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# SCALE-4 Analysis of Pressurized Water Reactor Critical Configurations: Volume 5 — North Anna Unit 1 Cycle 5

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# SCALE-4 ANALYSIS OF PRESSURIZED WATER REACTOR CRITICAL CONFIGURATIONS: VOLUME 5—NORTH ANNA UNIT 1 CYCLE 5

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## FOREWORD

The work described in this report was performed under a quality assurance (QA) program consistent with DOE/RW-214, "Quality Assurance Requirements," as directed by Sandia National Laboratories (SNL) Contract 66-0162. Specifically, work was performed under the QA plan developed in 1992 at Oak Ridge National Laboratory (ORNL) and documented in ORNL QA records as document BCAV-QAAP-002. The analyses, computer codes, and documentation that served as a basis for this report were produced, reviewed, and controlled as per the requirements of the ORNL QA plan. Subsequent documentation of the work in the form of this report was performed under an OCRWM-approved QA program, consistent with DOE/RW-0333P, "Quality Assurance Requirements and Descriptions," as stipulated in SNL Contract No. AD-4072.

Reactor design and burnup cycle data used in this work were obtained primarily from the North Anna Unit 1 Cycle 5 design report, issued by Virginia Electric and Power Company. Core design reports are mandated by the Nuclear Regulatory Commission (NRC); parameters described in the report serve as the basis for startup testing. Use of such data in startup procedures is in accordance with NRC requirements. Thus although the data contained in the core design report are not explicitly qualified under the OCRWM program, they are considered to be consistent with the nature of qualified data under OCRWM QA procedures, and are therefore considered to be appropriate for use in this work.

## ABSTRACT

The requirements of ANSI/ANS 8.1 specify that calculational methods for away-from-reactor (AFR) criticality safety analyses be validated against experimental measurements. If credit for the negative reactivity of the depleted (or spent) fuel isotopics is desired, it is necessary to benchmark computational methods against spent fuel critical configurations. This report summarizes a portion of the ongoing effort to benchmark AFR criticality analysis methods using selected critical configurations from commercial pressurized-water reactors (PWR).

The analysis methodology selected for all calculations reported herein was the codes and data provided in the SCALE-4 code system. The isotopic densities for the spent fuel assemblies in the critical configurations were calculated using the SAS2H analytical sequence of the SCALE-4 system. The sources of data and the procedures for deriving SAS2H input parameters are described in detail. The SNIKR code module was used to extract the necessary isotopic densities from the SAS2H results and to provide the data in the format required by the SCALE criticality analysis modules. The CSASN analytical sequence in SCALE-4 was used to perform resonance processing of the cross sections. The KENO V.a module of SCALE-4 was used to calculate the effective multiplication factor ($k_{eff}$) of each case. The SCALE-4 27-group burnup library containing ENDF/B-IV (actinides) and ENDF/B-V (fission products) data was used for all the calculations.

This volume of the report documents the SCALE system analysis of one reactor critical configuration for North Anna Unit 1 Cycle 5. This unit and cycle were chosen for a previous analysis using a different methodology because detailed isotopics from multidimensional reactor calculations were available from the Virginia Power Company. These data permitted comparison of criticality calculations directly using the utility-calculated isotopics to those using the isotopics generated by the SCALE-4 SAS2H sequence. This reactor critical benchmark has been reanalyzed using the methodology described above. The benchmark critical calculation was the beginning-of-cycle (BOC) startup at hot, zero power (HZP). The $k_{eff}$ result was 1.0040, with a standard deviation of 0.0005.

# 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 five-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 directly correspond 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 that 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 the ability of an analysis methodology 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); (2) the need to verify consistency in calculated results for different reactor conditions; and (3) the need to provide a comparison with the results of ref. 8. 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 of the report is to describe the reanalysis of the hot, zero power (HZP) reactor critical configuration obtained during beginning-of-cycle (BOC) startup physics testing for Virginia Power's North Anna Unit 1 Cycle 5. This unit was previously analyzed in ref. 8, along with a hot, full-power (HFP) BOC configuration. It has since been determined that the HFP case was not an actual measured critical configuration, but merely a calculated critical configuration generated by the utility's reactor physics codes. These two cases were originally selected because of the availability of the operating data and the three-dimensional (3-D) calculated nuclide density distributions from the utility's reactor physics calculations. Differences of approximately 2% $\Delta k$ were observed between the results of the original and revised methodologies in the reanalysis of Surry Unit 1 Cycle 2 in Vol. 3 of this report. To investigate these differences further, the North Anna BOC, HZP reactor critical has been reanalyzed using the revised SCALE methodology.

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 North Anna 1 Cycle 5. The results and conclusions are discussed in Sect. 4.

## 2. OVERVIEW OF THE METHODOLOGY

An essential part of any analysis validation effort is to use the same codes, input options, and technical approach for the validation study as that used for the application. To this end, a straightforward calculational strategy was established that minimizes the data required to characterize the spent fuel and is appropriate for use by a cask designer performing criticality analysis for spent fuel assemblies.

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 assemblies modeled 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 Fig. 1 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 step three, the SNIKR code package (not a part of the SCALE system) is used to interpolate between isotopics for appropriate timesteps 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 three are used in step four to create fuel pin models based on the average composition of an assembly subgroup; the CSASN sequence in SCALE is used to calculate the problem-dependent, group-weighted cross sections for each subgroup. The SCALE WAX module combines 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 five a KENO V.a model is created based on the core geometry, again assuming eighth-core symmetry. Thus even though 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

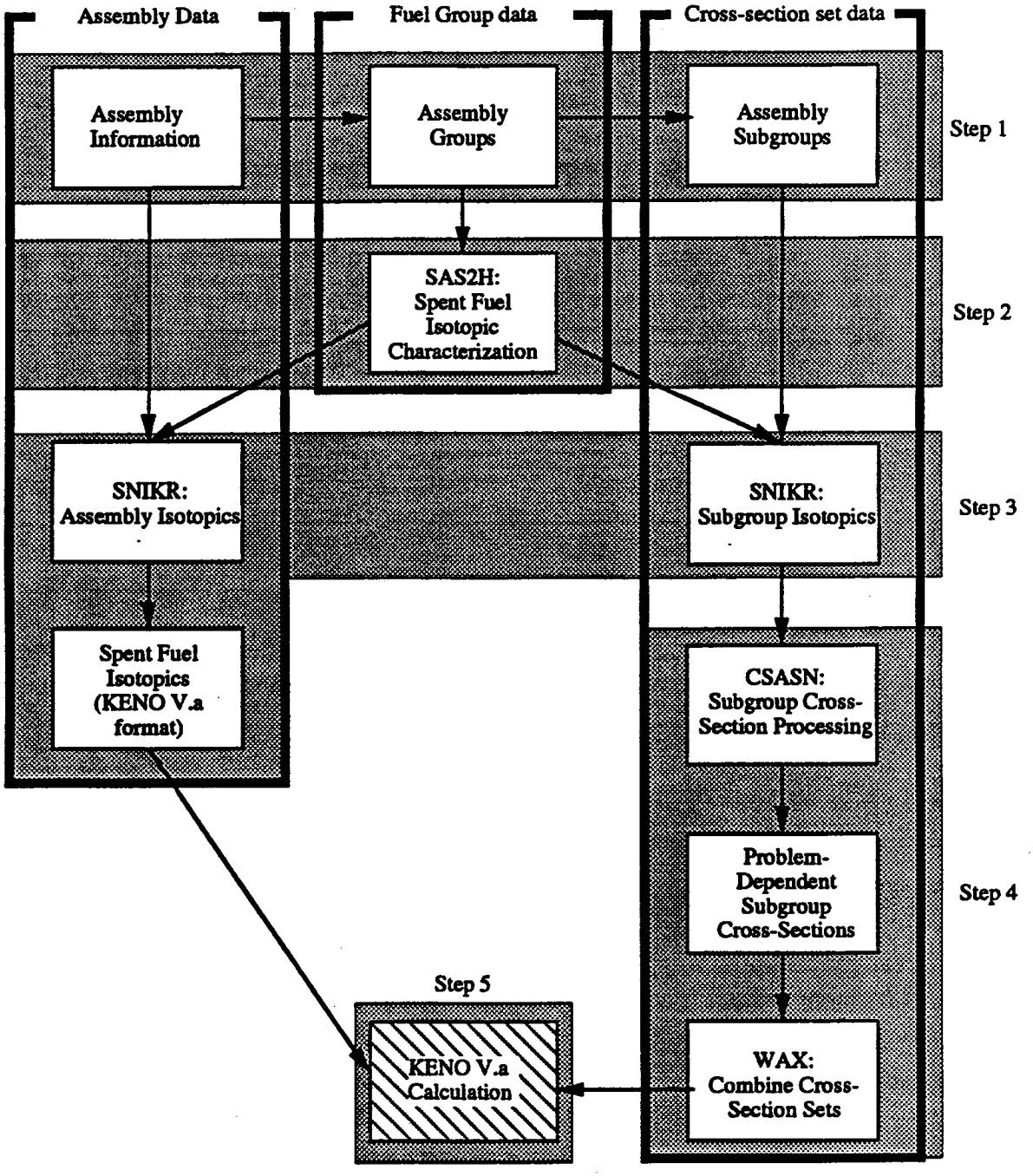



Fig. 1. Overview of the reactor critical calculation procedure.

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. 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

Since many assemblies in a reactor begin with identical initial compositions and experience simultaneous operating histories, these similar fuel assemblies can be collected effectively into groups with one depletion calculation performed for each group. It is assumed that at a given burnup, all assemblies within a group 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 burnup. This interpolation is discussed further in Sect. 2.3.

A minimum granularity for grouping is to collect fuel assemblies by reactor fuel batch. In the nomenclature generally applied by commercial PWR core designers, a fuel batch is typically comprised of a single enrichment fuel, all loaded at the same time, and all residing in-core for the same fuel cycles. Three fuel batches (i.e., enrichments) are usually present in the first operating cycle of a reactor. These batches are typically designated by the numbers 1, 2, and 3. Prior to each subsequent cycle of operation, one new batch of fuel is usually added and some of the depleted fuel assemblies are removed. Each new batch of fuel is assigned a number unique to that reactor. If the new fuel assemblies to be loaded consist of more than one enrichment, they may be assigned as a "split batch," using the same number with a different letter appended to each enrichment. For example, if two enrichments were to be added to Cycle 2, the fuel assemblies of one enrichment would be designated as batch 4A, and those of the other enrichment would be designated as batch 4B. Hence if a given batch of assemblies has experienced identical operating periods, downtimes, and roughly the same power history, the batch meets the minimum requirements for a calculational fuel group. However, within a given fuel batch, additional fuel groups (i.e., separate depletion calculations) may be required when absorber materials [i.e., burnable poison rods (BPRs) or control rods] are present in certain assemblies within a fuel batch.

As discussed, within a fuel group it is possible to interpolate between a series of burnups to determine the isotopic concentrations corresponding to a specific burnup. This interpolation procedure can be used to calculate the contents of each individual assembly. Based on these assembly isotopics, it is possible to generate a content-specific cross-section set for each assembly. However, since nuclide cross sections vary slowly with burnup (after the initial startup of approximately 150 MWd/MTU) the analysis methodology can be accurately simplified by preparing problem-dependent cross sections for a set of similar assemblies with similar burnups. Unfortunately, because of specific power variations related to the assembly locations in the core, it is possible to have a relatively wide range of burnups within a single fuel group. Thus it may be necessary to divide fuel groups into subgroups or cross-section sets based on burnup such that all assemblies included in a

cross-section set are within a limited burnup range; the number of cross-section sets will depend on the range of burnups contained in the fuel group. Previous work[8] has indicated that cross-section sets with burnup ranges of no more than 2 GWd/MTU can be adequately represented by the average burnup value within the cross-section set.

## 2.2 DEPLETION CALCULATIONS

Depletion calculations were performed using the SAS2H[5] sequence of the SCALE-4 code system and the 27-group burnup library. The SAS2H sequence invokes the ORIGEN-S[9] code to perform depletion and decay calculations. The SAS2H procedure uses a 1-D two-part spectrum calculation (part 1 is a pin-cell model, part 2 is an assembly model) at selected times in the irradiation history to generate burnup-dependent cross sections based on the given design and operating parameters. 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 fuel group as a function of its operating history. For fuel groups comprised of fresh (unburned) fuel at the time of the critical measurements, SAS2H calculations are not necessary; the isotopic content is based on that of the fresh fuel specifications.

Although it is necessary to model the presence of BPRs for the cycle for which the criticality calculation is to be performed, previous studies[10,11] have shown that the history of the assembly with respect to the insertion and removal of BPRs in earlier reactor cycles is small enough to be neglected (<1% $\Delta k/k$). To model the influence of the BPRs in the cycle of interest, an effective cell is derived. This effective cell conserves the mass of the nuclides comprising the BPRs, guide tube, and fuel rods. In this effective cell, the densities of the isotopes remain unchanged, but the rod diameters of the glass and stainless steel in the BPRs are modified appropriately for the 1-D assembly model required by SAS2H.

Since, within a fuel group, it is assumed that isotopic content is a function only of burnup, it is possible to calculate 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 power history. To provide sufficient points for interpolation, the burnup history was broken into equal intervals of no more than 5 GWd/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 fuel groups were depleted at least 1.2 times the maximum burnup ($B_{max}$) of the fuel group. Note that it is generally sufficient to calculate burnups out to the maximum burnup in a group, as this will bound all burnups in the group. A value of $1.2*B_{max}$ was used to allow for the capability of modeling axial burnup variations where volume-averaged center region burnups may be up to 1.2 times larger than the assembly average. However, axial burnup variations are not included in the models presented in this report.

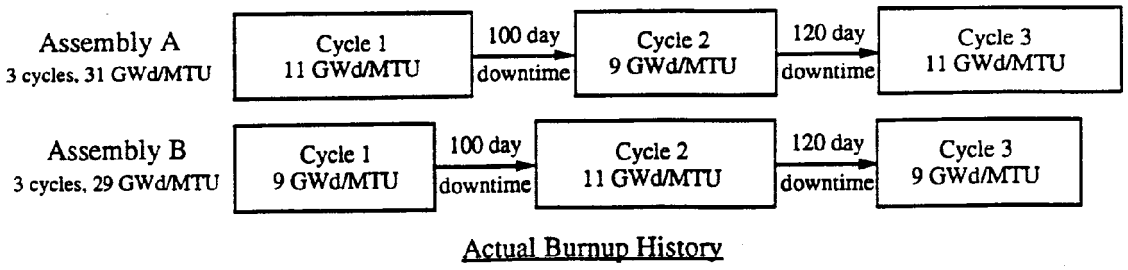
To make it possible to interpolate between burnup steps and account for downtime between cycles, a simplification is made in the burnup model. Since the burnup actually accumulated during each cycle varies for each fuel assembly in a group, the downtime was split and applied at the end of

each burnup interval. This practice ensures that the spent fuel isotopics for all fuel assemblies contain the impact of the reactor cycle downtime when interpolation on burnup is performed. The ratio of uptime to downtime for each operating cycle was used to determine the downtime for each burnup interval. Average values for specific power were computed from the fuel group average burnups and the total uptime for the cycle. The average soluble boron concentrations were based on boron letdown curves for each operating cycle. Isotopics for assembly-specific burnups may then be obtained via interpolation between calculated isotopics at the end of each burnup interval (prior to downtime). This approach is illustrated in Fig. 2. The top portion of the picture shows the "actual" burnup histories for two hypothetical assemblies in a fuel group. Note that in this example the number of cycles and downtimes are the same but that 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 depletion, using a single calculation to represent the entire fuel group. Each cycle is broken down into multiple burnup intervals, each followed by a downtime (for the first two cycles). The final cycle is calculated with a sufficient number of burnup intervals 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 so as to represent average cycle burnups for the group. Any downtime immediately before the reactor critical conditions was not included in the SAS2H depletion, but was explicitly modeled as described in Sect. 2.3.

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 quantities 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 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. 12. 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.[10,13]

Any additional cross sections required for depletion calculations are obtained from the more than 1000 nuclides available within the ORIGEN-S one-group LWR library and are adjusted with burnup using the ORIGEN-S spectral parameters (THERM, RES, and FAST)[9] calculated using fluxes calculated by XSDRNPM. The ORIGEN-S one-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 one-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 fact is not felt to have a significant effect on isotopic calculations.




Actual Burnup History

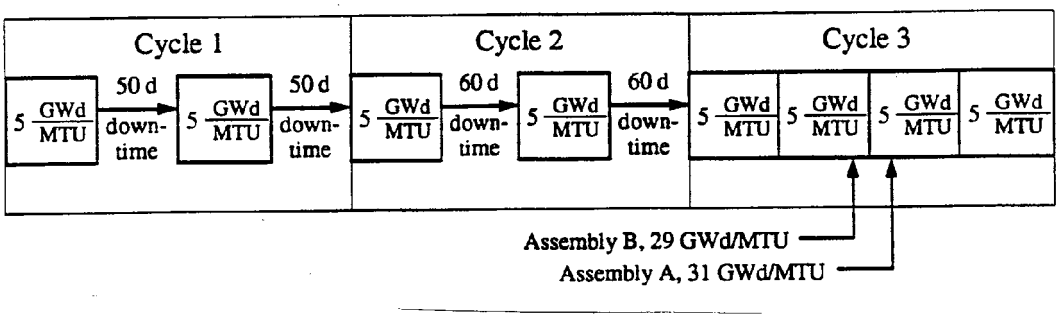



Fig. 2. SAS2H burnup model of assemblies within a fuel group.

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.

## 2.3 NUCLIDE CONCENTRATIONS FOR REACTOR CRITICALITY CALCULATIONS

As has been indicated in previous sections, the isotopic content may be determined for each assembly or cross-section set by interpolating between burnups for which SAS2H/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 prior to shutdown or discharge. For a criticality condition obtained after the shutdown of the last cycle, it is necessary to perform decay calculations to account for the change in composition due to 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 has not been incorporated into SCALE at this time; thus input descriptions and code listings have been included in Appendix C.

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 1 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 $k_\infty$ (i.e., 1-D infinite-lattice calculation) values. The results of these comparisons indicated agreement to within 0.1% $\Delta k$ in the $k_\infty$ values calculated using isotopics derived from the two methods.

SNIKR1 then sets up the input needed to decay these 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 the burnup credit criticality analysis. Number densities for these nuclides are then written to output files in the SCALE standard composition input format and the 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 consists 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 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. 10 and 13.

## 2.4 CROSS-SECTION PROCESSING BY CROSS-SECTION SET

The CSASN[6] sequence of the SCALE system is used to compute problem-dependent fuel pin cross sections based on the isotopic content and geometry of a lattice fuel cell. Based on a 1-D fuel pin 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 using the Nordheim Integral Treatment.

CSASN cross-section processing is applied only to cross-section-set-averaged nuclide concentrations. As discussed earlier in Sect. 2.1, effective cross sections are not strongly coupled to burnup; hence it is sufficient to compute cross sections for the average burnup of a cross-section set, provided the range of burnups in the cross-section set is not too large (less than 2 GWd/MTU). Nuclide concentrations for use in the CSASN calculation are provided in the SCALE standard composition format in the output from the SNIKR cross-section set calculations.

Because fission-product nuclides represent only a small fraction of the total number density of the fuel, fission-product cross sections are relatively insensitive to the varying isotopic content and need only be calculated for one cross-section set. This insensitivity is also true of many fuel activation products and minor actinides; however, cross sections for seven actinides are known to have a more 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 cross-section set fuel pin models include the appropriate SNIKR-computed concentrations for each of these isotopes; the remaining nuclides are included only in the highest burnup cross-section set. The highest burnup is

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. 10).
[d]Additional reactor physics nuclides from Yankee Atomic's CASMO-3/SIMULATE-3 calculations (ref. 13).

chosen because it will result in the lowest resonance absorption, and therefore results in a higher and more conservative $k_{eff}$; however, the effect is extremely small (<0.1% $\Delta k/k$).

Once cross sections are computed for each cross-section set, the SCALE utility module WAX[16] is used to combine all CSASN cross-section set working libraries into a single working library for subsequent use by KENO V.a. All cross sections from the highest burnup cross-section set (containing all fission and activation isotopes) are copied into the combined library. For each of the remaining cross-section-set libraries, only the seven burnup-dependent actinides are copied. In addition, for each of the seven burnup-dependent actinides in each cross-section set, the cross-section ID number is modified by prefixing the cross-section set number to the cross-section ID so that the KENO V.a core model can reference the appropriate cross section for each cross-section set. The cross sections with modified ID numbers 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; the detailed mechanics of the geometry model are discussed later. Using one-eighth-core symmetry,

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 KENO V.a mixing table format; thus there are unique mixture data for each assembly type in the model. Within each set of mixing table data, the nuclide ID number of each of the seven burnup-dependent actinides is prefixed by the cross-section-set number that represents that assembly (this can be done automatically by SNIKR), so that the effective cross sections computed for the corresponding cross-section set are utilized. These cross sections are located in the working library prepared as described in the previous subsection.

## 3. PREPARATION OF THE NORTH ANNA 1 CYCLE 5 CORE MODEL

The previous section has given an overview of the technical procedure used in setting up the North Anna 1 Cycle 5 reactor critical calculations to provide a broad overview of the entire process before concentrating on the details. This section describes the North Anna 1 Cycle 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. 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 results will be provided in Sect. 4 of this report.

### 3.1 CORE DESCRIPTION

The North Anna 1 Cycle 5 core consisted of 157 Westinghouse fuel assemblies, each comprised of a 17 × 17 lattice containing 264 fuel rods, 24 control rod guide tubes, and 1 instrument tube. The core configuration is shown in Fig. 3 where each square represents an assembly position. At-power reactivity control was maintained using four control banks and two shutdown banks of full-length Ag-In-Cd control rod clusters, 68 BPR clusters containing a total of 912 fresh and 192 depleted BPRs, and soluble boron. Within each assembly, the lattice positions of guide tubes and/or BPRs are located as illustrated in Fig. 4. The loading of the BPR clusters in Cycle 5 is shown in Fig. 5. Design data were obtained from ref. 17.

The critical condition modeled in this report is based on HZP startup testing for BOC-5. The critical boron concentration was 1836 ppm. All core components were assumed to be at a constant temperature of 559 K (547°F) based on nominal HZP conditions. All control rods were fully withdrawn to the all-rods-out (ARO) position. The downtime between Cycles 4 and 5 was 136 days (0.372 years).

For Cycle 5, five fuel batches were present in the core. Fuel batch 4 was manufactured with 3.21 wt % $^{235}$U. The batch 4 fuel assemblies loaded in Cycle 5 were loaded in Cycles 2 and 3 but were discharged prior to Cycle 4. Batch 5 was manufactured with 3.41 wt % $^{235}$U and was loaded in Cycles 3 and 4. Batch 6 was manufactured with 3.59 wt % $^{235}$U and was initially loaded in Cycle 4. Two fresh fuel batches, 7 (3.60 wt % $^{235}$U) and N2/5 (3.59 wt % $^{235}$U) were loaded in Cycle 5. The batch N2/5 fuel assemblies were originally manufactured for North Anna Unit 2 but were transferred to Unit 1 when damaged fuel assemblies caused an emergency redesign for North Anna Unit 1 Cycle 5. A full-core loading map and assembly burnup data for Cycle 2 are included in Appendix A. Table 3 provides a physical description of the significant aspects of the fuel design for all assemblies.

To simplify and reduce the volume of input in the KENO V.a model, eighth-core symmetry was assumed in the isotopic input. This assumption reduces the number of fuel assemblies with unique enrichment and burnup specifications to 26 (Fig. 6). The loading pattern for North Anna Unit 1 Cycle 5 (Fig. A.1) was approximately eighth-core symmetric. One batch N2/5 assembly (3.59 wt % $^{235}$U) was loaded with three batch 7 assemblies (3.60 wt % $^{235}$U) as a symmetric grouping. The assembly burnups were averaged from Table A.1 based on the eighth-core symmetry shown in Fig. 6. Assembly burnups listed throughout the remainder of this report are eighth-core average values.

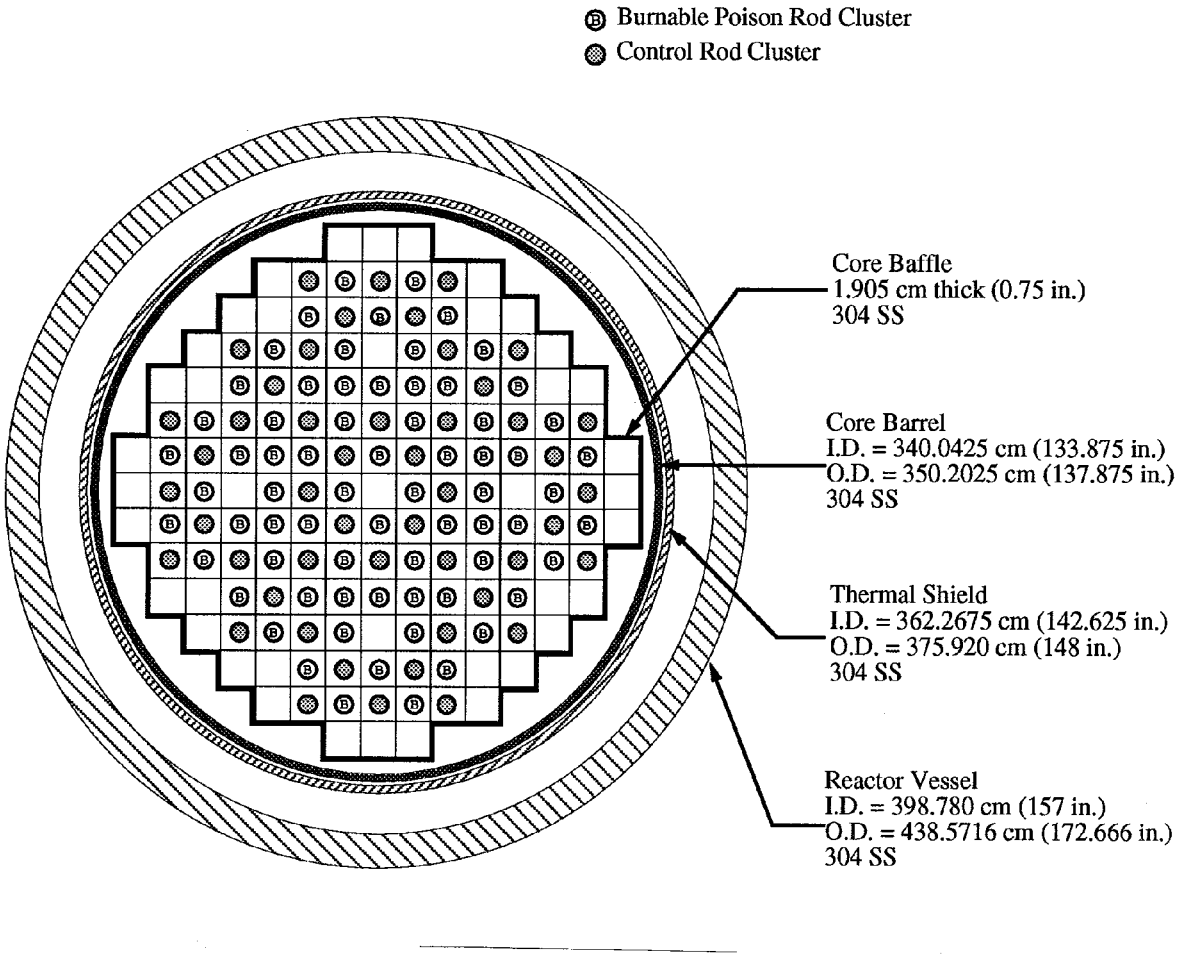



Fig. 3. North Anna Unit 1 Cycle 5 core configuration.

