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**THE DEPTH-CHARGE STATIC AND TIME-DEPENDENT
PERTURBATION/SENSITIVITY SYSTEM FOR
NUCLEAR REACTOR CORE ANALYSIS**

(Revision I)

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ABSTRACT

This report provides the background theory, user input, and sample problems required for the efficient application of the DEPTH-CHARGE system—a code block for both static and time-dependent perturbation theory and data sensitivity analyses. The DEPTH-CHARGE system is of modular construction and has been implemented within the VENTURE-BURNER computational system at Oak Ridge National Laboratory. The DEPTH module (coupled with VENTURE) solves for the three adjoint functions of Depletion Perturbation Theory and calculates the desired time-dependent derivatives of the response with respect to the nuclide concentrations and nuclear data utilized in the reference model. The CHARGE code is a collection of utility routines for general data manipulation and input preparation and considerably extends the usefulness of the system through the automatic generation of adjoint sources, estimated perturbed responses, and relative data sensitivity coefficients. Combined, the DEPTH-CHARGE system provides, for the first time, a complete generalized first-order perturbation/sensitivity theory capability for both static and time-dependent analyses of realistic multidimensional reactor models.

This current documentation incorporates minor revisions to the original DEPTH-CHARGE documentation (ORNL/CSD-78) to reflect some new capabilities within the individual codes. Most of the modifications, however, are transparent to the user. Changes that are under user control are described in the updated General Input Description and deal mainly with the processing and manipulation of data sensitivity files. Finally, it should also be noted that the sample problem input files have been modified to reflect these changes and to include the job control instructions for execution from a complete BOLD VENTURE-IV program package.

COMPUTER CODE ABSTRACT

1. **Program Identification:** The DEPTH-CHARGE system is a set of code modules (SUBMRG, CHARGE, and DEPTH) for generalized static and time-dependent perturbation/sensitivity calculations.
2. **Function:** This code system (coupled with a neutronics module) prepares the required adjoint sources, solves the adjoint equations of Depletion Perturbation Theory, and calculates static and/or time-dependent nuclide and data sensitivity coefficients for a wide variety of final-time response functionals.
3. **Method of Solution:** The DEPTH module (for DEpletion PERTurbation THEory) is the main calculational code in the system. It uses a straightforward series expansion method for the matrix exponential solution of the forward and adjoint nuclide density equations and a numerical integration technique is utilized to evaluate the time integrals appearing in the formulations for several of the adjoint functions. In the system in use at Oak Ridge National Laboratory (ORNL), the VENTURE module is utilized to solve the generalized adjoint flux equation.
4. **Related Material:** This system assumes that a reference forward calculation has been performed, with the storage of the appropriate flux and nuclide density files for use in the adjoint computations. The standard interface data files adopted in the DOE Reactor Physics code coordination effort are used. Other modules using consistent formulations and interface data file specifications will couple directly with this set of modules.
5. **Restrictions:** The DEPTH-CHARGE system is not a stand-alone code; it must be implemented in a modular environment. Variable dimensioning is used throughout and a compromise between data transfer and core storage was made for "reasonable" fuel burnup calculations. Very large static calculations having many regions, nuclides, and energy groups may require large amounts of core storage.
6. **Computer:** This code system has been run as part of the ORNL VENTURE computational system on the IBM models 360/370 and 3033 computers.
7. **Running Time:** Required time depends on the problem being solved. Execution of the DEPTH module requires 2-3 times the CPU time as a forward depletion calculation in the BURNER exposure module. However, for most realistic problems, the required CPU time is totally dominated by the generalized adjoint flux calculation in the neutronics module, which again is directly related to problem size.
8. **Programming Languages:** Most of the programming is in FORTRAN IV; however, a few special-purpose routines (e.g., memory allocation, direct access transfer, etc.) are programmed in IBM assembler language.
9. **Operating System:** The basic OS-360 IBM operating system with a FORTRAN IV, H-level compiler version 21.8 has been used.
10. **Machine Requirements:** Machine requirements for application of the DEPTH-CHARGE system is usually dominated by the neutronics code used for the generalized adjoint calculation (locally, the VENTURE code).

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12. References:

- (1) J. R. White, "The DEPTH-CHARGE Static and Time-Dependent Perturbation/Sensitivity System," Oak Ridge National Laboratory, ORNL/CSD-78R (1984).
- (2) D. R. Vondy et al., "The BOLD VENTURE Computation System for Nuclear Reactor Core Analysis, Version III," Oak Ridge National Laboratory, ORNL-5711 (1981).

I. INTRODUCTION

This report provides the primary documentation required for the application of the DEPTH-CHARGE static and time-dependent perturbation/sensitivity system. This current documentation incorporates minor revisions to the original DEPTH-CHARGE documentation (CRNL/CSD-78) to reflect some new capabilities within the individual codes. Most of the modifications, however, are transparent to the user. Changes that are under user control are described in the updated General Input Description and deal mainly with the processing and manipulation of data sensitivity files. Finally, it should also be noted that the sample problem input files have been modified to reflect these changes and to include the job control instructions for execution from a complete BOLD VENTURE-IV program package.

The DEPTH-CHARGE code system is the result of extended investigations¹⁻⁵ of the applicability of time-dependent perturbation theory methods⁶⁻¹⁶ to realistic fuel depletion problems. In particular, the DEPTH-CHARGE system represents the formal implementation of an extended version⁴ of the coupled neutron/nuclide depletion perturbation theory (DPT) originally presented by Williams.¹³⁻¹⁵ It contains nuclide perturbation and cross section data sensitivity formulations, with the more familiar static generalized perturbation theory formulation contained as a special case of the more general time-dependent methodology.

The present DEPTH-CHARGE system is of modular construction and consists of three new code modules^{*} (SUBMRG, CHARGE, and DEPTH) implemented as part of the VENTURE-BURNER computational system.¹⁷⁻²⁴ The SUBMRG code is a set of subroutines that can merge the large number of interface data files²⁵⁻²⁶ (fluxes, nuclide densities, etc.) from a forward depletion calculation into a more manageable set of "stacked" files for use with the DEPTH and CHARGE modules. The CHARGE code is a collection of utility routines for general input preparation and data manipulation and considerably extends the usefulness of the system through the automatic generation of adjoint sources, estimated perturbed responses, and relative data sensitivity coefficients. DEPTH (for Depletion Perturbation Theory) is the last module of the set and represents most of the calculational capability of the new system. Coupled with the VENTURE code, it solves for the adjoint functions of DPT and calculates the desired time-dependent derivatives of the response with respect to the nuclide concentrations and nuclear data utilized in the reference reactor model. The overall DEPTH-CHARGE-VENTURE system provides, for the first time, a complete generalized first-order perturbation/sensitivity theory capability for both static and time-dependent analyses of realistic multidimensional reactor models. Thus, it represents a unique capability and significantly enhances ORNL's present sensitivity analysis capabilities.

The remainder of this report provides detailed documentation for the DEPTH-CHARGE system. Sections II and III describe, respectively, the background theory and user input instructions required for the efficient application of the overall DEPTH-CHARGE system. Section IV contains several sample problems illustrating some of the main features and capabilities of the individual codes. These examples should adequately demonstrate the use of the system and hopefully will emphasize the relative ease of performing a time-dependent perturbation/sensitivity analysis for a particular reactor design once a reference forward computation has been performed. The several Appendices at the end of this report contain a more detailed description of multicycle time-dependent perturbation theory as implemented within the present system. This additional information is included in an attempt to make the present document a comprehensive guide for the application of DPT methods. However, the serious user is urged to consult the references (especially Refs. 1-5) for further details and applications of the methods discussed here.

*An additional module is available for transforming the TDSSENS sensitivity file into GENPRO format (see Appendix F).

As a final introductory remark, it should be noted that the DEPTH-CHARGE system was developed as a research tool for the evaluation of a particular time-dependent perturbation theory method applicable to fuel burnup analyses. As such, it originally was not intended to be widely distributed as a production module of the VENTURE system. However, as the capabilities of the system matured, the usefulness of the DEPTH-CHARGE system for routine sensitivity studies became apparent, and documentation and release of the code seemed prudent.

On the other hand, care was taken throughout the programming phase of this work to insure an end product that was flexible, easy to use, and reasonably compatible with the strict organizational requirements of the VENTURE system. Thus, although some restrictions do exist relative to the generality and structure of the VENTURE-BURNER system, it is felt that the unique capabilities of the present version far out-shadow its minor inconsistencies with the rest of the VENTURE system.

Extensive testing of the present system has also been performed to guarantee with a high degree of reliability that the codes perform as intended. Much of the documentation for this effort is contained in Refs. 1-5. However, the user should be cautioned that actual application testing is quite limited. In this light, the present DEPTH-CHARGE system should be coined a "preliminary" version, subject to revision if coding errors are found or if additional flexibility is deemed necessary for realistic application by the user community. Also in this regard, the author would appreciate feedback from the user community as to the accuracy, flexibility, and usefulness of the present system.

II. GENERAL BACKGROUND THEORY

The purpose of this section is to outline the time-dependent perturbation/sensitivity formulation implemented into the DEPTH-CHARGE system and to supply the user enough theoretical background for its efficient application to realistic problems. However, the reader is cautioned that this section is intended only as a minimum introduction to multicycle depletion perturbation theory (DPT), and it is highly recommended that the Appendices at the end of this report and Refs. 1-5 be utilized for further details.

II.1 Forward and Adjoint Burnup Formulations

We will begin the introduction of DPT methods with a brief review of the forward burnup problem. In burnup analyses, one is interested in the interaction between the nuclide density field and the neutron flux field within the reactor over relatively long periods of time. The nuclide field obeys the nuclide transmutation equation, while the flux field is assumed to obey the diffusion theory approximation to the neutron transport equation. In these basic equations, the flux field is dependent on the nuclide field through the diffusion operator and the nuclide field is a function of the neutron flux through its coupling in the transmutation operator. In addition to this interaction, the flux and nuclide fields are also coupled through the reactor power constraint. In this study, the system of three coupled nonlinear equations for the nuclide field, flux field, and flux normalization are referred to as the general forward nonlinear burnup equations.

Present methods for solving the nonlinear burnup equations essentially decouple the flux and nuclide fields by assuming that the neutron flux is separable in time and can be written as

$$\phi(\vec{r}, E, t) = \alpha(t)\psi(\vec{r}, E) \text{ for } t_1 < t < t_2 \quad (2.1)$$

where $\alpha(t)$ is a time-dependent normalization and $\psi(\vec{r}, E)$ is the space- and energy-dependent neutron flux that satisfies the time-dependent diffusion equation. In this "quasi-static" approximation, t_1 and t_2 define the time interval over which $\psi(\vec{r}, E)$ is assumed constant. During this interval the depletion equation becomes

$$\frac{dN(\vec{r}, t)}{dt} = \underline{M}(\vec{r}, t)N(\vec{r}, t) \quad (2.2)$$

where $N(\vec{r}, t)$ is the space- and time-dependent nuclide density vector and $\underline{M}(\vec{r}, t)$ is the space- and time-dependent transmutation matrix (consisting of microscopic reaction rates and decay constants).

It should be pointed out that the time dependence of the transmutation matrix is due to the flux normalization and not the flux shape. In practice the time-dependent flux normalization is also approximated as a piecewise constant function of time; essentially breaking the interval $t_1 < t < t_2$ into several subintervals. Within each subinterval the transmutation matrix is constant in time, making the solution of Eq. (2.2) quite straightforward. At t_2 a new flux-eigenvalue calculation is performed, and the depletion equation solved once more using the new $\psi(\vec{r}, E)$. Using this procedure, one can predict the time-dependent isotopic changes that occur in a nuclear reactor.

A schematic representation of this quasi-static burnup approximation is given in Fig. 2.1. It should be noted that this approximation introduces discontinuities into the burnup equations. That is, the nuclide density is discontinuous at cycle and time-step boundaries, the flux shape becomes discontinuous at time-step boundaries, and the flux or power normalization is characterized by discrete step changes at substep interfaces. As will be shown later, the quasi-static adjoint burnup equations also exhibit a similar behavior at the time boundaries.

OPERATION	TIME BOUNDARY WHERE OPERATION IS ALLOWED		
	CYCLE k	TIME STEP i	SUBSTEP j
REFUELING/SHUFFLING/DISCHARGE	X		
CONTROL MOVEMENT/NUCLIDE SEARCHES	X	X	
FLUX-EIGENVALUE CALC	X	X	
CROSS SECTION ASSIGNMENT	X	X	
POWER NORMALIZATION	X	X	X

NOTATION

x^{ijk} INDICATES THAT x IS CONSTANT OVER THE ijk INTERVAL

$y^{ijk}(t)$ INDICATES THAT y IS A CONTINUOUS FUNCTION OF TIME WITHIN THE ijk INTERVAL

z INDICATES THAT z IS INDEPENDENT OF TIME

Figure 2.1. Schematic Representation of Quasi-Static Burnup Approximation.

The detailed forward quasi-static depletion equations, employing the notation described in Appendix A, are summarized in the first half of Table 2.1. Under the quasi-static approximation, Eqs. (2.3) through (2.8) completely define the state of the reactor at any point in time. The first of these equations describes the zone-averaged depletion process for each ijk time interval within each reactor region. The sz subscripts represent subzone s in zone z . The terms in the brackets of Eq. (2.3) are just a more detailed representation of the transmutation matrix given in Eq. (2.1), showing its dependence on both the shape and magnitude of the flux. The initial condition at the cycle boundary represents the refueling process, while this condition at the time-step interface accounts for control rod movement or any other discontinuity in the nuclide field.

