
cylinder  0123  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 124
cylinder  0124  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 125
cylinder  0125  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 126
cylinder  0126  1  0.46812  360.17  0.0
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cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 127
cylinder  0127  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 128
cylinder  0128  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0
unit 129
cylinder  0129  1  0.46812  360.17  0.0
cylinder     0  1  0.47879  360.17  0.0
cylinder     2  1  0.54610  360.17  0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0

'APSR rod - contains Ag/Cd/In poison in a 36" slug
unit 200
'            ZrO2 spacer
cylinder     6  1  0.5055   139.99  139.23
'            Ag/Cd/In Poison
cylinder     4  1  0.5055   231.39  139.23
'            Air (void) region
cylinder     0  1  0.5055   236.34  139.23
'            Upper SS304 plug
cylinder     5  1  0.5055   237.61  139.23
'            Water above plug, to top of core
cylinder     3  1  0.5055   360.17  139.23
'            Stainless clad and bottom end plug
cylinder     5  1  0.5588   360.17   136.69
'            Water inside guide tube
cylinder     3  1  0.6223   360.17    0.0
'            Zircaloy guide tube
cylinder     2  1  0.6731   360.17    0.0
'            Water cuboid surrounding guide tube
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0

'Water filled guide tube
unit 201
cylinder     3  1  0.6223   360.17    0.0
cylinder     2  1  0.6731   360.17    0.0
cuboid       3  1  2p0.72136  2p0.72136  360.17  0.0

'Assembly 1
unit 1
array     0101 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 2
unit 2
array     0102 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 3
unit 3
array     0103 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 4
unit 4
array     0104 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 5
unit 5
array     0105 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 6
unit 6
```

```
array     0106 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 7
unit 7
array     0107 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 8
unit 8
array     0108 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 9
unit 9
array     0109 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 10
unit 10
array     0110 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 11
unit 11
array     0111 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 12
unit 12
array     0112 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 13
unit 13
array     0113 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 14
unit 14
array     0114 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 15
unit 15
array     0115 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 16
unit 16
array     0116 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 17
unit 17
array     0117 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 18
unit 18
array     0118 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 19
unit 19
array     0119 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 20
unit 20
array     0120 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 21
unit 21
array     0121 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 22
unit 22
array     0122 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 23
unit 23
```

```
array     0123 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 24
unit 24
array     0124 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 25
unit 25
array     0125 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 26
unit 26
array     0126 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 27
unit 27
array     0127 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 28
unit 28
array     0128 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0
'Assembly 29
unit 29
array     0129 2r-21.6408  0.0
cuboid  3  1  0.0 -21.6810000 0.0 -21.6810000 360.17  0.0

'Baffle components
'short horizontal segment
unit 31
cuboid  5  1  2p10.84050 2p0.95250  360.17  0.0
'corner segment
unit 32
cuboid  5  1  2p0.95250  2p0.95250  360.17  0.0
'long horizontal segment
unit 33
cuboid  5  1  2p21.681  2p0.95250  360.17  0.0
'vertical segment
unit 34
cuboid  5  1  2p0.95250  2p10.84050  360.17  0.0

'Rows of assemblies w/ baffle components
'Bottom of baffle + row 1
unit 41
array  1  -56.1086  -12.74572  0.0
'Row 2
unit 42
array 2  -99.47148  -10.84072  0.0
'Row 3
unit 43
array 3  -121.15292  -10.84072  0.0
'Rows 4&5
unit 44
array 4  -142.83436  -21.68144  0.0
'Rows 11&12
unit 46
array 6  -142.83436  -21.68144  0.0
'Row 13
unit 47
array 7  -121.15292  -10.84072  0.0
'Row 14
unit 48
array 8  -99.47148  -10.84072  0.0
'Row 15 + top of baffle
unit 49
array 9  -56.1086  -10.84072  0.0

