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

**S. M. Bowman
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Computational Physics and Engineering Division

**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 standard² (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 system³ 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 sequence⁵ 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 code⁷ 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 criticals⁸ 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% Δk 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

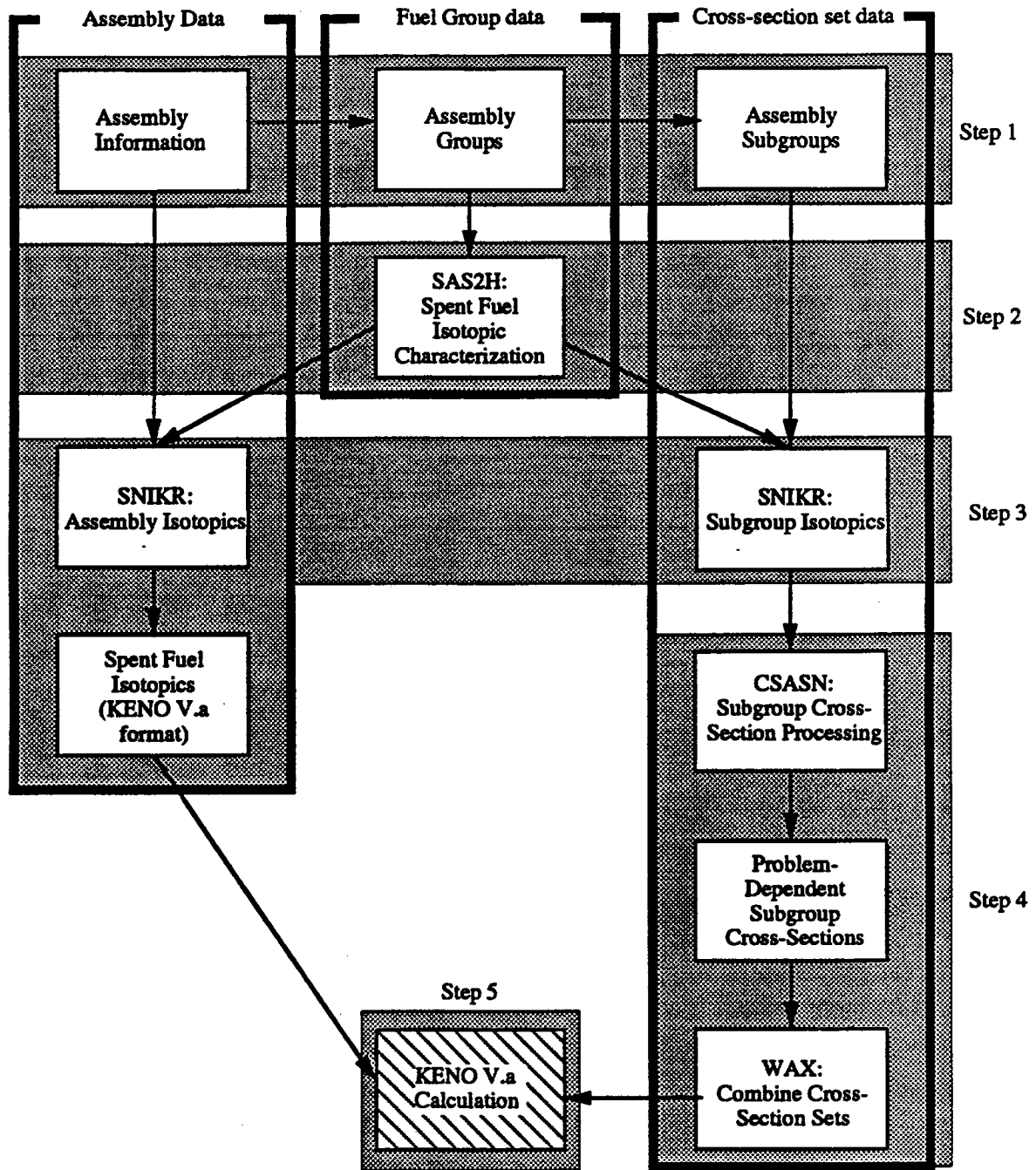


Fig. 1. Overview of the reactor critical calculation procedure.