The reactor power constraint [Eq. (2.6)] along with Eq. (2.8) are the defining equations for the normalization constant, α^{ijk} . Similarly, the time-independent diffusion equation written in operator notation [Eq. (2.7)] defines the spectral and spatial flux distribution. When taken together, the normalization and distribution functions describe the total group flux vector, $\phi(\vec{r})$, in the reactor system.

The solution of the above equations is straightforward and several computer codes have been written specifically for this purpose. The specific calculational scheme utilized for this work is briefly outlined in Sect. II.2.

TABLE 2.1
FORWARD AND ADJOINT QUASI-STATIC BURNUP EQUATIONS

FORWARD	ADJOINT
1. Nuclide Density: $\frac{d}{dt} N_{sz}^{ijk}(t) = \left[\alpha^{ijk} \underline{x}_{sz}^{ik} \underline{\psi}_z^{ik} + \underline{D} \right] N_{sz}^{ijk}(t) \quad (2.3)$ <p>with initial condition</p> $N_{sz}^{ik}(t_{ik}) = C_{sz}^{ik}(t_{ik})$ <p>where</p> $\underline{C}^{ik} = \begin{bmatrix} N \\ \vdots \\ N_{NREG} \end{bmatrix}^{ik} = \underline{P}_{SD}^{ik} \underline{Z}^{ik-} + \underline{M}^{ik}$ $\underline{Z}^{ik-} = \begin{bmatrix} N \\ \vdots \\ N_{NREG} \end{bmatrix}^{ik-} \quad \underline{M}^{ik} = \begin{bmatrix} M \\ \vdots \\ M_{NREG} \end{bmatrix}^{ik}$ <p>with</p> <p>$\underline{P}_{SD}^{ik}$ = shuffling/discharge operator</p> <p>$\underline{M}^{ik}$ = makeup feed vector</p> <p>N_{NREG} = total number of regions in problem</p>	1. Adjoint Nuclide Density: $\frac{d}{dt} N_{sz}^{*ijk}(t) = - \left[\alpha^{ijk} \underline{x}_{sz}^{ik} \underline{\psi}_z^{ik} + \underline{D} \right]^T N_{sz}^{*ijk}(t) \quad (2.15)$ <p>with final condition</p> $N_{sz}^{*}(t_f) = \frac{\partial R}{\partial N_{sz}}(t_f) \quad (2.16)$ <p>and jump condition</p> $N_{sz}^{*ijk} = N_{sz}^{*ijk+} + \underline{P}_{sz}^{*ijk+} \text{effect} + \underline{\Gamma}_{sz}^{*ijk+} \text{effect} \quad (2.17)$ <p>where</p> $\underline{P}_{sz}^{*ijk+} \text{effect} = -\underline{P}^{*ijk} \alpha^{ijk} \underline{E}_p \underline{a}_{f,sz}^{ik} \underline{\psi}_z^{ik} \quad (2.18)$ $\underline{\Gamma}_{sz}^{*ijk+} \text{effect} = -\frac{1}{v_z} \int_{v_z} \underline{\Gamma}^{*ijk}(\vec{r}) \frac{\partial}{\partial N_{sz}^{ik}} \left\{ (\underline{L} - \lambda \underline{F}) \underline{\psi}^{ik}(\vec{r}) \right\} \quad (2.19)$ <p>for $j = 1$</p> $\underline{\Gamma}_{sz}^{*ijk+} \text{effect} = 0 \text{ for } j \neq 1$ <p>and adjoint refueling discontinuity</p> $\underline{Z}^{*ijk-} = \underline{P}_{SD}^{Tijk} \underline{Z}^{*ijk} \quad (2.20)$

TABLE 2.1 (continued)

FORWARD	ADJOINT
<p>2. Power Normalization:</p> $p^{ijk} = \alpha^{ijk} \sum_z \sum_s \frac{N_{sz}^{Tijk}}{N_{sz}} E_p \frac{\sigma_f^{ik}}{\sigma_f} \psi_z^{ik} v_{sz} \quad (2.6)$	<p>2. Power Adjoint:</p> $p^{*ijk} = \frac{1}{p^{ijk}} \left[\left(\alpha \frac{\partial R}{\partial \alpha} \right)^{ijk} + \alpha^{ijk} \sum_z \sum_s v_{sz} \int_{\text{substep } j} \frac{N_{sz}^{*Tijk}(t)}{N_{sz}} \chi_{sz}^{ik} \psi_z^{ik} \frac{N_{sz}^{ijk}(t)}{N_{sz}} dt \right] \quad (2.21)$
<p>3. Flux Shape:</p> $(\underline{L} - \lambda \underline{F})^{ik} \psi^{ik}(\vec{r}) = 0 \quad (2.7)$ <p>where $\psi^{ijk}(\vec{r}) = \alpha^{ijk} \psi_z^{ik}(\vec{r})$</p> <p>$\underline{L}$ = leakage, removal and inscatter operator</p> <p>$\underline{F}$ = fission source operator</p> <p>$\lambda = \frac{1}{k_{eff}}$ = lambda mode eigenvalue</p>	<p>3. Adjoint Flux Shape:</p> $(\underline{L} - \lambda \underline{F})^{Tijk} \psi^{*ik}(\vec{r}) = \underline{S}_z^{*ik} \quad (2.22)$ <p>where</p> $\underline{S}_z^{*ik} = \frac{\partial R}{\partial \psi_z^{ik}} + (A^{*ik}, 1) \quad (2.23)$ $+ \sum_j \frac{\alpha^{ijk}}{v_z} \sum_s v_{sz} \int_{\text{substep } j} \frac{N_{sz}^{*Tijk}(t)}{N_{sz}} \chi_{sz}^{ik} \frac{N_{sz}^{ijk}(t)}{N_{sz}} dt$ $- \sum_j \frac{1}{v_z} \sum_s v_{sz} p^{*ijk} \alpha^{ijk} \frac{N_{sz}^{Tijk}}{N_{sz}} E_p \frac{\sigma_f^{ik}}{\sigma_f}$

TABLE 2.1 (continued)

FORWARD	ADJOINT
<p>4. Flux Shape Normalization:</p> $\sum_z v_z \sum_g \psi_{gz}^{ik} = 1 \quad (2.8)$	<p>4. Additional Relationships:</p> $A^{*ijk} = - \sum_j \left(\alpha \frac{\partial R}{\partial \alpha} \right)^{ijk} + \int_{\text{all space}} \left(\psi(\vec{r}) \frac{\partial R}{\partial \psi(\vec{r})} \right)^{ik} d\vec{r} \quad (2.24)$ $\int_{\text{all space}} \left(\Gamma^{*T}(\vec{r}) \underline{F} \psi(\vec{r}) \right)^{ik} d\vec{r} = 0 \quad (2.25)$ $\sum_z v_z (\psi_z^T \underline{S}_z^*)^{ik} = 0 \quad (2.26)$

With the forward burnup equations clearly defined, we now continue with the adjoint depletion process and the concept of time-dependent perturbation theory. The goal of any perturbation theory, whether static or time-dependent, is the prediction of a perturbed response without direct recalculation of the forward problem. In most reactor physics studies, a response of interest is generally a final-time functional of both the independent and dependent variables describing the reference reactor system, and can be written as,

$$R(t_f) = \int f[\underline{N}(\vec{r}, t), \underline{\beta}(\vec{r}, E, t), \alpha(t), \psi(\vec{r}, E, t)] \delta(t - t_f) d\vec{r} dE dt \quad (2.9)$$

where $\underline{N}$, $\underline{\beta}$, α , and ψ are the nuclide density vector, data vector, flux normalization, and neutron flux shape function, respectively.

From Eq. (2.9) one sees that there are only four possible ways in which R can be altered:

1. Variation in $\underline{N}(\vec{r}, t)$ — direct 'N*' effect'

$$\Delta R = \int \frac{\partial R(t_f)}{\partial \underline{N}(t)} * \Delta \underline{N}(t) d\vec{r} \quad (2.10)$$

2. Variation in $\alpha(t_i)$ — direct or indirect 'P*' effect'

$$\Delta R = \frac{\partial R(t_f)}{\partial P(t_i)} * \Delta P(t_i) + \int \frac{\partial R(t_f)}{\partial P(t_i)} * \frac{\partial P(t_i)}{\partial \underline{N}(t_i)} * \Delta \underline{N}(t_i) d\vec{r} \quad (2.11)$$

where P reactor power = $f(\alpha)$

3. Variation in $\psi(\vec{r}, E, t_i)$ — indirect 'Γ*' effect'

$$\Delta R = \int \frac{\partial R(t_f)}{\partial Q(t_i)} * \frac{\partial Q(t_i)}{\partial \underline{N}(t_i)} * \Delta \underline{N}(t_i) d\vec{r} dE \quad (2.12)$$

where $Q(\vec{r}, E, t_i)$ = neutron source strength = $f(\psi)$

4. Variation in $\underline{\beta}(\vec{r}, E, t)$ — 'direct' or indirect 'β*' effect'

$$\begin{aligned} \Delta R = & \int \frac{\partial R(t_f)}{\partial \underline{\beta}(t_i)} * \Delta \underline{\beta}(t_i) d\vec{r} dE \\ & + \int \frac{\partial R(t_f)}{\partial \underline{\beta}(t_i)} * \frac{\partial \underline{\beta}(t_i)}{\partial \underline{N}(t_i)} * \Delta \underline{N}(t_i) d\vec{r} dE \end{aligned} \quad (2.13)$$

Finally, adding Eqs. (2.10)-(2.13) gives the total perturbed response,

$$\Delta R_{total} = N^*_{effect} + P^*_{effect} + \Gamma^*_{effect} + \beta^*_{effect} \quad (2.14)$$

Now, in the design and operation of a reactor, the independent variables most commonly employed to optimize system performance are the reactor power and nuclide density field. Thus, in perturbation studies it is necessary to relate variations in these independent variables to the performance parameters of interest. Equations (2.10)–(2.14) indicate that the desired relationships can be obtained by simply taking the partial time-dependent derivatives of the response definition with respect to the four variables in Eq. (2.9) and by using the chain rule to relate ΔR to the independent system perturbations, ΔP and ΔN .

It should be noted that the $\Delta\beta$ term in Eq. (2.13) is zero for typical design perturbation studies (data sensitivity theory in which $\Delta\beta$ is not zero is discussed in Sect. II.3), and the $\partial\beta/\partial N$ term is usually assumed to be negligible (for fast reactor studies at least). Therefore, Eq. (2.14) with the β^* effect term set to zero is the generalized perturbation theory formulation utilized in this work for both static and time-dependent (quasi-static) analysis. It simply states that the estimated change in response $R(t_f)$ due to a design perturbation at $t = t_i \leq t_f$ is the sum of the N^* , P^* , and Γ^* effects at that time, given, respectively, by Eqs. (2.10), (2.11), and (2.12). Thus, all that is required are the $\partial R/\partial N$, $\partial R/\partial P$, and $\partial R/\partial Q$ time-dependent derivatives.

At this point, it is important to emphasize the simple relationship of the above formulation to the more familiar concept of static perturbation theory. To distinguish between static and time-dependent perturbation theory in the present formulation, one need only specify the time at which the perturbation is made. If $t = t_i = t_f$, static perturbation theory results. If, however, t and $t_i \leq t_f$, the $\partial R/\partial N$, $\partial R/\partial P$, and $\partial R/\partial Q$ derivatives in Eqs. (2.10)–(2.12) become time-dependent functions and thus relate the change in the final-time response to perturbations made prior to t_f .

This rather simplified explanation and rationalization of DPT will hopefully serve as a bridge between the detailed theory and the terminology necessary for an adequate understanding of the application of DPT methods. Comparison of Eqs. (2.10)–(2.12) with the corresponding detailed equations in Appendix A (see Eqs. A.15–A.19) shows that the $N^*(\vec{r}, t)$, $P^*(t_i)$, and $\Gamma^*(\vec{r}, E, t_i)$ adjoint functions are just the $\partial R/\partial N(\vec{r}, t)$, $\partial R/\partial P(t_i)$, and $\partial R/\partial Q(\vec{r}, E, t_i)$ time-dependent derivatives needed in the perturbation expression of Eq. (2.14). Not only does this simple comparison define the desired terminology, it also provides a physical basis for the three adjoint functions of DPT.

Although the detailed structure of the three adjoint equations is not required for application purposes, it is important to note that a one-to-one correspondence exists between the forward and adjoint quasi-static burnup equations. This correspondence is illustrated in the second half of Table 2.1, which contains, for reference purposes, the detailed adjoint equations programmed within the DEPTH-CHARGE system. Table 2.2 also attempts to display the same relationships in a more concise form, and thus explain the purpose of each adjoint equation. As apparent in these comparisons, each operation performed during the forward depletion calculation has a corresponding adjoint expression. The forward equations represent an initial value problem while the adjoint set defines a final value problem of similar construction. Thus, the algorithm previously described for solution of the forward quasi-static burnup equations, if reversed in time, can generally be applied to the adjoint problem. Therefore, in principle, solving for the time-dependent derivatives required for the evaluation of Eq. (2.14) is no more difficult than solving the forward depletion problem.

TABLE 2.2

ONE-TO-ONE CORRESPONDENCE BETWEEN FORWARD
AND ADJOINT DEPLETION OPERATIONS

FORWARD	ADJOINT
Initial condition on nuclide field	Final condition on nuclide adjoint field
Forward depletion calculation	Adjoint depletion calculation
Power normalization	Power adjoint calculation
Flux-eigenvalue calculation	Generalized fixed-source adjoint calculation
Normalization discontinuity	P^* jump condition
Flux shape discontinuity	Γ^* jump condition
Refueling/discontinuous nuclide field	Adjoint refueling discontinuity

II.2 Forward and Adjoint Solution Algorithms

As stated previously, several computer codes have been written specifically for the accurate and efficient solution of the forward quasi-static burnup equations. Because of its availability (and modular construction), the VENTURE-BURNER code system was chosen as the basis for the solution of the adjoint system of equations. The purposes of this subsection, therefore, are to familiarize the reader with the basic structure of the VENTURE/BURNER computational system and to briefly describe the solution algorithms for the forward and adjoint burnup equations within this modular system.