'Reactor vessel and all components
```

```
'  In this global coordinate system, the bottom center of the cylindrical
'  vessel is the origin.
global unit 50
'Rows 6-10 of assemblies
array 5  -164.51580  -54.20360  0.0
'Water inside core barrel
cylinder  3  1  179.07  360.17  0.0
'Row 1 of assemblies
hole 41  0.0 -151.77008  0.0
'Row 2 of assemblies
hole 42  0.0 -130.08864  0.0
'Row 3 of assemblies
hole 43  0.0 -108.40720  0.0
'Rows 4&5 of assemblies
hole 44  0.0 -75.88504  0.0
'Rows 11&12 of assemblies
hole 46  0.0  75.88504  0.0
'Row 13 of assemblies
hole 47  0.0  108.40720  0.0
'Row 14 of assemblies
hole 48  0.0  130.08864  0.0
'Row 15 of Assemblies
hole 49  0.0  151.77008  0.0
'Long baffle segment at upper right (above row 14)
hole 33  77.79005  141.88187  0.0
'Long baffle segment at upper left (above row 14)
hole 33 -77.79005  141.88187  0.0
'Long baffle segment at lower right (below row 2)
hole 33  77.79005 -141.88187  0.0
'Long baffle segment at lower left (below row 2)
hole 33 -77.79005 -141.88187  0.0
'Short horizontal baffle segments in upper right quadrant, above rows 13, 12
'and 10, respectively.
hole 31  110.312201  120.200421  0.0
hole 31  131.993641  98.518981  0.0
hole 31  153.675081  55.156101  0.0
'Short horizontal baffle segments in upper left quadrant, above rows 13, 12
'and 10, respectively.
hole 31 -110.312201  120.200421  0.0
hole 31 -131.993641  98.518981  0.0
hole 31 -153.675081  55.156101  0.0
'Short horizontal baffle segments in lower right quadrant, below rows 3, 4,
'and 6, respectively.
hole 31  110.312201 -120.200421  0.0
hole 31  131.993641 -98.518981  0.0
hole 31  153.680000 -55.160000  0.0
'Short horizontal baffle segments in lower left quadrant, below rows 3, 4,
'and 6, respectively.
hole 31 -110.312201 -120.200421  0.0
hole 31 -131.993641 -98.518981  0.0
hole 31 -153.680000 -55.160000  0.0
'top and bottom "structure" beyond active core
cylinder  7  1  179.07  385.17  -25.0
'core barrel
cylinder  5  1  184.15  385.17  -25.0
'Water between core barrel and thermal shield
cylinder  3  1  186.69  385.17  -25.0
'Thermal shield
cylinder  5  1  191.77  385.17  -25.0
'Water between thermal shield and reactor vessel
cylinder  3  1  217.17  385.17  -25.0
'Reactor vessel
cylinder  5  1  239.17  385.17  -25.0
'Bounding cuboid (void)
cuboid  0  1  2p245.0  2p245.0 385.17  -25.0
end geom

read array
```

```
'*****************************************************************************
'  Array number designations:
'
'           1  Bottom of baffle + row 1 of fuel assemblies + r & l baffle segs.
'           2  Row 2 of fuel assemblies + r & l baffle segments
'           3  Row 3 of fuel assemblies + r & l baffle segments
'           4  Rows 4 & 5 of fuel assemblies + r & l baffle segments
'           5  Rows 6 - 10 of fuel assemblies + r & l baffle segments
'           6  Rows 11 & 12 of fuel assemblies + r & l baffle segments
'           7  Row 13 of fuel assemblies + r & l baffle segments
'           8  Row 14 of fuel assemblies + r & l baffle segments
'           9  Row 15 of fuel assemblies + r & l baffle segs. + top of baffle
'   101 - 129  Fuel assemblies for positions 1 - 29
'*****************************************************************************
ara=1 nux=7 nuy=2 nuz=1 fill
               32 31 31 31 1b3
               34 21 15  8 1b3 end fill
ara=2 nux=11 nuy=1 nuz=1 fill
         34 28 25 20 14  7 1b5 end fill
ara=3 nux=13 nuy=1 nuz=1 fill
      34 29 27 24 19 13  6 1b6 end fill
ara=4 nux=15 nuy=2 nuz=1 fill
   34 28 27 26 23 18 12  5 1b7
   34 25 24 23 22 17 11  4 1b7 end fill
ara=5 nux=17 nuy=5 nuz=1 fill
34 21 20 19 18 17 16 10  3 1b8
34 15 14 13 12 11 10  9  2 1b8
34  8  7  6  5  4  3  2  1 1b8
34 15 14 13 12 11 10  9  2 1b8
34 21 20 19 18 17 16 10  3 1b8 end fill
ara=6 nux=15 nuy=2 nuz=1 fill
   34 25 24 23 22 17 11  4 1b7
   34 28 27 26 23 18 12  5 1b7 end fill
ara=7 nux=13 nuy=1 nuz=1 fill
      34 29 27 24 19 13  6 1b6 end fill
ara=8 nux=11 nuy=1 nuz=1 fill
         34 28 25 20 14  7 1b5 end fill
ara=9 nux=7 nuy=2 nuz=1 fill
               34 21 15  8 1b3
               32 31 31 31 1b3 end fill
'Individual fuel assemblies
'assembly 1
ara=101 nux=15 nuy=15 nuz=1  fill
f101
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 2
ara=102 nux=15 nuy=15 nuz=1  fill
f102
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 3
ara=103 nux=15 nuy=15 nuz=1  fill
f103
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 4
ara=104 nux=15 nuy=15 nuz=1  fill
f104
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 5
ara=105 nux=15 nuy=15 nuz=1  fill
f105
```