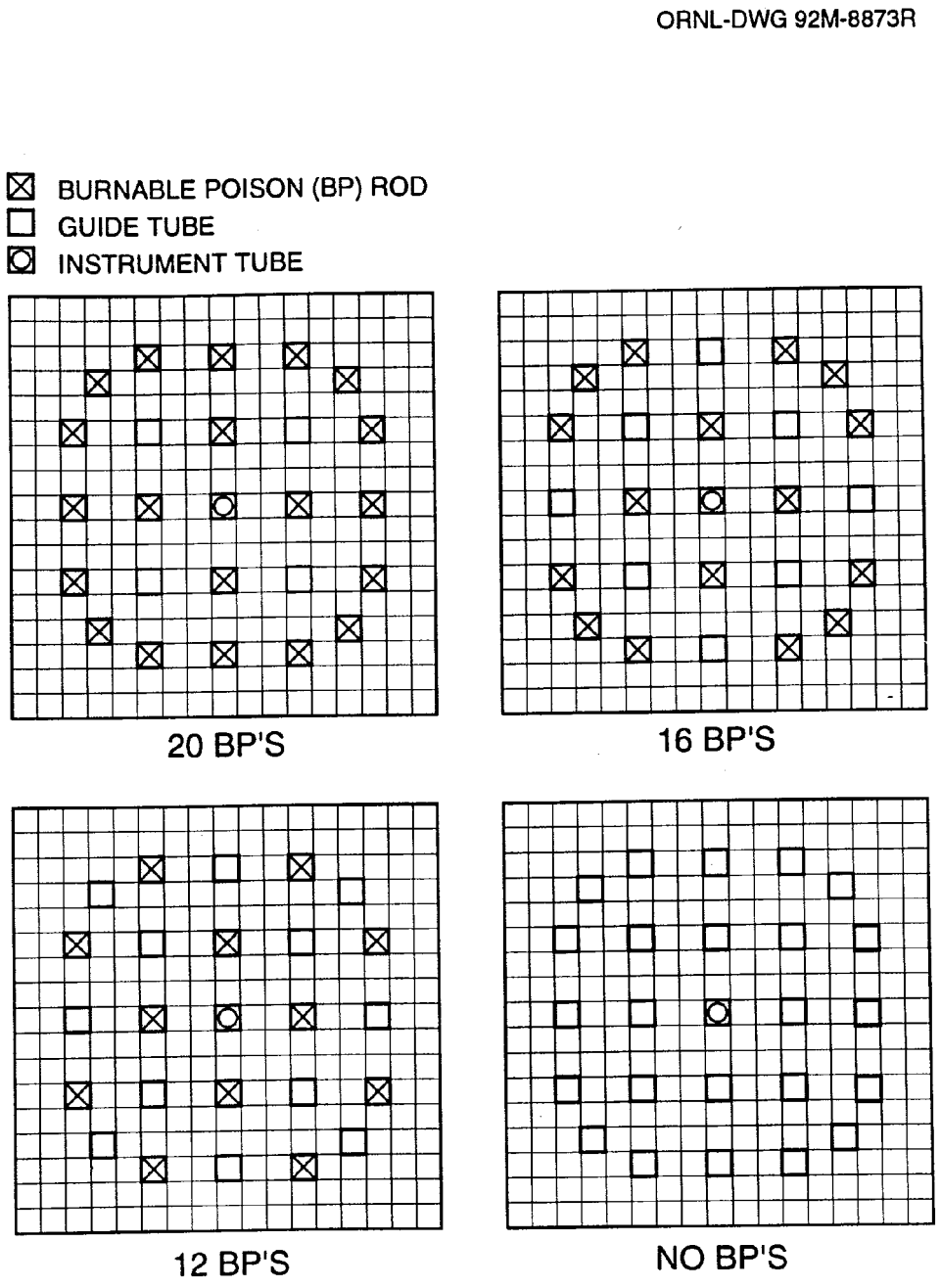
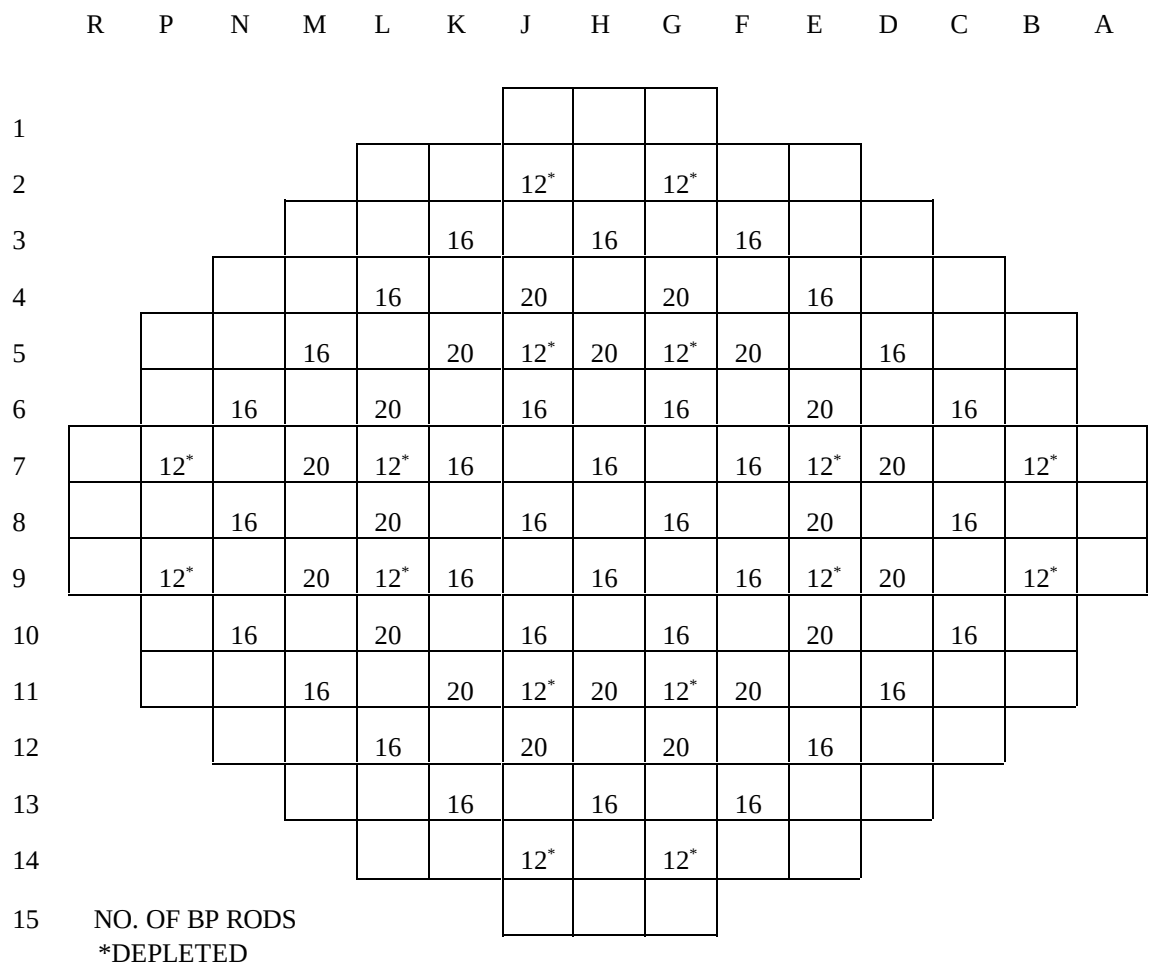



Fig. 4. Fuel assembly lattice arrangements in North Anna Unit 1 Cycle 5.




1104 BP RODS

52 FRESH BP CLUSTERS

16 DEPLETED BP CLUSTERS

Fig. 5. North Anna Unit 1 Cycle 5 burnable poison loading configuration.

Table 3. North Anna PWR Unit 1 assembly design description

| Parameter | Data |
|---|---|
| Assembly general data | |
| Number of assemblies | 157 |
| Designer | Westinghouse |
| Lattice | 17 × 17 |
| Coolant pressure, psia | 2250 |
| Water temperature, K (°F) | 583.4 (590.8)[a] |
| Water density, g/cm$^3$ | 0.7041[a,b] |
| Number of fuel rods | 264 |
| Number of guide tubes | 24 |
| Number of instrument tubes | 1 |
| Lattice pitch, cm (in.) | 21.50364 (8.466) |
| Fuel rod data | |
| Type fuel pellet | $UO_2$ |
| Rod pitch, cm (in.) | 1.25984 (0.496) |
| Rod OD, cm (in.) | 0.94966 (0.374) |
| Rod ID, cm (in.) | 0.83566 (0.329) |
| Pellet diameter, cm (in.) | 0.81915 (0.3225) |
| Active fuel length, cm (in.) | 365.8 (144) |
| Effective fuel temperature, K (°F) | 901 (1162)[c] |
| Clad temperature, K (°F) | 629 (670)[c] |
| Clad material | Zircaloy-4 |
| Guide tube data | |
| ID, in. | 1.143 (0.45) |
| OD, in. | 1.22428 (0.482) |
| Tube material | Zircaloy-4 |

[a] Average HFP value.

[b] Interpolated from the water-density-vs-pressure-and-temperature table in the SAS2H input guide (ref. 5).

[c] See ref. 18.

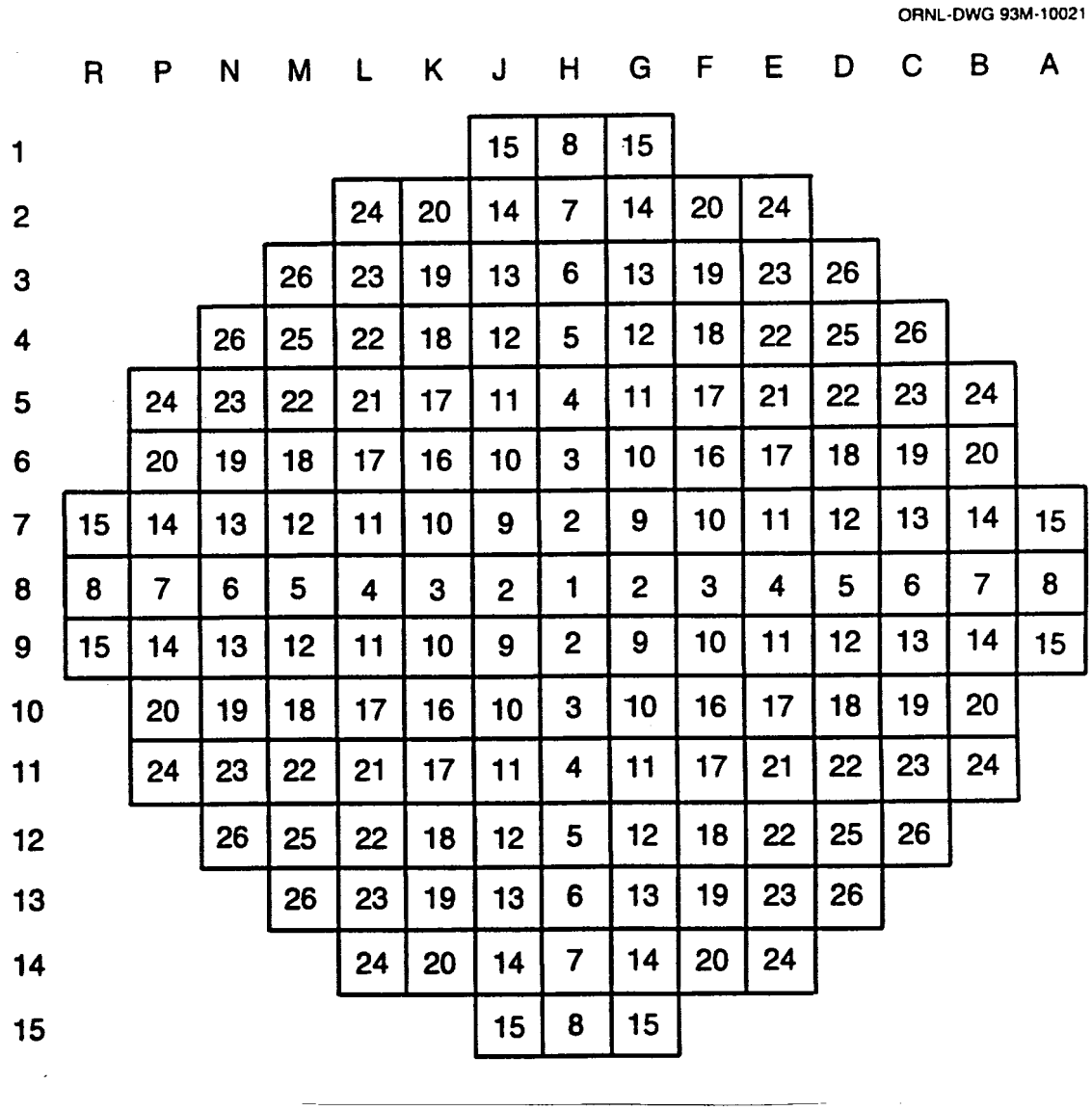



Fig. 6. North Anna Unit 1 eighth-core symmetric configuration.

## 3.2 SAS2H FUEL GROUPS

Assemblies of a given fuel batch are generally relocated within the core between cycles, resulting in a more evenly distributed burnup among assemblies. Because all fuel assemblies in a batch are loaded in the core during the same operating cycles, each assembly in a batch experiences the same operating (uptime/downtime) history. Thus a starting point for the process of grouping similar-content assemblies is to begin with fuel batches. As indicated in Fig. 1, assembly group information was used in preparation of SAS2H input for depletion calculations. For BOC-5, the North Anna 1 core was comprised of five fuel batches. Because BPR clusters were loaded in certain assemblies in batches 6 and 7, additional subdivision of these batches was necessary. Each of these batches was divided into two fuel groups. Each depleted fuel group was modeled as a single unit in a SAS2H depletion calculation over the range of burnups represented by the assemblies in the group. Table 4 provides relevant information about each fuel group.

Because the only critical configuration to be modeled is at BOC-5, it was not necessary to model fuel depletion in Cycle 5. Based on the reasons presented in Sect. 2.2, it was not considered necessary to model BPRs in previous cycles to generate the depleted fuel isotopics. Thus both Batch 6 fuel groups, 6B and 6N, were modeled with a single SAS2H depletion using the group 6N (no BP) model. This modeling simplification was done to remain consistent with the simplifying assumptions in the general methodology. However, 16 depleted BP clusters of 12 BPRs, each from Batch 6 fuel in Cycle 4, were loaded in Cycle 5. Although the group 6N SAS2H depletion was used for the fuel isotopics, it was necessary to perform a SAS2H depletion using the group 6B (12 BP) model to generate the depleted BPR isotopics only.

The initial uranium content of each group was determined from the initial $^{235}U$ enrichment of the associated fuel batch. The following empirical relationship was used to determine relative isotopic content:[19]

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

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

In addition to the heavy-metal fuel material, light elements are also present in the fuel assembly in the fuel clad and grid. Elements whose masses are typically found to be in excess of 0.5 g/kgU, plus manganese and cobalt, are shown in Table 6, along with their estimated masses. These masses are required by SAS2H. They are not used in the neutronics model, but are applied in determining the $(n,\gamma)$ 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. The only thermal data available were average fuel, clad, and moderator temperatures as given in Table 3.

Table 4. Fuel group data for BOC-5

| SAS2H fuel group | North Anna-1 fuel batch | No. of assemblies | Contain BPRs in Cycle 5 | Cycles in-core | Av. B/U (MWd/MTU) | Min. B/U (MWd/MTU) | Max. B/U (MWd/MTU) | Enrichment (wt %) |
|---|---|---|---|---|---|---|---|---|
| 4 | 4 | 12 | No | 2,3,5 | 24,986 | 21,493 | 26,732 | 3.21 |
| 5 | 5 | 20 | No | 3,4,5 | 29,255 | 20,951 | 32,048 | 3.41 |
| 6B | 6 | 8 | Depleted | 4,5 | 14,081 | 14,081 | 14,081 | 3.59 |
| 6N | 6 | 49 | No | 4,5 | 15,101 | 9,801 | 17,390 | 3.59 |
| 7B | 7 | 52 | Fresh | 5 | 0 | 0 | 0 | 3.60 |
| 7N | 7 | 8 | No | 5 | 0 | 0 | 0 | 3.60 |
| N2/5 | N2/5 | 8 | Depleted | 5 | 0 | 0 | 0 | 3.59 |

Table 5. Initial uranium isotopic content of fresh fuel

| Fuel batch | % Theoretical density | Initial U isotopes, wt % | | | |
|---|---|---|---|---|---|
| | | $^{234}U$ | $^{235}U$ | $^{236}U$ | $^{238}U$ |
| 4 | 94.55 | 0.027 | 3.21 | 0.015 | 96.748 |
| 5 | 94.58 | 0.029 | 3.41 | 0.016 | 96.545 |
| 6 | 94.58 | 0.031 | 3.59 | 0.017 | 96.363 |
| 7 | 94.89 | 0.031 | 3.60 | 0.017 | 96.352 |
| N2/5 | 94.88 | 0.031 | 3.59 | 0.017 | 96.352 |

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 |

### 3.2.1 SAS2H Fuel Cell Without BPRs

The SAS2H fuel cell model input for the three fuel groups without BPR clusters, groups 4, 5, and 6N, was relatively simple. Requirements included the dimensions of the fuel rod, clad, control-rod guide tube, and lattice pitch and the number of lattice positions in each fuel assembly not occupied by fuel rods (i.e., control rod guide tubes or instrumentation tubes). From this basic information included in Table 3, SAS2H constructed a 1-D effective assembly model, consisting of a guide tube surrounded by a fuel/moderator region with a volume proportional to the fuel/guide tube volume ratio in the assembly. Cross sections for the fuel region are obtained from a pin cell calculation. More details of this default SAS2H assembly model can be found in ref. 5.

### 3.2.2 SAS2H Fuel Cell With BPRs

For fuel group 6B with BPR clusters, an effective fuel cell was derived to incorporate the BPR cell together with the guide tube cell in SAS2H. In the effective cell, the densities of the isotopes or elements remained unchanged from their actual densities, but rod diameters of the glass and stainless steel in the BPRs were reduced to account for their absence in the guide tube positions. The method of deriving the effective cell was such that the various material total masses were conserved.

The composition of the borosilicate glass as modeled is listed in Table 7. The value for $B_2O_3$ was obtained from Vol. 2 of this report.[18] All other data for typical borosilicate glass were obtained from ref. 20. These data and atomic weights of the elements and isotopic abundance values,[21] were applied in deriving the atomic densities of the borosilicate glass in Table 8. The glass density, 2.23 g/cm$^3$, was also obtained from ref. 20.

The number of BPRs was 12, and the number of guide tubes (including the instrumentation tube) was 13 per assembly—a total of 25 nonfuel locations per assembly. Applying these totals and the dimensions of the BPRs, guide tubes, and lattice pitch, a set of effective unit cell dimensions was computed. Note that in the analyses previously performed for Sequoyah and Surry in Vols. 2 and 3 of this report, the instrumentation tube was inadvertently omitted from the fuel cell calculations. The radius bounding each material was calculated from the outer to inner zone boundary for each average material volume. For example, the water moderator average volume, $\bar{V}_w$ , is

$$\bar{V}_w = (12)(V_T - V_{GT} - V_{BP})/25 + (13)(V_T - V_{GT})/25 ,$$

where

$V_T$ = total cell volume = (pitch)$^2$ × (length),
$V_{GT}$ = guide tube volume (same as outer tube in BPR cell),
$V_{BP}$ = BP rod total volume.

Then the inner radius of the water, or the effective radius of the BP rod, is

$$R_{BP} = \sqrt{(V_T - \bar{V}_w - V_{GT})/(\pi L)} ,$$

Table 7. Borosilicate glass composition in BPR assemblies

| Compound | Weight fraction |
|---|---|
| $SiO_2$ | 0.805 |
| $B_2O_3$ | 0.125 |
| $Na_2O$ | 0.038 |
| $K_2O$ | 0.004 |
| $Al_2O_3$ | 0.022 |

Table 8. Borosilicate glass input atom densities[a]

| Element | Isotope | Weight fraction | Density, atoms/(barn·cm) |
|---|---|---|---|
| O | | 0.5358 | 0.04497 |
| Na | | 0.0282 | 0.00165 |
| Al | | 0.0116 | 0.00058 |
| Si | | 0.3763 | 0.01799 |
| K | | 0.0033 | 0.00011 |
| B | | 0.03882 | |
| | $^{10}B$ | | 9.595E-4[b] |
| | $^{11}B$ | | 3.863E-3 |
| Total | | 0.99402 | |

[a]Applying weight fractions of compounds in Table 7 and 2.23 g/cm$^3$ glass density.

[b]Read as $9.595 \times 10^{-4}$.

where $L$ is the active fuel length used in computing the volumes. The guide tube dimensions remain the same because they are identical in both types of cells. Each average volume, $V_{ave}$, within the effective BP rod is calculated from the corresponding actual BP rod dimensions (and the number of BPRs and guide tubes):

$$V_{ave} = (12\pi L)(B^2 - A^2)/25 \ , \qquad (1)$$

where

$A$ = the material's inner radius in an actual BP rod,
$B$ = the same material zone's outer radius.

Using the prior calculation of the effective outer radius, $B_e$, the effective inner radius, $A_e$, is

$$A_e = \sqrt{B_e^2 - V_{ave}/(\pi L)} \ . \qquad (2)$$

Equations (1) and (2) are used repeatedly for each material zone for the entire effective cell determination. Applying the above procedure, the effective cell mockup dimensions were computed as listed in Table 9.

The densities listed in the table were used only in computing material mass for verification of data. The total material masses of the actual BP rods plus that of the guide tubes were compared with the effective cell total masses. The data were used to verify the cell dimensions. In all cases identical weights were computed for the same materials, verifying that the effective cells conserve mass.

### 3.3 SIMILAR-BURNUP SUBGROUPING FOR CROSS-SECTION SETS

Although the assemblies of a given fuel group are identical in terms of initial composition, time in core, and operating history, there may be a relatively broad range of burnups within a fuel group. Even though effective cross sections are felt to be insensitive to minor variations in burnups, it is necessary to set a maximum range of burnups 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; this value was used in subdividing fuel groups into similar-burnup cross-section sets. As shown in Fig. 1, cross-section-set information is provided to SNIKR for subsequent use in setting up CSASN calculations. CSASN is used to compute effective cross sections for each cross-section set.

To determine cross-section sets for each fuel group, the fuel assembly burnups in each group were sorted and divided into subgroups where the minimum to maximum burnup range was no larger than 2 GWd/MTU. Eighth-core-averaged assembly burnups are given in Table 10, along with fuel batch, SAS2H fuel group, and cross-section set information. The cross-section-set groupings are shown in Table 11. Table 12 shows the cross-section sets, with the actual burnup ranges for assemblies within each cross-section set, along with the mean average burnup of all assemblies in each cross-section set.

### 3.4 SAS2H DEPLETION CALCULATIONS

SAS2H depletion calculations were required for fuel groups 4, 5, and 6 only, since the other groups consisted of fresh fuel at the time of startup. In the standard composition section of the SAS2H input for each fuel group, the initial uranium isotopic contents for the fuel were as given in Table 5. Although not initially present in the fuel, the additional 44 nuclides from Table 1 were

Table 9. Effective fuel cell with 12 BPRs

| Zone | Material | Density, ($g/cm^3$) | SAS2H mixture number | Radius in cell (cm) |
|---|---|---|---|---|
| 1 | Air | 1.22E-3[a] | 4 | 0.14826 |
| 2 | SS-304 | 7.92 | 5 | 0.15970 |
| 3 | Air | 1.22E-3 | 4 | 0.16718 |
| 4 | Glass | 2.23 | 6 | 0.29564 |
| 5 | Air | 1.22E-3 | 4 | 0.30268 |
| 6 | SS-304 | 7.92 | 5 | 0.33523 |
| 7 | Mod | 0.7149 | 3 | 0.57150 |
| 8 | Zr-4 | 6.44 | 2 | 0.61214 |
| 9 | Mod | 0.7149 | 3 | 0.71079 |
| 10 | Fuel | -- | 500 | 2.41668 |

[a]Read as $1.22 \times 10^{-3}$.