The VENTURE modular computation system for nuclear reactor core analysis has been under continuing development at ORNL for the last several years. Reactor analysis problems are solved using multigroup finite-difference diffusion theory techniques. Depletion calculations are possible and one-, two-, and three-dimensional geometries can be employed. Emphasis in the methods development has been placed on satisfying the requirements for analysis of fast breeder reactors. However, thermal reactor calculations using a simplified cross-section treatment can also be performed.

Some of the major code modules in this system and their computational functions are listed in Table 2.3. These modules, along with many others under development, communicate with each other through the use of standardized interface data files.²⁵⁻²⁶ These data files, established by the Committee on Computer Code Coordination (CCCC), contain a variety of information ranging from cross-section data to module instructions. Many of the more frequently used interface files are described in Table 2.4.

TABLE 2.3
MAJOR MODULES OF THE VENTURE-BURNER AND DEPTH-CHARGE
COMPUTATIONAL SYSTEMS

MODULE	FUNCTION
VENTURE	Solves usual neutronic eigenvalue, adjoint, fixed source, adjoint fixed-source, and criticality search problems, treating up to three geometric dimensions. Also does first-order perturbation analysis.
BURNER	Solves the nuclide chain equations to estimate the nuclide concentrations at the end of an exposure time and also after a shutdown period.
PERTUBAT	Performs detailed first-order static perturbation calculation.
RODMOD	Used to position control rods during the calculation of a reactor history.
FUELMANG	Performs fuel management operations in multicycle problems.
DEPTH	New module for the solution of the adjoint equations of <u>DE</u> pletion <u>P</u> erturbation <u>T</u> heory.
CHARGE	New module for general data manipulation and input preparation for DEPTH. Also calculates data sensitivity coefficients.
SUBMRG	New module for interface file manipulation for use in DEPTH and CHARGE.

TABLE 2.4
COMMONLY USED INTERFACE DATA FILES

NAME	CONTENT
CONTRL	Module input instructions.
ISOTXS	Nuclide ordered microscopic cross-section data.
GRUPXS	Group ordered microscopic cross-section data.
GEODST	Geometry data.
NDXSRF	Nuclide referencing data.
ZNATDN	Nuclide concentrations.
RZFLUX	Zone average fluxes.
RTFLUX	Regular point fluxes.
ATFLUX	Adjoint point fluxes. (regular and fixed-source)
EXPOSE	Basic exposure data.
PERTUE	Perturbation integrals.
FIXSRC	Source for either regular or adjoint fixed-source calculation.
REFUEL	Basic fuel management data.

NOTE: Several additional "interface files" have been defined for use in the DEPTH-CHARGE system.

Of main concern here is the computational path one would follow in performing a typical burnup analysis with this modular system. If an adjoint calculation is to follow, the reference depletion solution is somewhat more complicated due to the amount of information that needs to be saved for the adjoint calculation. Since the adjoint formulation uses the unperturbed flux and nuclide fields from the reference case, the interface files containing this data must be retained. In addition, due to the method of solution of the fixed-source adjoint calculation, one also needs to perform (and store data from) a regular adjoint and perturbation calculation at each time step during the forward depletion calculation. These additional tasks roughly double the cost of a reference depletion calculation relative to one that is not to be followed by an adjoint calculation. However, the data generated from one reference calculation can be utilized in any number of adjoint calculations for various responses of interest.

The basic calculational path for a reference depletion calculation using the VENTURE modular system is shown in Fig. 2.2. It is simply the quasi-static algorithm discussed previously. Additional operations such as nuclide searches, control rod positioning, and more detailed perturbation calculations than provided in the VENTURE module could be performed at each time-step interface as desired. The end-of-cycle eigenvalue calculation, listed as optional in Fig. 2.2, is usually performed since this point is quite often the final time for the subsequent adjoint calculation. Data generated at this time point may possibly be needed for the final condition on N^* , as specified by Eq. (2.16).

Based on the previously noted similarity of the forward and adjoint equations, a time-dependent sensitivity module was developed and integrated within the VENTURE-BURNER modular code system. Called DEPTH (for DEpletion PERTurbation THEORY), the new module solves for the nuclide adjoint vector and normalization or power adjoint [$N^*(\vec{r}, t)$ and $P^*(t)$, respectively]. It then calculates the generalized adjoint source necessary for the flux adjoint calculation. Using this source, the VENTURE module solves for the generalized adjoint shape function, $\Gamma^*(\vec{r}, E)$, and evaluates several integrals involving both the forward and adjoint shape function. Calculational control is then returned to DEPTH where the time-step jump conditions are applied using the previously computed adjoint functions. This procedure is repeated for each depletion time step, backwards through time, until the initial time (in the forward sense) has been reached.

The above sequence of calculations is outlined in Fig. 2.3. Comparison of this solution algorithm for the adjoint equations with that of Fig. 2.2 once again emphasizes the parallelism of the two burnup formalisms. The type of calculations required in the adjoint mode closely resemble those of the forward problem, except now fixed-source adjoint calculations are performed instead of eigenvalue calculations. In addition, the order in which the depletion and flux calculations are completed is reversed relative to the forward case. A simplified flow chart of the calculational paths within the modular system, emphasizing the calling sequence and actual communication links between the DEPTH and VENTURE modules, is provided in Fig. 2.4. The simplicity of this diagram hopefully portrays to the potential user the relative ease of running an adjoint depletion calculation once the reference forward computation has been performed. This point is stressed further in Sect. IV with the use of illustrative examples.

Before leaving this subsection, it should be noted that DEPTH was developed originally as an aid in the evaluation of a new time-dependent perturbation method applicable to burnup analysis. Although considerable care was taken during the programming phase of this work to ensure a large degree of flexibility, several minor restrictions do exist (relative to the generality of the VENTURE-BURNER system). Some of the more apparent restrictions are:

1. If subzones are present in the problem specification, the zone is treated as a composite of the included subzones, and its assigned densities and volume fractions must be zero.
2. The adjoint depletion calculation is restricted to a matrix exponential solution technique.

PROBLEM SETUP

- A. Cross-section preparation
- B. User input

LOOP OVER NUMBER OF CYCLES

LOOP OVER NUMBER OF TIME STEPS PER CYCLE

1. VENTURE

- A. Flux-eigenvalue calculation and power normalization
- B. Regular adjoint calculation
- C. Perturbation calculation (optional)
- D. Write RTFLUX, ATFLUX and PERTUB interface files

2. BURNER

LOOP OVER NUMBER OF SUBSTEPS PER TIME STEP

- A. Depletion calculation (matrix exponential soln.)
- B. Power normalization
- C. Write end of time step ZNATDN file

3. VENTURE (optional)

- A. through D. above

4. FUELMANG

- A. Perform fuel shuffling/discharge/refuel
- B. Write new ZNATDN interface file

5. SUBMRG (interface file manipulation)

Figure 2.2 Computational Path for Reference Depletion Calculation.

PROBLEM SETUP

- A. Use cross section and input from reference calc.
- B. Interface files produced in reference calc.
- C. Setup DEPTH input with CHARGE module.

Figure 2.3 Computational Path for Adjoint Depletion Calculation

Figure 2.4 Simplified Flow Chart of Calculational Path Within Modular System.

3. Static sensitivity calculations require that some minimal burnup data be available, and a static adjoint calculation proceeds exactly as an adjoint burnup problem with a very short depletion time (0.001 days).
4. Reactor-averaged fission spectrum data must be available on the GRUPXS file and nuclide-dependent chi data are ignored.
5. Energy-dependent fission product yield data are not allowed.
6. Only P_0 cross-section data can be handled.

In addition to these restrictions, there may be some problems with extreme memory requirements when very large problems (large numbers of regions, nuclides, and energy groups) are attempted. Although some of the above limitations may seem severe, ample warning messages within the codes will notify the user of any inconsistencies in the problem being attempted and that allowed within the DEPTH-CHARGE system.

Further explanation as to the actual use of the system will be deferred until Sect. IV. At that time, several important points relative to the efficient use of the system will be noted.

II.3. Time-Dependent Data Sensitivity Theory

The broad areas of data sensitivity and uncertainty analysis have received much attention over the last several years, with most of the analyses performed to data being restricted to time-independent problems.²⁷⁻²⁹ However, the present developments in DPT methods have also created considerable interest in time-dependent data sensitivity and uncertainty analyses. As indicated in Eqs. (2.13) and (2.14), time-dependent data sensitivity theory is just a straightforward extension of the DPT methods already discussed.

As noted previously, the three adjoint functions of depletion perturbation theory, $\underline{N}^*(\vec{r}, t)$, $P^*(t)$, and $\underline{\Gamma}^*(\vec{r}, t)$, account respectively for variations in a specified response due to changes in the nuclide density field, flux normalization, and space- and energy-dependent neutron source strength within the reactor model. If these time-dependent importance functions are combined with a first-order estimate of the change in the nuclide density field, flux normalization, and neutron source strength due to a variation in some data parameter, a first-order expression for the change in the response with respect to the data results. The time-dependent derivative of the response with respect to a data parameter β can be written as,

$$\begin{aligned}
 \frac{dR(t_f)}{d\beta(t_{ik})} = & \frac{dR(t_f)}{d\beta(t_{ik})} \delta(t_{ik} - t_f) \\
 & + \left[\left(\frac{\partial R(t_f)}{\partial Q(t)} \frac{\partial Q(t)}{\partial \beta(t)} \right) + \left(\frac{\partial R(t_f)}{\partial P(t)} \frac{\partial P(t)}{\partial \beta(t)} \right) \right] \\
 & + \left[\left(\frac{\partial R(t_f)}{\partial \underline{N}(t)} \frac{\partial \underline{N}(t)}{\partial \beta(t)} \right) \right] \delta(t - t_{ik})
 \end{aligned} \tag{2.27}$$

where Q , P , and $\underline{N}$ represent the neutron source strength, reactor power, and nuclide field vector, respectively. The $()$ indicate integration over space and energy where appropriate.

The first term on the right-hand side (RHS) of Eq. (2.27) is just the static derivative of the final-time response with respect to the data utilized at that time. This is typically the sum of the "direct" and "indirect" effects of static sensitivity theory. The remaining three terms on the RHS of Eq. (2.27) represent the indirect effects of a data variation during the burnup process on the response of interest. Explicit representations of the time-dependent indirect flux, normalization, and transmutation effects indicated in Eq. (2.27) are:

1. Flux Effect =

$$- \int d\vec{r} \, \underline{\Gamma}^{*T}(\vec{r}) \frac{\partial}{\partial \beta^{ik}} [(\underline{L} - \lambda \underline{E}) \underline{\Psi}(\vec{r})]^{ik} \quad (2.28)$$

2. Normalization Effect =

$$- \rho^{*ik} \alpha^{ik} \int d\vec{r} \frac{\partial}{\partial \beta^{ik}} [\underline{N}^{*T}(\vec{r}) \underline{E} \rho^{*ik} \underline{\Psi}^{ik}(\vec{r})] \quad (2.29)$$

3. Transmutation Effect =

$$+ \int d\vec{r} \int_{t_i}^{t_{i+1}} dt \, \underline{N}^{*T}(\vec{r}, t) \frac{\partial}{\partial \beta^{ik}} [(\underline{L}^{ik}(\vec{r}) + \underline{Q}) \underline{N}(\vec{r}, t)] \quad (2.30)$$

It is the combination of Eqs. (2.28)-(2.30) that allows the determination of data sensitivity coefficients in realistic reactor depletion studies.

Relative data sensitivity coefficients can also be obtained from Eq. (2.27) by simply multiplying by β^{ik}/R and integrating over time. This procedure gives

$$S_\beta = \frac{\beta}{R} \frac{dR}{d\beta} \Big|_{t_f} + \sum_k \sum_i \frac{\beta^{ik}}{R} \frac{dR}{d\beta^{ik}} \quad (2.31)$$

(static effect) (burnup effect)

Thus, the percent change in response R due to a 1% variation in the data utilized in a depletion calculation is just the sum of the static sensitivity coefficient at t_f and the indirect burnup sensitivities integrated over time.

The above time-dependent data sensitivity formulation has been implemented as an additional capability of the DEPTH-CHARGE system. Further details of the theory as well as information concerning the programming of the equations are given in Appendix C.

Although this is a relatively unexplored area of research, preliminary investigations³ indicate that the burnup effect in Eq. (2.31) can be a substantial portion of the overall sensitivity coefficient for many data/response pairs. Thus, the additional capability of the DEPTH-CHARGE system to calculate time-dependent sensitivity information appears to have significantly enhanced the present static sensitivity analysis capability at ORNL. In fact, static analyses are just a subset of the more general time-dependent capability now available within the DEPTH-CHARGE DPT system.

III. GENERAL INPUT DESCRIPTION

The purpose of this section is to provide user input instructions for the three modules comprising the DEPTH-CHARGE system--SUBMRG, CHARGE, and DEPTH. A brief description of each code, their respective interface file requirements, and their specific input descriptions follow. The input instructions given here reflect changes to the codes since the original publication of ORNL/CSD-78.

SUBMRG is probably the first code that will be needed since it is usually required at the end of a reference forward calculation. It is a set of subroutines that can merge the large number of interface data files from a forward calculation into a more manageable set of "stacked" files for use with the DEPTH and CHARGE modules. Its three main functions are to (1) stack files from a reference forward depletion calculation, (2) select appropriate files from a stacked file and create a new file, and (3) combine stacked files together to make a new composite file.