```
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 6
ara=106 nux=15 nuy=15 nuz=1  fill
f106
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 7
ara=107 nux=15 nuy=15 nuz=1  fill
f107
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 8
ara=108 nux=15 nuy=15 nuz=1  fill
f108
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 9
ara=109 nux=15 nuy=15 nuz=1  fill
f109
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 10
ara=110 nux=15 nuy=15 nuz=1  fill
f110
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 11
ara=111 nux=15 nuy=15 nuz=1  fill
f111
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 12
ara=112 nux=15 nuy=15 nuz=1  fill
f112
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 13
ara=113 nux=15 nuy=15 nuz=1  fill
f113
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 14
ara=114 nux=15 nuy=15 nuz=1  fill
f114
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 15
ara=115 nux=15 nuy=15 nuz=1  fill
f115
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 16
ara=116 nux=15 nuy=15 nuz=1  fill
f116
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
```

```
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 17
ara=117 nux=15 nuy=15 nuz=1  fill
f117
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 18 - contains APSRs in all but center position
ara=118 nux=15 nuy=15 nuz=1  fill
f118
 a36 200   a40 200   a49 200   a57 200   a78 200   a81 200
 a85 200   a88 200  a113 201  a138 200  a141 200  a145 200
a148 200  a169 200  a177 200  a186 200  a190 200  end fill
'assembly 19
ara=119 nux=15 nuy=15 nuz=1  fill
f119
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 20
ara=120 nux=15 nuy=15 nuz=1  fill
f120
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 21
ara=121 nux=15 nuy=15 nuz=1  fill
f121
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 22
ara=122 nux=15 nuy=15 nuz=1  fill
f122
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 23
ara=123 nux=15 nuy=15 nuz=1  fill
f123
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 24
ara=124 nux=15 nuy=15 nuz=1  fill
f124
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 25
ara=125 nux=15 nuy=15 nuz=1  fill
f125
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 26
ara=126 nux=15 nuy=15 nuz=1  fill
f126
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 27
ara=127 nux=15 nuy=15 nuz=1  fill
f127
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 28
```

```
ara=128 nux=15 nuy=15 nuz=1  fill
f128
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
'assembly 29
ara=129 nux=15 nuy=15 nuz=1  fill
f129
 a36 201   a40 201   a49 201   a57 201   a78 201   a81 201
 a85 201   a88 201  a113 201  a138 201  a141 201  a145 201
a148 201  a169 201  a177 201  a186 201  a190 201  end fill
end array

read plot
ttl=! TMI Unit 1, BOC-5 Full Core by UNIT !
pic=unit
xul=-200 yul=200 xlr=200 ylr=-200 uax=1 vdn=-1 nax=130 end
ttl=! TMI Unit 1, BOC-5 Full Core by MIX !
pic=mix nch=! 23456ABCDEFGHIJKLMNOPQRSTUVWXYZ*@%$!
xul=-200 yul=200 xlr=200 ylr=-200 uax=1 vdn=-1 nax=130 end
end plot
end data
end
```

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