Table 10. Fuel assembly data for eighth-core geometry

| Eighth-core location | North Anna fuel batch | SAS2H fuel group | Cross-section set | Average burnup (MWd/MTU) |
|---|---|---|---|---|
| 1 | 6 | 6N | 7 | 17105 |
| 2 | 7 | 7B | 11 | 0 |
| 3 | 4 | 4 | 1 | 21493 |
| 4 | 7 | 7B | 11 | 0 |
| 5 | 6 | 6N | 7 | 17322 |
| 6 | 7 | 7B | 11 | 0 |
| 7 | 6 | 6N | 7 | 17390 |
| 8 | 6 | 6N | 5 | 9801 |
| 9 | 5 | 5 | 3 | 20951 |
| 10 | 7 | 7B | 11 | 0 |
| 11 | 6 | 6N | 8 | 14081 |
| 12 | 7 | 7B | 11 | 0 |
| 13 | 6 | 6N | 6 | 12890 |
| 14 | N2/5 | N2/5 | 9 | 0 |
| 15 | 5 | 5 | 4 | 30615 |
| 16 | 6 | 6N | 7 | 17158 |
| 17 | 7 | 7B | 11 | 0 |
| 18 | 6 | 6N | 7 | 15802 |
| 19 | 7 | 6N | 11 | 0 |
| 20 | 6 | 7B | 7 | 16831 |
| 21 | 6 | 6N | 7 | 15852 |
| 22 | 7 | 7B | 11 | 0 |
| 23 | 7 | 7N | 10 | 0 |
| 24 | 5 | 5 | 4 | 32048 |
| 25 | 6 | 6N | 6 | 12139 |
| 26 | 4 | 4 | 2 | 26732 |

Table 11. Cross-section sets for one-eighth-core assemblies

| Cross-section set No. | Assembly No. | Burnup (MWd/MTU) |
|---|---|---|
| 1 | 3 | 21,493 |
| | Average | 21,493 |
| 2 | 26 | 26,732 |
| | Average | 26,732 |
| 3 | 9 | 20,951 |
| | Average | 20,951 |
| 4 | 15 | 30,615 |
| | 24 | 32,048 |
| | Average | 31,332 |
| 5 | 8 | 9,801 |
| | Average | 9,801 |
| 6 | 13 | 12,890 |
| | 25 | 12,139 |
| | Average | 12,640 |
| 7 | 1 | 17,105 |
| | 5 | 17,322 |
| | 7 | 17,390 |
| | 16 | 17,158 |
| | 18 | 15,802 |
| | 20 | 16,831 |
| | 21 | 15,852 |
| | Average | 16,638 |
| 8 | 11 | 14,081 |
| | Average | 14,081 |
| 9 | 14 | 0 |
| | Average | 0 |
| 10 | 23 | 0 |
| | Average | 0 |
| 11 | 2 | 0 |
| | 4 | 0 |
| | 6 | 0 |
| | 10 | 0 |
| | 12 | 0 |
| | 17 | 0 |
| | 19 | 0 |
| | 22 | 0 |
| | Average | 0 |

Table 12. Cross-section sets for North Anna Unit 1 Cycle 5 KENO V.a model

| Cross-section set No. | SAS2H fuel group | Enrichment | Burnable poison rods (BPR) | Average burnup | Burnup range | No. of assemblies |
|---|---|---|---|---|---|---|
| 1 | 4 | 3.21 | None | 21,493 | 21,493 | 1 |
| 2 | 4 | 3.21 | None | 26,732 | 26,732 | 1 |
| 3 | 5 | 3.41 | None | 20,951 | 20,951 | 1 |
| 4 | 5 | 3.41 | None | 31,332 | 30,615–32,048 | 2 |
| 5 | 6N | 3.59 | None | 9,801 | 9,801 | 1 |
| 6 | 6N | 3.59 | None | 12,640 | 12,139–12,890 | 2 |
| 7 | 6N | 3.59 | None | 16,638 | 15,802–17,390 | 7 |
| 8 | 6N | 3.59 | Depleted | 14,081 | 14,081 | 1 |
| 9 | N2/5 | 3.59 | Depleted | 0 | 0 | 1 |
| 10 | 7N | 3.60 | None | 0 | 0 | 1 |
| 11 | 7B | 3.60 | Fresh | 0 | 0 | 8 |

included at an atom density of $1 \times 10^{-20}$ ($^{135}$Xe was specified with an initial density on the order of its equilibrium concentration, 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 as discussed previously in Sect. 2.2. The remainder of the fuel pin cell was described as Zircaloy clad in water, with temperature and geometry data as specified in Table 4. The active fuel length was divided by the total weight of heavy metal in the assembly. This modification gives results in units of burnup per MTU rather than burnup per assembly. Since SAS2H uses a 1-D assembly cell model, the fuel length is arbitrary and may be used as a conversion factor.

Table 13 gives the power history data used for each SAS2H fuel group. Note that a constant burnup per interval was used for each fuel group; this constant spacing is required by SNIKR when interpolating from SAS2H/ORIGEN output. Shorter burnup intervals were used for the once-burned fuel group 6 to have a sufficient number of data points for SNIKR to interpolate. The number of intervals for each group was chosen so that the maximum assembly burnup was exceeded by at least 20%. The average specific power for each fuel group was calculated by dividing the group average burnup by the total uptimes for all cycles that the fuel was in the core.

A copy of the SAS2H input for fuel group 4 is included in Appendix B. With the exception of the uranium isotopics and the burnup steps, inputs for the other fuel group calculations were identical.

## 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 burnup intervals to estimate the isotopic

Table 13. SAS2H operating history data by fuel group and cycle

| SAS2H fuel group | Reactor cycles | Average power (MW/MTU) | Actual uptime (d) | Actual downtime[a] (d) | Number of intervals @ burnup per interval (GWd/MTU) | Modeled burn time per interval (d) | Modeled downtime per interval (d) | Cumulative burnup (GWd/MTU) |
|---|---|---|---|---|---|---|---|---|
| 4 | 2,3 | 33.719 | 741 | 103 | 7@5 | 148.28 | 20.61 | 35 |
| 5 | 3,4 | 31.023 | 943 | 185 | 8@5 | 161.17 | 31.62 | 40 |
| 6 | 4 | 27.649 | 541 | 0 | 6@4 | 144.67 | 0 | 24 |

[a]Does not include downtime after last cycle of operation prior to Cycle 5.

concentration corresponding to the burnup of each assembly and cross-section set in the North Anna 1 models at BOC-2 and EOC-2. This step was the only one necessary for the EOC-2 case, since it occurred at HFP, equilibrium conditions. For the BOC-2 case, SNIKR1 then used these isotopics (which represented nuclide concentrations at the end of the depletion prior to the critical condition at BOC-2) and prepared an ORIGEN-S decay calculation to obtain the concentration of the isotopes after the appropriate downtime of 0.271 years prior to the BOC-2 startup. After ORIGEN-S was executed, SNIKR3 read the ORIGEN-S output and prepared isotopic concentration tables in both SCALE standard composition input format and KENO mixing table format for the selected set of isotopes listed previously in Table 2.

The SNIKR sequence consists of three codes, described earlier in Sect. 2.3, and requires two files. The first file is a SNIKR input file describing the calculation to be performed for a specific assembly or cross-section set; the second is the SAS2H output file containing the atom density data for the appropriate fuel group. SNIKR calculations are automated in a manner similar to SCALE calculational sequences such that the multistep calling of the individual code packages is transparent to the user. Appendix C lists a user input guide for SNIKR Version 1.0, which was used in these analyses, and FORTRAN listings of SNIKR1 and SNIKR3.

Slightly different approaches are taken between preparation of assembly isotopics and cross-section-set isotopics as 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 North Anna Unit 1 Cycle 5 eighth-core-averaged 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 identical 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 North Anna KENO V.a model, mixture numbers 101 through 126 correspond to SNIKR calculations for assemblies 1 through 26, respectively. Eighth-core-averaged assembly burnups are given in Table 10, along with fuel group and cross-section set information.

As discussed earlier in Sect. 2.4, cross-section-set-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 cross-section set 2). Burnable poison isotopics were similarly generated for each of the two eighth-core fuel assembly locations where depleted BPRs were present in Cycle 5. Sample SNIKR input files are included in Appendix C.

The SNIKR output file consists of three sections: a summary of the input and coarsely formatted ORIGEN-S results, isotopic concentrations in SCALE standard composition input format, and isotopic concentrations in KENO V.a mixing table input format. For each assembly calculation, only the latter was of interest; this section was copied and placed directly into KENO V.a input to describe the isotopic composition for the burnup of a specific assembly. A sample SNIKR output is also listed in Appendix C.

### 3.5.2 Cross-Section Set Isotopics

Burnup-dependent cross sections were required for the seven burnup-dependent actinides. As was previously mentioned, cross-section set calculations were performed with CSASN to obtain the cross sections for these actinides for each cross-section set based on the average burnup groupings shown in Table 13; these groupings were selected based on the burnup range criterion of 2 GWd/MTU discussed earlier. SNIKR calculations were required for cross-section sets 1 through 8. The seven burnup-dependent actinides were needed for each set of burned fuel. In addition, cross-section set 4 also included the other actinides and fission products in the fuel mixture.

The SNIKR output file is the same format as was produced for the assembly calculations; however, the region of output data which was of interest was different. The isotopic concentrations in SCALE standard composition input format were copied to a CSASN input file.

## 3.6 GENERATION OF CROSS SECTIONS USING CSASN

Problem-dependent cross-section libraries were produced using the CSASN sequence of SCALE; the details of this process were described in Sect. 2.4. For each cross-section set, a CSASN input deck containing cross-section-set average isotopics was created. Because the physical geometries of all fuel pins were identical, input specifications differed only in the isotopic compositions specified for each set. 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, with dimensions as specified in Table 4. A borated-water moderator was specified, with a soluble boron concentration. All components were specified with a temperature of 559 K (547°F), corresponding to HZP conditions. An example input listing is shown in Appendix D.

Isotopic concentrations were obtained from the earlier SNIKR cross-section set calculations. Since only the seven burnup-dependent actinides were required for sets 1 through 3 and 5 through 8, all other actinides and fission products were deleted from the fuel mixture specifications for these cases. Cross-section sets 9 through 11, comprised only of fresh fuel were specified using the fresh isotopic compositions given in Table 6. The microscopic cross-section calculations for cross-section set 4 also included the other actinides and fission products in the fuel mixture, along with mixtures for the moderator and structural materials. Cross-section set 4 was selected for these calculations because its spent fuel isotopics represented the highest average burnup. The input listing for cross-section set 4 is also included in Appendix D. The microscopic cross-section calculations for cross-section sets 8, 9, and 11 included the BPR nuclides. CSASN calculations were then performed, with the resulting microscopic working format cross-section library saved for each cross-section set.

## 3.7 COMBINING CROSS-SECTION SET LIBRARIES USING WAX

The WAX [16] code was used to combine the individual working format libraries (one per cross-section set) into a single library to be used in the KENO V.a core calculation. For cross-section set 4, selected to include the fission products and additional actinides, WAX copied all cross sections into the combined library. For the cross-section sets selected for the BPR cross sections, WAX copied

those cross sections in addition to the seven burnup-dependent actinides. For the remaining cross-section sets, WAX copied only the cross sections for the seven burnup-dependent actinides. For each of these actinides, the cross-section ID was modified by adding the cross-section set number as a prefix, to be consistent with the numbering scheme used in the SNIKR-produced KENO V.a mixing-table-format isotopics for each assembly. The WAX input listing is provided in Appendix E.

## 3.8 PREPARATION OF KENO V.a CORE MODEL

The KENO V.a model used to determine $k_{eff}$ for the North Anna 1 BOC-5 core consists of four parts. The first section of input contains code parameter specifications. The only significant aspect of this section is the use of 1003 generations of 1000 neutrons per generation; hence, the calculation was based on one million histories (three generations were automatically 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 rods 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, as this information was not readily available and should have little effect on the computed solution. Thus only a single fuel rod description is necessary to describe all fuel rods 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) burnup distribution along the 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,[22] this assumption has a minor effect (<0.1% $\Delta k/k$) that is probably conservative for the average burnup in these models. Because it is possible to take advantage of the one-eighth-core symmetry of the core, only 26 assemblies are required to represent all 157 assembly positions in the core. Hence only 26 material mixtures are necessary for the full-core model. These mixture specifications come from the 26 assembly calculations performed earlier using SNIKR for mixtures 101 through 126. The portions of the SNIKR output copied into the KENO V.a input represent complete mixture specifications for each of the 26 materials.

Material specifications were also required for all remaining materials (i.e., clad, borated water, and BPR materials). Concentrations for each isotope were obtained from the output of the CSASN cross-section calculations. Mixture numbers 11 through 13 were used for the burnable poison materials. A unique mixture number was assigned the BPR in each eighth-core fuel assembly that contained depleted BPRs. Table 14 lists all materials included in the core model by mixture number.

Table 14. Mixtures in KENO V.a model

| Mixture No. | Description |
|---|---|
| 1 | Clad |
| 2 | Stainless steel (BP clad, baffle) |
| 3 | Borated moderator |
| 4 | 50% borated moderator, 50% stainless steel (top and bottom reflector) |
| 5 | Stainless steel (core barrel) |
| 6 | Borated moderator (outside core barrel) |
| 7 | Stainless steel (thermal shield) |
| 8 | Borated moderator (outside thermal shield) |
| 9 | Stainless steel (reactor vessel) |
| 11–13 | Burnable poison: fresh BP for assemblies 2, 4, 6, 10, 12, 17, 19, 22; depleted BP for assembly 11; depleted BP for assembly 14 |
| 101–126 | Fuel, assemblies 1–26 |

### 3.8.2 KENO V.a Geometry Specifications

A fuel rod was defined for each of the 26 one-eighth-core fuel assemblies based on the dimensions given in Table 4. Identical dimensions were used for all rod specifications. Fuel rods were assigned to Unit Numbers 101 to 126, respectively; the fuel region of each rod was linked to its corresponding material number (e.g., fuel rod 101 used material 101 for the fuel region). All rods were specified with a void gap and Zircaloy clad, centered in a water cuboid. Fuel rods and enclosing cuboids were modeled as having a length equal to that of the active fuel length of the rod (i.e., fuel assembly top and bottom structures were neglected). A 50:50 mixture of borated $H_2O$ and stainless steel was used as a top and bottom reflector (25 cm thick) to account for structural materials above and below the active fuel region.

Unit 161, representing a control rod guide tube, was created using the dimensions in Table 4, with water inside the tube and centered within a water cuboid. Burnable poison rods were created as Units 162–164. Each BPR was put inside a control rod guide tube.

A 17 × 17 array was then defined for each of the 26 fuel assemblies, which were assigned Unit numbers 1–26 corresponding to their eighth-core location. The 264 fuel rod locations in each assembly were filled with the fuel rod containing the assembly average isotopics. The remaining array locations were appropriately filled with guide tubes or BPRs according to the full-core BPR loading configuration in Fig. 5 and the fuel assembly lattice arrangements in Fig. 4. Each array was surrounded by a thin layer of moderator to obtain an assembly lattice spacing of 21.50364 cm (8.466 in.).

The core baffle surrounding the outermost assemblies was created as a composite of several smaller segments, comprised of four different cuboid shapes. Units 41 to 44 were used to define

these shapes. Figure 7 illustrates the use of these four unit types in modeling the core baffle. The figure also shows assembly position numbers for the full core, based on one-eighth-core symmetry and the numbering scheme shown in Fig. 6. Using these position numbers, arrays of assemblies and core baffle segments were used to define larger units, to minimize the number of KENO V.a "holes" placed in the global unit. Figure 8 illustrates the grouping of assemblies used. Global Unit 70 contained the core barrel, thermal shield, and reactor vessel. All other units were placed within Unit 70 using KENO V.a "holes." Note that core baffle 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 15.

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

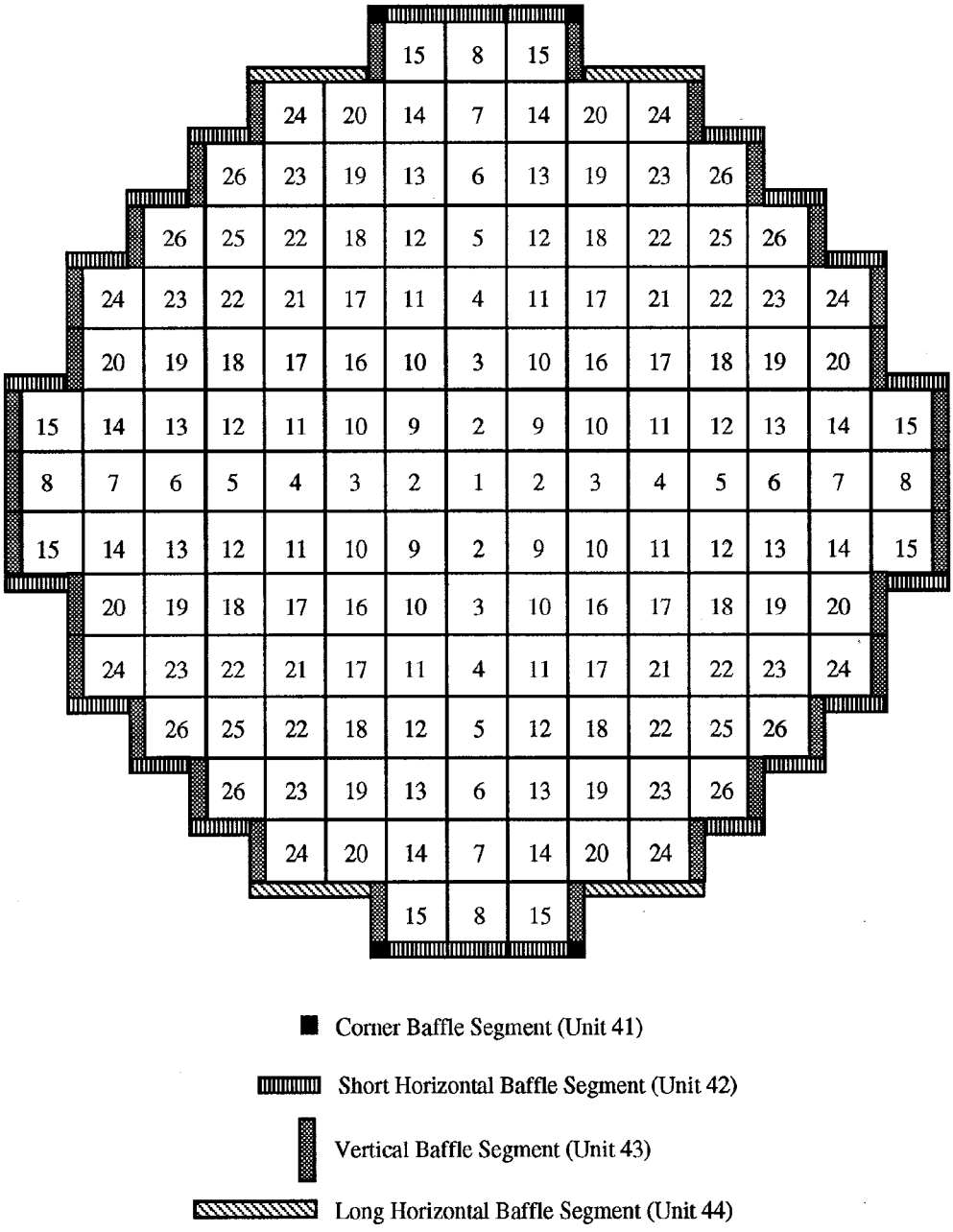



Fig. 7. Full-core-assembly positions and core baffle configuration.

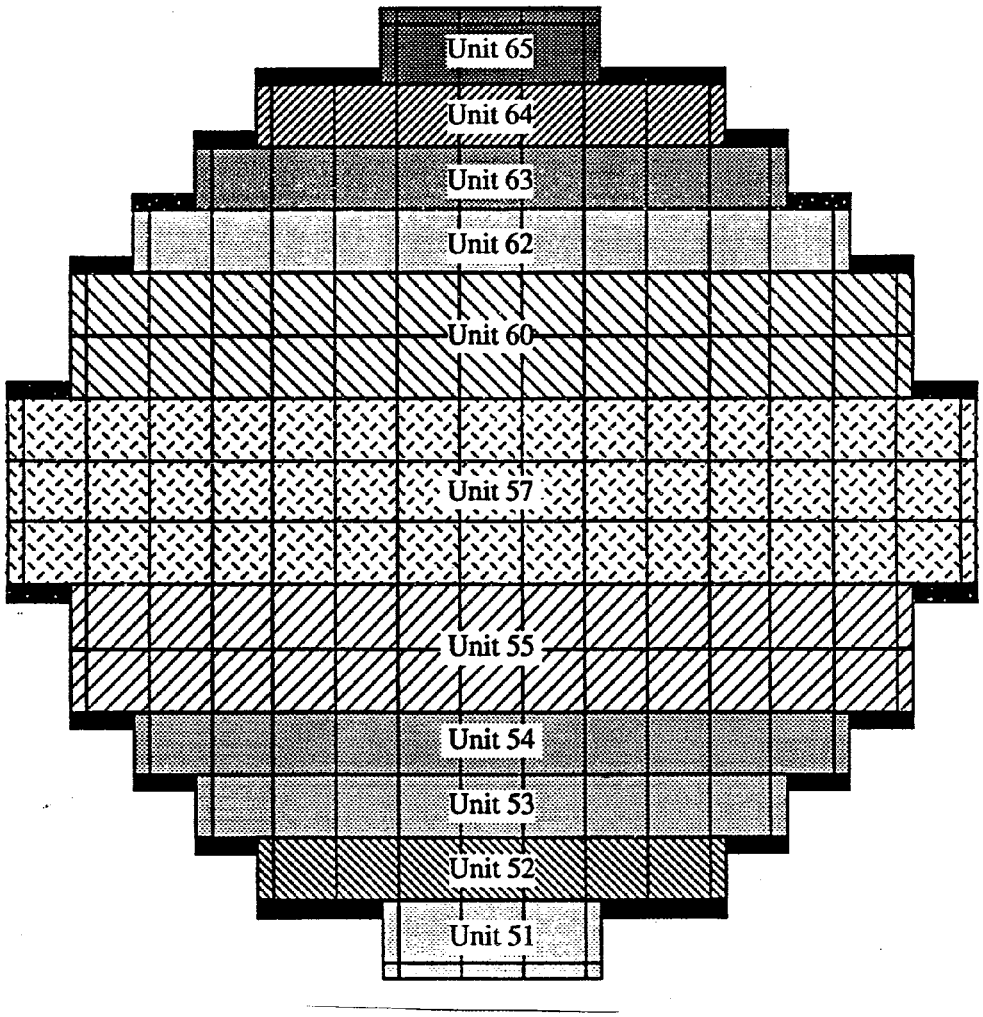



Fig. 8. KENO V.a unit definitions based on component arrays.

Table 15. Unit numbers used in North Anna KENO V.a core model

| Unit No. | Description |
|---|---|
| 1–26 | Fuel assemblies for positions 1 to 26, respectively |
| 41 | 1.905 × 1.905 cm (corner) segment of core baffle |
| 42 | 21.50364 × 1.905 cm (horizontal) segment of core baffle |
| 43 | 1.905 × 21.50364 cm (vertical) segment of core baffle |
| 44 | 43.00728 × 1.905 cm (horizontal) segment of core baffle |
| 51 | “Bottom” of baffle + row 1 of assemblies + vertical baffle ends |
| 52 | Row 2 of assemblies + vertical baffle ends |
| 53 | Row 3 of assemblies + vertical baffle ends |
| 54 | Row 4 of assemblies + vertical baffle ends |
| 55 | Rows 5 and 6 of assemblies + vertical baffle ends |
| 57 | Rows 7-9 of assemblies + vertical baffle ends |
| 60 | Rows 10 and 11 of assemblies + vertical baffle ends |
| 62 | Row 12 of assemblies + vertical baffle ends |
| 63 | Row 13 of assemblies + vertical baffle ends |
| 64 | Row 14 of assemblies + vertical baffle ends |
| 65 | Row 15 of assemblies + vertical baffle ends + "top" of baffle |
| 70 (GLOBAL) | Reactor vessel + thermal shield + core barrel + vertical baffle ends |
| 101–126 | Fuel rods for assemblies 1–26, respectively |
| 161 | Water-filled control rod guide tube |
| 162–164 | BPRs in control rod guide tubes |

## 4. RESULTS AND CONCLUSIONS

The KENO V.a criticality calculations for the North Anna 1 Cycle 5 BOC model described in this report yielded a value for $k_{eff}$ of 1.0040 ± 0.0005. The results are based on 1000 generations of 1000 neutrons per generation, for a total of $1 \times 10^6$ histories. The average fission group reported by SCALE, representing the average neutron energy at which fission occurs, was calculated to be 20.3838 ± 0.0038. 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 these solutions are well converged and adequate source sampling achieved (see ref. 7 for a discussion of what constitutes convergence).

The relative fission density distribution (normalized to the core-average value) computed by KENO V.a is shown in Fig. 9 for a one-eighth-core average. These data 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. Note that even though $k_{eff}$, 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.

These $k_{eff}$ results are approximately 2% $\Delta k/k$ greater than those reported for the North Anna and North Anna reactor critical benchmark calculations[8] performed with the original SCALE scoping calculations but are consistent with the results performed with the revised methodology as summarized in Vol. 1 of this report. Differences in the earlier analyses that have been identified and their probable order of importance are use of a lumped fission product to account for all nuclides not explicitly modeled, fewer fuel batches and cross-section sets, fewer neutrons per generation and fewer total neutron histories, and use of an earlier version of SAS2H. The consistency in results for the revised methodology and its straightforward procedure for calculating isotopics provide a high level of confidence in these results. The complexity in the isotopic calculational procedure of the initial methodology, the use of lumped fission products, and the inability to reproduce results due to loss of data from the earlier work reduces confidence in the original calculations.

The results of these calculations demonstrate that even with a relatively simple core model using eighth-core assembly-averaged burnups, it is possible to closely predict, in a best-estimate fashion, the critical condition 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.[23] Hence one may conclude that the methodology applied in performing these reactor critical calculations is valid for performing criticality safety analyses for systems with spent fuel.

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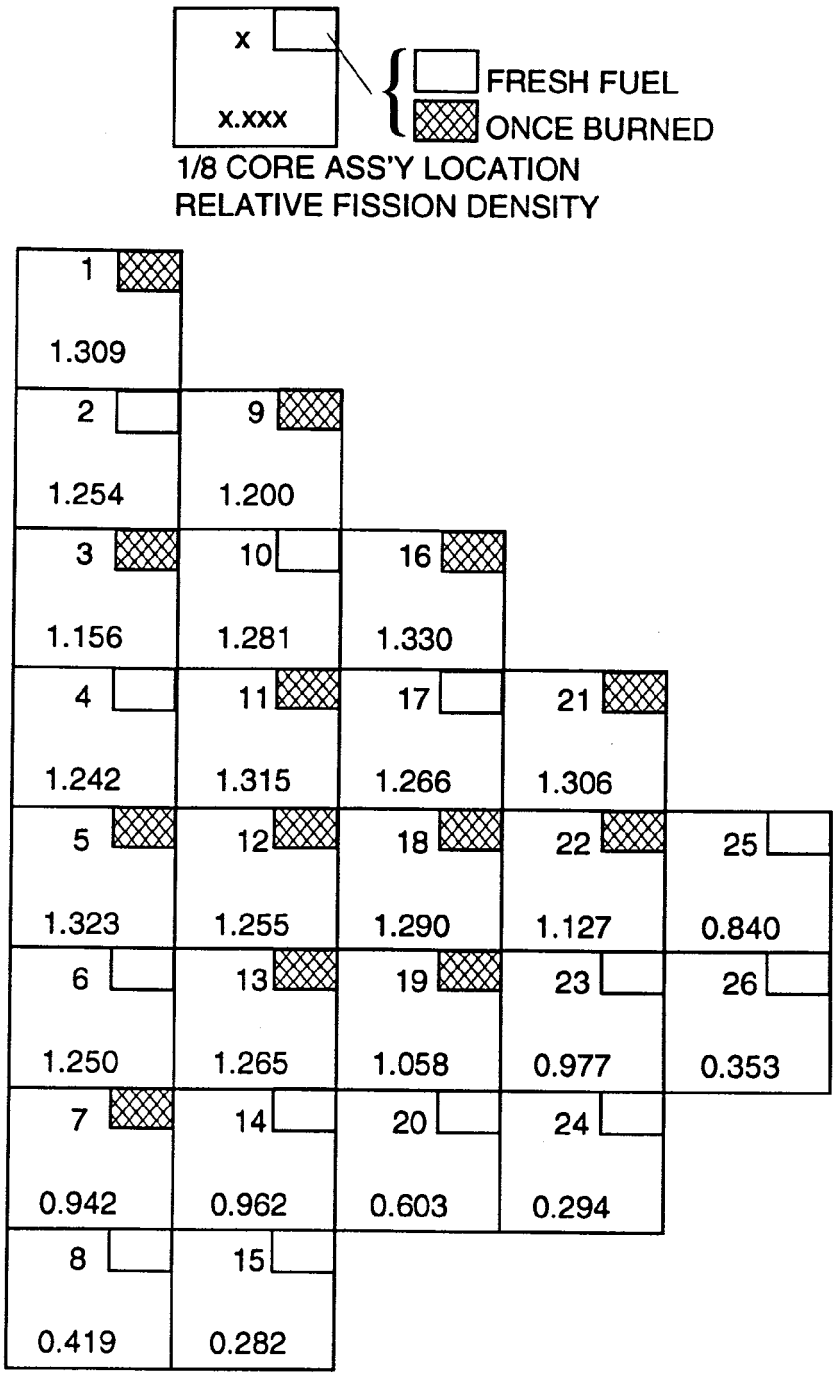


Fig. 9. BOC, HZP eighth-core relative fission density distribution.