There are no specific input/output (IO) unit assignments for SUBMRG since these are input to the code. A complete set of input instructions for the SUBMRG module is given in Sect. III.1.

The next code in the set is the CHARGE module. CHARGE is a collection of utility routines for general data manipulation and input preparation. It greatly extends the usefulness of the overall DPT system through the automatic generation of (1) adjoint sources ($N^* = \partial R / \partial N$ and $S^* = \partial R / \partial \Psi$), (2) estimated perturbed responses, and (3) relative data sensitivity coefficients. Other useful capabilities include the preparation of RTFLUX and ATFLUX files for plotting with external codes³⁰ and the flexibility to extend present capabilities with minimum effort.

Table 3.1 provides the default IO assignments required for both the CHARGE and DEPTH modules. These default unit numbers are in addition to any "standard" interface files required in a given calculation. In particular, the CHARGE code always requires that the following standard interface files be present:

1. CONTRL, NDXSRF, and GEODST (usually obtained from the local DVENTR input processor),
2. GRUPXS, and
3. EXPOSE (used primarily to define the adjoint nuclide vector).

Additionally, a stacked ZNATDN file is always assumed to be present with the remaining files listed in Table 3.1 required depending on the calculational options chosen for a specific run. Detailed input instructions for the CHARGE code are provided in Sect. III.2.

The major calculational module in the system is the DEPTH code (for DEpletion Perturbation Theory). The DEPTH module (coupled with VENTURE) solves for the three adjoint functions of DPT and calculates the desired time-dependent derivatives of the final-time response with respect to the nuclide concentrations and nuclear data utilized in the reference model. Output from DEPTH are the NSTARR and DRDATA files, containing the time-dependent derivatives with respect to the nuclide vector and data vector, respectively. These files are then used in the CHARGE code to calculate perturbed responses and/or data sensitivity coefficients (see Appendix E for file specifications).

Default IO assignments for DEPTH are similar to those in CHARGE and are listed in Table 3.1. In particular, the DATAIN and stacked ZNATDN and RZFLUX files are always required. The stacked RTFLUX, ATFLUX, and PERTUB files may be utilized on option. Also, as noted above, the NSTARR and DRDATA files are output from DEPTH and job control instructions should be provided for these units.

TABLE 3.1

DEFAULT IO ASSIGNMENTS FOR THE DEPTH AND CHARGE MODULES

UNIT NUMBER	FILE NAME	FILE DESCRIPTION
55	DATAIN	Control instructions for DEPTH
56	RZFLUX	Stacked RZFLUX files
57	ZNATDN	Stacked ZNATDN files
58	NSTARR	Time-dependent nuclide derivatives
59	ZNDKDN	Nuclide derivatives for static k_{eff} response
61	RTFLUX	Stacked RTFLUX files
62	ATFLUX	Stacked regular ATFLUX files
63	PERTUB	Stacked PERTUB files
65	DFDATA	Time-dependent data derivatives
66	TDSENS	Relative data sensitivity coefficients
67	TMPFLX	Reformatted flux files for plotting

Standard interface files also required in DEPTH include:

1. CONTRL, NDXSRF, and GEODST (usually obtained from the local DVENTR special input processor),
2. GRUPXS,
3. EXPOSE and the EXPINS record on CONTRL.

In contrast to the CHARGE module, DEPTH utilizes data from the latter two files to define the adjoint nuclide vector as well as the overall adjoint depletion process. Therefore, specification of the EXPOSE and EXPINS files is important and should be similar to those used in the forward burnup calculation. Examples illustrating the use of these interface files will be given in Sect. IV.

The initial control instructions for the DEPTH module are contained in the DATAIN file, which is generated initially with the CHARGE module. However, DEPTH does require some minimal input each time it is called. A description of this required data is given in Section III.3.

The above brief description of the modules of the DPT system, coupled with the theoretical background given in Section II, should provide enough information for a general understanding of the DEPTH-CHARGE system. The remainder of this section contains specific input instructions for each module and the next section supplies detailed sample input and output descriptions as well as illustrations of the use of the overall system. These sample problems will illustrate several of the main characteristics of Depletion Perturbation Theory and will demonstrate the efficient use of the DEPTH-CHARGE system for both static and time-dependent perturbation/sensitivity studies.

III.1. Input for SUBMRG

Header Card: SUBMRG in columns 1-6

Data Card 1: (2I3) format

IFILE - number of different interface files to be manipulated

NOPT - + combine NOPT stacked files together to make a new file
 0 stack files from a reference VENTURE run (default)
 -1 select files from a stacked file and create a new file

Data Card 2 through IFILE + 1 (A8,20I3) format

HNAM1 - name of interface file to be manipulated

Note: Presently accepted files are ZNATDN, RZFLUX, RTFLUX, ATFLUX, PERTUB, and ZNDKDN.

IP(1) - unit number of stacked file to be created

IP(2-20) - meaning depends on value of NOPT

1. If NOPT is positive, IP(2-20) contain NOPT pairs of numbers. The first is the unit number of a stacked file to be combined and the second is the number of files on this stacked file (stack the stacked files in reverse time order).
2. If NOPT is zero, IP(2-20) contain the version numbers of the files to be stacked (stack files in reverse time order).
3. If NOPT is -1, IP(2-20) first contain the unit number of the present stacked file, then the number of files on this stacked file, and finally the order numbers of the files to be selected and put on IP(1).

Final Card: END in columns 1-3

Note: SURMRG was written to combine a large number of interface files into a more manageable set for use in the DEPTH-CHARGE system. DEPTH does the adjoint depletion calculation in reverse time order (relative to a forward burnup problem) and assumes that the necessary stacked files are in the correct order. Therefore, when NOPT is greater than or equal to zero, be sure to arrange the files properly.

III.2. Input for CHARGE

The CHARGE module uses the free-form FIDO input system.³¹

Header Card: CHARGE in columns 1-6

INPUT SECTION 1 Computational Options (always required)

1\$\$ Array (40 entries)

KEY(1) - KEY(20) - used as switches to select which operations are to be performed

IO(1) - IO(20) - used to override default IO unit assignments (usually zero)

KEY(1) - 0 no effect
 1 prepare flux file for plotting (1-D space-energy)
 2 prepare flux file for plotting (2-D space-space)

Note: Use of this option requires input file RTFLUX or ATFLUX (KEY(3) $\neq$ 0) and output file TMPFLX. Also, for KEY(1) = 2, if KEY(3) = -N, see Input Section 5 for further input.

KEY(2) - 0 no effect
 1 calculate mesh intervals and point volumes
 -1 also punch (free-form FIDO) first and/or second dimension boundaries

KEY(3) - 0 no effect
 N read stacked RTFLUX file (file N)
 -N read stacked ATFLUX file (file N)

Note: Use of this option requires input file RTFLUX or ATFLUX and the stacked files are assumed to be arranged in reverse time order.

KEY(4) - 0 no effect
 1 calculate $\bar{N}^*(t_f) = \partial K / \partial \bar{N}$
 -1 punch $\bar{N}^*(t_f)$ in free-form FIDO
 -2 create NSTARR interface file

Note: Use of this option requires input file ZNDKDN and possibly output file NSTARR. ZNDKDN can be created during the reference VENTURE calculation with a special modification to the PERTUBAT module. Also see Input Section 6 for further input. (Use of this option is no longer required.)

KEY(5) - 0 no effect
 1 calculate perturbed responses using the ZNATDN file
 -1 calculate perturbed responses using the REFUEL file

Note: Use of this option requires input file NSTARR and possibly REFUEL (if KEY(5) = -1). See Input Sections 2 or 3 for further input for KEY(5) = 1 or -1, respectively.

KEY(6) - 0 no effect
 1 calculate adjoint sources $\partial R/\partial N$, $\partial R/\partial \Psi$, and $\partial R/\partial \alpha$ and direct data sensitivity coefficients
 -1 also punch $\partial R/\partial N$ and $\partial R/\partial \Psi$ in free-form FIDO
 -2 create FIXSRC interface file with $\partial R/\partial \Psi$

Note: Use of this option requires input file RZFLUX. If KEY(6) = -2, the output FIXSRC file is added to the IO file management table structure as done in other modules of the VENTURE system. Also see Input Section 4 for further input.

KEY(7) - 0 no effect
 1 calculate power variance = $\int [P(\vec{r}) - \bar{P}]^2 d\vec{r}$
 2 also calculate adjoint sources required as input to DEPTH (not implemented)

Note: Use of this option requires input file RTFLUX (KEY(3) = N) and also that option KEY(2) $\neq$ 0. See Input Section 7 for further input.

KEY(8) - N file number of interest in stacked ZNATDN file (default N = 1)

KEY(9) - 0 no effect
 NOPT calculate relative data sensitivity coefficients where

NOPT - 1 calculate fission, capture, nu, transport, total scatter and chi sensitivity coefficients
 2 also calculate (n, α), (n,p), (n,2n), (n,D), and (n,T) sensitivities if these reactions are present in the GRUPXS file
 3 also calculate energy/fission, decay constant and fission yield sensitivity coefficients
 4 also calculate group-to-group scattering sensitivity coefficients

Note: Use of this option requires input file DRDATA and output file TDSENS. Also see Input Section 8 for further input.

KEY(10) - 0 no effect
 1 setup initial input instructions for the DEPTH module [$N^*(t_f)$ and/or $S^*(t_f)$ input from cards]
 -1 same as 1 with N^* and S^* calculated in present step [see KEY(4) and/or KEY(6)]

Note: Use of this option requires output file DATAIN. Also see Input Section 9 for further input.

KEY(11) - Input zero for this option (capability for calculation of generalized forward and adjoint sources for a worth-type response has not been implemented in this version of CHARGE).

KEY(12) - 0 no effect
NFILE combine NFILE TDSSENS files into a single file

Note: Use of this option requires input TDSSENS files (on units other than #66) and an output TDSSENS file on unit #66. See Input Section 11 for further input.

Fill remainder of the KEY and IO arrays with zeros.

T End data block

INPUT SECTION 2 Calculate Perturbed Responses Using ZNATDN File [required if KEY(5) = 1]

2\$\$ Array (10 entries)

ITY - 0 DEL contains percent change from reference densities ($\% \Delta N$)
1 DEL contains actual change in densities (ΔN)
-1 DEL contains perturbed densities and ΔN will be calculated from $\Delta N = N_P - N_R$

NSET - number of sets of perturbations

NZZT - maximum number of regions to be perturbed

NRESP - response number of interest (note that N^* may be dimensioned by NR = number of responses)

NEDIT - 0 minimum edit
1 also edit perturbed responses by nuclide (summed over regions) and by region (summed over nuclides)
2 also edit perturbed responses by nuclide and region

Fill remainder of array with zeros.

6** Array (2 entries)

RREF - reference response (for that portion of the reactor treated in the computational model)

XNORM - normalization factor that multiplies N^* (usually 1.0)

Note: XNORM can be utilized to alleviate problems in normalization. For example, when treating the K_{eff} response, it is sometimes necessary to let

$$XNORM = ALPHA * BIGDAD * K_{eff}$$

where

$$\text{ALPHA} = \int \phi(\vec{r}, E) d\vec{r} dE$$

$$\text{BIGDAD} = 1/\frac{1}{K_{eff}} \int d\vec{r} \int dE' \chi(E') \phi^*(\vec{r}, E') \int dE v \Sigma_f(\vec{r}, E) \phi(\vec{r}, E)$$

T End data block

3\$\$ Array (NSET entries)

NTP(NSET) - time step at which perturbation occurs (reverse time order relative to stacked ZNATDN file as in adjoint depletion calculation)

Note: If NTP is less than zero, the ABS(NTP) will be used for the ZNATDN file number but the first NSTARR record will be used.

T End data block

4\$\$ Array (NZZT entries)

NRP(NZZT) - regions to be perturbed

5** Array (NISOE * NZZT entries)

DEL(NISOE, NZZT) - defines perturbation to be made depending on value of ITY

T End data block

Note: Repeat 4\$\$ and 5** arrays NSET times.

INPUT SECTION 3 Calculate Perturbed Responses Using REFUEL File (required if KEY(5) = -1)

7\$\$ Array (5 entries)

NSET - number of sets of perturbations

NRESP - response number of interest

NEDIT - 0 minimum edit

1 also edit variation in density field due to fuel management perturbation

2 also edit perturbed responses by nuclide (summed over regions) and by region (summed over nuclide)

3 also edit perturbed responses by nuclide and region

Fill remainder of array with zeros.