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 work⁸ 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 SAS2H⁵ sequence of the SCALE-4 code system and the 27-group burnup library. The SAS2H sequence invokes the ORIGEN-S⁹ 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 $1.2 \cdot B_{\max}$ 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.

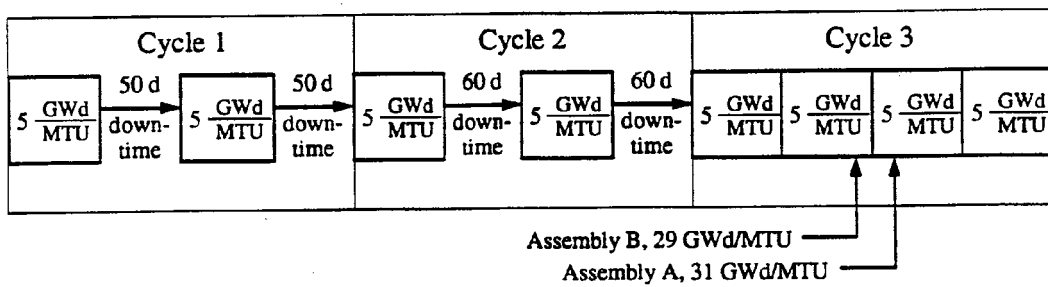
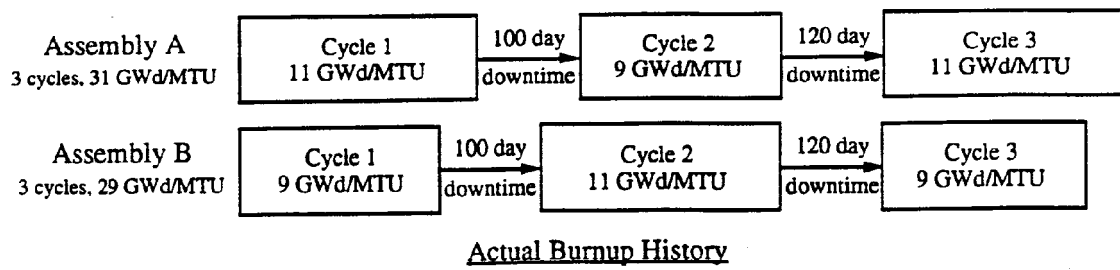


Fig. 2. SAS2H burnup model of assemblies within a fuel group.

Table 1. Nuclides updated by SAS2H

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

^aAutomatically updated by SAS2H.

^bNot 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_{∞} (i.e., 1-D infinite-lattice calculation) values. The results of these comparisons indicated agreement to within 0.1% Δk in the k_{∞} values calculated using isotopics derived from the two methods.

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 CSASN⁶ 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-S¹⁴ to perform resonance-shielding calculations using Bondarenko factors, followed by NITAWL-II¹⁵ 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

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

^aThe 25 nuclides to be used in burnup credit analysis (ref. 4).

^bAdditional burnup credit nuclides from ref. 1.

^cAdditional reactor physics nuclides from Virginia Power's PDQ calculations (ref. 10).

^dAdditional 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 WAX¹⁶ 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.