## 5. REFERENCES


1. T. L. Sanders and R. M. Westfall, "Feasibility and Incentives for Burnup Credit in Spent Fuel Transport Casks," *Nucl. Sci. Eng.* **104** (1990).

2. "American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors," ANSI/ANS-8.1-1983.

3. *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. 1, 2, and 3 (February 1995). Available from Radiation Shielding Information Center as CCC-545.

4. M. C. Brady and T. L. Sanders, "A Validated Methodology for Evaluating Burnup Credit in Spent Fuel Casks," *Proc. of International Conference on Nuclear Criticality Safety*, Christ Church, Oxford, United Kingdom, September 9–31, 1991.

5. O. W. Hermann and C. V. Parks, "SAS2H: A Coupled One-Dimensional Depletion and Shielding Analysis Code," Sect. S2 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. 1, 2 and 3 (February 1995). Available from Radiation Shielding Information Center as CCC-545.

6. N. F. Landers and L. M. Petrie, "CSAS4: An Enhanced Criticality Safety Analysis Module with an Optimum Pitch Search Option," Sect. C4 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. 1, 2 and 3 (February 1995). Available from Radiation Shielding Information Center as CCC-545.

7. L. M. Petrie and N. F. Landers, "KENO V.a: An Improved Monte Carlo Criticality Program with Supergrouping," Sect. F11 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. 1, 2, and 3 (February 1995). Available from Radiation Shielding Information Center as CCC-545.

8. J.-P. Renier and C. V. Parks, "Reactor Critical Calculations for Validation of Burnup Credit Analysis Methods," *Trans. Am. Nucl. Soc.* **62**, 308 (1990).

9. O. W. Hermann and R. M. Westfall, "ORIGEN-S: A SCALE System Module to Calculate Fuel-Depletion, Actinide Transmutation, Fission Product Buildup and Decay, and Associated Radiation Source Terms," Sect. F7 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. 1, 2 and 3 (February 1995). Available from Radiation Shielding Information Center as CCC-545.

10. B. H. Wakeman and S. A. Ahmed, *Evaluation of Burnup Credit for Dry Storage Casks*, EPRI NP-6494, Electric Power Research Institute, August 1989.

11. O. W. Hermann and M. C. Brady, *Comparisons of SAS2H and CASMO-3 Benchmark $k_\infty$ Calculations for Reactor Fuel With and Without Burnable Poisons*, ORNL/TM-12490, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab. (to be published).

12. B. L. Broadhead et al., *Investigation of Nuclide Importance to Functional Requirements Related to Transport and Long-Term Storage of LWR Spent Fuel*, ORNL/TM-12742, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab. (to be published).

13. D. G. Napolitano and D. G. Adli, *Burnup Credit Criticality Analysis Using Advanced Nodal Techniques*, Yankee Atomic Electric Co., March 1992.

14. N. M. Greene, "BONAMI-S: Resonance Self-Shielding by the Bondarenko Method," Sect. F1 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/ CSD-2/R4), Vols. 1, 2, and 3 (February 1995). Available from Radiation Shielding Information Center as CCC-545.

15. N. M. Greene, L. M. Petrie, and R. M. Westfall, "NITAWL-II: SCALE System Module for Performing Resonance Shielding and Working Library Production," Sect. F2 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/ CSD-2/R4), Vols. 1, 2 and 3 (February 1995). Available from Radiation Shielding Information Center as CCC-545.

16. N. M. Greene, "User's Guide for Utility Modules," Sect. M15 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2/R4), Vols. 1, 2 and 3 (February 1995). Available from Radiation Shielding Information Center as CCC-545.

17. C. B. LaRoe, A. Abbasi, *North Anna Unit 1 Cycle 5 Design Report*, N. E. Technical Report No. 384, Virginia Electric and Power Company (July 1984).

18. S. M. Bowman, O. W. Hermann, and M. C. Brady, *SCALE-4 Analysis of Pressurized Water Reactor Critical Configurations: Volume 2 —Sequoyah Unit 2 Cycle 3*, ORNL/TM-12294, Vol. 2, Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., March 1995.

19. O. W. Hermann, J-P. Renier, and C. V. Parks, *Technical Support for a Proposed Decay Heat Guide Using SAS2H/ORIGEN-S Data*, NUREG/CR-5625 (ORNL-6698), Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., September 1994.

20. G. W. Morey, *The Properties of Glass*, 2nd ed., Reinhold, New York, 1954.

21. F. W. Walker, J. R. Parrington, and F. Feiner (revisors of edition), *Nuclides and Isotopes*, 14th ed., General Electric Co., San Jose, California, 1989.

22. S. E. Turner, "An Uncertainty Analysis-Axial Burnup Distribution Effects," *Proc. Workshop Use of Burnup Credit in Spent Fuel Transport Casks*, Washington, D.C., February 21–22, 1988, SAND89-0018, TTC-0884, UC-820, T. L. Sanders, Ed., Sandia National Laboratories, October 1989.

23. S. M. Bowman et al., "Validation of SCALE-4 for Burnup Credit Applications," *Nucl. Tech.* **110**, 3.

# APPENDIX A

## NORTH ANNA UNIT 1 CYCLE 5 DATA

The initial core loading pattern of Cycle 5 is shown in Fig. A.1. The initial and final burnup distributions in the core for Cycle 5 are listed in Table A.1. The assemblies are grouped in the table into the eighth-core symmetric sets as loaded in Cycle 5.

| | R | P | N | M | L | K | J | H | G | F | E | D | C | B | A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | E37 | F23 | E12 | | | | | | |
| 2 | | | | | E54 | F07 | S64 12BP | F14 | S60 12BP | F35 | E22 | | | | |
| 3 | | | | D05 | G55 | G10 16BP | F34 | G45 16BP | F58 | G54 16BP | G05 | D47 | | | |
| 4 | | | D07 | F39 | G30 16BP | F20 | G02 20BP | F63 | G28 20BP | F08 | G34 16BP | F21 | D37 | | |
| 5 | | E39 | G48 | G24 16BP | F36 | G37 20BP | F69 12BP | G17 20BP | F31 12BP | G42 20BP | F47 | G23 16BP | G11 | E25 | |
| 6 | | F56 | G03 16BP | F22 | G19 20BP | F24 | G21 16BP | D36 | G15 16BP | F15 | G47 20BP | F48 | G50 16BP | F46 | |
| 7 | E31 | S58 12BP | F53 | G41 20BP | F33 12BP | G58 16BP | E43 | G26 16BP | E33 | G31 16BP | F61 12BP | G38 20BP | F26 | S63 12BP | E63 |
| 8 | F30 | F45 | G33 16BP | F59 | G39 20BP | D42 | G08 16BP | F40 | G57 16BP | D41 | G56 20BP | F49 | G01 16BP | F32 | F64 |
| 9 | E56 | S62 12BP | F27 | G22 20BP | F17 12BP | G16 16BP | E20 | G43 16BP | E59 | G20 16BP | F50 12BP | G25 20BP | F68 | S59 12BP | E24 |
| 10 | | F16 | G13 16BP | F10 | G04 20BP | F09 | G53 16BP | D51 | G49 16BP | F03 | G07 20BP | F38 | G12 16BP | F13 | |
| 11 | | E29 | G35 | G51 16BP | F42 | G40 20BP | F51 12BP | S61 20BP | F60 12BP | G59 20BP | F65 | G32 16BP | G44 | E17 | |
| 12 | | | D29 | F43 | G29 16BP | P67 | G46 20BP | F11 | G27 20BP | F44 | G52 16BP | F02 | D21 | | |
| 13 | | | | D11 | G09 | G14 16BP | F18 | G36 16BP | F04 | G06 16BP | G18 | D04 | | | |
| 14 | | | | | E30 | F66 | S57 12BP | F05 | S65 12BP | F52 | E26 | | | | |
| 15 | | | | | | | E06 | F37 | E18 | | | | | | |

Fig. A.1. North Anna Unit 1 Cycle 5 core loading pattern.

Table A.1. Fuel assembly burnups at BOC for North Anna Unit 1 Cycle 5

| Assembly ID | Batch | Burnup (MWd/MTU) | Assembly ID | Batch | Burnup (MWd/MTU) |
|---|---|---|---|---|---|
| D04 | 4 | 21732 | F14 | 6 | 12870 |
| D05 | 4 | 21191 | F15 | 6 | 13206 |
| D07 | 4 | 21611 | F16 | 6 | 12008 |
| D11 | 4 | 21439 | F17 | 6 | 11904 |
| D21 | 4 | 25272 | F18 | 6 | 12022 |
| D29 | 4 | 27402 | F20 | 6 | 12621 |
| D36 | 4 | 26307 | F21 | 6 | 15892 |
| D37 | 4 | 27427 | F22 | 6 | 15899 |
| D41 | 4 | 26415 | F23 | 6 | 15887 |
| D42 | 4 | 26573 | F24 | 6 | 15730 |
| D47 | 4 | 26829 | F26 | 6 | 15937 |
| D51 | 4 | 27631 | F27 | 6 | 16049 |
| E06 | 5 | 21047 | F30 | 6 | 15926 |
| E12 | 5 | 21002 | F31 | 6 | 15805 |
| E17 | 5 | 20992 | F32 | 6 | 15575 |
| E18 | 5 | 20764 | F33 | 6 | 15620 |
| E20 | 5 | 30537 | F34 | 6 | 15756 |
| E22 | 5 | 30731 | F35 | 6 | 15747 |
| E24 | 5 | 30766 | F36 | 6 | 17105 |
| E25 | 5 | 30471 | F37 | 6 | 17248 |
| E26 | 5 | 30478 | F38 | 6 | 17191 |
| E29 | 5 | 30827 | F39 | 6 | 17010 |
| E30 | 5 | 30943 | F40 | 6 | 17182 |
| E31 | 5 | 30164 | F42 | 6 | 17196 |
| E33 | 5 | 32157 | F43 | 6 | 17055 |
| E37 | 5 | 32152 | F44 | 6 | 17655 |
| E39 | 5 | 32200 | F45 | 6 | 17382 |
| E43 | 5 | 32077 | F46 | 6 | 17546 |
| E54 | 5 | 32015 | F47 | 6 | 17490 |
| E56 | 5 | 32122 | F48 | 6 | 17208 |
| E59 | 5 | 32110 | F49 | 6 | 17317 |
| E63 | 5 | 31554 | F50 | 6 | 17023 |
| F02 | 6 | 10012 | F51 | 6 | 16784 |
| F03 | 6 | 9846 | F52 | 6 | 16920 |
| F04 | 6 | 9831 | F53 | 6 | 16873 |
| F05 | 6 | 9513 | F56 | 6 | 16707 |
| F07 | 6 | 13382 | F58 | 6 | 16762 |
| F08 | 6 | 12644 | F59 | 6 | 16771 |
| F09 | 6 | 11907 | F60 | 6 | 16810 |
| F10 | 6 | 12814 | F61 | 6 | 13932 |
| F11 | 6 | 13304 | F63 | 6 | 14347 |
| F13 | 6 | 12995 | F64 | 6 | 14172 |

Table A.1. (continued)

| Assembly ID | Batch | Burnup (MWd/MTU) | Assembly ID | Batch | Burnup (MWd/MTU) |
|---|---|---|---|---|---|
| F65 | 6 | 13886 | G31 | 7 | 17338 |
| F66 | 6 | 14131 | G32 | 7 | 17246 |
| F67 | 6 | 14145 | G33 | 7 | 17071 |
| F68 | 6 | 13944 | G34 | 7 | 16731 |
| F69 | 6 | 14094 | G35 | 7 | 16975 |
| G01 | 7 | 13540 | G36 | 7 | 16727 |
| G02 | 7 | 13371 | G37 | 7 | 17097 |
| G03 | 7 | 13191 | G38 | 7 | 17003 |
| G04 | 7 | 13358 | G39 | 7 | 16868 |
| G05 | 7 | 13353 | G40 | 7 | 16771 |
| G06 | 7 | 13541 | G41 | 7 | 15737 |
| G07 | 7 | 13044 | G42 | 7 | 15641 |
| G08 | 7 | 13385 | G43 | 7 | 15957 |
| G09 | 7 | 18084 | G44 | 7 | 15695 |
| G10 | 7 | 18116 | G45 | 7 | 16033 |
| G11 | 7 | 17679 | G46 | 7 | 15919 |
| G12 | 7 | 17913 | G47 | 7 | 15730 |
| G13 | 7 | 18009 | G48 | 7 | 15737 |
| G14 | 7 | 17593 | G49 | 7 | 16170 |
| G15 | 7 | 17838 | G50 | 7 | 16183 |
| G16 | 7 | 18010 | G51 | 7 | 16226 |
| G17 | 7 | 18038 | G52 | 7 | 16199 |
| G18 | 7 | 17500 | G53 | 7 | 14752 |
| G19 | 7 | 17620 | G54 | 7 | 14843 |
| G20 | 7 | 17728 | G55 | 7 | 14988 |
| G21 | 7 | 17525 | G56 | 7 | 15090 |
| G22 | 7 | 16991 | G57 | 7 | 14661 |
| G23 | 7 | 17218 | G58 | 7 | 14754 |
| G24 | 7 | 16976 | G59 | 7 | 14809 |
| G25 | 7 | 17441 | S57 | N2/5 | 15037 |
| G26 | 7 | 17349 | S58 | N2/5 | 13276 |
| G27 | 7 | 17305 | S59 | N2/5 | 12693 |
| G28 | 7 | 17297 | S60 | N2/5 | 12918 |
| G29 | 7 | 17408 | S61 | N2/5 | 12790 |
| G30 | 7 | 17409 | S62 | N2/5 | 12530 |
| | | | S63 | N2/5 | 12740 |
| | | | S64 | N2/5 | 12841 |
| | | | S65 | N2/5 | 12606 |

# APPENDIX B

# SAS2H CASE INPUT LISTING

```
=sas2     parm='halt08,skipshipdata'
sas2h: north anna critical isotopes, batch 5, 5gwd/mtu int, x 8 cycles
27burnuplib    latticecell
'
'   mixtures of fuel-pin-unit-cell:
'
uo2  1 0.9458 901 92234 0.029 92235 3.41 92236 0.016 92238 96.545  end
kr-83    1 0 1-20 901  end
kr-85    1 0 1-20 901  end
sr-90    1 0 1-20 901  end
 y-89    1 0 1-20 901  end
mo-95    1 0 1-20 901  end
zr-93    1 0 1-20 901  end
zr-94    1 0 1-20 901  end
zr-95    1 0 1-20 901  end
nb-94    1 0 1-20 901  end
tc-99    1 0 1-20 901  end
rh-103   1 0 1-20 901  end
rh-105   1 0 1-20 901  end
ru-101   1 0 1-20 901  end
ru-106   1 0 1-20 901  end
pd-105   1 0 1-20 901  end
pd-108   1 0 1-20 901  end
ag-109   1 0 1-20 901  end
sb-124   1 0 1-20 901  end
i-135    1 0 1-20 901  end
xe-131   1 0 1-20 901  end
xe-132   1 0 1-20 901  end
xe-135   1 0 6-9  901  end
xe-136   1 0 1-20 901  end
cs-133   1 0 1-20 901  end
cs-134   1 0 1-20 901  end
cs-135   1 0 1-20 901  end
cs-137   1 0 1-20 901  end
ba-136   1 0 1-20 901  end
la-139   1 0 1-20 901  end
pr-141   1 0 1-20 901  end
pr-143   1 0 1-20 901  end
ce-144   1 0 1-20 901  end
nd-143   1 0 1-20 901  end
nd-145   1 0 1-20 901  end
pm-147   1 0 1-20 901  end
pm-148   1 0 1-20 901  end
pm-149   1 0 1-20 901  end
nd-147   1 0 1-20 901  end
sm-147   1 0 1-20 901  end
sm-149   1 0 1-20 901  end
sm-150   1 0 1-20 901  end
sm-151   1 0 1-20 901  end
sm-152   1 0 1-20 901  end
gd-155   1 0 1-20 901  end
eu-153   1 0 1-20 901  end
eu-154   1 0 1-20 901  end
eu-155   1 0 1-20 901  end
zircalloy  2 1  629   end
h2o  3 den=0.7041  1  583  end
arbm-bormod  0.7041 1 1 0 0 5000 100 3 575.0e-6  583  end
'
'  575 pm(wt) boron (550 ppm at cycle 3 and 600 ppm at cycle 4)
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

```
end comp
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
'      fuel-pin-cell geometry:
'
squarepitch   1.25984 0.81915 1 3 0.94996 2 0.83566 0  end
'
' - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
'
more data   szf=0.6  end
'
'    assembly and cycle parameters:
'
npin/assm=264 fuelngth=790.81 ncycles=8  nlib/cyc=1
printlevel=4  lightel=9       inplevel=1
numinstr=1    ortube=0.61214  srtube=0.5715  end
'
power=31.023  burn=161.17  down=31.62   end
power=31.023  burn=161.17  down=31.62   end
power=31.023  burn=161.17  down=31.62   end
power=31.023  burn=161.17  down=31.62   end
power=31.023  burn=161.17  down=31.62   end
power=31.023  burn=161.17  down=31.62   end
power=31.023  burn=161.17  down=31.62   end
power=31.023  burn=161.17  down=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
```

# APPENDIX C

# SNIKR VERSION 1.0 DOCUMENTATION

## SNIKR VERSION 1.0 USER'S INPUT GUIDE

Each entry below must begin in column 1. Recommended values are given in parentheses.

Line 1 SNIKR1

Line 2 Title card for SNIKR1 (80-character maximum)

Line 3 READ BURNUP

Line 4 N72=ii (I2 format)
Unit number for SAS2H atom density file (72)

Line 5 NOUT=ii (I2 format)
Unit number for SNIKR1 output file (70)

Line 6 BURN=xxxxxx.x (F8.1 format)
Desired burnup in MWd/MTU for interpolation

Line 7 NCYC=ii (I2 format)
Number of cycles in SAS2H depletion

Line 8 END BURNUP

Line 9 READ DECAY

Line 10 NORS=ii (I2 format)
Unit number for ORIGEN-S input file created by SNIKR1 (74)

Line 11 N71=ii (I2 format)
Unit number to which ORIGEN-S will write the restart file containing the isotopic data at the requested cooling times. This file will then be read by SNIKR3 (71)

Line 12 COOLTME=xxx.xx (F6.2 format)
Cooling time in years at which isotopics are desired

Line 13 LIGHTEL=ii (I2 format)
Number of light-element nuclides for which isotopics are desired. Data will be read after "END DECAY." This option allows the user to extract light-element data in addition to actinide and fission-product data and/or to adjust the concentrations of light-element nuclides.

Line 14 END DECAY

If LIGHTEL > 0, enter the following data for each light-element nuclide (free format):

a. Nuclide ID number
b. Atom density of nuclide
c. Option flag
   1= replace SAS2H atom density with value entered above
   2= replace SAS2H atom density only if SAS2H value is zero

   3= add the atom density to the SAS2H value. Using this option and an atom density of zero above will extract data from SAS2H without modification.

Line 15 SNIKR3

Line 16 Title card for SNIKR3 (80-character maximum)

Line 17 READ MXFUEL

Line 18 N71=ii (I2 format)
Unit number from which SNIKR3 will read the ORIGEN-S restart file containing the isotopic data at the requested cooling times (71)

Line 19 NICE=ii (I2 format)
Unit number to which SNIKR3 writes the data for input to ICE (75)

Line 20 NOUT3=ii (I2 format)
Unit number to which SNIKR3 writes the data in SCALE standard composition and KENO V.a mixing table input formats (73)

Line 21 NCOOL=ii (I2 format)
Cooling time step in ORIGEN-S output from which isotopic data are to be extracted

Line 22 FISPROD=iii (I3 format)
Actinide and fission-product nuclides for which isotopic data are to be extracted
 0= 25 burnup credit nuclides from ref. 4
-1= 37 burnup credit nuclides from ref. 1
-2= 48 nuclides used in reactor critical calculations (Table 2)
-3= 193 nuclides (all nuclides in 27-group burnup library)
 N= Read N nuclides specified by user after "END MXFUEL"

Line 23 MIXF=iiii (I4 format)
Mixture number for SCALE standard composition input

Line 24 IDMOD=ii (I2 format)
Fuel nuclide ID modifier for seven burnup-dependent actinides

Line 25 END MXFUEL

If FISPROD > 0, enter the nuclide IDs here. (Format 10(1X,I5))

## C.2 SNIKR1 FORTRAN LISTING

```
c
      program snikr1
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20)
       dimension tstep(10)
c  read input to snikr needed to set up ors runs
      data tstep/0.08,0.25,0.5,1.0,2.0,3.0,5.0,10,15,20/
      call rdinpt1
c
c  write input to nout
c
      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)cool
      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(8x,f6.2)
  190 format(8x,i2)
c
c  retrieve number densities from sas2h output (n71) for burn
      call density
c     write(nout,110)(iddk(i),addk(i),i=1,itot)
c 110 format(4(i8,2x,1p,e10.4))
c
c  if the requested burnup or cooling time is 0, it is not necessary
c  to perform the origen-s step
      if(burn.eq.0.0.or.cool.eq.0.0)go to 1000
c  set up origen-s run to decay isotopics for requested cool time
      call tymstp(ncool,tstep)
      write(nout,100)ncool
 100  format('****needed for phase 3 input****    ncool= ',i2,'.')
      call litel(0)
      call wrtors(tstep)
      go to 2000
c  **********check file nout for messages
 1000 continue
      ncool=0
      call rdinpt3(ncool)
      call litel(0)
      call clect(1)
      call wrtice
c
c  write number densities for mixing in keno to ...nout3
      call wrtkeno
 2000 stop
      end
c---------------------------------------------------------------------
c
c  read input data for phase one calculations, reading sas2h output
c  and setting up origen-s decay only case
c
```

```
c---------------------------------------------------------------
      subroutine rdinpt1
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20)
      character*6 ichk
      n5=5
      read(n5,110)ichk
c  read and check if appropriate phase input - snikr1
      if(ichk.ne.'snikr1')stop 5101
c  read title card
      read(n5,120)ittl
c  read label and check to be sure burn data is next
      read(n5,110)ichk
      if(ichk.ne.'read b')stop 5102
c  read n72, unit number for sas2h file 72 output to be read from
      read(n5,130)n72
c  read nout, unit number for output to be written to
      read(n5,140)nout
c  read burnup in mwd/mtu that number densities are to be retrieved from n72
      read(n5,150)burn
c  read metal (mtu/assembly), bconv is conversion factor for burnups
c  read from n72
c     read(n5,160)bconv
c   **** modified snikr, now read from sas2h output
c
c  read ncyc, number of burn cycles used to produce sas2h output on n72
      read(n5,170)ncyc
c  read and check that this is end of burnup data
      read(n5,110)ichk
      if(ichk.ne.'end bu')stop 5103
c  read and check that decay data begins with next card
      read(n5,110)ichk
      if(ichk.ne.'read d')stop 5104
c  read nors, unit number for origen-s input to be written
      read(n5,140)nors
c  read n71, unit number for origen-s output to be written for phase 3
      read(n5,130)n71
c  read cooling time in years to be used to set up origen-s decay case
      read(n5,180)cool
c  read the number of light elements to be specified in the decay case
      read(n5,190)nlitl
c  read and check that this is the end of decay data
      read(n5,110)ichk
      if(ichk.ne.'end de')stop 5105
c  if nlitl is greater than zero read in id's of light elements
      if(nlitl.eq.0)go to 1000
      read(n5,*)(idlitl(i),adlitl(i),ltyp(i),i=1,nlitl)
 1000 continue
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  returns iddk and addk arrays for the appropriate burnup, burn
c
c---------------------------------------------------------------------
      subroutine density
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20)
       dimension rdburn(10),idplt(26),a(2000),b(2000),ad(2000,10)
      data idplt/92234,92235,92236,92238,94238,94239,94240,94241,
     &94242,95241,8016,42095,43099,45103,55133,55135,60143,60145,
     &62147,62149,62150,62151,62152,63153,64155,13027/
       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(nc.lt.ncyc)go to 1000
c  *********************************************************************
c   this section temporary to plot number density with burnup
       do 3 j=1,26
       write(nout,332)idplt(j)
       idplt(j)=idplt(j)*10
       do 2 i=1,itot
       if(iddk(i).ne.idplt(j)) go to 2
       do 1 k=1,nbn
   1   write(nout,333)rdburn(k),ad(i,k)
   2   continue
   3   continue
  333  format(f8.1,1x,',',1x,1p,e11.3)
  332  format('pairs of burnup(mwd/mtu) and number density for ',i10)
c  *********************************************************************
       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=0
       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@@@**********begin linear interpolation************************
c     do 25 k=1,itot
c     a(k)=ad(k,ilow)
c  25 b(k)=ad(k,ihi)
c     call interp(a,b,rdburn(ilow),rdburn(ihi))
c***************end linear interpolation************************
c@@@**********begin lagrangian interpolation************************
      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***************end lagrangian interpolation************************
      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
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(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  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  8/16/91 - modified original subroutine to check for zero or near
c  zero number densities before interpolating
      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 interp(a1,a2,b1,b2)
c
c  this routine linearly interpolates atom density as a
c  function of burnup
c
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20)
       dimension a1(2000),a2(2000)
       db=b2-b1
       delb=b2-burn
       do 10 i=1,itot
       slope=(a2(i)-a1(i))/db
       addk(i)=a2(i)-slope*delb
       if(addk(i).lt.0.0)stop 7299
       if(iddk(i).ne.922350)go to 10
       write(nout,111)b1,a1(i),b2,a2(i),slope,delb
       write(nout,112)addk(i)
  10   continue
 111   format('b1=',f8.1,' a1=',e11.4,' b2=',f8.1,' a2=',e11.4,
     &' slope=',e11.4,' delb=',e11.4)
 112   format('value for linear interp for 92235',1x,e11.4)
       return
       end
c-----------------------------------------------------------------------
      subroutine tymstp(ncool,tstep)
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20)
      dimension tstep(10)
c
c  this routine will check requested cooling time against the
c  default tstep array and make any changes that are necessary
c  to accommodate the user's request
c
```