8** Array (2 entries)

RREF - reference response (for that portion of the reactor treated in problem)

XNORM - normalization factor that multiplies N^* (see note under 6** array)

T End data block

9\$\$ Array (2* NSET entries)

NTP(NSE(1,2)) where

NTP(I,1) - file number in stacked ZNATDN file containing the zone concentrations prior to the present fuel management operation ($I \rightarrow t_{ik}$)

$$\text{Note: } \Delta \underline{C}^{ik} = \underline{P}_{SD}^{ik} \underline{Z}^{ik} + \Delta \underline{M}^{ik}$$

$$\begin{pmatrix} \text{change in} \\ \text{initial} \\ \text{condition} \\ \text{for time} \\ t_{ik} \end{pmatrix} = \begin{pmatrix} \text{change in} \\ \text{shuffling/} \\ \text{discharge} \\ \text{operator at} \\ t_{ik} \end{pmatrix} \begin{pmatrix} \text{reference} \\ \text{densities} \\ \text{at } t_{ik} \end{pmatrix} + \begin{pmatrix} \text{change in} \\ \text{makeup feed} \\ \text{vector at} \\ t_{ik} \end{pmatrix}$$

NTP(J,2) - time step number in NSTARR file corresponding to NTP(I,1), usually
 $\text{NTP(J,2)} = \text{NTP(I,1)} + 1 \text{ (} J \rightarrow t_{ik} \text{)}$

$$\text{Note: } \Delta R^{ik} = \underline{Z}^{Tik} \Delta \underline{C}^{ik}$$

$$\begin{pmatrix} \text{change in} \\ \text{response} \\ \text{due to per-} \\ \text{turbation} \\ \text{at } t_{ik} \end{pmatrix} = \begin{pmatrix} \text{transpose} \\ \text{of adjoint} \\ \text{nuclide} \\ \text{densities} \\ \text{at } t_{ik} \end{pmatrix} * \begin{pmatrix} \text{change in} \\ \text{density} \\ \text{field at} \\ t_{ik} \end{pmatrix}$$

10\$\$ Array (8 * NSET entries)

NSPEC (2,4,NSET) - specifies fuel management specification in effect, where

NSPEC (1,K,J) - reference fuel management specification K (up to 4) used in the unperturbed calculation at time step of interest

NSPEC (2,K,J) - fuel management specification K to be used in perturbed calculation at time step of interest

T End data block

INPUT SECTION 4 Calculate Adjoint Sources and Direct Data Sensitivity Coefficients for Responses of the form $R = R1/R2$ (required if KEY(6) $\neq 0$)

11\$\$ Array (10 entries)

MM - 0 microscopic reaction rate (ratio) response
 1 macroscopic reaction rate (ratio) response

NTFILE - stacked file number of interest in stacked RZFLUX file

NACT1 - R1 reaction type

NACT2 - R2 reaction type

Note: If NACT1 = 0 and NACT2 $\neq 0$ then $R = 1.0/R2$.

Choices for NACT1 and NACT2 are:

- 0 - not present
- 1 - absorption
- 2 - fission
- 3 - capture
- 4 - n, α
- 5 - n,p
- 6 - n,2n
- 7 - n,D
- 8 - n,T
- 9 - power
- 10 - cross sections for nuclide 1 are defaulted to unity and the rest are set to zero (can treat flux response when MM = 0)

NSET - 0 no effect
 N sum direct data sensitivity coefficients over N cross-section sets (NSET $\leq$ NSN = number of cross-section sets)

NKP - 0 no effect
 1 save direct sensitivity coefficients on scratch for later use [see option KEY(9)]
 -1 punch direct sensitivity coefficients in free-form FIDO

Fill remainder of array with zeros.

T End data block

12** Array (NISOE * NXS entries)

H1(I,NXS) - 1.0 include nuclide I
 0.0 exclude nuclide I

Note: R1 and R2 are of the form

$$R = \sum_{NZ} \int_{V_{NZ}} \alpha \underline{N}^T(\vec{r}) \underline{H}_1(\vec{r}) \underline{H}_2(\vec{r}) d\vec{r}$$

and

NXS = 1 if NACT1 or NACT2 $\neq$ 0
 NXS = 2 if NACT1 and NACT2 $\neq$ 0

13** Array (NGROUP * NXS entries)

H2(J,NXS) - 1.0 include group J
 0.0 exclude group J

14\$\$ Array (NREG * NXS entries)

NRZ(NZ,NXS) - 1 include region NZ
 0 exclude region NZ

15\$\$ Array (NSET entries)

ISSET(NSET) - cross-section set numbers to be included in summation over cross-section sets

T End data block

16\$\$ Array (3 entries) omit if KEY(6) $\neq$ -2

NBO1 - number of first dimension fine mesh intervals

NBO2 - number of second dimension fine mesh intervals

NBO3 - number of third dimension fine mesh intervals

T End data block

INPUT SECTION 5 Adjoint Flux Averaging Over Energy (required if KEY(1) = 2 and KEY(3) = -N)

18** Array (NGROUP entries)

GMULT(NGROUP) - group multipliers for averaging the 2-D adjoint flux over energy

Note:

$$\bar{\phi}^* = \frac{\sum_g \phi_g^* \Delta E_g GMULT_g}{\sum_g \Delta E_g GMULT_g}$$

where $GMULT_g = \begin{matrix} 1.0 & \text{include group } g \\ 0.0 & \text{exclude group } g \end{matrix}$

T End data block

INPUT SECTION 6 Calculate $N^*(t_f) = \Delta K / \Delta N$ from ZNDKDN File (required if KEY(4) $\neq$ 0)

19\$\$ Array (1 entry)

NTPZ - file number in stacked ZNDKDN file containing the $(\Delta K / \Delta N)_{t_f}$ values at time of interest

T End data block

INPUT SECTION 7 Calculate Power Variance (required if KEY(7) $\neq$ 0)

21\$\$ Array (5 entries)

NEDIT - 0 minimum edit

Fill remainder of array with zeros.

22\$\$ Array (NZONE entries)

NRP (I) - 0 exclude zone I from power variance calculation
 1 include zone I in power variance calculation

T End data block

INPUT SECTION 8 Calculate Relative Data Sensitivity Coefficients Using DRDATA File
 [required if KEY(9) $\neq$ 0]

26\$\$ Array (10 entries)

NSET - 0 no effect
 N sum sensitivity coefficients over N cross-section sets ($NSET \leq NSN$ = number of cross-section sets)

Note: If $NSET > 0$ only integrated sensitivity coefficients will be saved on interface file TDSSENS.

NINT - 0 no effect
 N sum sensitivity coefficients over N time steps ($NINT \leq NTOT$ = total number of time steps)

Note: If $NINT > 0$ only integrated sensitivity coefficients will be saved on interface file TDSSENS.

NEDIT - 0 no group-dependent edit
 1 edit capture, fission, nu, transport, total scatter, and chi sensitivity coefficients
 2 also edit optional cross-section data sensitivities
 3 also edit burnup data sensitivities
 4 also edit group-to-group scatter sensitivity coefficients

NSUM - 0 no effect
 1 sum principle sensitivities over energy and edit

NCORR - 0 apply transport cross-section correction to partial sensitivities
 1 do not apply correction

NDIR - 0 no effect
 -1 read direct sensitivity coefficients from scratch file [see KEY(6)] and add to indirect sensitivity coefficients calculated in this step
 N same as -1 but N sets of direct sensitivity coefficients from cards

Note: Direct effects are added to first-time step indirect effects

NDRDAT - 0 (default #65)
 N unit number of input DRDATA file

NTDSRN - 0 (default #66)
 N unit number of output TDSSENS file

NEL - number of materials for which elastic scattering data will be supplied

Note: If $NEL > 0$, an elastic scattering matrix will be constructed from the data input in the 32\$\$, 33**, and 34** Arrays. This matrix will then be subtracted from the total scattering matrix present in the GRUPXS file, giving an approximate inelastic scattering matrix. Sensitivity data will then be generated for both the elastic and inelastic scattering components

NTEST - 0 no effect
1 set 1-D total scatter sensitivity coefficients to be the sum of the elastic and inelastic sensitivity coefficients

27 Array** (2 entries)

RREF - reference response (for that portion of the reactor being modeled)

XNORM - normalization factor that multiplies all sensitivity coefficients (see note under 6** array)

T End data block

28\$\$ Array (NSET entries)

ISSET(NSET) - cross-section set numbers to be included in summation over cross-section sets

29\$\$ Array (NINT entries)

INT(NINT) - time step numbers to be included in summation over time steps (reverse time order)

T End data block

30\$\$ Array (1 entry) include if $NDIR > 0$

NTYPE - cross-section type included in direct effects, where
1 $\rightarrow$ capture, 2 $\rightarrow$ fission, 3 $\rightarrow$ n, α
4 $\rightarrow$ n,p, 5 $\rightarrow$ n,2n, 6 $\rightarrow$ n,D, and 7 $\rightarrow$ n,T

T End data block

31 Array** ($NISOE * NGROUP * NXSET$ entries) include if $NDIR > 0$

DIRS(NISOE,NGROUP,NXSET) - direct effect relative sensitivity coefficients

T End data block

Note: Repeat 30\$\$ and 31** arrays $NDIR$ times.

32\$\$ Array (NEL entries) include if $NEL > 0$

INEL(NEL) - position of nuclide in HNUC list for which elastic scattering data will be supplied

33** Array (NGROUP*NEL entries) include if NEL > 0

ELAST(NGROUP,NEL) - elastic scattering cross section by group and nuclide

34** Array (NGROUP*NEL entries) include if NEL > 0

EDREC(NGROUP,NEL) - average logarithmic energy decrement by group and nuclide

Note:

If energy-dependent data for EDREC is not available, use a constant value for each nuclide I, $EDREC = \frac{2}{A_I + 2/3}$, where A_I is the atomic mass number

T End data block

INPUT SECTION 9 Create Initial DATAIN Input File for DEPTH Module (required if KEY(10) ≠ 0)

35\$\$ Array (10 entries)

NZED - region number for special edit (usually used when IKEY(5) ≤ 1)

NTOT - total number of time steps (number of flux calculations)

NSSUB - number of sub-substeps (used to control the number of integration steps in the P* and S* calculations)

NNUC - number of nuclides in adjoint density vector (same as NISOE in the EXPOSE file)

NR - number of responses (must be 1 if I* calculation is to be done)

NREG - number of regions in problem

Note: If there are subzones then NREG = NSZ; if not, NREG = NZONE. In problems with subzones, it is assumed that zero nuclide densities have been assigned to the zones and that the zone densities can be calculated using

$$\underline{N}_z = \frac{1}{V_z} \sum_s \underline{N}_{zs} V_{zs}$$

where

$$V_z = \sum_s V_{zs} \quad \begin{array}{l} s \rightarrow \text{subzone} \\ z \rightarrow \text{zone} \end{array}$$

NBO1 - number of first dimension fine mesh intervals

NBO2 - number of second dimension fine mesh intervals

NBO3 - number of third dimension fine mesh intervals

NBO4 - number of energy groups

36\$\$ Array (10 entries)

IKEY(1) - 0 (counter that keeps track of present time step number)

IKEY(2) - 0 no effect
1 do S^* calculation

IKEY(3) - 0 no effect
1 do Γ^* calculation

IKEY(4) - 0 no effect
+N input $\partial R / \partial \underline{\Psi}_i$ (see option KEY(10) or 38** array)
-N also input $\partial R / \partial \alpha$ (not implemented)

where N - 1 no effect
2 multiply $\partial R / \partial \underline{\Psi}$ and $\partial R / \partial \alpha$ by α within DEPTH
3 divide $\partial R / \partial \underline{\Psi}$ and $\partial R / \partial \alpha$ by α within DEPTH

IKEY(5) - N various levels of edit, where

- N -0 N^* x volume at time step level
- 1 ALPHA (α) at time step level
 P^* at time step and substep levels
 S^* by group and zone at time step level
 $\int S^*(\vec{r}, E) \Psi(\vec{r}, E) d\vec{r} dE$ at time step level
- 2 N^{*+} effect by region
 P^{*+} effect by region
 Γ^{*+} effect (leakage, removal, inscatter, fission and total effects) by region
- 3 initial forward densities at time-step level
end of time-step densities
- 4 1-D reaction rates by nuclide and region
decay constants by nuclide
energy/fission by nuclide
diffusion coefficients by group and region
- 5 scattering cross section matrix by nuclide group-to-group
scattering sensitivity data

Note: The above quantities are printed only if calculated as specified by other options. Also, it should be cautioned that $N > 1$ can produce a sizeable amount of output if NREG is very large.

IKEY(6) - 0 no effect
 ±1 stacked ϕ , ϕ^* , and PERTUB files for Γ^* calculation are present (+1 write over existing file, -1 write new file)
 ±2 stacked ϕ and ϕ^* files for Γ^* calculation are present (+2 write over existing file, -2 write new file)

IKEY(7) - 0 no effect
 1 set P^* to zero within DEPTH

IKEY(8) - 0 account for additional term in evaluation of time-integrals resulting from equilibrium nuclides (see Appendix D)
 1 do not account for additional term

IKEY(9) - 0 no effect
 1 compute time-dependent data derivatives and store on DRDATA file (no edit)
 2 same as 1 with principle derivative edits

IKEY(10) - not used

T End data block

37** Array (NNUC * NREG entries) omit if KEY(10) $\neq$ 1

YNSTAR(NNUC,NREG) - final-time adjoint nuclide density by nuclide and region

T End data block

Note: Repeat 37** array NR times

38** Array (NGROUP*NZONE entries) omit if KEY(10) $\neq$ 1 or IKEY(4) = 0

DRDS(NGROUP,NZONE) - final-time $\partial R / \partial \Psi$ by group and zone

T End data block

INPUT SECTION 10 Calculate Generalized Sources and Direct Data Derivatives for Worth Response [required if KEY(11) $\neq$ 0] (not implemented)

INPUT SECTION 11 Combine NFILE TDSENS Files into a Single File [required if KEY(12) $\neq$ 0]

45\$\$ Array (5 entries)

NEDIT - 0 edit energy-integrated sensitivities after summation
 1 also 1-D energy-dependent sensitivities
 2 also optional cross-section sensitivities
 3 also burnup data sensitivities
 4 also 2-D scattering sensitivities

Fill remainder of array with zeros.

46\$\$ Array (NFILE entries)

IFILE(NFILE) - logical unit numbers of NFILE TDSENS files to be summed and output on unit #66

T End data block

Final Card: END in columns 1-3

III.3 Input for DEPTH

Header Card: DEPTH in columns 1-5

Data Card 1: (24I3) format

IFUEL(1) thru IFUEL(4) - fuel management specification number as specified in REFUEL file

IFUEL(5) thru IFUEL(24) - used to override default IO assignments (usually zero)

Notes:

(1) IFUEL(1) - 0 indicates that no adjoint refueling is to be done this time step.

(2) IFUEL(1) - (4) allow up to four fuel management specifications each time step.

(3) The adjoint calculation is done in reverse time order. Therefore, if specifications 1→N were used for an N cycle reference calculation, then specifications N→1 would be used in the adjoint calculation.