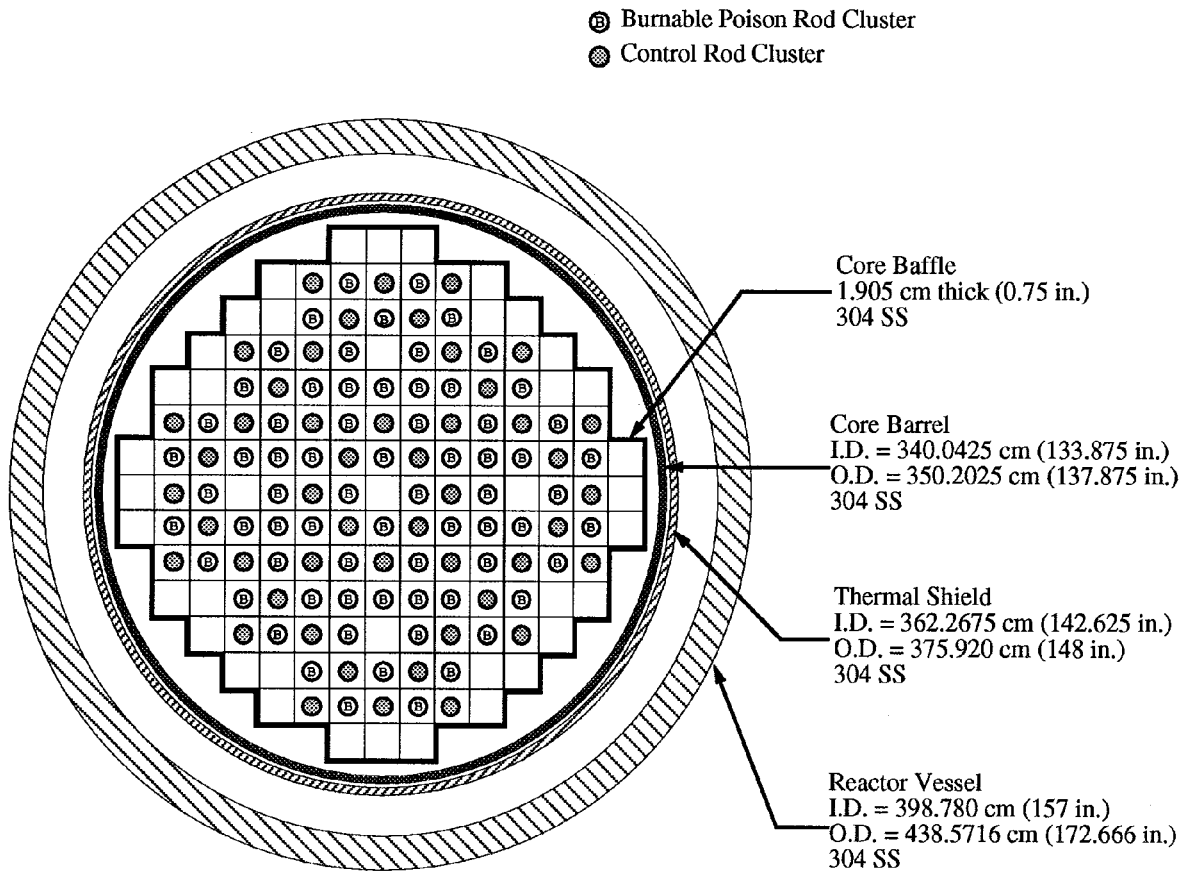
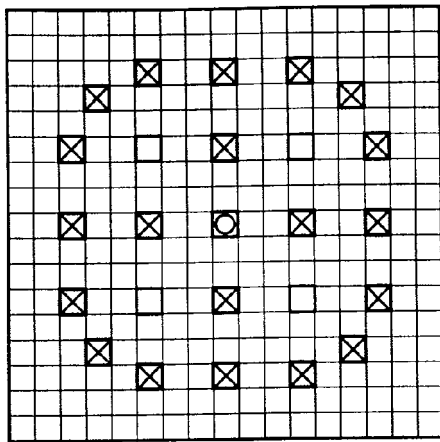


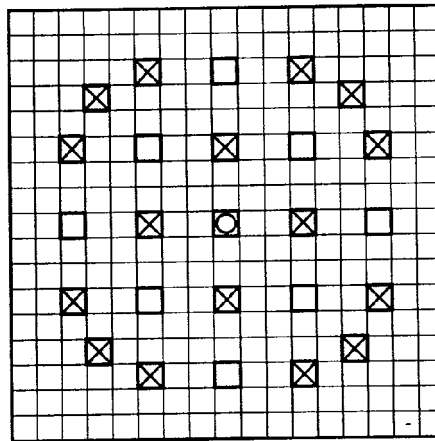
Fig. 3. North Anna Unit 1 Cycle 5 core configuration.