```
c  if the user request a decay step not in the default list,
c  the time step nearest the requested cooling time will be
c  altered.  the longest cooling time allowed is 20 years.
c
      coolmx=20
      do 10 i=1,10
      if(cool.ne.tstep(i))go to 10
      ncool=i
      return
  10  continue
      if(cool.le.coolmx)go to 20
      write(nout,100)cool,coolmx
      stop 801
  20  continue
      do 30 j=1,9
      if(tstep(j).lt.cool.and.cool.lt.tstep(j+1))then
         jcool=j
         go to 40
         end if
  30  continue
      tstep(10)=cool
      ncool=10
      return
  40  f1=cool-tstep(jcool)
      f2=tstep(jcool+1)-cool
      if(f1.gt.f2)jcool=jcool+1
         tstep(jcool)=cool
         ncool=jcool
      return
 100  format('requested cooling time ',f7.2,' larger than maximum of ',
     &f4.1,' years')
      end
c----------------------------------------------------------------------
       subroutine litel(iflag)
c
c  this subroutine checks to see if any
c  light elements are requested by the
c  user, if oxygen is not explicitly
c  requested it is added.
c
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(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 the binary output file 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
      common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
      common /untnos/ n72,nout,n71,nors,nice
      common /ident/ idlitl(40),idcrit(200),iddk(2000)
      common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
      common /title/ ittl(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,209)(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))
  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 rdinpt3(ncool)
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(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
      read(n5,110)ichk
c  read and check if appropriate phase input - snikr3
      if(ichk.ne.'snikr3')stop 5301
c  read title card
      read(n5,120)ittl
c  read label and check to be sure mxfuel data is next
      read(n5,110)ichk
      if(ichk.ne.'read m')stop 5302
c  read n72, unit number for origen-s file 71 output to be read from
      read(n5,130)n71
c  read nice, unit number for ice input to be written to
      read(n5,140)nice
c  read nout, unit number for output to be written to
      read(n5,140)nout
c  read ncool, number of cooling step for which densities are to be read
      if(ncool.gt.0)read(n5,110)
      if(ncool.eq.0)read(n5,145)ncool
```

```
c  read 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
      read(n5,150)nfis
      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  read mixture number to be used for fuel of this burn in keno calculations
      read(n5,160)mixf
c  read integer modifier for fuel nuclide id's for use in ice run
      read(n5,145)idmod
c  read and check that this is end of fuel mix data
      read(n5,110)ichk
      if(ichk.ne.'end mx')stop 5303
c  if fisprod is greater than zero read in id's of elements in fuel for
c  criticality calculations
      if(nfis.le.0)go to 1000
      read(n5,170)(idcrit(i),i=1,ncrit)
 1000 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,145)ncool
      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
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(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   compute number density for lumped-fission product if requested
c   only available for nfis=-2  (for mikey's use only)***
       adlfp=0.0
       ifp0=ile+iact
c  do we need to calculate a lumped fission product
c  check to see if idcrit=99999, if so calculate lfp
c  also (if ickfp=1) check to see if any nuclide in idcrit is also
c  in idlfp, if so set idlfp to zero
c
c  ickfp=0 will calculate the virginia power lumped fission product
c  explicitly
       ickfp=0
c
c ickfp=1 calculates vp lfp minus fp in idcrit array ###don't use now
c      ickfp=1
       k99=0
       do 92 kl=1,ncrit
       if(idcrit(kl).eq.99999)k99=kl
       if(ickfp.eq.0)go to 92
       do 90 j=1,nlfp
       if(idlfp(j).ne.idcrit(kl))go to 90
       write(nout,110)idlfp(j)
       idlfp(j)=0
       go to 92
   90  continue
   92  continue
  110  format(i10,' nuclide was in idlfp and idcrit')
c   no lfp calculation is required if k99=0
       if(k99.eq.0)return
       do 95 i=1,ifp
       j=ifp0+i
       do 94 kj=1,nlfp
       if(iddk(j).ne.idlfp(kj))go to 94
       adlfp=adlfp+addk(j)
       go to 95
  94   continue
  95   continue
       adcrit(k99)=adlfp
       return
       end
c
c
c
c---------------------------------------------------------------------
      subroutine wrtice
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(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
  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
      return
      end
c----------------------------------------------------------------------
      subroutine wrtkeno
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(200),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
```

```
       common /title/ ittl(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
   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)
       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
c---------------------------------------------------------------------
```

## C.3 SNIKR3 FORTRAN LISTING

```
c
      program snikr3
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20)
       dimension tym(20)
c  read snikr1 input again
      call rdinpt1
c  read input to snikr needed to set up ice run
      ncool=0
      call rdinpt3(ncool)
c  retrieve number densities at cooltime for nuclides to be used in
c  criticality analyses
      nnct=0
      nncl=1
      if(ncool.lt.0)then
      ncool=0
      nncl=11
      end if
 1000 continue
      nnct=nnct+1
      npos=ncool+nnct
      call rdf71(npos,tym)
      rewind n71
      call litel(1)
      call clect(0)
c  set up ice run to create mixture cross sections for keno calcs
c  first remove any nuclides with number densities less than 1e-24
      write(nout,107)npos
      write(nout,108)tym(npos)
      write(nice,107)npos
      write(nice,108)tym(npos)
      call wrtice
c  use mixed cross sections written on unit nice in keno calc
c  **********check file nout for messages
c
c  write number densities for mixing in keno to ...nout3
  107 format('isotopic results for cool step ',i2)
  108 format('origens cooling time (yr) =',f6.2)
      call wrtkeno
      if(nnct.lt.nncl)go to 1000
      stop
      end
c
c  read input data for phase one calculations, reading sas2h output
c  and setting up origen-s decay only case
c
c----------------------------------------------------------------------
      subroutine rdinpt1
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20)
      character*6 ichk
      n5=5
      read(n5,110)ichk
c  read and check if appropriate phase input - snikr1
      if(ichk.ne.'snikr1')stop 5101
c  read title card
      read(n5,120)ittl
```

```
c  read label and check to be sure burn data is next
      read(n5,110)ichk
      if(ichk.ne.'read b')stop 5102
c  read n72, unit number for sas2h file 72 output to be read from
      read(n5,130)n72
c  read nout, unit number for output to be written to
      read(n5,140)nout
c  read burnup in mwd/mtu that number densities are to be retrieved from n72
      read(n5,150)burn
c  read metal (mtu/assembly), bconv is conversion factor for burnups
c  read from n72
c     read(n5,160)bconv
c   **** modified snikr, now read from sas2h output
c
c  read ncyc, number of burn cycles used to produce sas2h output on n72
      read(n5,170)ncyc
c  read and check that this is end of burnup data
      read(n5,110)ichk
      if(ichk.ne.'end bu')stop 5103
c  read and check that decay data begins with next card
      read(n5,110)ichk
      if(ichk.ne.'read d')stop 5104
c  read nors, unit number for origen-s input to be written
      read(n5,140)nors
c  read n71, unit number for origen-s input to be written for phase 3
      read(n5,130)n71
c  read cooling time in years to be used to set up origen-s decay case
      read(n5,180)cool
c  read the number of light elements to be specified in the decay case
      read(n5,190)nlitl
c  read and check that this is the end of decay data
      read(n5,110)ichk
      if(ichk.ne.'end de')stop 5105
c  if nlitl is greater than zero read in id's of light elements
      if(nlitl.eq.0)go to 1000
      read(n5,195)(idlitl(i),adlitl(i),ltyp(i),i=1,nlitl)
 1000 continue
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)
  195 format(1x,i5,1p,e10.4,0p,2x,i1)
      end
c
c
c-----------------------------------------------------------------------
      subroutine rdinpt3(ncool)
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
```

```
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(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
      read(n5,110)ichk
c  read and check if appropriate phase input - snikr3
      if(ichk.ne.'snikr3')stop 5301
c  read title card
      read(n5,120)ittl
c  read label and check to be sure mxfuel data is next
      read(n5,110)ichk
      if(ichk.ne.'read m')stop 5302
c  read n72, unit number for origen-s file 71 output to be read from
      read(n5,130)n71
c  read nice, unit number for ice input to be written to
      read(n5,140)nice
c  read nout, unit number for output to be written to
      read(n5,140)nout
c  read ncool, number of cooling step for which densities are to be read
      if(ncool.gt.0)read(n5,110)
      if(ncool.eq.0)read(n5,145)ncool
c  read 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
      read(n5,150)nfis
      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  read mixture number to be used for fuel of this burn in keno calculations
      read(n5,160)mixf
c  read integer modifier for fuel nuclide id's for use in ice run
      read(n5,145)idmod
c  read and check that this is end of fuel mix data
      read(n5,110)ichk
      if(ichk.ne.'end mx')stop 5303
c  if fisprod is greater than zero read in id's of elements in fuel for
c  criticality calculations
      if(nfis.le.0)go to 1000
      read(n5,170)(idcrit(i),i=1,ncrit)
 1000 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,145)ncool
      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 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
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
```

```
      common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
      common /title/ ittl(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 -- added this line to eliminate double entries caused by metastable
c -- isotopes (e.g., gd-155m) when dividing by 10 -- smb 6/16/93
         if (mod(iddk(i),10) .gt. 0) iddk(i)=0
  15     iddk(i)=iddk(i)/10
         ia1=ile+1
         ia2=ile+iact+ifp
         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),f6.2)
  103  format(4(i8,2x,1p,e10.4))
       return
       end
c----------------------------------------------------------------------
       subroutine litel(iflag)
c
c  this subroutine checks to see if any
c  light elements are requested by the
c  user, if oxygen is not explicitly
c  requested it is added.
c
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(20)
c
       if(nlitl.ne.0)go to 10
       nlitl=1
       idlitl(1)=8016
       ltyp(1)=1
c -- commented this out to get oxygen automatically added -- smb 6/16/93
c      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 clect(iflag)
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(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)
```

```
      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   compute number density for lumped-fission product if requested
c   only available for nfis=-2  (for mikey's use only)***
      adlfp=0.0
      ifp0=ile+iact
c  do we need to calculate a lumped fission product
c  check to see if idcrit=99999, if so calculate lfp
c  also (if ickfp=1) check to see if any nuclide in idcrit is also
c  in idlfp, if so set idlfp to zero
c
c  ickfp=0 will calculate the virginia power lumped fission product
c  explicitly
      ickfp=0
c
c ickfp=1 calculates vp lfp minus fp in idcrit array ###don't use now
c      ickfp=1
      k99=0
      do 92 kl=1,ncrit
      if(idcrit(kl).eq.99999)k99=kl
      if(ickfp.eq.0)go to 92
      do 90 j=1,nlfp
      if(idlfp(j).ne.idcrit(kl))go to 90
      write(nout,110)idlfp(j)
      idlfp(j)=0
      go to 92
   90 continue
   92 continue
  110 format(i10,' nuclide was in idlfp and idcrit')
c   no lfp calculation is required if k99=0
      if(k99.eq.0)return
      do 95 i=1,ifp
```

```
       j=ifp0+i
       do 94 kj=1,nlfp
       if(iddk(j).ne.idlfp(kj))go to 94
       adlfp=adlfp+addk(j)
       go to 95
  94   continue
  95   continue
       adcrit(k99)=adlfp
       return
       end
c
c
c
c---------------------------------------------------------------------
      subroutine wrtice
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(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
  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
      return
      end
c----------------------------------------------------------------------
      subroutine wrtkeno
       common /const/ bconv,burn,cool,mixf,idmod,smact0
       common /index/ nburn,ncrit,nlitl,ile,iact,ifp,itot,ncyc
       common /untnos/ n72,nout,n71,nors,nice
       common /ident/ idlitl(40),idcrit(210),iddk(2000)
       common /adens/ adlitl(40),ltyp(40),adcrit(200),addk(2000)
       common /title/ ittl(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
    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)
       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
```

## C.4 SNIKR INPUT LISTING FOR SPENT FUEL ISOTOPICS

```
snikr1
n1c5 (batch 5) cross section set #3  20951 mwd/mtu
read burnup
n72=72
nout=70
burn=20951.0
ncyc= 8
end burnup
read decay
nors=74
n71=71
cooltme=0.372
lightel=0
end decay
snikr3
n1c5 (batch 5) cross section set #3  20951 mwd/mtu
read mxfuel
n71=71
nice=75
nout=73
ncool= 2
fisprod= -2
mixf=   1
idmod= 0
end mxfuel
```

## C.5 SNIKR INPUT LISTING FOR DEPLETED BP ISOTOPICS

```
snikr1
n1c4 bp for 8th-core loc #11 in cycle 5 @ boc 13028 mwd/mtu
read burnup
n72=72
nout=70
burn=13028.0
ncyc= 6
end burnup
read decay
nors=74
n71=71
cooltme=0.372
lightel=5
end decay
  8016  0.04497   1
 11023  0.0       3
 13027  0.0       3
  5010  0.0       3
  5011  0.0       3
snikr3
n1c4 bp for 8th-core loc #11 in cycle 5 @ boc 13028 mwd/mtu
read mxfuel
n71=71
nice=75
nout=73
ncool= 2
fisprod=  5
mixf=   1
idmod= 0
end mxfuel
  8016 11023 13027  5010  5011
```

## C.6 SAMPLE SNIKR OUTPUT

```
n1c5 (batch 5) cross section set #3  20951 mwd/mtu
    71
     75
     73
       2
         -2
        1
       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   .08
 1697  689  129  879    3   .37
    2004  1.3950E-07   81206  1.8919E-31   81207  9.2165E-23   81208  4.6274E-20
   81209  1.2860E-26   82206  4.5267E-21   82207  4.8387E-18   82208  9.2674E-15
   82209  5.4329E-23   82210  4.0003E-19   82211  6.9940E-22   82212  2.6918E-17
   82214  1.2295E-23   83208  0.0000E+00   83209  4.5963E-19       0  0.0000E+00
   83210  2.4633E-22   83211  4.1460E-23   83212  2.5533E-18   83213  1.2689E-23
   83214  9.1292E-24   84210  4.3414E-21       0  0.0000E+00   84211  4.5820E-28
   84212  1.3417E-28   84213  1.9076E-32   84214  1.2923E-30   84215  5.7476E-28
   84216  1.0191E-22   84218  1.4224E-24   85217  1.4987E-28   86218  7.7319E-30
   86219  1.2787E-24   86220  3.9076E-20   86222  2.5267E-21   87221  1.3641E-24
   87223  6.4704E-24   88222  8.3947E-27   88223  3.1899E-19   88224  2.2223E-16
   88225  5.6970E-21   88226  3.8612E-16   88228  1.6064E-22   89225  4.0088E-21
   89227  2.4626E-16   89228  1.9608E-26   90226  4.0957E-25   90227  5.3612E-19
   90228  4.2293E-14   90229  1.1090E-15   90230  2.9891E-11   90231  1.5422E-15
   90232  3.7479E-12   90233  0.0000E+00   90234  3.2441E-13   91231  1.0163E-11
   91232  0.0000E+00   91233  2.2475E-13       0  1.0938E-17   91234  4.8858E-18
   91235  0.0000E+00   92230  3.9657E-22   92231  1.4743E-28   92232  6.7165E-12
   92233  5.7737E-11   92234  5.0225E-06   92235  3.7284E-04   92236  7.8727E-05
   92237  7.5212E-13   92238  2.1970E-02   92239  0.0000E+00   92240  9.8816E-31
   92241  0.0000E+00   93235  1.4834E-13       0  0.0000E+00   93236  1.7745E-11
   93237  6.5255E-06   93238  2.2774E-15   93239  3.7263E-13       0  8.4333E-33
   93240  8.6762E-35   93241  0.0000E+00   94236  1.8796E-11   94237  1.0693E-13
   94238  1.2760E-06   94239  1.2597E-04   94240  3.1510E-05   94241  1.9067E-05
   94242  3.2565E-06   94243  3.6528E-23   94244  4.9214E-20   94245  0.0000E+00
   94246  6.0828E-29   95239  0.0000E+00   95240  4.2951E-34   95241  8.2065E-07
       0  1.2313E-08   95242  1.5885E-13   95243  4.2591E-07       0  0.0000E+00
   95244  0.0000E+00   95245  1.2932E-24   95246  1.5197E-31   96241  1.8949E-18
   96242  5.6508E-08   96243  2.0461E-09   96244  5.8912E-08   96245  1.6737E-09
   96246  1.0513E-10   96247  1.0338E-12   96248  4.7605E-14   96249  2.0832E-28
   96250  1.4267E-22   96251  0.0000E+00   97249  3.3406E-16   97250  4.2123E-31
   97251  0.0000E+00   98249  1.5671E-16   98250  4.7196E-17   98251  2.1653E-17
   98252  4.6633E-18   98253  2.6802E-23   98254  1.1592E-25   98255  0.0000E+00
   99253  2.3090E-22       0  0.0000E+00   99254  0.0000E+00   99255  0.0000E+00
   16250  0.0000E+00    1003  5.6574E-08    3006  1.5730E-10    3007  5.1087E-12
    4009  7.6542E-12    4010  4.5944E-11    6014  6.6352E-12   28066  2.5634E-34
   29066  3.9961E-37   30066  3.1317E-14   29067  4.3357E-33   30067  4.1637E-15
   30068  3.5390E-16   30069  0.0000E+00       0  0.0000E+00   31069  1.2734E-14
   30070  3.3258E-13   31070  0.0000E+00   32070  4.5042E-16   30071  0.0000E+00
       0  0.0000E+00   31071  3.2701E-12   32071  6.6598E-23       0  0.0000E+00
   27072  0.0000E+00   28072  0.0000E+00   29072  0.0000E+00   30072  1.0686E-33
   31072  4.6506E-34   32072  2.1585E-10   27073  0.0000E+00   28073  0.0000E+00
   29073  0.0000E+00   30073  0.0000E+00   31073  0.0000E+00   32073  6.8707E-10
       0  0.0000E+00   27074  0.0000E+00   28074  0.0000E+00   29074  0.0000E+00
   30074  0.0000E+00   31074  0.0000E+00   32074  5.7965E-10   27075  0.0000E+00
   28075  0.0000E+00   29075  0.0000E+00   30075  0.0000E+00   31075  0.0000E+00
   32075  0.0000E+00       0  0.0000E+00   33075  5.5666E-09   28076  0.0000E+00
   29076  0.0000E+00   30076  0.0000E+00   31076  0.0000E+00   32076  1.7032E-08
   33076  0.0000E+00   34076  9.6360E-11   28077  0.0000E+00   29077  0.0000E+00
   30077  0.0000E+00   31077  0.0000E+00   32077  0.0000E+00       0  0.0000E+00
   33077  1.0092E-35   34077  3.8186E-08       0  4.0315E-42   28078  0.0000E+00
```

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 29078 | 0.0000E+00 | 30078 | 0.0000E+00 | 31078 | 0.0000E+00 | 32078 | 0.0000E+00 |
| 33078 | 0.0000E+00 | 34078 | 1.1520E-07 | 29079 | 0.0000E+00 | 30079 | 0.0000E+00 |
| 31079 | 0.0000E+00 | 32079 | 0.0000E+00 | 33079 | 0.0000E+00 | 34079 | 2.2128E-07 |
| 0 | 0.0000E+00 | 35079 | 6.6724E-12 | 0 | 0.0000E+00 | 36079 | 0.0000E+00 |
| 29080 | 0.0000E+00 | 30080 | 0.0000E+00 | 31080 | 0.0000E+00 | 32080 | 0.0000E+00 |
| 33080 | 0.0000E+00 | 34080 | 6.1714E-07 | 35080 | 0.0000E+00 | 0 | 0.0000E+00 |
| 36080 | 2.0735E-12 | 29081 | 0.0000E+00 | 30081 | 0.0000E+00 | 31081 | 0.0000E+00 |
| 32081 | 0.0000E+00 | 33081 | 0.0000E+00 | 34081 | 0.0000E+00 | 0 | 0.0000E+00 |
| 35081 | 9.0651E-07 | 36081 | 9.6998E-14 | 0 | 0.0000E+00 | 30082 | 0.0000E+00 |
| 31082 | 0.0000E+00 | 32082 | 0.0000E+00 | 33082 | 0.0000E+00 | 0 | 0.0000E+00 |
| 34082 | 1.4705E-06 | 35082 | 2.3318E-38 | 0 | 0.0000E+00 | 36082 | 1.7168E-08 |
| 30083 | 0.0000E+00 | 31083 | 0.0000E+00 | 32083 | 0.0000E+00 | 33083 | 0.0000E+00 |
| 34083 | 0.0000E+00 | 0 | 0.0000E+00 | 35083 | 0.0000E+00 | 36083 | 2.0737E-06 |
| 0 | 0.0000E+00 | 31084 | 0.0000E+00 | 32084 | 0.0000E+00 | 33084 | 0.0000E+00 |
| 34084 | 0.0000E+00 | 35084 | 0.0000E+00 | 0 | 0.0000E+00 | 36084 | 4.9444E-06 |
| 31085 | 0.0000E+00 | 32085 | 0.0000E+00 | 33085 | 0.0000E+00 | 34085 | 0.0000E+00 |
| 0 | 0.0000E+00 | 35085 | 0.0000E+00 | 36085 | 1.0199E-06 | 0 | 0.0000E+00 |
| 37085 | 4.1748E-06 | 32086 | 0.0000E+00 | 33086 | 0.0000E+00 | 34086 | 0.0000E+00 |
| 35086 | 0.0000E+00 | 0 | 0.0000E+00 | 36086 | 8.2430E-06 | 37086 | 4.3974E-12 |
| 0 | 0.0000E+00 | 38086 | 8.7322E-09 | 32087 | 0.0000E+00 | 33087 | 0.0000E+00 |
| 34087 | 0.0000E+00 | 35087 | 0.0000E+00 | 36087 | 0.0000E+00 | 37087 | 1.0639E-05 |
| 38087 | 4.0808E-11 | 0 | 0.0000E+00 | 32088 | 0.0000E+00 | 33088 | 0.0000E+00 |
| 34088 | 0.0000E+00 | 35088 | 0.0000E+00 | 36088 | 0.0000E+00 | 37088 | 0.0000E+00 |
| 38088 | 1.5089E-05 | 33089 | 0.0000E+00 | 34089 | 0.0000E+00 | 35089 | 0.0000E+00 |
| 36089 | 0.0000E+00 | 37089 | 0.0000E+00 | 38089 | 2.7779E-07 | 39089 | 1.9765E-05 |
| 0 | 9.4986E-17 | 33090 | 0.0000E+00 | 34090 | 0.0000E+00 | 35090 | 0.0000E+00 |
| 36090 | 0.0000E+00 | 37090 | 0.0000E+00 | 0 | 0.0000E+00 | 38090 | 2.3318E-05 |
| 39090 | 6.0600E-09 | 0 | 0.0000E+00 | 40090 | 8.9208E-07 | 0 | 0.0000E+00 |
| 34091 | 0.0000E+00 | 35091 | 0.0000E+00 | 36091 | 0.0000E+00 | 37091 | 0.0000E+00 |
| 38091 | 0.0000E+00 | 39091 | 5.2846E-07 | 0 | 0.0000E+00 | 40091 | 2.4592E-05 |
| 41091 | 3.4168E-17 | 34092 | 0.0000E+00 | 35092 | 0.0000E+00 | 36092 | 0.0000E+00 |
| 37092 | 0.0000E+00 | 38092 | 0.0000E+00 | 39092 | 0.0000E+00 | 40092 | 2.6120E-05 |
| 41092 | 4.1732E-15 | 34093 | 0.0000E+00 | 35093 | 0.0000E+00 | 36093 | 0.0000E+00 |
| 37093 | 0.0000E+00 | 38093 | 0.0000E+00 | 39093 | 0.0000E+00 | 40093 | 1.8868E-05 |
| 41093 | 8.0728E-13 | 0 | 1.2292E-11 | 35094 | 0.0000E+00 | 36094 | 0.0000E+00 |
| 37094 | 0.0000E+00 | 38094 | 0.0000E+00 | 39094 | 0.0000E+00 | 40094 | 2.9886E-05 |
| 41094 | 1.5712E-11 | 0 | 0.0000E+00 | 35095 | 0.0000E+00 | 36095 | 0.0000E+00 |
| 37095 | 0.0000E+00 | 38095 | 0.0000E+00 | 39095 | 0.0000E+00 | 40095 | 8.5482E-07 |
| 41095 | 8.5610E-07 | 0 | 5.6704E-10 | 42095 | 2.8097E-05 | 35096 | 0.0000E+00 |
| 36096 | 0.0000E+00 | 37096 | 0.0000E+00 | 38096 | 0.0000E+00 | 39096 | 0.0000E+00 |
| 40096 | 3.0216E-05 | 41096 | 0.0000E+00 | 42096 | 7.1582E-07 | 36097 | 0.0000E+00 |
| 37097 | 0.0000E+00 | 38097 | 0.0000E+00 | 39097 | 0.0000E+00 | 40097 | 0.0000E+00 |
| 41097 | 0.0000E+00 | 0 | 0.0000E+00 | 42097 | 2.7969E-05 | 36098 | 0.0000E+00 |
| 37098 | 0.0000E+00 | 38098 | 0.0000E+00 | 39098 | 0.0000E+00 | 40098 | 0.0000E+00 |
| 41098 | 0.0000E+00 | 0 | 0.0000E+00 | 42098 | 2.9627E-05 | 43098 | 1.6686E-10 |
| 37099 | 0.0000E+00 | 38099 | 0.0000E+00 | 39099 | 0.0000E+00 | 40099 | 0.0000E+00 |
| 41099 | 0.0000E+00 | 0 | 0.0000E+00 | 42099 | 2.8010E-22 | 43099 | 2.9112E-05 |
| 0 | 2.4722E-23 | 44099 | 1.1238E-09 | 37100 | 0.0000E+00 | 38100 | 0.0000E+00 |
| 39100 | 0.0000E+00 | 40100 | 0.0000E+00 | 41100 | 0.0000E+00 | 0 | 0.0000E+00 |
| 42100 | 3.2675E-05 | 43100 | 0.0000E+00 | 44100 | 2.2200E-06 | 37101 | 0.0000E+00 |
| 38101 | 0.0000E+00 | 39101 | 0.0000E+00 | 40101 | 0.0000E+00 | 41101 | 0.0000E+00 |
| 42101 | 0.0000E+00 | 43101 | 0.0000E+00 | 44101 | 2.6768E-05 | 38102 | 0.0000E+00 |
| 39102 | 0.0000E+00 | 40102 | 0.0000E+00 | 41102 | 0.0000E+00 | 42102 | 0.0000E+00 |
| 43102 | 0.0000E+00 | 0 | 0.0000E+00 | 44102 | 2.5179E-05 | 45102 | 2.3936E-11 |
| 46102 | 0.0000E+00 | 38103 | 0.0000E+00 | 39103 | 0.0000E+00 | 40103 | 0.0000E+00 |
| 41103 | 0.0000E+00 | 42103 | 0.0000E+00 | 43103 | 0.0000E+00 | 44103 | 1.8295E-07 |
| 45103 | 1.7001E-05 | 0 | 1.8129E-10 | 38104 | 0.0000E+00 | 39104 | 0.0000E+00 |
| 40104 | 0.0000E+00 | 41104 | 0.0000E+00 | 42104 | 0.0000E+00 | 43104 | 0.0000E+00 |
| 44104 | 1.5875E-05 | 45104 | 0.0000E+00 | 0 | 0.0000E+00 | 46104 | 4.3522E-06 |
| 39105 | 0.0000E+00 | 40105 | 0.0000E+00 | 41105 | 0.0000E+00 | 42105 | 0.0000E+00 |
| 43105 | 0.0000E+00 | 44105 | 0.0000E+00 | 45105 | 1.3399E-35 | 0 | 0.0000E+00 |
| 46105 | 1.1091E-05 | 39106 | 0.0000E+00 | 40106 | 0.0000E+00 | 41106 | 0.0000E+00 |
| 42106 | 0.0000E+00 | 43106 | 0.0000E+00 | 44106 | 3.7340E-06 | 45106 | 3.4654E-12 |
| 0 | 0.0000E+00 | 46106 | 5.0473E-06 | 47106 | 0.0000E+00 | 39107 | 0.0000E+00 |
| 40107 | 0.0000E+00 | 41107 | 0.0000E+00 | 42107 | 0.0000E+00 | 43107 | 0.0000E+00 |
| 44107 | 0.0000E+00 | 45107 | 0.0000E+00 | 46107 | 5.4116E-06 | 0 | 0.0000E+00 |
| 47107 | 6.7756E-13 | 40108 | 0.0000E+00 | 41108 | 0.0000E+00 | 42108 | 0.0000E+00 |
| 43108 | 0.0000E+00 | 44108 | 0.0000E+00 | 45108 | 0.0000E+00 | 0 | 0.0000E+00 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 46108 | 3.3965E-06 | 47108 | 1.2978E-20 | 0 | 4.2046E-12 | 48108 | 4.3323E-12 |
| 40109 | 0.0000E+00 | 41109 | 0.0000E+00 | 42109 | 0.0000E+00 | 43109 | 0.0000E+00 |
| 44109 | 0.0000E+00 | 45109 | 0.0000E+00 | 0 | 0.0000E+00 | 46109 | 0.0000E+00 |
| 0 | 0.0000E+00 | 47109 | 2.2758E-06 | 0 | 2.8264E-21 | 48109 | 2.8528E-15 |
| 41110 | 0.0000E+00 | 42110 | 0.0000E+00 | 43110 | 0.0000E+00 | 44110 | 0.0000E+00 |
| 45110 | 0.0000E+00 | 0 | 0.0000E+00 | 46110 | 9.9313E-07 | 47110 | 1.4044E-16 |
| 0 | 9.0585E-09 | 48110 | 5.4691E-07 | 41111 | 0.0000E+00 | 42111 | 0.0000E+00 |
| 43111 | 0.0000E+00 | 44111 | 0.0000E+00 | 45111 | 0.0000E+00 | 46111 | 0.0000E+00 |
| 0 | 0.0000E+00 | 47111 | 4.4963E-14 | 0 | 0.0000E+00 | 48111 | 5.1666E-07 |
| 0 | 0.0000E+00 | 41112 | 0.0000E+00 | 42112 | 0.0000E+00 | 43112 | 0.0000E+00 |
| 44112 | 0.0000E+00 | 45112 | 0.0000E+00 | 46112 | 0.0000E+00 | 47112 | 0.0000E+00 |
| 48112 | 2.7112E-07 | 42113 | 0.0000E+00 | 43113 | 0.0000E+00 | 44113 | 0.0000E+00 |
| 45113 | 0.0000E+00 | 46113 | 0.0000E+00 | 47113 | 0.0000E+00 | 0 | 0.0000E+00 |
| 48113 | 4.7748E-09 | 0 | 2.9133E-09 | 49113 | 1.7972E-10 | 0 | 0.0000E+00 |
| 42114 | 0.0000E+00 | 43114 | 0.0000E+00 | 44114 | 0.0000E+00 | 45114 | 0.0000E+00 |
| 46114 | 0.0000E+00 | 47114 | 0.0000E+00 | 48114 | 3.0224E-07 | 49114 | 2.2748E-18 |
| 0 | 1.4143E-13 | 50114 | 4.4456E-12 | 42115 | 0.0000E+00 | 43115 | 0.0000E+00 |
| 44115 | 0.0000E+00 | 45115 | 0.0000E+00 | 46115 | 0.0000E+00 | 47115 | 0.0000E+00 |
| 0 | 0.0000E+00 | 48115 | 3.1574E-28 | 0 | 6.0067E-11 | 49115 | 4.9537E-08 |
| 0 | 2.7812E-17 | 50115 | 4.7124E-09 | 43116 | 0.0000E+00 | 44116 | 0.0000E+00 |
| 45116 | 0.0000E+00 | 46116 | 0.0000E+00 | 47116 | 0.0000E+00 | 0 | 0.0000E+00 |
| 48116 | 1.3474E-07 | 49116 | 0.0000E+00 | 0 | 0.0000E+00 | 50116 | 4.6549E-08 |
| 43117 | 0.0000E+00 | 44117 | 0.0000E+00 | 45117 | 0.0000E+00 | 46117 | 0.0000E+00 |
| 47117 | 0.0000E+00 | 0 | 0.0000E+00 | 48117 | 0.0000E+00 | 0 | 0.0000E+00 |
| 49117 | 0.0000E+00 | 0 | 0.0000E+00 | 50117 | 1.1910E-07 | 0 | 1.7732E-14 |
| 43118 | 0.0000E+00 | 44118 | 0.0000E+00 | 45118 | 0.0000E+00 | 46118 | 0.0000E+00 |
| 47118 | 0.0000E+00 | 0 | 0.0000E+00 | 48118 | 0.0000E+00 | 49118 | 0.0000E+00 |
| 0 | 0.0000E+00 | 50118 | 9.7726E-08 | 44119 | 0.0000E+00 | 45119 | 0.0000E+00 |
| 46119 | 0.0000E+00 | 47119 | 0.0000E+00 | 48119 | 0.0000E+00 | 0 | 0.0000E+00 |
| 49119 | 0.0000E+00 | 0 | 0.0000E+00 | 50119 | 1.0305E-07 | 0 | 2.1967E-10 |
| 44120 | 0.0000E+00 | 45120 | 0.0000E+00 | 46120 | 0.0000E+00 | 47120 | 0.0000E+00 |
| 48120 | 0.0000E+00 | 49120 | 0.0000E+00 | 0 | 0.0000E+00 | 50120 | 1.0036E-07 |
| 45121 | 0.0000E+00 | 46121 | 0.0000E+00 | 47121 | 0.0000E+00 | 48121 | 0.0000E+00 |
| 49121 | 0.0000E+00 | 0 | 0.0000E+00 | 50121 | 4.5254E-14 | 0 | 1.0391E-09 |
| 51121 | 1.0251E-07 | 45122 | 0.0000E+00 | 46122 | 0.0000E+00 | 47122 | 0.0000E+00 |
| 48122 | 0.0000E+00 | 49122 | 0.0000E+00 | 0 | 0.0000E+00 | 50122 | 1.2820E-07 |
| 51122 | 4.8479E-26 | 0 | 0.0000E+00 | 52122 | 4.2525E-09 | 45123 | 0.0000E+00 |
| 46123 | 0.0000E+00 | 47123 | 0.0000E+00 | 48123 | 0.0000E+00 | 49123 | 0.0000E+00 |
| 0 | 0.0000E+00 | 50123 | 1.2580E-09 | 0 | 0.0000E+00 | 51123 | 1.1885E-07 |
| 52123 | 2.8620E-11 | 0 | 3.7719E-12 | 46124 | 0.0000E+00 | 47124 | 0.0000E+00 |
| 48124 | 0.0000E+00 | 49124 | 0.0000E+00 | 50124 | 2.1173E-07 | 51124 | 1.7210E-10 |
| 0 | 0.0000E+00 | 52124 | 3.3484E-09 | 46125 | 0.0000E+00 | 47125 | 0.0000E+00 |
| 48125 | 0.0000E+00 | 49125 | 0.0000E+00 | 0 | 0.0000E+00 | 50125 | 9.5338E-14 |
| 0 | 0.0000E+00 | 51125 | 1.8450E-07 | 52125 | 6.7924E-08 | 0 | 2.5160E-09 |
| 46126 | 0.0000E+00 | 47126 | 0.0000E+00 | 48126 | 0.0000E+00 | 49126 | 0.0000E+00 |
| 50126 | 4.5570E-07 | 51126 | 9.1507E-14 | 0 | 1.6461E-16 | 52126 | 7.0256E-09 |
| 54126 | 1.0267E-16 | 47127 | 0.0000E+00 | 48127 | 0.0000E+00 | 49127 | 0.0000E+00 |
| 0 | 0.0000E+00 | 50127 | 0.0000E+00 | 0 | 0.0000E+00 | 51127 | 2.9839E-19 |
| 52127 | 7.0219E-11 | 0 | 2.0058E-08 | 53127 | 1.0299E-06 | 54127 | 1.5169E-15 |
| 47128 | 0.0000E+00 | 48128 | 0.0000E+00 | 49128 | 0.0000E+00 | 50128 | 0.0000E+00 |
| 51128 | 0.0000E+00 | 0 | 0.0000E+00 | 52128 | 2.3079E-06 | 53128 | 0.0000E+00 |
| 54128 | 3.3416E-08 | 48129 | 0.0000E+00 | 49129 | 0.0000E+00 | 50129 | 0.0000E+00 |
| 0 | 0.0000E+00 | 51129 | 0.0000E+00 | 52129 | 3.9395E-12 | 0 | 4.2729E-09 |
| 53129 | 4.7079E-06 | 54129 | 9.4557E-11 | 0 | 8.0185E-17 | 48130 | 0.0000E+00 |
| 49130 | 0.0000E+00 | 50130 | 0.0000E+00 | 51130 | 0.0000E+00 | 0 | 0.0000E+00 |
| 52130 | 9.6244E-06 | 53130 | 0.0000E+00 | 0 | 0.0000E+00 | 54130 | 1.0312E-07 |
| 48131 | 0.0000E+00 | 49131 | 0.0000E+00 | 50131 | 0.0000E+00 | 51131 | 0.0000E+00 |
| 52131 | 0.0000E+00 | 0 | 0.0000E+00 | 53131 | 2.5150E-12 | 54131 | 1.3135E-05 |
| 0 | 5.3197E-12 | 48132 | 0.0000E+00 | 49132 | 0.0000E+00 | 50132 | 0.0000E+00 |
| 51132 | 0.0000E+00 | 0 | 0.0000E+00 | 52132 | 5.3067E-20 | 53132 | 1.5966E-21 |
| 54132 | 2.6443E-05 | 55132 | 3.5509E-18 | 56132 | 4.3998E-12 | 49133 | 0.0000E+00 |
| 50133 | 0.0000E+00 | 51133 | 0.0000E+00 | 52133 | 0.0000E+00 | 0 | 0.0000E+00 |
| 53133 | 0.0000E+00 | 0 | 0.0000E+00 | 54133 | 7.8902E-15 | 0 | 2.1046E-27 |
| 55133 | 3.2005E-05 | 56133 | 2.1633E-15 | 49134 | 0.0000E+00 | 50134 | 0.0000E+00 |
| 51134 | 0.0000E+00 | 0 | 0.0000E+00 | 52134 | 0.0000E+00 | 53134 | 0.0000E+00 |
| 0 | 0.0000E+00 | 54134 | 3.9754E-05 | 0 | 0.0000E+00 | 55134 | 1.8282E-06 |
| 0 | 0.0000E+00 | 56134 | 7.4911E-07 | 50135 | 0.0000E+00 | 51135 | 0.0000E+00 |
| 52135 | 0.0000E+00 | 53135 | 0.0000E+00 | 54135 | 0.0000E+00 | 0 | 0.0000E+00 |