Data Card 2: (24I3) format

IDATE - 0 no effect
1 update following option switches for present time step

NZED - region number for special edit

NSSUB - number of sub-substeps

IKEY(2) - 0 no effect
1 do S* calculation

IKEY(3) - 0 no effect
1 do Γ^* calculation

IKEY(5) - N various edit levels (see 36\$\$ array in Section III.2)

IKEY(7) - 0 no effect
1 set P* to zero

IKEY(8) - 0 account for additional integral term resulting from equilibrium nuclides
1 no effect

IUPDATE(9) - unit number of stacked RTFLUX file to be written for use with VENTURE
(default #61)

IUPDATE(10) - unit number of stacked ATFLUX file to be written for use with VENTURE
(default #62)

Note: Remaining entries not used.

Final Card: END in columns 1-3

IV. ILLUSTRATIVE EXAMPLES

The purpose of this section is to provide the potential user some experience in setting up and performing DPT calculations with the DEPTH-CHARGE-VENTURE system. The sequence of calculations outlined in the following sample problems are representative of those required in a typical DPT analysis. The reference forward calculation which is required prior to any DPT analysis is first described. Illustrative adjoint computations with associated auxiliary calculations are then examined for three different responses of interest. Also contained in Sections IV.2-IV.5 are listings of the input and selected output files for the reference and adjoint sample cases discussed below. Reference to these sections may be useful during the discussion of the various calculations.

It should be noted that the input files in this current documentation have been modified to reflect changes in the code input specifications since the original documentation (ORNL/CSD-78) and also to reflect changes in the sample job control language needed to run the codes under the new BOLD VENTURE IV program package. However, the reader should be cautioned that the selected output files have not been updated, since there were only minor changes in edit headings, etc., and it was decided that the effort required to modify these was not warranted. Therefore, the user should note that there will be minor differences in computer printed output and the output listings given here (especially Version II versus Version I headings). Hopefully, these minor inconsistencies will not hinder the use of these problems as illustrative examples of the overall DPT methodology.

IV.1. Problem Description

Reference Calculation: During the development of the DEPTH module, several sample problems illustrating the use, accuracy, and benefits of DPT methods were formulated. However, a one-dimensional spherical fast reactor model was the real workhorse of the overall study. It was first utilized as a check on the equations coded into DEPTH and later used to investigate several aspects of the new method. Thus, since many of the DPT results published to date have been associated with this specific model, it will also be utilized here for the DPT demonstration problems.

This simplified 1-D calculational model consists of a three-region core surrounded by two radial blanket regions. The initial nuclide concentrations are representative of a $^{233}\text{U}/^{238}\text{U}$ denatured LMFBR core with a THO_2 radial blanket. A single set of core- and blanket-averaged cross sections in nine energy groups are utilized throughout the burnup cycle. Specific information relative to the transmutation processes modeled in the burnup calculations can be extracted, if desired, from the input listing in Sect. IV.2. However, of real interest here is the general method of performing DPT studies and not the analysis of a real reactor system. In this light, the reader is cautioned that the LMFBR model described here is not very realistic, and that the sensitivity data generated in the following examples should not be utilized outside the framework of the intended sample problems.

The first step in performing a static or time-dependent perturbation/sensitivity analysis is the calculation of the reference reactor. For our purposes, the reference calculation will consist of a single depletion cycle, a refueling, and the calculation of the beginning-of-cycle-two (BOC2) reference state. This particular computation allows the illustration of several aspects of DPT, including the multicycle capability of the method. The actual sequence of calculations performed can be observed from inspection of the input listing given in Sect. IV.2. As apparent, the calculation proceeds as would any VENTURE-BURNER depletion calculation. However, in this case, a forward and regular-adjoint flux calculation is required since both the ϕ and ϕ^* flux files are utilized in the calculation of the generalized adjoint flux during subsequent DPT adjoint computations. However, since all future DPT analyses use data from this one reference calculation, the initial cost increase in this step does not appear to be overly restrictive.

Since the present reference calculation represents a straightforward application of the VENTURE-BURNER computational system, no further details will be presented here and no output from these modules will be listed. The last step in the reference calculation is the manipulation of the many data files required for future DPT studies. The SUBMRG module, in its capacity to stack interface data files, is utilized for this purpose. The use of this module is straightforward and its input and printed output are contained in the next subsection. The storage of the necessary data files for future use completes the forward reference calculation.

Sample Problem #1: One consideration of relative importance when analyzing fast reactors operating on the denatured fuel cycle is the inventory of ^{232}U present in the fuel cycle and the consequences of its highly radioactive decay chain. Since this nuclide is created during the burnup of thorium-bearing fuel, time-dependent methods are required if sensitivity studies are to be performed. Therefore, as a first application of DPT, let us consider the simple case of the ^{232}U inventory in the reactor after a single burnup time step as our response of interest.

This particular sample problem is treated in some detail in Ref. 1, where explanations as to the meaning and use of the adjoint functions are given. For our purposes, however, an outline of the steps required in the adjoint depletion calculation is sufficient. This outline is provided in Table 4.1 and illustrates all the basic steps needed for a simple DPT analysis using the DEPTH-CHARGE-VENTURE system. The first step is to retrieve the required data from the forward calculation using the SUBMRG code. In this case, we have chosen the fifth file in each stacked file since these correspond to the initial conditions for the time step of interest. Then, using essentially the same input as for the forward case, the problem geometry, exposure information, and cross section referencing information are reconstructed as detailed in the input listing given in Sect. IV.3. It should be noted that the nuclide density arrays in the forward DVENTR input are no longer required since this information will be supplied through the use of the DEPTH module. With this exception, the only variation in the input from the reference case should be the specification telling VENTURE to solve the generalized adjoint problem rather than the forward problem. Also, since DEPTH uses the exposure data from the EXPINS and EXPOSE files, these interface file specifications generally should be the same as in the forward problem. The final input preparation step involves the setup for the CHARGE and DEPTH modules and, as illustrated in the input listing and in the input descriptions for the individual modules, preparation of this data is rather straightforward.

Once the input has been prepared, the calculational flow proceeds as follows:

A. DEPTH:

1. using the input source $[N^*(t_i) = \Delta R / \Delta N|_{t_i}]$, solve the nuclide adjoint and power adjoint equations
2. sum the N^* effect and P^* effect at the initial time, $t = t_i^*$, and write NSTARR file
3. compute the generalized adjoint source and write FIXSRC file
4. from stacked file, write appropriate ZNATDN, RTFLUX, and ATFLUX files

B. VENTURE:

1. using FIXSRC file, compute generalized adjoint flux
2. calculate appropriate $\Gamma^*\phi$ integrals and write PERTUB file

TABLE 4.1
SEQUENCE OF COMPUTATIONS PERFORMED IN
DPT SAMPLE PROBLEM #1

Order #	Module #	Module Name	Function
1	99	SUBMRG	select BOC1 files from stacked files
2	2	DVENTR	input for VENTURE module
3	2	DUTLIN	input for EXPINS file for exposure control
4	1	INPUT PROCESSOR	create EXPOSE file with basic exposure specifications
5	99	CHARGE	create initial input for DEPTH
6	99	DEPTH	compute N*, P*, and S* adjoint functions and write NSTARR file
7	7	VENTURE	compute generalized adjoint flux and perturbation integrals
8	99	DEPTH	calculate Γ^* effect and update NSTARR file

C. DEPTH:

1. using PERTUB file, compute Γ^* effect
2. update NSTARR file

$$N^* \text{effect}|_n = [(N^* \text{effect} + P^* \text{effect}) + \Gamma^* \text{effect}]_n^+$$

3. exit

Note that this calculation has only one depletion step, but extension to multiple time steps is simple and just involves alternating between DEPTH and VENTURE calculations. From the viewpoint of VENTURE, the sole purpose of the DEPTH module is to supply the FIXSRC file (stacked files are just "unstacked" by DEPTH). From the viewpoint of DEPTH, the primary role of VENTURE is the production of the PERTUB file. It is important that the user understands this simple relationship since it allows considerable flexibility within the system (as we will see in the next sample problem).

At this point in the calculation, we have an NSTARR file that contains the $N^*(t_i)$ importance functions that relate changes in the beginning-of-cycle (BOC) nuclide density field to the response of interest--the ^{232}U inventory after one depletion step. Thus we could easily estimate what design variations would be needed to alter the response in some prescribed manner. If, on the other hand, this was only a secondary response that had little weight in the overall design, we could still estimate the change in the ^{232}U inventory due to design alterations from reference (due to other considerations). Actual use of the NSTARR file will be deferred to the third sample problem.

Thus, we have completed the first sample problem with relatively little effort. A complete listing of the input and selected printed output from this problem are contained in Sect. IV.3. Consideration of the input shows that the majority of the required data is taken directly from the reference case. Thus, as stated earlier, once the forward calculation has been performed with the VENTURE-BURNER system, the adjoint calculation within the DEPTH-CHARGE-VENTURE system becomes trivial. Lastly, it should be noted that the edit from the adjoint case should be self-explanatory, especially when one compares the printed output with the appropriate equations described in Sect. II.

Sample Problem #2: The next problem to be examined will be the generation of data sensitivity coefficients for a BOC k_{eff} response. This response is of special interest for several reasons. First of all, the criticality of the system is one of the most important parameters in reactor physics studies, and it is important to know the sensitivity of this parameter to the data utilized. Also since we have chosen a BOC response, we are really addressing a static sensitivity problem, thus illustrating the methodology of performing static sensitivity analyses with the DEPTH-CHARGE system. Lastly, the static k_{eff} response is special in that no generalized adjoint flux calculation is required since the sensitivity coefficients are expressed in terms of $\phi^* \phi$ integrals rather than $\Gamma^* \phi$ integrals.

The data and sequence of calculations required for this case are generally similar to Sample Problem #1, with some slightly different interpretations. Referring to the input listing in Sect. IV.4, we first note that the SUBMRG module has selected the BOC PERTUB file as well as the files retrieved for case 1. This file contains the $\phi^* \phi$ integrals calculated in the forward problem and thus has all the information needed for the problem at hand. However, in order to use the capabilities of the CHARGE module, this data must be in the format of the DRDATA file.

We therefore proceed as if a static sensitivity calculation were to be performed, and, as noted in Sect. II, this is the same as a single depletion step problem with a very small time interval. Thus the EXPINS file for this case has been modified to indicate a 0.001 day time step. Also, since the DEPTH module is to perform an adjoint depletion calculation, an EXPOSE file must be supplied. This file could have been the same as for case 1; however, for users interested in only static sensitivity studies, a "dummy" EXPOSE file can be easily prepared (see input listing). The main purpose of a dummy EXPOSE file is the definition of the adjoint nuclide density vector (nuclide names).

Continuing as in case 1, DEPTH now performs a dummy adjoint calculation for a time step of 0.001 days (this is extremely fast, of course). The input sources, $\partial R/\partial N$ and $\partial R/\partial \Psi$, were zero and all the output quantities are also zero. However, several internal flags (in the DATAIN file) are now set that allows one to continue the desired calculation. It is at this point that we deviate from the sequence of case 1. Instead of calling the VENTURE model, we directly recall the DEPTH code. On its first call, DEPTH unstacked the appropriate PERTUB file for future use, and therefore, the second call proceeds as if the PERTUB file presently available had just been supplied by a VENTURE adjoint flux calculation. Thus, an NSTARR file is written containing only the Γ^* effect and a DRDATA file containing the desired data derivatives is produced, completing the dummy adjoint calculation.

In the final step of this sample problem, CHARGE processes the DRDATA file, calculates relative data sensitivity coefficients, and creates a TDSSENS file for future use. This step is normally performed in a job separate from the adjoint depletion calculation since it is an auxiliary calculation only requiring that the DRDATA file exist. Also, in this case, the value of ALPHA calculated in DEPTH is required to specify XNORM (see note after 6** Array in Sect. III.2).

Finally, it should be emphasized that static calculations in practice are much easier than indicated above, since most of the details of the calculations are transparent to the user. All the user needs to remember for a static calculation is to supply a dummy EXPOSE file and a small depletion step; the rest of the calculation proceeds as normal.

Sample Problem #3: This final test case combines several of the features discussed previously into a full static and time-dependent perturbation/sensitivity study. The response of interest here is the "static" breeding ratio (B.R.) at the BOC2. Although this is a "static" response, the operating history of the reactor prior to this point influences the calculation of the BOC2 B.R. Thus, a time-dependent analysis is in order to assess the impact of the burnup process on the response of interest.

The sequence of required calculations is similar to that for the previous cases. We first retrieve the necessary data files using the SUBMRG module, being careful to pick only the files required in this calculation. For example, the EOC1 flux files saved from the forward calculation are not actually used during the calculation of the forward problem. They only allowed one to investigate the state of the reactor at shutdown. Thus, since this data was not utilized in the forward case, it should not be included in the adjoint depletion problem either.

The next step in the calculation is the specification of the necessary input files. This is done in the same manner discussed previously, except for the DATAIN input file for DEPTH. This is created with the CHARGE module, and in this case, must contain both the $\partial R/\partial N$ and $\partial R/\partial \Psi$ sources since the B.R. response depends directly on both the nuclide and flux fields at BOC2. These sources are calculated on option [see KEY(6)] in the CHARGE module and require relatively little effort on the part of the user. With the specification of the initial DATAIN file, the adjoint depletion calculation proceeds as normal, alternating between DEPTH and VENTURE calculations.