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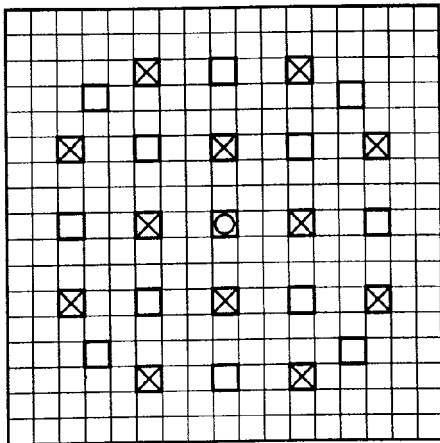
- ☒ BURNABLE POISON (BP) ROD
□ GUIDE TUBE
⊙ INSTRUMENT TUBE



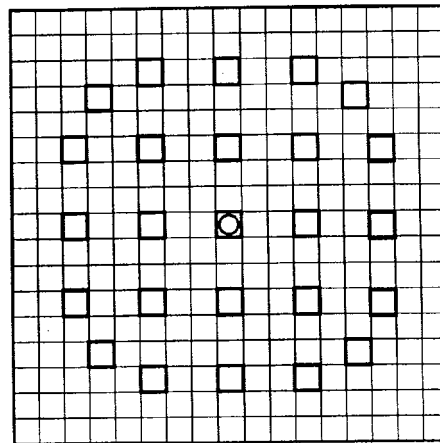
20 BP'S



16 BP'S



12 BP'S



NO BP'S

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

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1															
2							12*		12*						
3						16		16		16					
4					16		20		20		16				
5				16		20	12*	20	12*	20		16			
6			16		20		16		16		20		16		
7		12*		20	12*	16		16		16	12*	20		12*	
8			16		20		16		16		20		16		
9		12*		20	12*	16		16		16	12*	20		12*	
10			16		20		16		16		20		16		
11				16		20	12*	20	12*	20		16			
12					16		20		20		16				
13						16		16		16					
14							12*		12*						
15															

NO. OF BP RODS
*DEPLETED

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.

	R	P	N	M	L	K	J	H	G	F	E	D	C	B	A
1							15	8	15						
2					24	20	14	7	14	20	24				
3				26	23	19	13	6	13	19	23	26			
4			26	25	22	18	12	5	12	18	22	25	26		
5		24	23	22	21	17	11	4	11	17	21	22	23	24	
6		20	19	18	17	16	10	3	10	16	17	18	19	20	
7	15	14	13	12	11	10	9	2	9	10	11	12	13	14	15
8	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8
9	15	14	13	12	11	10	9	2	9	10	11	12	13	14	15
10		20	19	18	17	16	10	3	10	16	17	18	19	20	
11		24	23	22	21	17	11	4	11	17	21	22	23	24	
12			26	25	22	18	12	5	12	18	22	25	26		
13				26	23	19	13	6	13	19	23	26			
14					24	20	14	7	14	20	24				
15							15	8	15						

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

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

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,γ) fraction of energy per fission.

Each SAS2H calculation also requires specification of the temperature of each material for use in cross-section Doppler broadening corrections. However, since material and, therefore, thermal properties change with exposure, and because an assembly's peak temperature is a function of its linear heat rate, the average temperature in the fuel (and to a lesser extent the average clad temperature) will change with burnup and location. 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

$$\begin{aligned} V_T &= \text{total cell volume} = (\text{pitch})^2 \times (\text{length}), \\ V_{GT} &= \text{guide tube volume (same as outer tube in BPR cell)}, \\ V_{BP} &= \text{BP rod total volume.} \end{aligned}$$

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 ₂ O ₃	0.125
Na ₂ O	0.038
K ₂ O	0.004
Al ₂ O 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	

^aApplying weight fractions of compounds in Table 7 and 2.23 g/cm³ glass density.

^bRead as 9.595×10^{-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):

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

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

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

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

^aRead as 1.22×10^{-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 1×10^{-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

^aDoes 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 27BURNULIB 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 WAX¹⁶ 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 H₂O 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.