```
   55135  1.1423E-05       0  0.0000E+00   56135  2.0482E-09       0  0.0000E+00
   50136  0.0000E+00   51136  0.0000E+00   52136  0.0000E+00   53136  0.0000E+00
       0  0.0000E+00   54136  5.6098E-05   55136  1.3331E-11   56136  3.2227E-07
       0  4.0498E-19   51137  0.0000E+00   52137  0.0000E+00   53137  0.0000E+00
   54137  0.0000E+00   55137  3.1560E-05   56137  1.0725E-06       0  4.8196E-12
   51138  0.0000E+00   52138  0.0000E+00   53138  0.0000E+00   54138  0.0000E+00
   55138  0.0000E+00       0  0.0000E+00   56138  3.3027E-05   57138  1.9481E-10
   51139  0.0000E+00   52139  0.0000E+00   53139  0.0000E+00   54139  0.0000E+00
   55139  0.0000E+00   56139  0.0000E+00   57139  3.1165E-05   58139  2.0342E-13
   59139  0.0000E+00   52140  0.0000E+00   53140  0.0000E+00   54140  0.0000E+00
   55140  0.0000E+00   56140  5.2736E-10   57140  7.9904E-11   58140  3.2688E-05
   59140  0.0000E+00   52141  0.0000E+00   53141  0.0000E+00   54141  0.0000E+00
   55141  0.0000E+00   56141  0.0000E+00   57141  0.0000E+00   58141  1.0619E-07
   59141  2.8332E-05   60141  0.0000E+00   52142  0.0000E+00   53142  0.0000E+00
   54142  0.0000E+00   55142  0.0000E+00   56142  0.0000E+00   57142  0.0000E+00
   58142  2.8510E-05   59142  0.0000E+00       0  0.0000E+00   60142  2.5954E-07
   53143  0.0000E+00   54143  0.0000E+00   55143  0.0000E+00   56143  0.0000E+00
   57143  0.0000E+00   58143  0.0000E+00   59143  8.1420E-10   60143  2.3776E-05
   53144  0.0000E+00   54144  0.0000E+00   55144  0.0000E+00   56144  0.0000E+00
   57144  0.0000E+00   58144  8.0591E-06   59144  3.3946E-10       0  1.9798E-12
   60144  2.1664E-05   53145  0.0000E+00   54145  0.0000E+00   55145  0.0000E+00
   56145  0.0000E+00   57145  0.0000E+00   58145  0.0000E+00   59145  0.0000E+00
   60145  1.7626E-05   61145  4.9083E-12   62145  4.8917E-12   54146  0.0000E+00
   55146  0.0000E+00   56146  0.0000E+00   57146  0.0000E+00   58146  0.0000E+00
   59146  0.0000E+00   60146  1.5902E-05   61146  1.6980E-10   62146  1.1010E-10
   54147  0.0000E+00   55147  0.0000E+00   56147  0.0000E+00   57147  0.0000E+00
   58147  0.0000E+00   59147  0.0000E+00   60147  5.0822E-11   61147  5.3698E-06
   62147  2.2786E-06   55148  0.0000E+00   56148  0.0000E+00   57148  0.0000E+00
   58148  0.0000E+00   59148  0.0000E+00   60148  8.6713E-06   61148  2.9608E-11
       0  4.3056E-09   62148  2.0767E-06   55149  0.0000E+00   56149  0.0000E+00
   57149  0.0000E+00   58149  0.0000E+00   59149  0.0000E+00   60149  0.0000E+00
   61149  1.7264E-26   62149  1.4566E-07   63149  1.2650E-18   55150  0.0000E+00
   56150  0.0000E+00   57150  0.0000E+00   58150  0.0000E+00   59150  0.0000E+00
   60150  3.9449E-06   61150  0.0000E+00   62150  7.0318E-06   63150  1.0917E-14
   56151  0.0000E+00   57151  0.0000E+00   58151  0.0000E+00   59151  0.0000E+00
   60151  0.0000E+00   61151  0.0000E+00   62151  5.0671E-07   63151  2.1663E-09
   56152  0.0000E+00   57152  0.0000E+00   58152  0.0000E+00   59152  0.0000E+00
   60152  0.0000E+00   61152  0.0000E+00       0  0.0000E+00   62152  3.0500E-06
   63152  1.3842E-09       0  0.0000E+00   64152  1.2533E-09   57153  0.0000E+00
   58153  0.0000E+00   59153  0.0000E+00   60153  0.0000E+00   61153  0.0000E+00
   62153  1.7194E-29   63153  2.1152E-06   64153  3.2023E-11   57154  0.0000E+00
   58154  0.0000E+00   59154  0.0000E+00   60154  0.0000E+00   61154  0.0000E+00
       0  0.0000E+00   62154  7.0382E-07   63154  5.4250E-07   64154  4.5063E-08
   57155  0.0000E+00   58155  0.0000E+00   59155  0.0000E+00   60155  0.0000E+00
   61155  0.0000E+00   62155  0.0000E+00   63155  2.2792E-07       0  0.0000E+00
   64155  1.5023E-08   58156  0.0000E+00   59156  0.0000E+00   60156  0.0000E+00
   61156  0.0000E+00   62156  0.0000E+00   63156  9.0630E-11   64156  6.7034E-07
   58157  0.0000E+00   59157  0.0000E+00   60157  0.0000E+00   61157  0.0000E+00
   62157  0.0000E+00   63157  0.0000E+00   64157  2.6112E-09   59158  0.0000E+00
   60158  0.0000E+00   61158  0.0000E+00   62158  0.0000E+00   63158  0.0000E+00
   64158  2.4271E-07   59159  0.0000E+00   60159  0.0000E+00   61159  0.0000E+00
   62159  0.0000E+00   63159  0.0000E+00   64159  0.0000E+00   65159  3.5961E-08
   60160  0.0000E+00   61160  0.0000E+00   62160  0.0000E+00   63160  0.0000E+00
   64160  1.5820E-08   65160  2.4982E-10   66160  2.3477E-09   60161  0.0000E+00
   61161  0.0000E+00   62161  0.0000E+00   63161  0.0000E+00   64161  0.0000E+00
   65161  2.4865E-16   66161  5.8293E-09   61162  0.0000E+00   62162  0.0000E+00
   63162  0.0000E+00   64162  0.0000E+00   65162  0.0000E+00       0  0.0000E+00
   66162  3.8839E-09   62163  0.0000E+00   63163  0.0000E+00   64163  0.0000E+00
   65163  0.0000E+00       0  0.0000E+00   66163  2.4270E-09   62164  0.0000E+00
   63164  0.0000E+00   64164  0.0000E+00   65164  0.0000E+00   66164  6.4211E-10
   62165  0.0000E+00   63165  0.0000E+00   64165  0.0000E+00   65165  0.0000E+00
   66165  0.0000E+00       0  0.0000E+00   67165  6.1531E-10   66166  3.7455E-25
   67166  1.8314E-25       0  1.4677E-12   68166  9.6500E-11   68167  1.4629E-12
       0  0.0000E+00   68168  1.1356E-12   70168  0.0000E+00   68169  7.3101E-20
   69169  4.9006E-14   70169  0.0000E+00   68170  5.1903E-14   69170  4.9314E-17
       0  0.0000E+00   70170  2.5417E-16   68171  0.0000E+00   69171  4.6099E-14
   70171  2.2735E-14   68172  4.6708E-36   69172  7.7005E-31   70172  4.4126E-14
adlitl for 8016= 0.0000E+00
```

```
isotopic results for cool step  3
origens cooling time (yr) =   .37



 for use in csas

   u-234    1  0  5.0225E-06  end
   u-235    1  0  3.7284E-04  end
   u-236    1  0  7.8727E-05  end
   u-238    1  0  2.1970E-02  end
  np-237    1  0  6.5255E-06  end
  pu-238    1  0  1.2760E-06  end
  pu-239    1  0  1.2597E-04  end
  pu-240    1  0  3.1510E-05  end
  pu-241    1  0  1.9067E-05  end
  pu-242    1  0  3.2565E-06  end
  am-241    1  0  8.2065E-07  end
  am-243    1  0  4.2591E-07  end
  cm-244    1  0  5.8912E-08  end
   o        1  0  4.6252E-02  end
  kr-83     1  0  2.0737E-06  end
  zr-93     1  0  1.8868E-05  end
  mo-95     1  0  2.8097E-05  end
  tc-99     1  0  2.9112E-05  end
  ru-101    1  0  2.6768E-05  end
  ru-103    1  0  1.8295E-07  end
  rh-103    1  0  1.7001E-05  end
  rh-105    1  0  1.3399E-35  end
  pd-105    1  0  1.1091E-05  end
  pd-108    1  0  3.3965E-06  end
  ag-109    1  0  2.2758E-06  end
   i-135    1  0  0.0000E+00  end
  xe-131    1  0  1.3135E-05  end
  xe-135    1  0  0.0000E+00  end
  cs-133    1  0  3.2005E-05  end
  cs-134    1  0  1.8282E-06  end
  cs-135    1  0  1.1423E-05  end
  pr-141    1  0  2.8332E-05  end
  nd-143    1  0  2.3776E-05  end
  nd-145    1  0  1.7626E-05  end
  nd-147    1  0  5.0822E-11  end
  nd-148    1  0  8.6713E-06  end
  pm-147    1  0  5.3698E-06  end
  pm-148    1  0  2.9608E-11  end
  pm-149    1  0  1.7264E-26  end
  sm-147    1  0  2.2786E-06  end
  sm-149    1  0  1.4566E-07  end
  sm-150    1  0  7.0318E-06  end
  sm-151    1  0  5.0671E-07  end
  sm-152    1  0  3.0500E-06  end
  eu-153    1  0  2.1152E-06  end
  eu-154    1  0  5.4250E-07  end
  eu-155    1  0  2.2792E-07  end
  gd-155    1  0  1.5023E-08  end



 for use when mixing in keno

 mix=   1
    92234  5.0225E-06
    92235  3.7284E-04
    92236  7.8727E-05
    92238  2.1970E-02
    93237  6.5255E-06
```

| | |
|---|---|
| 94238 | 1.2760E-06 |
| 94239 | 1.2597E-04 |
| 94240 | 3.1510E-05 |
| 94241 | 1.9067E-05 |
| 94242 | 3.2565E-06 |
| 95241 | 8.2065E-07 |
| 95243 | 4.2591E-07 |
| 96244 | 5.8912E-08 |
| 8016 | 4.6252E-02 |
| 36083 | 2.0737E-06 |
| 40093 | 1.8868E-05 |
| 42095 | 2.8097E-05 |
| 43099 | 2.9112E-05 |
| 44101 | 2.6768E-05 |
| 44103 | 1.8295E-07 |
| 45103 | 1.7001E-05 |
| 45105 | 1.3399E-35 |
| 46105 | 1.1091E-05 |
| 46108 | 3.3965E-06 |
| 47109 | 2.2758E-06 |
| 53135 | 0.0000E+00 |
| 54131 | 1.3135E-05 |
| 54135 | 0.0000E+00 |
| 55133 | 3.2005E-05 |
| 55134 | 1.8282E-06 |
| 55135 | 1.1423E-05 |
| 59141 | 2.8332E-05 |
| 60143 | 2.3776E-05 |
| 60145 | 1.7626E-05 |
| 60147 | 5.0822E-11 |
| 60148 | 8.6713E-06 |
| 61147 | 5.3698E-06 |
| 61148 | 2.9608E-11 |
| 61149 | 1.7264E-26 |
| 62147 | 2.2786E-06 |
| 62149 | 1.4566E-07 |
| 62150 | 7.0318E-06 |
| 62151 | 5.0671E-07 |
| 62152 | 3.0500E-06 |
| 63153 | 2.1152E-06 |
| 63154 | 5.4250E-07 |
| 63155 | 2.2792E-07 |
| 64155 | 1.5023E-08 |
| 99999 | 9.7763E-04 |

# APPENDIX D

# CSASN INPUT LISTINGS

## D.1 CSASN INPUT LISTING FOR CROSS-SECTION SET 3

```
=csasn
north anna unit 1 cycle 5 boc batch 5 xs set 3
27burnup  latticecell
'n1c5 (batch 5) cross section set #3  20951 mwd/mtu
   u-234    1  0  5.0225E-06  559  end
   u-235    1  0  3.7284E-04  559  end
   u-236    1  0  7.8727E-05  559  end
   u-238    1  0  2.1970E-02  559  end
  pu-239    1  0  1.2597E-04  559  end
  pu-240    1  0  3.1510E-05  559  end
  pu-241    1  0  1.9067E-05  559  end
 o        1  0  4.6252e-02       559  end
zircalloy 2  1                    559  end
h2o       3  den=0.7540  1       559  end
boron     3  den=0.7540 1836.e-6 559  end
end comp
squarepitch   1.25984 0.81915 1 3 0.94996 2 0.83566 0  end
end
```

## D.2 CSASN INPUT LISTING FOR CROSS-SECTION SET 4

```
=csasn
north anna unit 1 cycle 5 boc batch 5 xs set 4 (includes fp's & struct. matls)
27burnup  latticecell
' i-135, xe-135 are omitted because of 0 conc.
'n1c5 (batch 5) cross section set #4  31332 mwd/mtu
   u-234    10  0  4.2422E-06  559  end
   u-235    10  0  2.4556E-04  559  end
   u-236    10  0  9.7627E-05  559  end
   u-238    10  0  2.1773E-02  559  end
  np-237    10  0  1.1022E-05  559  end
  pu-238    10  0  3.4056E-06  559  end
  pu-239    10  0  1.4100E-04  559  end
  pu-240    10  0  4.7495E-05  559  end
  pu-241    10  0  3.0731E-05  559  end
  pu-242    10  0  8.6066E-06  559  end
  am-241    10  0  1.6053E-06  559  end
  am-243    10  0  1.7368E-06  559  end
  cm-244    10  0  3.9796E-07  559  end
   o        10  0  4.6252E-02  559  end
  kr-83     10  0  2.7123E-06  559  end
  zr-93     10  0  2.6737E-05  559  end
  mo-95     10  0  4.0766E-05  559  end
  tc-99     10  0  4.1565E-05  559  end
  ru-101    10  0  3.9799E-05  559  end
  ru-103    10  0  1.9965E-07  559  end
  rh-103    10  0  2.3987E-05  559  end
  rh-105    10  0  1.5785E-35  559  end
  pd-105    10  0  1.8985E-05  559  end
  pd-108    10  0  6.5394E-06  559  end
  ag-109    10  0  4.0296E-06  559  end
  xe-131    10  0  1.7873E-05  559  end
  cs-133    10  0  4.5501E-05  559  end
  cs-134    10  0  3.6458E-06  559  end
  cs-135    10  0  1.6898E-05  559  end
  pr-141    10  0  4.1514E-05  559  end
  nd-143    10  0  3.1386E-05  559  end
  nd-145    10  0  2.4796E-05  559  end
  nd-147    10  0  5.0116E-11  559  end
  nd-148    10  0  1.2881E-05  559  end
  pm-147    10  0  5.8797E-06  559  end
  pm-148    10  0  3.2891E-11  559  end
  pm-149    10  0  1.8778E-26  559  end
  sm-147    10  0  3.5453E-06  559  end
  sm-149    10  0  1.5058E-07  559  end
  sm-150    10  0  1.0886E-05  559  end
  sm-151    10  0  6.0731E-07  559  end
  sm-152    10  0  4.3816E-06  559  end
  eu-153    10  0  3.6390E-06  559  end
  eu-154    10  0  1.2127E-06  559  end
  eu-155    10  0  4.6472E-07  559  end
  gd-155    10  0  3.0594E-08  559  end
zircalloy 1  1                    559  end
ss304     2  1                    559  end
h2o       3  den=0.7540  1        559  end
boron     3  den=0.7540 1836.e-6  559  end
ss304     4  0.5                  559  end
h2o       4  den=0.7540 0.5       559  end
```