Of special interest are the first two calls to the DEPTH module. Since we are initially treating a "static" response, the first call to DEPTH only sets the appropriate internal flags so that the calculation may continue. VENTURE is then accessed to compute the "static" generalized adjoint flux and appropriate perturbation integrals (recall that for the k_{eff} response, this step was bypassed). DEPTH then computes the indirect I^* effect as usual. However, at this point in its second call, DEPTH has been instructed to perform an adjoint fuel management calculation, since it was at this point in the forward calculation that the refueling for cycle 2 was initiated. Although this process is somewhat difficult to explain (see Refs. 1-2), all the user is required to supply is the fuel management specification number that was utilized in the forward problem. Thus again we see that, once the forward problem has been solved, the adjoint calculational setup becomes trivial.

The final step in this third sample problem is a set of auxiliary calculations performed using the CHARGE module. Using the NSTARR file, we first assess the impact of nuclide perturbations at the BOC1 on the B.R. response at the BOC2. In the present case, we uniformly perturbed the BOC1 density field by 1%. Although this is not a realistic perturbation, it does allow one to investigate the relative importance of the various nuclides and space regions to the response of interest. The printed output is the estimated ΔR caused by the specified perturbation. Thus for a 1% perturbation, we see that this is one method of obtaining nuclide sensitivity coefficients by zone (or summed over all space).

The second computation performed by the CHARGE module is the calculation of relative data sensitivity coefficients. In this case, we first calculate the direct effect and then add this component to the indirect burnup effects summed over time. The final result is a TDSSENS file containing sensitivity data that relates a change in a specified data parameter throughout the burnup process to the response of interest.

This completes the discussion of the sample problems. The next four subsections provide input and selected output listings from the reference case and three examples just discussed. Hopefully, this data coupled with the brief theoretical descriptions provided earlier will be sufficient for the efficient use of the DEPTH-CHARGE Depletion Perturbation Theory System within the framework of the VENTURE-BURNER modular system. Extension of the modules described here for use with other modular systems should be straightforward if one assumes compatibility with the CCCC interface file structure. If this requirement is not met, considerable reprogramming may be required.

IV.2. Input/Output for Reference Calculation

This section contains a partial input and output listing for the reference sample problem. To conserve space, most of the cross-section card input has been omitted. Also as mentioned previously, since this calculation represents a straightforward application of the VENTURE-BURNER modular system, the output is limited to that from the SUBMRG module. These partial input/output listings are contained in Tables 4.2 and 4.3, respectively.

IV.3. Input/Output for Problem #1

This section contains a complete input listing and partial output listing for Sample Problem #1. The output listing is fairly representative of the typical printed output from the various codes and therefore provides a detailed account of the actual calculational sequence. It is suggested that this sample problem's output be utilized as the basis for a general understanding of the information provided from a simple DPT calculation. The reader should also refer to Ref. 1 where this sample problem is treated in much more detail. The input/output listings for Sample Problem #1 are contained in Tables 4.4 and 4.5, respectively.

IV.4. Input/Output for Problem #2

This section contains a complete input listing and partial output listing for Sample Problem #2. The key points to note in this example are the general method of performing static sensitivity calculations and the specific treatment of the static k_{eff} response. The input/output listings for Sample Problem #2 are contained in Tables 4.6 and 4.7, respectively.

IV.5. Input/Output for Problem #3

This section contains a complete input listing and partial output listing for the last sample problem. This case represents the most general DPT calculation of the three discussed in this report. Also, since this case represents a full multicycle depletion calculation (four time steps), the actual edit from the code was considerably more than could be reproduced here. For this reason, data from time steps 3 and 4 have been completely omitted. Partial edit from the CHARGE module and the first few calls to DEPTH have been included to illustrate the calculation of adjoint sources and the adjoint refueling process, respectively. Also included is output from the auxiliary calculations performed in the last step of the calculation. The input/output listings for Sample Problem #3 are contained in Tables 4.8 and 4.9, respectively.

TABLE 4.2

INPUT FOR REFERENCE CALCULATION

```

//JRWPROB0 JOB (19934,IO15),'JR WHITE UNIV LOWELL',TIME=(1,40)
/*JOBPARM LINES=20
/*ROUTE PRINT RMT162
//BOLDFOUR PROC GOSIZE=520K,GOTIME=,MODULE=SCALE,
// NB1=1,NB2=1,B1=3520,B2=32000,NX=2,NS=50,N1=100,
// N2=1,N3=1,N4=1,N5=1,N6=1,N7=1,N8=1,N9=1,N10=1,N11=1,N12=1,N13=1,
// N14=1,N15=1,N16=1
//GO EXEC PGM=qMODULE,
// REGION=qGOSIZE,TIME=qGOTIME
//STEPLIB DD UNIT=3330V,VOL=SER=VLFS01,DISP=SHR,
// DSN=JLL.BVFOUR.LOADM
// DD UNIT=3330-1,VOL=SER=NE3330,DISP=SHR,DSN=E.LMP00000.SCALF.PGMS
//PRINT DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//FT01F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT02F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT03F001 DD UNIT=SYSDA,SPACE=(80,(10)),
// DCB=(RECFM=F,BLKSIZE=80)
//FT04F001 DD UNIT=SYSDA,SPACE=(3200,(qN1,qNX)),
// DCB=(RECFM=FBS,LRECL=80,BLKSIZE=3200)
//FT05F001 DD UNIT=SYSDA,SPACE=(3120,(200,100)),
// DCB=(RECFM=FB,BUFNO=1,LRECL=80,BLKSIZE=3120)
//FT06F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//FT07F001 DD SYSOUT=B,DCB=(RECFM=F,BLKSIZE=80)
//FT08F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,2)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT09F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT10F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT11F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,qNX)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT12F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,qNX)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT13F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,2)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT14F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT15F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT16F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,qNX)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT17F001 DD UNIT=SYSDA,SPACE=(qB1,(qN16)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)

```

TABLE 4.2 (Contd.)

```

//FT18F001 DD UNIT=SYSDA, SPACE=(qB1,(qN16)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT19F001 DD UNIT=SYSDA, SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT20F001 DD UNIT=SYSDA, SPACE=(qB1,(qN13)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT21F001 DD UNIT=SYSDA, SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT22F001 DD UNIT=SYSDA, SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT23F001 DD UNIT=SYSDA, SPACE=(qB1,(qN3)),
//          DCB=(RECFM=FT,BUFNO=qNB1)
//FT24F001 DD UNIT=SYSDA, SPACE=(qB1,(qN2)),
//          DCB=(RECFM=FT,BUFNO=qNB2)
//FT25F001 DD UNIT=SYSDA, SPACE=(qB1,(qN12)),
//          DCB=(RECFM=FT,BUFNO=qNB1)
//FT26F001 DD UNIT=SYSDA, SPACE=(qB1,(qN12)),
//          DCB=(RECFM=FT,BUFNO=qNB1)
//FT27F001 DD UNIT=SYSDA, SPACE=(qB1,(qN2)),
//          DCB=(RECFM=FT,BUFNO=qNB2)
//FT28F001 DD UNIT=SYSDA, SPACE=(qB1,(qN2)),
//          DCB=(RECFM=FT,BUFNO=qNB2)
//FT29F001 DD UNIT=SYSDA, SPACE=(qB1,(qN14)),
//          DCB=(RECFM=FT,BUFNO=qNB2)
//FT30F001 DD UNIT=SYSDA, SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT31F001 DD UNIT=SYSDA, SPACE=(qB1,(qN1,qNX)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT32F001 DD UNIT=SYSDA, SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT33F001 DD UNIT=SYSDA, SPACE=(qB1,(qN4)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT34F001 DD UNIT=SYSDA, SPACE=(qB1,(qN1,qNX)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT35F001 DD UNIT=SYSDA, SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT36F001 DD UNIT=SYSDA, SPACE=(qB1,(qN6,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT37F001 DD UNIT=SYSDA, SPACE=(qB1,(qN15,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT38F001 DD UNIT=SYSDA, SPACE=(qB1,(qN15,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT39F001 DD UNIT=SYSDA, SPACE=(qB1,(qN15,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT40F001 DD UNIT=SYSDA, SPACE=(qB2,(qN5)),
//          DCB=(RECFM=FT,BUFNO=qNB2)
//FT41F001 DD UNIT=SYSDA, SPACE=(qB1,(qN4)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT42F001 DD UNIT=SYSDA, SPACE=(qB2,(qN7)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB2,BLKSIZE=qB2)
//FT43F001 DD UNIT=SYSDA, SPACE=(qB2,(qN8)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB2,BLKSIZE=qB2)

```

TABLE 4.2 (Contd.)

```

//FT44F001 DD UNIT=SYS DA, SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT45F001 DD UNIT=SYS DA, SPACE=(qB1,(qN9)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT46F001 DD UNIT=SYS DA, SPACE=(qB1,(qN10)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT47F001 DD UNIT=SYS DA, SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT48F001 DD UNIT=SYS DA, SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT49F001 DD UNIT=SYS DA, SPACE=(qB1,(qN11)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT50F001 DD UNIT=SYS DA, SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT51F001 DD UNIT=SYS DA, SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT52F001 DD UNIT=SYS DA, SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT53F001 DD UNIT=SYS DA, SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT54F001 DD UNIT=SYS DA, SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT55F001 DD UNIT=SYS DA, SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT56F001 DD UNIT=SYS DA, SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT96F001 DD UNIT=SYS DA, SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT97F001 DD UNIT=SYS DA, SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT98F001 DD UNIT=SYS DA, SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=qNB1, BLKS IZ E=qB1)
//FT99F001 DD SYSOUT=A, DCB=(RECFM=VBA, LRECL=137, BLKS IZ E=1100)
//BOLDFOUR PEND
/*
// EXEC SPDASCR
//SYSIN DD *
      T.JRW00000.GRUPXS.DPT.NSAMPLE
      T.JRW00000.ZNATDN.NALL
      T.JRW00000.RZFLUX.NALL
      T.JRW00000.RTFLUX.NALL
      T.JRW00000.ATFLUX.NALL
      T.JRW00000.PERTUB.NALL
//BURN EXEC BOLDFOUR,
// NB1=1,NB2=1,N1=4088,B2=7200,N1=10,N2=60,N3=20,N4=10,N5=30,N6=10,
// N7=10,N8=10,N9=10,N10=10,N11=10,
// N12=10,N13=10,N14=10,N15=10,NX=20,NS=30,N16=10,
// GOSIZE=520K
//GO.FT12F001 DD UNIT=SPDA, DISP=(NEW,CATLG),
// DSN=T.JRW00000.GRUPXS.DPT.NSAMPLE,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=1, BLKS IZ E=3520)

```

TABLE 4.2 (Contd.)

```

//GO.FT55F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT56F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.RZFLUX.NALL,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT57F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.ZNATDN.NALL,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT61F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.HTFLUX.NALL,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT62F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.ATFLUX.NALL,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT63F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.PERTUB.NALL,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT70F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT71F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT72F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT73F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT74F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT75F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT76F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT77F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT78F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT79F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT80F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT81F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT82F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT83F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)

```

TABLE 4.2 (Contd.)

```

//GO.FT84F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT85F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.SYSIN DD *
=CONTROL1
PROB0A REFERENCE CALCULATION FOR DPT SAMPLE PROBLEMS
060C00 0 1
1 2 6 2 2 1 2 1 99 7 13 7 13 7 13 7 2 99 7 99
END
INPUT PROCESSOR
OV ISOTXS $CITATI ON XS $
1D 9 52 0 8 0 1 3R
2D /
* ANISN TO CITATION MODULE - 9 GROUP URANIUM RUN *
TH228CTH232CPA231CPA233CU-232CU-233CU-234CU-235C*
*U-236CU-238CNP237CNP239CPU238CPU239CPU240CPU241CPU242CAM241C*
*AM243CCM244CSS CNA CO-16 CCHAN CCTLRDCFP CTH228RTH232R*
*PA231RPA233RU-232RU-233RU-234RU-235RU-236RU-238RNP237RNP239R*
*PU238RPU239RPU240RPU241RPU242RAM241RAM243RCM244RSS RNA R*
*O-16 RCHAN RCTLRDRFP R*
4.83000E-02 6.12700E-01 2.08600E-01 1.28600E-01 3.60600E-03
0.0 4R 1.00000E 00 9R 1.49180E 07 6.06530E 06

COMPLETE CROSS SECTION EDIT IS OMITTED HERE

1.10800E 06 4.97870E 05 4.08680E 04 3.35460E 03 2.61260E 03 1.01300E 03
1.00000E-01 1.00003E-04
0 3 6 9 12 15 18 21 24 27
30 33 36 39 42 45 48 51 54 57
60 63 66 69 72 75 78 81 84 87
90 93 96 99 102 105 108 111 114 117
120 123 126 129 132 135 138 141 144 147
150 153
*FP RL CITNXSFP RJ. *
1.17000E 02 0.0 5R
4 0 7R 1 2R 0 2R 1 2R 2
3 4 2 5R 1 9R
5D 8.79669E 00 1.20290E 01 1.41180E 01 1.43950E 01 1.69200E 01
1.97550E 01 2.46910E 01 6.17299E 01 9.00900E 00 0.0 9R
1.23710E-02 5.13249E-02 9.05599E-02 2.72920E-01 8.92650E-01 1.86400E 00
4.31740E 00 2.33710E 01 6.58500E 00
7D 4.89580E 00 9.66759E 00 2.33040E 00 1.31090E 01 1.42590E 00
1.11700E 00 1.40470E 01 9.46230E-01 8.48880E-01 5.13370E-01 1.60030E 01
5.60339E-02 1.60700E 01 2.37110E-02 2.03250E 01 1.82100E 00 3.83580E 01
4.72140E-02 2.42400E 00 3.98400E-04
STOP
END
DCRSPR
1
END

```

TABLE 4.2 (Contd.)