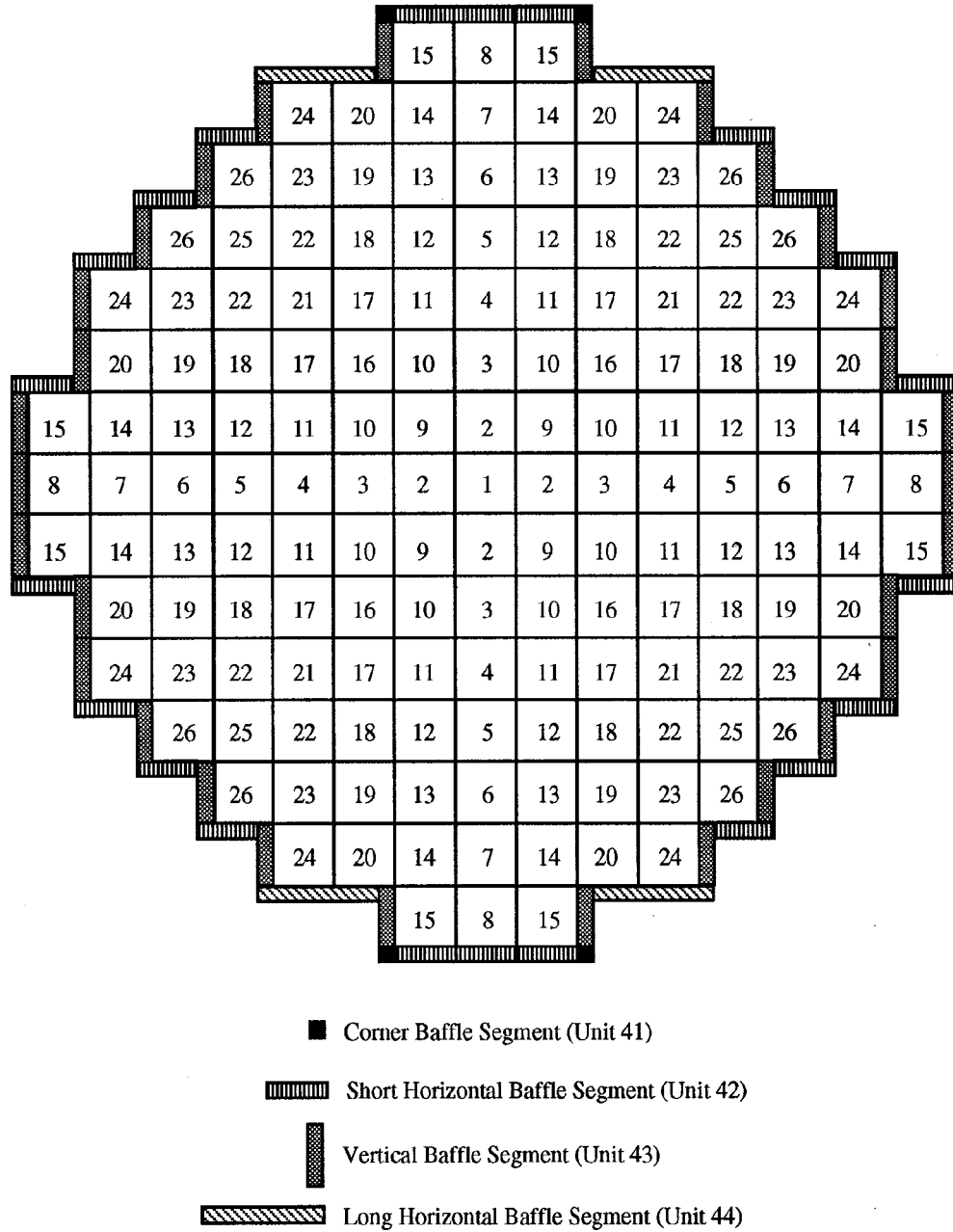


Fig. 7. Full-core-assembly positions and core baffle configuration.