```
boron     4  den=0.7540  918.e-6  559  end
ss304     5  1                    559  end
h2o       6  den=0.7540  1        559  end
boron     6  den=0.7540 1836.e-6  559  end
ss304     7  1                    559  end
h2o       8  den=0.7540  1        559  end
boron     8  den=0.7540 1836.e-6  559  end
ss304     9  1                    559  end
end comp
squarepitch   1.25984 0.81915 10 3 0.94996 1 0.83566 0  end
end
```

# APPENDIX E

# WAX INPUT LISTING

```
=wax
'write final library to unit 4 / biggest input lib is on unit 36
0$$ 4 36
'input xsec's from 11 libs
1$$ 11    t
'input xsec's for fuel xsec set 1
2$$ 33 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 192234 192235 192236 192238 194239 194240 194241 t
'input xsec's for fuel xsec set 2
2$$ 34 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 292234 292235 292236 292238 294239 294240 294241 t
'input xsec's for fuel xsec set 3
2$$ 35 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 392234 392235 392236 392238 394239 394240 394241 t
'input xsec's for fuel xsec set 4 + fp's + struct. mat'ls
2$$ 36 0 t
'input xsec's for fuel xsec set 5
2$$ 37 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 592234 592235 592236 592238 594239 594240 594241 t
'input xsec's for fuel xsec set 6
2$$ 38 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 692234 692235 692236 692238 694239 694240 694241 t
'input xsec's for fuel xsec set 7
2$$ 39 7 t
3$$  92234  92235  92236  92238  94239  94240  94241
4$$ 792234 792235 792236 792238 794239 794240 794241 t
'input xsec's for fuel xsec set 8 + bp's
2$$ 40 10 t
3$$  92234  92235  92236  92238  94239  94240  94241
    408016  405010  405011
4$$ 892234 892235 892236 892238 894239 894240 894241
    818016 815010 815011  t
'input xsec's for fuel xsec set 9 + bp's
2$$ 41 7 t
3$$  92234  92235  92236  92238
    408016  405010  405011
4$$ 992234 992235 992236 992238
    918016 915010 915011  t
'input xsec's for fuel xsec set 10
2$$ 42 4 t
3$$  92234  92235  92236  92238
4$$ 1092234 1092235 1092236 1092238 t
'input xsec's for fuel xsec set 11 + bp's
2$$ 43 9 t
3$$  92234  92235  92236  92238
    408016   11023   13027  405010  405011
4$$ 1192234 1192235 1192236 1192238
    1118016   11023   13027 1115010  1115011  t
end
```

# APPENDIX F

# KENO V.a INPUT LISTING

```
#kenov
north anna 1 cycle 5 boc (1/8 core sym) hzp, aro no xe
'
' *** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
' *** *                                                               *
' *** *            full core keno5a reactor configuration             *
' *** *            for north anna unit-1 boc-5 hzp, aro no xe         *
' *** *                        1 plane  model                         *
' *** *                                                               *
' *** *                              by                               *
' *** *                           toshi suto                          *
' *** *                   oak ridge national laboratory               *
' *** *                                                               *
' *** *                            jan. 1994                          *
' *** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
'
read parm
run=yes plt=yes nub=yes fdn=yes tme=150.0 gen=1003 npg=1000
wrs=34 res=100
lib=4 nb8=2400  nl8=880 end parm

read mixt
mix=101
'assy 1
'north anna unit 1 cycle 5  8th-core loc # 1 (batch 6) 17105 mwd/mtu
   792234  5.7385E-06
   792235  4.6697E-04
   792236  7.1038E-05
   792238  2.2002E-02
    93237  4.9494E-06
    94238  7.5252E-07
   794239  1.1648E-04
   794240  2.4147E-05
   794241  1.3613E-05
    94242  1.7351E-06
    95241  5.3413E-07
    95243  1.7644E-07
    96244  1.8586E-08
     8016  4.6253E-02
    36083  1.7991E-06
    40093  1.5833E-05
    42095  2.3250E-05
    43099  2.4205E-05
    44101  2.1873E-05
    44103  1.5857E-07
    45103  1.4037E-05
    45105  1.0782E-35
    46105  8.3341E-06
    46108  2.3370E-06
    47109  1.6128E-06
    54131  1.1091E-05
    55133  2.6685E-05
    55134  1.2472E-06
    55135  1.0390E-05
    59141  2.3376E-05
    60143  2.0527E-05
    60145  1.4802E-05
    60147  4.5744E-11
    60148  7.1021E-06
    61147  5.0048E-06
    61148  2.6979E-11
    61149  1.4519E-26
    62147  1.7722E-06
    62149  1.4014E-07
    62150  5.5943E-06
    62151  4.7969E-07
    62152  2.4864E-06
    63153  1.5608E-06
```

```
    63154  3.4161E-07
    63155  1.6085E-07
    64155  1.0871E-08
mix=102
'assy 2
'n1c5 ec loc #2 (batch 7)     0 mwd/mtu
1192234     7.31252E-06
1192235     8.45571E-04
1192236     3.97603E-06
1192238     2.23454E-02
   8016     4.64044E-02
mix=103
'assy 3
'north anna unit 1 cycle 5  8th-core loc # 3 (batch 4) 21493 mwd/mtu
   192234  4.6097E-06
   192235  3.2910E-04
   192236  7.7105E-05
   192238  2.1991E-02
    93237  6.7204E-06
    94238  1.4072E-06
   194239  1.2586E-04
   194240  3.3528E-05
   194241  1.8464E-05
    94242  3.8076E-06
    95241  2.6858E-06
    95243  5.2330E-07
    96244  7.1478E-08
     8016  4.6236E-02
    36083  2.0775E-06
    40093  1.9138E-05
    42095  3.0331E-05
    43099  2.9715E-05
    44101  2.7471E-05
    44103  5.4164E-13
    45103  1.7763E-05
    45105  0.0000E+00
    46105  1.1723E-05
    46108  3.7133E-06
    47109  2.4697E-06
    54131  1.3384E-05
    55133  3.2656E-05
    55134  1.0203E-06
    55135  1.0607E-05
    59141  2.9040E-05
    60143  2.3900E-05
    60145  1.7900E-05
    60147  6.4858E-31
    60148  8.8911E-06
    61147  3.2464E-06
    61148  1.5294E-16
    61149  0.0000E+00
    62147  4.3981E-06
    62149  1.4671E-07
    62150  7.4510E-06
    62151  4.9084E-07
    62152  3.1643E-06
    63153  2.2346E-06
    63154  5.0685E-07
    63155  1.8230E-07
    64155  7.8302E-08
mix=104
'assy 4
'n1c5 ec loc #4 (batch 7)     0 mwd/mtu
1192234     7.31252E-06
1192235     8.45571E-04
1192236     3.97603E-06
1192238     2.23454E-02
   8016     4.64044E-02
```

```
mix=105
'assy 5
'north anna unit 1 cycle 5  8th-core loc # 5 (batch 6) 17322 mwd/mtu
   792234  5.7198E-06
   792235  4.6335E-04
   792236  7.1648E-05
   792238  2.1998E-02
    93237  5.0370E-06
    94238  7.7644E-07
   794239  1.1715E-04
   794240  2.4520E-05
   794241  1.3889E-05
    94242  1.7970E-06
    95241  5.4834E-07
    95243  1.8538E-07
    96244  1.9826E-08
     8016  4.6253E-02
    36083  1.8171E-06
    40093  1.6015E-05
    42095  2.3541E-05
    43099  2.4490E-05
    44101  2.2149E-05
    44103  1.5899E-07
    45103  1.4204E-05
    45105  1.0837E-35
    46105  8.4734E-06
    46108  2.3857E-06
    47109  1.6442E-06
    54131  1.1212E-05
    55133  2.6997E-05
    55134  1.2762E-06
    55135  1.0520E-05
    59141  2.3662E-05
    60143  2.0737E-05
    60145  1.4970E-05
    60147  4.5726E-11
    60148  7.1911E-06
    61147  5.0337E-06
    61148  2.7154E-11
    61149  1.4559E-26
    62147  1.8002E-06
    62149  1.4041E-07
    62150  5.6744E-06
    62151  4.8221E-07
    62152  2.5177E-06
    63153  1.5891E-06
    63154  3.5098E-07
    63155  1.6403E-07
    64155  1.1085E-08
mix=106
'assy 6
'n1c5 ec loc #6 (batch 7)     0 mwd/mtu
1192234     7.31252E-06
1192235     8.45571E-04
1192236     3.97603E-06
1192238     2.23454E-02
   8016     4.64044E-02
mix=107
'assy 7
'north anna unit 1 cycle 5  8th-core loc # 7 (batch 6) 17390 mwd/mtu
   792234  5.7141E-06
   792235  4.6222E-04
   792236  7.1838E-05
   792238  2.1997E-02
    93237  5.0645E-06
    94238  7.8404E-07
   794239  1.1736E-04
   794240  2.4636E-05
```

```
    794241  1.3976E-05
     94242  1.8166E-06
     95241  5.5283E-07
     95243  1.8826E-07
     96244  2.0228E-08
      8016  4.6253E-02
     36083  1.8227E-06
     40093  1.6072E-05
     42095  2.3633E-05
     43099  2.4579E-05
     44101  2.2236E-05
     44103  1.5912E-07
     45103  1.4257E-05
     45105  1.0854E-35
     46105  8.5171E-06
     46108  2.4011E-06
     47109  1.6540E-06
     54131  1.1250E-05
     55133  2.7095E-05
     55134  1.2854E-06
     55135  1.0561E-05
     59141  2.3751E-05
     60143  2.0802E-05
     60145  1.5023E-05
     60147  4.5720E-11
     60148  7.2190E-06
     61147  5.0427E-06
     61148  2.7208E-11
     61149  1.4572E-26
     62147  1.8090E-06
     62149  1.4050E-07
     62150  5.6995E-06
     62151  4.8300E-07
     62152  2.5274E-06
     63153  1.5981E-06
     63154  3.5395E-07
     63155  1.6504E-07
     64155  1.1153E-08
mix=108
'assy 8
'north anna unit 1 cycle 5  8th-core loc # 8 (batch 6)  9801 mwd/mtu
    592234  6.3813E-06
    592235  6.0311E-04
    592236  4.7375E-05
    592238  2.2124E-02
     93237  2.2682E-06
     94238  1.9147E-07
    594239  8.5423E-05
    594240  1.1634E-05
    594241  4.9424E-06
     94242  3.2996E-07
     95241  1.5014E-07
     95243  1.7594E-08
     96244  9.7761E-10
      8016  4.6253E-02
     36083  1.1286E-06
     40093  9.4592E-06
     42095  1.3087E-05
     43099  1.4290E-05
     44101  1.2544E-05
     44103  1.4244E-07
     45103  8.1331E-06
     45105  8.7083E-36
     46105  4.0621E-06
     46108  9.4398E-07
     47109  6.7552E-07
     54131  6.7137E-06
     55133  1.5785E-05
```

```
     55134  4.3594E-07
     55135  5.9720E-06
     59141  1.3570E-05
     60143  1.2777E-05
     60145  8.8668E-06
     60147  4.6472E-11
     60148  4.0939E-06
     61147  3.6362E-06
     61148  1.8797E-11
     61149  1.2898E-26
     62147  8.6197E-07
     62149  1.2676E-07
     62150  2.9726E-06
     62151  3.8444E-07
     62152  1.3827E-06
     63153  7.0413E-07
     63154  1.0203E-07
     63155  7.6768E-08
     64155  5.1796E-09
mix=109
'assy 9
'north anna unit 1 cycle 5  8th-core loc # 9 (batch 5) 20951 mwd/mtu
    392234  5.0225E-06
    392235  3.7284E-04
    392236  7.8727E-05
    392238  2.1970E-02
     93237  6.5255E-06
     94238  1.2760E-06
    394239  1.2597E-04
    394240  3.1510E-05
    394241  1.9067E-05
     94242  3.2565E-06
     95241  8.2065E-07
     95243  4.2591E-07
     96244  5.8912E-08
      8016  4.6252E-02
     36083  2.0737E-06
     40093  1.8868E-05
     42095  2.8097E-05
     43099  2.9112E-05
     44101  2.6768E-05
     44103  1.8295E-07
     45103  1.7001E-05
     45105  1.3399E-35
     46105  1.1091E-05
     46108  3.3965E-06
     47109  2.2758E-06
     54131  1.3135E-05
     55133  3.2005E-05
     55134  1.8282E-06
     55135  1.1423E-05
     59141  2.8332E-05
     60143  2.3776E-05
     60145  1.7626E-05
     60147  5.0822E-11
     60148  8.6713E-06
     61147  5.3698E-06
     61148  2.9608E-11
     61149  1.7264E-26
     62147  2.2786E-06
     62149  1.4566E-07
     62150  7.0318E-06
     62151  5.0671E-07
     62152  3.0500E-06
     63153  2.1152E-06
     63154  5.4250E-07
     63155  2.2792E-07
     64155  1.5023E-08
```

```
mix=110
'assy 10
'n1c5 ec loc #10 (batch 7)     0 mwd/mtu
1192234     7.31252E-06
1192235     8.45571E-04
1192236     3.97603E-06
1192238     2.23454E-02
   8016     4.64044E-02
mix=111
'assy 11
'north anna unit 1 cycle 5  8th-core loc #11 (batch 6) 14081 mwd/mtu
   892234  6.0007E-06
   892235  5.1989E-04
   892236  6.2001E-05
   892238  2.2053E-02
    93237  3.7702E-06
    94238  4.6480E-07
   894239  1.0574E-04
   894240  1.8935E-05
   894241  9.8226E-06
    94242  9.9571E-07
    95241  3.5071E-07
    95243  8.0913E-08
    96244  6.7642E-09
     8016  4.6253E-02
    36083  1.5372E-06
    40093  1.3254E-05
    42095  1.9123E-05
    43099  2.0176E-05
    44101  1.8018E-05
    44103  1.5243E-07
    45103  1.1647E-05
    45105  9.9821E-36
    46105  6.4637E-06
    46108  1.7000E-06
    47109  1.1954E-06
    54131  9.3487E-06
    55133  2.2263E-05
    55134  8.6963E-07
    55135  8.5704E-06
    59141  1.9352E-05
    60143  1.7485E-05
    60145  1.2407E-05
    60147  4.6012E-11
    60148  5.8602E-06
    61147  4.5380E-06
    61148  2.4170E-11
    61149  1.3912E-26
    62147  1.3847E-06
    62149  1.3566E-07
    62150  4.4887E-06
    62151  4.4304E-07
    62152  2.0415E-06
    63153  1.1802E-06
    63154  2.2431E-07
    63155  1.2091E-07
    64155  8.1712E-09
mix=112
'assy 12
'n1c5 ec loc #12 (batch 7)     0 mwd/mtu
1192234     7.31252E-06
1192235     8.45571E-04
1192236     3.97603E-06
1192238     2.23454E-02
   8016     4.64044E-02
mix=113
'assy 13
'north anna unit 1 cycle 5  8th-core loc #13 (batch 6) 12890 mwd/mtu
```

```
    692234  6.1056E-06
    692235  5.4203E-04
    692236  5.8156E-05
    692238  2.2073E-02
     93237  3.3301E-06
     94238  3.7384E-07
    694239  1.0076E-04
    694240  1.6880E-05
    694241  8.3841E-06
     94242  7.6678E-07
     95241  2.8719E-07
     95243  5.6242E-08
     96244  4.2411E-09
      8016  4.6253E-02
     36083  1.4281E-06
     40093  1.2216E-05
     42095  1.7465E-05
     43099  1.8561E-05
     44101  1.6496E-05
     44103  1.4985E-07
     45103  1.0684E-05
     45105  9.6464E-36
     46105  5.7650E-06
     46108  1.4718E-06
     47109  1.0414E-06
     54131  8.6351E-06
     55133  2.0487E-05
     55134  7.3641E-07
     55135  7.8496E-06
     59141  1.7753E-05
     60143  1.6223E-05
     60145  1.1440E-05
     60147  4.6129E-11
     60148  5.3698E-06
     61147  4.3181E-06
     61148  2.2855E-11
     61149  1.3650E-26
     62147  1.2351E-06
     62149  1.3351E-07
     62150  4.0601E-06
     62151  4.2780E-07
     62152  1.8614E-06
     63153  1.0396E-06
     63154  1.8511E-07
     63155  1.0729E-07
     64155  7.2492E-09
mix=114
'assy 14
'n1c5 ec loc #14 (batch n2/5)  0 mwd/mtu
992234      7.31175e-06
992235      8.43133e-04
992236      3.97561e-06
992238      2.23453e-02
  8016      4.63995e-02
mix=115
'assy 15
'north anna unit 1 cycle 5  8th-core loc #15 (batch 5) 30615 mwd/mtu
     92234  4.2932E-06
     92235  2.5303E-04
     92236  9.6617E-05
     92238  2.1787E-02
     93237  1.0711E-05
     94238  3.2232E-06
     94239  1.4036E-04
     94240  4.6494E-05
     94241  3.0028E-05
     94242  8.1707E-06
     95241  1.5530E-06
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     95243  1.6103E-06
     96244  3.5818E-07
      8016  4.6252E-02
     36083  2.6751E-06
     40093  2.6219E-05
     42095  3.9933E-05
     43099  4.0747E-05
     44101  3.8908E-05
     44103  1.9864E-07
     45103  2.3547E-05
     45105  1.5638E-35
     46105  1.8406E-05
     46108  6.2993E-06
     47109  3.9046E-06
     54131  1.7584E-05
     55133  4.4620E-05
     55134  3.5091E-06
     55135  1.6525E-05
     59141  4.0621E-05
     60143  3.0938E-05
     60145  2.4330E-05
     60147  5.0157E-11
     60148  1.2592E-05
     61147  5.8644E-06
     61148  3.2785E-11
     61149  1.8694E-26
     62147  3.4653E-06
     62149  1.5046E-07
     62150  1.0623E-05
     62151  6.0090E-07
     62152  4.2953E-06
     63153  3.5325E-06
     63154  1.1608E-06
     63155  4.4589E-07
     64155  2.9358E-08
mix=116
'assy 16
'north anna unit 1 cycle 5  8th-core loc #16 (batch 6) 17158 mwd/mtu
    792234  5.7339E-06
    792235  4.6609E-04
    792236  7.1187E-05
    792238  2.2001E-02
     93237  4.9707E-06
     94238  7.5832E-07
    794239  1.1665E-04
    794240  2.4238E-05
    794241  1.3681E-05
     94242  1.7501E-06
     95241  5.3759E-07
     95243  1.7859E-07
     96244  1.8883E-08
      8016  4.6253E-02
     36083  1.8035E-06
     40093  1.5877E-05
     42095  2.3322E-05
     43099  2.4275E-05
     44101  2.1940E-05
     44103  1.5868E-07
     45103  1.4078E-05
     45105  1.0796E-35
     46105  8.3681E-06
     46108  2.3488E-06
     47109  1.6205E-06
     54131  1.1121E-05
     55133  2.6761E-05
     55134  1.2542E-06
     55135  1.0422E-05
     59141  2.3445E-05
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    60143  2.0579E-05
    60145  1.4843E-05
    60147  4.5740E-11
    60148  7.1239E-06
    61147  5.0119E-06
    61148  2.7022E-11
    61149  1.4529E-26
    62147  1.7791E-06
    62149  1.4020E-07
    62150  5.6138E-06
    62151  4.8031E-07
    62152  2.4940E-06
    63153  1.5676E-06
    63154  3.4389E-07
    63155  1.6163E-07
    64155  1.0923E-08
mix=117
'assy 17
'n1c5 ec loc #17 (batch 7)     0 mwd/mtu
1192234     7.31252E-06
1192235     8.45571E-04
1192236     3.97603E-06
1192238     2.23454E-02
   8016     4.64044E-02
mix=118
'assy 18
'north anna unit 1 cycle 5  8th-core loc #18 (batch 6) 15802 mwd/mtu
   792234  5.8405E-06
   792235  4.8716E-04
   792236  6.7619E-05
   792238  2.2022E-02
    93237  4.4779E-06
    94238  6.2979E-07
   794239  1.1257E-04
   794240  2.2110E-05
   794241  1.2114E-05
    94242  1.4183E-06
    95241  4.5885E-07
    95243  1.3280E-07
    96244  1.2840E-08
     8016  4.6253E-02
    36083  1.6991E-06
    40093  1.4833E-05
    42095  2.1648E-05
    43099  2.2640E-05
    44101  2.0364E-05
    44103  1.5625E-07
    45103  1.3111E-05
    45105  1.0477E-35
    46105  7.5856E-06
    46108  2.0778E-06
    47109  1.4451E-06
    54131  1.0420E-05
    55133  2.4969E-05
    55134  1.0928E-06
    55135  9.6791E-06
    59141  2.1805E-05
    60143  1.9363E-05
    60145  1.3874E-05
    60147  4.5844E-11
    60148  6.6162E-06
    61147  4.8366E-06
    61148  2.5964E-11
    61149  1.4291E-26
    62147  1.6195E-06
    62149  1.3854E-07
    62150  5.1586E-06
    62151  4.6565E-07
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    62152  2.3142E-06
    63153  1.4080E-06
    63154  2.9266E-07
    63155  1.4426E-07
    64155  9.7496E-09
mix=119
'assy 19
'n1c5 ec loc #19 (batch 7)     0 mwd/mtu
1192234     7.31252E-06
1192235     8.45571E-04
1192236     3.97603E-06
1192238     2.23454E-02
   8016     4.64044E-02
mix=120
'assy 20
'north anna unit 1 cycle 5  8th-core loc #20 (batch 6) 16831 mwd/mtu
   792234  5.7620E-06
   792235  4.7158E-04
   792236  7.0261E-05
   792238  2.2006E-02
    93237  4.8393E-06
    94238  7.2295E-07
   794239  1.1560E-04
   794240  2.3677E-05
   794241  1.3266E-05
    94242  1.6587E-06
    95241  5.1636E-07
    95243  1.6557E-07
    96244  1.7108E-08
     8016  4.6253E-02
    36083  1.7763E-06
    40093  1.5602E-05
    42095  2.2880E-05
    43099  2.3845E-05
    44101  2.1524E-05
    44103  1.5805E-07
    45103  1.3824E-05
    45105  1.0713E-35
    46105  8.1593E-06
    46108  2.2759E-06
    47109  1.5736E-06
    54131  1.0937E-05
    55133  2.6290E-05
    55134  1.2107E-06
    55135  1.0226E-05
    59141  2.3013E-05
    60143  2.0261E-05
    60145  1.4588E-05
    60147  4.5767E-11
    60148  6.9898E-06
    61147  4.9675E-06
    61148  2.6753E-11
    61149  1.4467E-26
    62147  1.7369E-06
    62149  1.3979E-07
    62150  5.4932E-06
    62151  4.7648E-07
    62152  2.4468E-06
    63153  1.5250E-06
    63154  3.2995E-07
    63155  1.5691E-07
    64155  1.0604E-08
mix=121
'assy 21
'north anna unit 1 cycle 5  8th-core loc #21 (batch 6) 15852 mwd/mtu
   792234  5.8405E-06
   792235  4.8716E-04
   792236  6.7619E-05
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   792238  2.2022E-02
    93237  4.4779E-06
    94238  6.2979E-07
   794239  1.1257E-04
   794240  2.2110E-05
   794241  1.2114E-05
    94242  1.4183E-06
    95241  4.5885E-07
    95243  1.3280E-07
    96244  1.2840E-08
     8016  4.6253E-02
    36083  1.6991E-06
    40093  1.4833E-05
    42095  2.1648E-05
    43099  2.2640E-05
    44101  2.0364E-05
    44103  1.5625E-07
    45103  1.3111E-05
    45105  1.0477E-35
    46105  7.5856E-06
    46108  2.0778E-06
    47109  1.4451E-06
    54131  1.0420E-05
    55133  2.4969E-05
    55134  1.0928E-06
    55135  9.6791E-06
    59141  2.1805E-05
    60143  1.9363E-05
    60145  1.3874E-05
    60147  4.5844E-11
    60148  6.6162E-06
    61147  4.8366E-06
    61148  2.5964E-11
    61149  1.4291E-26
    62147  1.6195E-06
    62149  1.3854E-07
    62150  5.1586E-06
    62151  4.6565E-07
    62152  2.3142E-06
    63153  1.4080E-06
    63154  2.9266E-07
    63155  1.4426E-07
    64155  9.7496E-09
mix=122
'assy 22
'n1c5 ec loc #22 (batch 7)     0 mwd/mtu
1192234     7.31252E-06
1192235     8.45571E-04
1192236     3.97603E-06
1192238     2.23454E-02
   8016     4.64044E-02
mix=123
'assy 23
'n1c5 ec loc #23 (batch 7)     0 mwd/mtu
1092234     7.31252E-06
1092235     8.45571E-04
1092236     3.97603E-06
1092238     2.23454E-02
   8016     4.64044E-02
mix=124
'assy 24
'north anna unit 1 cycle 5  8th-core loc #24 (batch 5) 32048 mwd/mtu
    92234  4.1917E-06
    92235  2.3828E-04
    92236  9.8594E-05
    92238  2.1759E-02
    93237  1.1333E-05
    94238  3.5926E-06
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     94239  1.4160E-04
     94240  4.8476E-05
     94241  3.1416E-05
     94242  9.0501E-06
     95241  1.6567E-06
     95243  1.8686E-06
     96244  4.4078E-07
      8016  4.6252E-02
     36083  2.7485E-06
     40093  2.7251E-05
     42095  4.1592E-05
     43099  4.2376E-05
     44101  4.0688E-05
     44103  2.0065E-07
     45103  2.4419E-05
     45105  1.5928E-35
     46105  1.9567E-05
     46108  6.7822E-06
     47109  4.1549E-06
     54131  1.8158E-05
     55133  4.6373E-05
     55134  3.7838E-06
     55135  1.7270E-05
     59141  4.2403E-05
     60143  3.1823E-05
     60145  2.5257E-05
     60147  5.0074E-11
     60148  1.3169E-05
     61147  5.8926E-06
     61148  3.2982E-11
     61149  1.8860E-26
     62147  3.6240E-06
     62149  1.5068E-07
     62150  1.1148E-05
     62151  6.1362E-07
     62152  4.4669E-06
     63153  3.7453E-06
     63154  1.2653E-06
     63155  4.8381E-07
     64155  3.1846E-08
mix=125
'assy 25
'north anna unit 1 cycle 5  8th-core loc #25 (batch 6) 12139 mwd/mtu
    692234  6.1721E-06
    692235  5.5638E-04
    692236  5.5644E-05
    692238  2.2086E-02
     93237  3.0609E-06
     94238  3.2259E-07
    694239  9.7367E-05
    694240  1.5590E-05
    694241  7.5033E-06
     94242  6.4014E-07
     95241  2.5006E-07
     95243  4.3789E-08
     96244  3.0823E-09
      8016  4.6253E-02
     36083  1.3575E-06
     40093  1.1554E-05
     42095  1.6411E-05
     43099  1.7533E-05
     44101  1.5536E-05
     44103  1.4816E-07
     45103  1.0070E-05
     45105  9.4277E-36
     46105  5.3360E-06
     46108  1.3348E-06
     47109  9.4779E-07
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     54131  8.1773E-06
     55133  1.9356E-05
     55134  6.5722E-07
     55135  7.3941E-06
     59141  1.6742E-05
     60143  1.5409E-05
     60145  1.0823E-05
     60147  4.6206E-11
     60148  5.0601E-06
     61147  4.1677E-06
     61148  2.1958E-11
     61149  1.3477E-26
     62147  1.1421E-06
     62149  1.3203E-07
     62150  3.7922E-06
     62151  4.1788E-07
     62152  1.7464E-06
     63153  9.5395E-07
     63154  1.6244E-07
     63155  9.9261E-08
     64155  6.7055E-09
mix=126
'assy 26
'north anna unit 1 cycle 5  8th-core loc #26 (batch 4) 26732 mwd/mtu
    292234  4.2425E-06
    292235  2.6458E-04
    292236  8.6785E-05
    292238  2.1891E-02
     93237  8.9426E-06
     94238  2.3984E-06
    294239  1.3413E-04
    294240  4.1979E-05
    294241  2.4050E-05
     94242  6.4733E-06
     95241  3.6115E-06
     95243  1.1286E-06
     96244  2.0248E-07
      8016  4.6236E-02
     36083  2.4078E-06
     40093  2.3128E-05
     42095  3.6736E-05
     43099  3.6092E-05
     44101  3.4077E-05
     44103  5.6785E-13
     45103  2.1450E-05
     45105  0.0000E+00
     46105  1.5686E-05
     46108  5.2931E-06
     47109  3.3702E-06
     54131  1.5866E-05
     55133  3.9578E-05
     55134  1.4971E-06
     55135  1.3145E-05
     59141  3.5705E-05
     60143  2.7841E-05
     60145  2.1562E-05
     60147  6.4374E-31
     60148  1.1020E-05
     61147  3.4476E-06
     61148  1.6375E-16
     61149  0.0000E+00
     62147  5.1285E-06
     62149  1.5058E-07
     62150  9.4868E-06
     62151  5.4352E-07
     62152  3.8640E-06
     63153  3.0099E-06
     63154  7.8823E-07
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    63155  2.6820E-07
    64155  1.1519E-07
mix=1
 40302  4.25156e-02
mix=2
 24304  1.74286e-02
 25055  1.73633e-03
 26304  5.93579e-02
 28304  7.72074e-03
mix=3
  1001  5.04213e-02
308016  2.52107e-02
  5010  1.52384e-05
  5011  6.18633e-05
mix=4
 424304  8.71429e-03
 425055  8.68166e-04
 426304  2.96790e-02
 428304  3.86037e-03
 401001  2.52107e-02
 408016  1.26053e-02
 405010  7.61919e-06
 405011  3.09317e-05
mix=5
 524304  1.74286e-02
 525055  1.73633e-03
 526304  5.93579e-02
 528304  7.72074e-03
mix=6
601001  5.04213e-02
608016  2.52107e-02
605010  1.52384e-05
605011  6.18633e-05
mix=7
 724304  1.74286e-02
 725055  1.73633e-03
 726304  5.93579e-02
 728304  7.72074e-03
mix=8
801001  5.04213e-02
808016  2.52107e-02
805010  1.52384e-05
805011  6.18633e-05
mix=9
 924304  1.74286e-02
 925055  1.73633e-03
 926304  5.93579e-02
 928304  7.72074e-03
mix=11
'n1c5  fresh bp for ec loc #2,4,6,10,12,17,19,22  batch 7a
  1118016   4.49700e-02
  1115010   9.59500e-04
  1115011   3.86300e-03
    11023   1.65000e-03
    13027   5.80000e-04
mix=12
'n1c4 bp for 8th-core loc #11 in cycle 5 @ boc 13028 mwd/mtu
   818016  4.4970E-02
    11023  1.6494E-03
    13027  5.7990E-04
   815010  9.4860E-05
   815011  3.8630E-03
mix=13
'n1c4 bp for 8th-core loc #14 in cycle 5 @ boc 14081 mwd/mtu
   918016  4.4970E-02
    11023  1.6493E-03
    13027  5.7989E-04
   915010  7.5489E-05
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   915011  3.8630E-03
end mixt