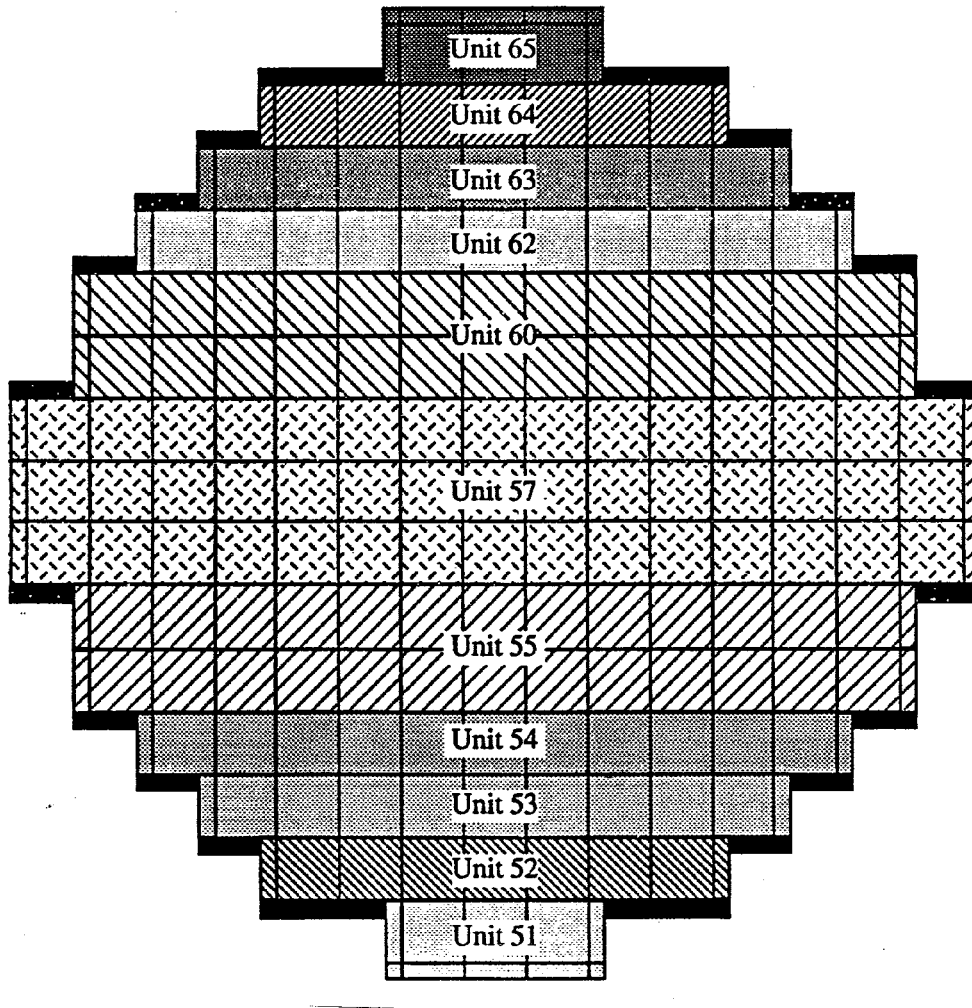


Fig. 8. KENO V.a unit definitions based on component arrays.

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 1×10^6 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 calculations⁸ 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.

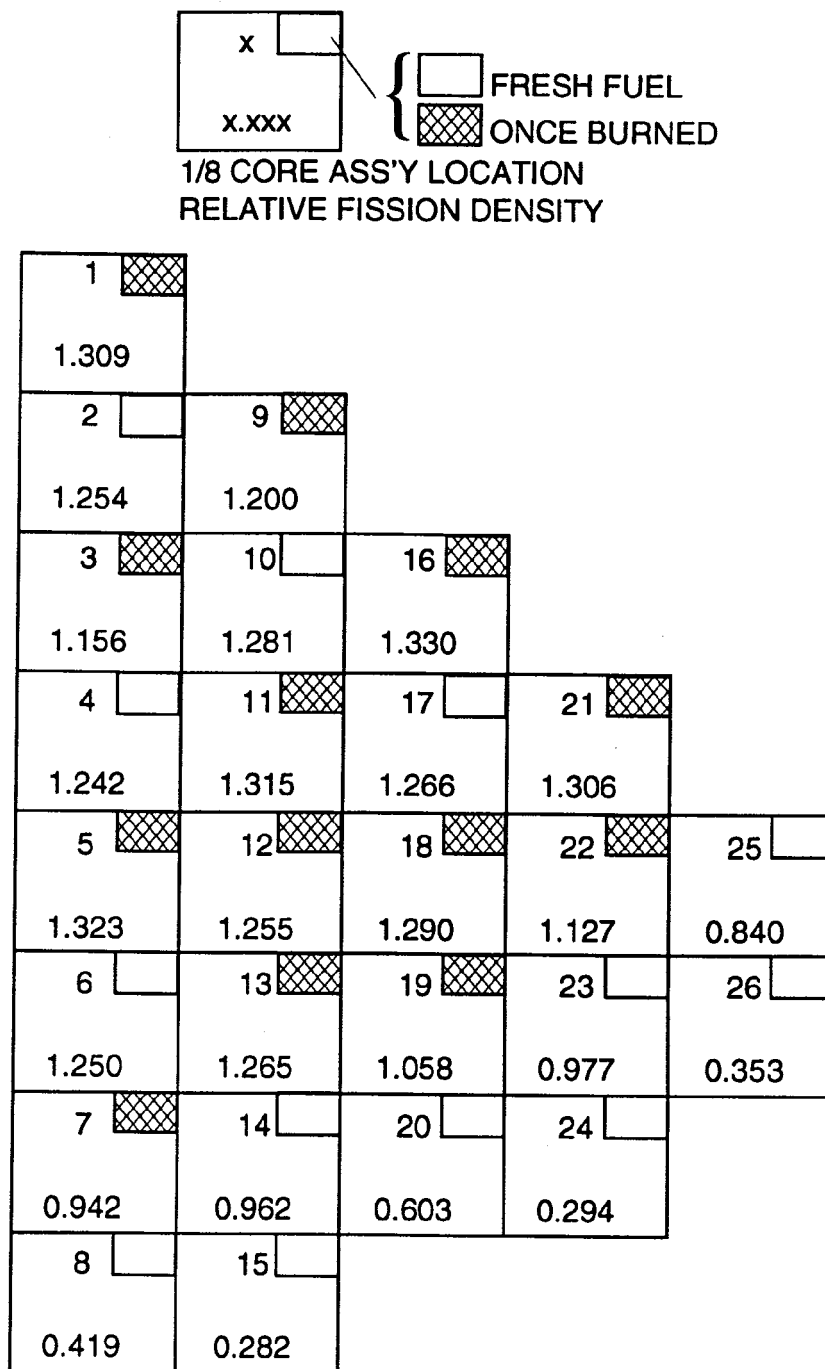


Fig. 9. BOC, HZP eighth-core relative fission density distribution.

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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,nlit1,ile,iact,ifp,itot,ncyc
    common /untnos/ n72,nout,n71,nors,nice
    common /ident/ idlit1(40),idcrit(200),iddk(2000)
    common /adens/ adlit1(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)nlit1
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
  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
      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,rdburn)
c
c convert rdburn from mwd/assy to mwd/mtu
c
      rdburn=rdburn/bconv
      write(nout,130)rdburn
      rdburn(nbn)=rdburn
      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.
      il=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('rdburn=',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)tt172
      write(nout,125)tt172
c      write(nout,160)rdburn,nct
c 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
      nml=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.nml)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,nl1tl,ile,iact,ifp,itot,ncyc
      common /untnos/ n72,nout,n71,nors,nice
      common /ident/ idl1tl(40),idcrit(200),iddk(2000)
      common /adens/ adl1tl(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/
      nlf=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 nl1tl 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,nl1tl
      do 30 j=1,ile
          if(iddk(j).ne.idl1tl(i)) go to 30
          adl1tl(i)=addk(j)
          go to 40
30   continue
      write(nout,102)idl1tl(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,nl1tl
          if(idcrit(i).eq.idl1tl(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
  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
c   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,
&64157,64158,64160,65159,66160,66161,66162,66163,66164,67165,
&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 /unthos/ 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
ial=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/
    nlf=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,nlit1
        do 30 j=1,ile
        if(iddk(j).ne.idlit1(i)) go to 30
        adlit1(i)=addk(j)
        go to 40
30      continue
        write(nout,102)idlit1(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,nlit1
        if(idcrit(i).eq.idlit1(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,nlit1
        do 80 j=1,ncrit
        if(idcrit(j).ne.idlit1(i))go to 80
        adcrit(j)=adcrit(j)+adlit1(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

adl1t1 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
'nlc5 (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.
'nlc5 (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$$ 392234 392235 392236 392238 394239 394240 394241 t
'input xsec's for fuel xsec set 4 + fp's + struct. mat's
2$$ 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

[illegible]

```

        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
      94239 1.2586E-04
      94240 3.3528E-05
      94241 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

```



```

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

```

```

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

```

```

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

```


[illegible]

```

'--- 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

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```

                                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 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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