read geom

'--- fuel pins
unit 101
cylinder 0101 1  0.409575            365.76 0.0
cylinder   0  1  0.41783             365.76 0.0
cylinder   1  1  0.47498             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 102
cylinder 0102 1  0.409575            365.76 0.0
cylinder   0  1  0.41783             365.76 0.0
cylinder   1  1  0.47498             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 103
cylinder 0103 1  0.409575            365.76 0.0
cylinder   0  1  0.41783             365.76 0.0
cylinder   1  1  0.47498             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 104
cylinder 0104 1  0.409575            365.76 0.0
cylinder   0  1  0.41783             365.76 0.0
cylinder   1  1  0.47498             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 105
cylinder 0105 1  0.409575            365.76 0.0
cylinder   0  1  0.41783             365.76 0.0
cylinder   1  1  0.47498             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 106
cylinder 0106 1  0.409575            365.76 0.0
cylinder   0  1  0.41783             365.76 0.0
cylinder   1  1  0.47498             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 107
cylinder 0107 1  0.409575            365.76 0.0
cylinder   0  1  0.41783             365.76 0.0
cylinder   1  1  0.47498             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 108
cylinder 0108 1  0.409575            365.76 0.0
cylinder   0  1  0.41783             365.76 0.0
cylinder   1  1  0.47498             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 109
cylinder 0109 1  0.409575            365.76 0.0
cylinder   0  1  0.41783             365.76 0.0
cylinder   1  1  0.47498             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 110
cylinder 0110 1  0.409575            365.76 0.0
cylinder   0  1  0.41783             365.76 0.0
cylinder   1  1  0.47498             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 111
cylinder 0111 1  0.409575            365.76 0.0
cylinder   0  1  0.41783             365.76 0.0
cylinder   1  1  0.47498             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 112
cylinder 0112 1  0.409575            365.76 0.0
cylinder   0  1  0.41783             365.76 0.0
cylinder   1  1  0.47498             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 113
cylinder 0113 1  0.409575            365.76 0.0
```

```
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 114
cylinder 0114 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 115
cylinder 0115 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 116
cylinder 0116 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 117
cylinder 0117 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 118
cylinder 0118 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 119
cylinder 0119 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 120
cylinder 0120 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 121
cylinder 0121 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 122
cylinder 0122 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 123
cylinder 0123 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 124
cylinder 0124 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 125
cylinder 0125 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 126
cylinder 0126 1  0.409575             365.76 0.0
cylinder   0  1  0.41783              365.76 0.0
cylinder   1  1  0.47498              365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
```

```
'--- guide tube
unit 161
cylinder   3  1  0.5715              365.76 0.0
cylinder   1  1  0.61214             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0

'--- bp rods
unit 162
com=/fresh bp for ec loc #2,4,6,10,12,17,19,22  batch 7a/
cylinder   0  1  0.213995            365.76 0.0
cylinder   2  1  0.229235            365.76 0.0
cylinder   0  1  0.237490            365.76 0.0
cylinder  11  1  0.428625            365.76 0.0
cylinder   0  1  0.43688             365.76 0.0
cylinder   2  1  0.48387             365.76 0.0
cylinder   3  1  0.5715              365.76 0.0
cylinder   1  1  0.61214             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 163
com=/depleted bp for ec loc #11  batch 6a/
cylinder   0  1  0.213995            365.76 0.0
cylinder   2  1  0.229235            365.76 0.0
cylinder   0  1  0.237490            365.76 0.0
cylinder  12  1  0.428625            365.76 0.0
cylinder   0  1  0.43688             365.76 0.0
cylinder   2  1  0.48387             365.76 0.0
cylinder   3  1  0.5715              365.76 0.0
cylinder   1  1  0.61214             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0
unit 164
com=/depleted bp for ec loc #14  batch 5b/
cylinder   0  1  0.213995            365.76 0.0
cylinder   2  1  0.229235            365.76 0.0
cylinder   0  1  0.237490            365.76 0.0
cylinder  13  1  0.428625            365.76 0.0
cylinder   0  1  0.43688             365.76 0.0
cylinder   2  1  0.48387             365.76 0.0
cylinder   3  1  0.5715              365.76 0.0
cylinder   1  1  0.61214             365.76 0.0
cuboid     3  1  2p0.62992 2p0.62992 365.76 0.0

'--- fuel assy's
unit 1
array     0101  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 2
array     0102  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 3
array     0103  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 4
array     0104  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 5
array     0105  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 6
array     0106  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 7
array     0107  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 8
array     0108  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 9
```

```
array     0109  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 10
array     0110  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 11
array     0111  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 12
array     0112  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 13
array     0113  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 14
array     0114  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 15
array     0115  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 16
array     0116  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 17
array     0117  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 18
array     0118  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 19
array     0119  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 20
array     0120  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 21
array     0121  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 22
array     0122  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 23
array     0123  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 24
array     0124  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 25
array     0125  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1
unit 26
array     0126  2r-10.70864 0.0
reflector   3   1 4r0.04318 2r0.0 1

'--- baffle region
unit 41
com=! corner square !
 cuboid   2 1    1.905     0.0       1.905     0.0  365.76 0.0
unit 42
com=! horizontal strip (1 ass'y wide) !
 cuboid   2 1   21.50364   0.0       1.905     0.0  365.76 0.0
unit 43
com=! vertical strip (1 ass'y high) !
 cuboid   2 1    1.905     0.0      21.50364   0.0  365.76 0.0
unit 44
com=! horizontal strip (2 ass'ys wide) !
cuboid   2 1     43.00728  0.0      1.905      0.0  365.76 0.0
unit 45
```

```
com=! horizontal strip (1 ass'y wide) bottom of y axis !
 cuboid   2 1    21.50364  0.0      0.0       -1.905 365.76 0.0
unit 46
com=! horizontal strip (2 ass'ys wide) bottom of y axis !
cuboid   2 1     43.00728  0.0      0.0       -1.905 365.76 0.0

'---rows of assy's w/ baffle regions on each end
unit 51
com=! row 1 !
array  1  -34.16046  -12.65682 0.0
unit 52
com=! row 2 !
array  2  -77.16774  -10.75182 0.0
unit 53
com=! row 3 !
array  3  -98.67138  -10.75182 0.0
unit 54
com=! row 4 !
array  4 -120.17502  -10.75182 0.0
unit 55
com=! rows 5 & 6 !
array  5 -141.67866  -21.50364 0.0
unit 57
com=! rows 7 - 9 !
array  7 -163.18230  -32.25546 0.0
unit 60
com=! rows 10 & 11 !
array 10 -141.67866  -21.50364 0.0
unit 62
com=! row 12 !
array 12 -120.17502  -10.75182 0.0
unit 63
com=! row 13 !
array 13  -98.67138  -10.75182 0.0
unit 64
com=! row 14 !
array 14  -77.16774  -10.75182 0.0
unit 65
com=! row 15 !
array 15  -34.16046  -10.75182 0.0

global unit 70
cylinder 3 1 170.02125 365.76 0.0
hole  57   0.0      0.0       0.0
hole  55   0.0    -53.75911   0.0
hole  60   0.0     53.75911   0.0
hole  54   0.0    -86.01458   0.0
hole  62   0.0     86.01458   0.0
hole  53   0.0   -107.51823   0.0
hole  63   0.0    107.51823   0.0
hole  52   0.0   -129.02188   0.0
hole  64   0.0    129.02188   0.0
hole  51   0.0   -150.52553   0.0
hole  65   0.0    150.52553   0.0
hole  44  -77.16775  139.77371  0
hole  46  -77.16775 -139.77471  0
hole  44   34.16047  139.77371  0
hole  46   34.16047 -139.77471  0
hole  42  -98.67139  118.27006  0
hole  45  -98.67139 -118.27006  0
hole  42   77.16776  118.27006  0
hole  45   77.16776 -118.27006  0
hole  42 -120.17503   96.76641  0
hole  45 -120.17503  -96.76741  0
hole  42   98.67140   96.76641  0
hole  45   98.67140  -96.76741  0
hole  42 -141.67867   75.26276  0
hole  45 -141.67867  -75.26276  0
```

```
hole  42  120.17503   75.26276  0
hole  45  120.17503  -75.26276  0
hole  42 -163.18231   32.25547  0
hole  45 -163.18231  -32.25547  0
hole  42  141.67867   32.25547  0
hole  45  141.67867  -32.25547  0
cylinder 4 1 170.02125 390.76 -25.0
reflector  5 1  5.08    0.0 0.0 1
reflector  6 1  6.0325  0.0 0.0 1
reflector  7 1  6.82625 0.0 0.0 1
reflector  8 1 11.43    0.0 0.0 1
reflector  9 1 19.89582 0.0 0.0 1
cuboid  0 1 2p220.0 2p220.0 390.76 -25.0
end geom

read array

'--- fuel assy's
com=/ assy 1 -- no bp /
ara=101   nux=17 nuy=17 nuz=1     fill  f101
  a40 161    a43 161    a46 161    a55 161    a65 161
  a88 161    a91 161    a94 161    a97 161   a100 161
 a139 161   a142 161   a145 161   a148 161   a151 161
 a190 161   a193 161   a196 161   a199 161   a202 161
 a225 161   a235 161   a244 161   a247 161   a250 161  end fill
com=/ assy 2 -- 16 fresh bp /
ara=102   nux=17 nuy=17 nuz=1     fill  f102
  a40 162    a43 161    a46 162    a55 162    a65 162
  a88 162    a91 161    a94 162    a97 161   a100 162
 a139 161   a142 162   a145 161   a148 162   a151 161
 a190 162   a193 161   a196 162   a199 161   a202 162
 a225 162   a235 162   a244 162   a247 161   a250 162  end fill
com=/ assy 3 -- no bp /
ara=103   nux=17 nuy=17 nuz=1     fill  f103
  a40 161    a43 161    a46 161    a55 161    a65 161
  a88 161    a91 161    a94 161    a97 161   a100 161
 a139 161   a142 161   a145 161   a148 161   a151 161
 a190 161   a193 161   a196 161   a199 161   a202 161
 a225 161   a235 161   a244 161   a247 161   a250 161  end fill
com=/ assy 4 -- 20 fresh bp /
ara=104   nux=17 nuy=17 nuz=1     fill  f104
  a40 162    a43 162    a46 162    a55 162    a65 162
  a88 162    a91 161    a94 162    a97 161   a100 162
 a139 162   a142 162   a145 161   a148 162   a151 162
 a190 162   a193 161   a196 162   a199 161   a202 162
 a225 162   a235 162   a244 162   a247 162   a250 162  end fill
com=/ assy 5 -- no fresh bp /
ara=105   nux=17 nuy=17 nuz=1     fill  f105
  a40 161    a43 161    a46 161    a55 161    a65 161
  a88 161    a91 161    a94 161    a97 161   a100 161
 a139 161   a142 161   a145 161   a148 161   a151 161
 a190 161   a193 161   a196 161   a199 161   a202 161
 a225 161   a235 161   a244 161   a247 161   a250 161  end fill
com=/ assy 6 -- 16 fresh bp /
ara=106   nux=17 nuy=17 nuz=1     fill  f106
  a40 162    a43 161    a46 162    a55 162    a65 162
  a88 162    a91 161    a94 162    a97 161   a100 162
 a139 161   a142 162   a145 161   a148 162   a151 161
 a190 162   a193 161   a196 162   a199 161   a202 162
 a225 162   a235 162   a244 162   a247 161   a250 162  end fill
com=/ assy 7 -- no bp /
ara=107   nux=17 nuy=17 nuz=1     fill  f107
  a40 161    a43 161    a46 161    a55 161    a65 161
  a88 161    a91 161    a94 161    a97 161   a100 161
 a139 161   a142 161   a145 161   a148 161   a151 161
 a190 161   a193 161   a196 161   a199 161   a202 161
 a225 161   a235 161   a244 161   a247 161   a250 161  end fill
com=/ assy 8 -- no bp /
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ara=108   nux=17 nuy=17 nuz=1     fill  f108
  a40 161     a43 161     a46 161     a55 161     a65 161
  a88 161     a91 161     a94 161     a97 161    a100 161
 a139 161    a142 161    a145 161    a148 161    a151 161
 a190 161    a193 161    a196 161    a199 161    a202 161
 a225 161    a235 161    a244 161    a247 161    a250 161  end fill
com=/ assy 9 -- no bp /
ara=109   nux=17 nuy=17 nuz=1     fill  f109
  a40 161     a43 161     a46 161     a55 161     a65 161
  a88 161     a91 161     a94 161     a97 161    a100 161
 a139 161    a142 161    a145 161    a148 161    a151 161
 a190 161    a193 161    a196 161    a199 161    a202 161
 a225 161    a235 161    a244 161    a247 161    a250 161  end fill
com=/ assy 10 -- 16 fresh bp /
ara=110   nux=17 nuy=17 nuz=1     fill  f110
  a40 162     a43 161     a46 162     a55 162     a65 162
  a88 162     a91 161     a94 162     a97 161    a100 162
 a139 161    a142 162    a145 161    a148 162    a151 161
 a190 162    a193 161    a196 162    a199 161    a202 162
 a225 162    a235 162    a244 162    a247 161    a250 162  end fill
com=/ assy 11 -- 12 depleted bp /
ara=111   nux=17 nuy=17 nuz=1     fill  f111
  a40 163     a43 161     a46 163     a55 161     a65 161
  a88 163     a91 161     a94 163     a97 161    a100 163
 a139 161    a142 163    a145 161    a148 163    a151 161
 a190 163    a193 161    a196 163    a199 161    a202 163
 a225 161    a235 161    a244 163    a247 161    a250 163  end fill
com=/ assy 12 -- 20 fresh bp /
ara=112   nux=17 nuy=17 nuz=1     fill  f112
  a40 162     a43 162     a46 162     a55 162     a65 162
  a88 162     a91 161     a94 162     a97 161    a100 162
 a139 162    a142 162    a145 161    a148 162    a151 162
 a190 162    a193 161    a196 162    a199 161    a202 162
 a225 162    a235 162    a244 162    a247 162    a250 162  end fill
com=/ assy 13 -- no bp /
ara=113   nux=17 nuy=17 nuz=1     fill  f113
  a40 161     a43 161     a46 161     a55 161     a65 161
  a88 161     a91 161     a94 161     a97 161    a100 161
 a139 161    a142 161    a145 161    a148 161    a151 161
 a190 161    a193 161    a196 161    a199 161    a202 161
 a225 161    a235 161    a244 161    a247 161    a250 161  end fill
com=/ assy 14 -- 12 depleted bp /
ara=114   nux=17 nuy=17 nuz=1     fill  f114
  a40 164     a43 161     a46 164     a55 161     a65 161
  a88 164     a91 161     a94 164     a97 161    a100 164
 a139 161    a142 164    a145 161    a148 164    a151 161
 a190 164    a193 161    a196 164    a199 161    a202 164
 a225 161    a235 161    a244 164    a247 161    a250 164  end fill
com=/ assy 15 -- no bp /
ara=115   nux=17 nuy=17 nuz=1     fill  f115
  a40 161     a43 161     a46 161     a55 161     a65 161
  a88 161     a91 161     a94 161     a97 161    a100 161
 a139 161    a142 161    a145 161    a148 161    a151 161
 a190 161    a193 161    a196 161    a199 161    a202 161
 a225 161    a235 161    a244 161    a247 161    a250 161  end fill
com=/ assy 16 -- no bp /
ara=116   nux=17 nuy=17 nuz=1     fill  f116
  a40 161     a43 161     a46 161     a55 161     a65 161
  a88 161     a91 161     a94 161     a97 161    a100 161
 a139 161    a142 161    a145 161    a148 161    a151 161
 a190 161    a193 161    a196 161    a199 161    a202 161
 a225 161    a235 161    a244 161    a247 161    a250 161  end fill
com=/ assy 17 -- 20 fresh bp /
ara=117   nux=17 nuy=17 nuz=1     fill  f117
  a40 162     a43 162     a46 162     a55 162     a65 162
  a88 162     a91 161     a94 162     a97 161    a100 162
 a139 162    a142 162    a145 161    a148 162    a151 162
 a190 162    a193 161    a196 162    a199 161    a202 162
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 a225 162   a235 162   a244 162   a247 162   a250 162  end fill
com=/ assy 18 -- no bp /
ara=118   nux=17 nuy=17 nuz=1     fill  f118
  a40 161    a43 161    a46 161    a55 161    a65 161
  a88 161    a91 161    a94 161    a97 161   a100 161
 a139 161   a142 161   a145 161   a148 161   a151 161
 a190 161   a193 161   a196 161   a199 161   a202 161
 a225 161   a235 161   a244 161   a247 161   a250 161  end fill
com=/ assy 19 -- 16 fresh bp /
ara=119   nux=17 nuy=17 nuz=1     fill  f119
  a40 162    a43 161    a46 162    a55 162    a65 162
  a88 162    a91 161    a94 162    a97 161   a100 162
 a139 161   a142 162   a145 161   a148 162   a151 161
 a190 162   a193 161   a196 162   a199 161   a202 162
 a225 162   a235 162   a244 162   a247 161   a250 162  end fill
com=/ assy 20 -- no bp /
ara=120   nux=17 nuy=17 nuz=1     fill  f120
  a40 161    a43 161    a46 161    a55 161    a65 161
  a88 161    a91 161    a94 161    a97 161   a100 161
 a139 161   a142 161   a145 161   a148 161   a151 161
 a190 161   a193 161   a196 161   a199 161   a202 161
 a225 161   a235 161   a244 161   a247 161   a250 161  end fill
com=/ assy 21 -- no bp /
ara=121   nux=17 nuy=17 nuz=1     fill  f121
  a40 161    a43 161    a46 161    a55 161    a65 161
  a88 161    a91 161    a94 161    a97 161   a100 161
 a139 161   a142 161   a145 161   a148 161   a151 161
 a190 161   a193 161   a196 161   a199 161   a202 161
 a225 161   a235 161   a244 161   a247 161   a250 161  end fill
com=/ assy 22 -- 16 fresh bp /
ara=122   nux=17 nuy=17 nuz=1     fill  f122
  a40 162    a43 161    a46 162    a55 162    a65 162
  a88 162    a91 161    a94 162    a97 161   a100 162
 a139 161   a142 162   a145 161   a148 162   a151 161
 a190 162   a193 161   a196 162   a199 161   a202 162
 a225 162   a235 162   a244 162   a247 161   a250 162  end fill
com=/ assy 23 -- no bp /
ara=123   nux=17 nuy=17 nuz=1     fill  f123
  a40 161    a43 161    a46 161    a55 161    a65 161
  a88 161    a91 161    a94 161    a97 161   a100 161
 a139 161   a142 161   a145 161   a148 161   a151 161
 a190 161   a193 161   a196 161   a199 161   a202 161
 a225 161   a235 161   a244 161   a247 161   a250 161  end fill
com=/ assy 24 -- no bp /
ara=124   nux=17 nuy=17 nuz=1     fill  f124
  a40 161    a43 161    a46 161    a55 161    a65 161
  a88 161    a91 161    a94 161    a97 161   a100 161
 a139 161   a142 161   a145 161   a148 161   a151 161
 a190 161   a193 161   a196 161   a199 161   a202 161
 a225 161   a235 161   a244 161   a247 161   a250 161  end fill
com=/ assy 25 -- no bp /
ara=125   nux=17 nuy=17 nuz=1     fill  f125
  a40 161    a43 161    a46 161    a55 161    a65 161
  a88 161    a91 161    a94 161    a97 161   a100 161
 a139 161   a142 161   a145 161   a148 161   a151 161
 a190 161   a193 161   a196 161   a199 161   a202 161
 a225 161   a235 161   a244 161   a247 161   a250 161  end fill
com=/ assy 26 -- no bp /
ara=126   nux=17 nuy=17 nuz=1     fill  f126
  a40 161    a43 161    a46 161    a55 161    a65 161
  a88 161    a91 161    a94 161    a97 161   a100 161
 a139 161   a142 161   a145 161   a148 161   a151 161
 a190 161   a193 161   a196 161   a199 161   a202 161
 a225 161   a235 161   a244 161   a247 161   a250 161  end fill

'--- rows of fuel assy's
ara=1   nux=5  nuy=2  nuz=1    fill
                          41  42  42 1b2
```

```
                          43  15   8 1b2
 end fill
ara=2   nux=9   nuy=1  nuz=1    fill
                  43  24  20  14   7 1b4
 end fill
ara=3   nux=11  nuy=1  nuz=1    fill
              43  26  23  19  13   6 1b5
 end fill
ara=4   nux=13  nuy=1  nuz=1    fill
           43  26  25  22  18  12   5 1b6
 end fill
ara=5   nux=15  nuy=2  nuz=1    fill
      43  24  23  22  21  17  11   4 1b7
      43  20  19  18  17  16  10   3 1b7
 end fill
ara=7   nux=17  nuy=3  nuz=1    fill
  43  15  14  13  12  11  10   9   2 1b8
  43   8   7   6   5   4   3   2   1 1b25
 end fill
ara=10  nux=15  nuy=2  nuz=1    fill
      43  20  19  18  17  16  10   3 1b7
      43  24  23  22  21  17  11   4 1b7
 end fill
ara=12  nux=13  nuy=1  nuz=1    fill
           43  26  25  22  18  12   5 1b6
 end fill
ara=13  nux=11  nuy=1  nuz=1    fill
              43  26  23  19  13   6 1b5
 end fill
ara=14  nux=9   nuy=1  nuz=1    fill
                  43  24  20  14   7 1b4
 end fill
ara=15  nux=5   nuy=2  nuz=1    fill
                          43  15   8 1b2
                          41  42  42 1b2                end fill
end array
read plot
ttl=! north anna unit 1 cycle 5 full core by geom unit !
pic=unit
xul=-200  yul=200  xlr=200  ylr=-200  uax=1 vdn=-1  nax=130  end
ttl=!  assembly loc 2 !
pic=mat  nch=! 12 45555567890abcdefghijklmnopqrstuvwxyz!
xul=-11  yul=32.5  xlr=11  ylr=10.5  uax=1 vdn=-1  nax=130  end
ttl=! north anna unit 1 cycle 5 full core by composition!
pic=mat  nch=! 1/ 4/ / /55555abcdefghijklmnopqrstuvwxyz!
xul=-200  yul=200  xlr=200  ylr=-200  uax=1 vdn=-1  nax=260 ndn=148  end
end plot
end data
end
```

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