DVENTR

001

1000.0+06

1.0
1.0-051.0
5.0-05

1 0 1 4 50
1 0 0 0 1 0 0 0 2 0 0 0

2 2 2

6 2

003

3 1 2

004

16 26.2133 16 26.2133 16 26.2133 10 22.2350 10 22.2350

005

1 2 3 4 5

012

0

1 3 1 1

4 5 2 2

0

013

26

26

TH22 8CTH232 CPA231 CPA23? CU-232 CU-233 CU-234 CU-235 CU-236 CU-238 CNP237 CNP239C
PU23 8CPU239 CPU240 CPU241 CPU242 CAM241 CAM243 CCM244 CSS CNA CO-16 CCHAN C
CTLRDCFP C

26

TH22 8RTH232 RPA231 RPA233 RU-232 RU-233 RU-234 RU-235 RU-236 RU-238 RNP237 RNP239R
PU23 8RPU239 RPU240 RPU241 RPU242 RAJ241 RAM243 RCM244 RSS RNA RO-16 RCHAN R
CTLRDRFP R

020

1 0.0

1 3

TH232C 2.76690-03U-233C 8.23240-04U-235C 6.25940-06U-238C 4.19700-03
PU239C 1.54670-04PU240C 8.62240-06PU241C 3.26950-07PU242C 1.11060-08
NA C 8.59360-03O-16 C 1.69590-02SS C 1.47570-02

4 5

TH232R 1.44750-02U-233R 1.64220-04NA R 7.00910-03O-16 R 2.33580-02
SS R 1.16980-02CTLRER 6.42050-04

0

END

DUTLIN

EXPINS

0 1 0 40

91.3125

0 1

0 1

1

0 0

1 1

0

0 0

BLANK

END

TABLE 4.2 (Contd.)

INPUT PROCESSOR

OV EXPOSE

1D / FILE REFERENCE INFORMATION

0 24 0 1 0 20 1 20 0 0 0 28 0 8R

2D / TITLE AND NUCLIDE NAMES

* DEPLETION MODULE WITH 20 HM 1 FP # 3 OTHER NUCLIDES *

*TH228 * *TH232 * *PA231 * *PA233 * *U 232 * *U 233 * *U 234 * *U 235 *

*U 236 * *U 238 * *NP237 * *NP239 * *PU238 * *PU239 * *PU240 * *PU241 *

*PU242 * *AM241 * *AM243 * *CM244 * *FP RL * *NA * *SS COR* *0 16 *

3D / REFERENCE DATA

0.0 /

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 /

21 /

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 /

4D / DECAY DATA

1.156-08 1.580-18 6.312-13 2.971-07 2.968-10 1.360-13 8.860-14 3.080-17

9.150-16 4.870-18 9.980-15 3.414-06 2.540-10 9.000-13 3.340-12 1.560-09

5.780-14 4.800-11 2.750-12 1.220-09

5D / FISSION PRODUCT YIELD DATA

1.0 20R

6D / CHAIN DATA FOR MATRIX EXPONENTIAL

2 4 2 2 3 5 3 5 2 4 5 5 4 6 1 4 7 2 5 1 1 5 6 2 6 5 5 6 7 2

7 8 2 8 9 2 9 11 2 10 11 5 10 12 2 11 13 2 12 14 1 13 14 2

14 15 2 15 16 2 16 17 2 16 18 1 17 19 2 19 20 2

21 21 2 22 22 2 23 23 2 24 24 2

STOP

END

DUTLIN

REFINS 0 20 0 20 1

1.0

-1

END

INPUT PROCESSOR

OV REFUEL

1D 0 0 24 0 0 0 0 0 2 11 1 0 1 24 2 0 5R

2D

*TH228 * *TH232 * *PA231 * *PA233 * *U 232 * *U 233 * *U 234 * *U 235 *

*U 236 * *U 238 * *NP237 * *NP239 * *PU238 * *PU239 * *PU240 * *PU241 *

*PU242 * *AM241 * *AM243 * *CM244 * *FP RL * *NA * *SS COR* *0 16 *

0.0 24R 0.0 24R 0.0 24R 0.0 24R

4D

2 6 8 10 14 15 16 17 22 23 24

2 6 8 10 14 15 16 17 22 23 24

2.7669-3 8.2324-4 6.2594-6 4.1970-3 1.5467-4 8.6224-6

3.2695-7 1.1106-8 8.5936-3 1.4757-2 1.6959-2

2.4902-3 8.2324-4 6.2594-6 4.4736-3 1.5467-4 8.6224-6

3.2695-7 1.1106-8 8.5936-3 1.4757-2 1.6959-2

TABLE 4.2 (Contd.)

```

5D
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
6D 0.0 0
7D 1 1 0 0 17R /REF FUEL MANG EOC1
8D 1 0 0 1 0 3
7D 1 1 0 0 17R /EXCHANGE 10% TH232 WITH U238 IN FEED (PERT #1)
8D 2 0 0 1 0 3
STOP
END
FUELMAN
END
DUTLIN
REFINS      0 20  0 20  1
              1.0

              1                      1

END
FUELMAN
END
SUBMRG
  5  0
KZFLUX  56  5  4  3  2  1
ZNATDN  57  5  4  3  2  1
RTFLUX  61  5  4  3  2  1
ATFLUX  62  5  4  3  2  1
PERTUB  63  5  4  3  2  1
END
//

```

TABLE 4.3

SELECTED OUTPUT FOR REFERENCE CALCULATION

*** MODULE *SUBMRG* VERSION 2 (08/09/83) IS BEING ACCESSED ***

IPLE = 5 NOPT = 0

RZFLUX IP(I) = 56 5 4 3 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 RZFLUX VERS 5 COPIED FROM UNIT 19 TO UNIT 56
 RZFLUX VERS 4 COPIED FROM UNIT 74 TO UNIT 56
 RZFLUX VERS 3 COPIED FROM UNIT 35 TO UNIT 56
 RZFLUX VERS 2 COPIED FROM UNIT 34 TO UNIT 56
 RZFLUX VERS 1 COPIED FROM UNIT 20 TO UNIT 56

ZWATDN IP(I) = 57 5 4 3 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 ZWATDN VERS 5 COPIED FROM UNIT 78 TO UNIT 57
 ZWATDN VERS 4 COPIED FROM UNIT 73 TO UNIT 57
 ZWATDN VERS 3 COPIED FROM UNIT 38 TO UNIT 57
 ZWATDN VERS 2 COPIED FROM UNIT 33 TO UNIT 57
 ZWATDN VERS 1 COPIED FROM UNIT 15 TO UNIT 57

RTFLUX IP(I) = 61 5 4 3 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 RTFLUX VERS 5 COPIED FROM UNIT 80 TO UNIT 61
 RTFLUX VERS 4 COPIED FROM UNIT 75 TO UNIT 61
 RTFLUX VERS 3 COPIED FROM UNIT 70 TO UNIT 61
 RTFLUX VERS 2 COPIED FROM UNIT 35 TO UNIT 61
 RTFLUX VERS 1 COPIED FROM UNIT 30 TO UNIT 61

ATFLUX IP(I) = 62 5 4 3 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 ATFLUX VERS 5 COPIED FROM UNIT 81 TO UNIT 62
 ATFLUX VERS 4 COPIED FROM UNIT 76 TO UNIT 62
 ATFLUX VERS 3 COPIED FROM UNIT 71 TO UNIT 62
 ATFLUX VERS 2 COPIED FROM UNIT 36 TO UNIT 62
 ATFLUX VERS 1 COPIED FROM UNIT 31 TO UNIT 62

PERTUB IP(I) = 63 5 4 3 2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 PERTUB VERS 1 COPIED FROM UNIT 82 TO UNIT 63
 PERTUB VERS 1 COPIED FROM UNIT 77 TO UNIT 63
 PERTUB VERS 1 COPIED FROM UNIT 72 TO UNIT 63
 PERTUB VERS 1 COPIED FROM UNIT 37 TO UNIT 63
 PERTUB VERS 1 COPIED FROM UNIT 32 TO UNIT 63

*** MODULE *SUBMRG* IS FINISHED ***

TABLE 4.4

INPUT FOR SAMPLE PROBLEM #1

```

//JRWPROB1 JOB (19934,104), 'JR WHITE UNIV LOWELL', TIME=(0,30)
/*JOBPARM LINES=10
/*ROUTE PRINT RMT162
//BOLDFOUR PROC GOSIZE=384K, GOTIME=, MODULE=SCALE,
// NB1=1, NB2=1, B1=3520, B2=32000, NX=2, NS=50, N1=100,
// N2=1, N3=1, N4=1, N5=1, N6=1, N7=1, N8=1, N9=1, N10=1, N11=1, N12=1, N13=1,
// N14=1, N15=1, N16=1
//GO EXEC PGM=MODULE,
// REGION=, GOSIZE=, TIME=, GOTIME=
//STEPLIB DD UNIT=3330V, VOL=SER=VLFS01, DISP=SHR,
// DSN=JLL.BVFOUR.LOADM
// DD UNIT=3330-1, VOL=SER=NE3330, DISP=SHR, DSN=E.LMP00000.SCALE.PGMS
//PRINT DD SYSOUT=A, DCB=(RECFM=VBA, LRECL=137, BLKSIZE=1100)
//FT01F001 DD UNIT=SYSDA, SPACE=(, (, NS, 1)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)
//FT02F001 DD UNIT=SYSDA, SPACE=(, (, NS, 1)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)
//FT03F001 DD UNIT=SYSDA, SPACE=(80, (10)),
// DCB=(RECFM=F, BLKSIZE=80)
//FT04F001 DD UNIT=SYSDA, SPACE=(3200, (, N1, NX)),
// DCB=(RECFM=FBS, LRECL=80, BLKSIZE=3200)
//FT05F001 DD UNIT=SYSDA, SPACE=(3120, (200, 100)),
// DCB=(RECFM=FB, BUFNO=1, LRECL=80, BLKSIZE=3120)
//FT06F001 DD SYSOUT=A, DCB=(RECFM=VBA, LRECL=137, BLKSIZE=1100)
//FT07F001 DD SYSOUT=B, DCB=(RECFM=F, BLKSIZE=80)
//FT08F001 DD UNIT=SYSDA, SPACE=(, (, N1, 2)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)
//FT09F001 DD UNIT=SYSDA, SPACE=(, (, NS, 1)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)
//FT10F001 DD UNIT=SYSDA, SPACE=(, (, NS, 1)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)
//FT11F001 DD UNIT=SYSDA, SPACE=(, (, N1, NX)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)
//FT12F001 DD UNIT=SYSDA, SPACE=(, (, N1, NX)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)
//FT13F001 DD UNIT=SYSDA, SPACE=(, (, N1, 2)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)
//FT14F001 DD UNIT=SYSDA, SPACE=(, (, NS, 1)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)
//FT15F001 DD UNIT=SYSDA, SPACE=(, (, NS, 1)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)
//FT16F001 DD UNIT=SYSDA, SPACE=(, (, N1, NX)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)
//FT17F001 DD UNIT=SYSDA, SPACE=(, (, N16)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)
//FT18F001 DD UNIT=SYSDA, SPACE=(, (, N16)),
// DCB=(RECFM=VBST, LRECL=X, BUFNO=NB1, BLKSIZE=B1)

```

Table 4.4 (Contd.)

```

//FT19F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT20F001 DD UNIT=SYSDA,SPACE=(#B1,(#N13)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT21F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT22F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT23F001 DD UNIT=SYSDA,SPACE=(#B1,(#N3)),
//          DCB=(RECFM=FT,BUFNO=#NB1)
//FT24F001 DD UNIT=SYSDA,SPACE=(#B1,(#N2)),
//          DCB=(RECFM=FT,BUFNO=#NB2)
//FT25F001 DD UNIT=SYSDA,SPACE=(#B1,(#N12)),
//          DCB=(RECFM=FT,BUFNO=#NB1)
//FT26F001 DD UNIT=SYSDA,SPACE=(#B1,(#N12)),
//          DCB=(RECFM=FT,BUFNO=#NB1)
//FT27F001 DD UNIT=SYSDA,SPACE=(#B1,(#N2)),
//          DCB=(RECFM=FT,BUFNO=#NB2)
//FT28F001 DD UNIT=SYSDA,SPACE=(#B1,(#N2)),
//          DCB=(RECFM=FT,BUFNO=#NB2)
//FT29F001 DD UNIT=SYSDA,SPACE=(#B1,(#N14)),
//          DCB=(RECFM=FT,BUFNO=#NB2)
//FT30F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT31F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,#NX)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT32F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT33F001 DD UNIT=SYSDA,SPACE=(#B1,(#N4)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT34F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,#NX)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT35F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT36F001 DD UNIT=SYSDA,SPACE=(#B1,(#N6,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT37F001 DD UNIT=SYSDA,SPACE=(#B1,(#N15,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT38F001 DD UNIT=SYSDA,SPACE=(#B1,(#N15,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT39F001 DD UNIT=SYSDA,SPACE=(#B1,(#N15,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT40F001 DD UNIT=SYSDA,SPACE=(#B2,(#N5)),
//          DCB=(RECFM=FT,BUFNO=#NB2)
//FT41F001 DD UNIT=SYSDA,SPACE=(#B1,(#N4)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT42F001 DD UNIT=SYSDA,SPACE=(#B2,(#N7)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB2,BLKSIZE=#B2)
//FT43F001 DD UNIT=SYSDA,SPACE=(#B2,(#N8)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB2,BLKSIZE=#B2)

```

Table 4.4 (Contd.)

```

//FT44F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT45F001 DD UNIT=SYSDA,SPACE=(qB1,(qN9)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT46F001 DD UNIT=SYSDA,SPACE=(qB1,(qN10)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT47F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT48F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT49F001 DD UNIT=SYSDA,SPACE=(qB1,(qN11)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT50F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT51F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT52F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT53F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT54F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT55F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT56F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT96F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT97F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT98F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT99F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//BOLDFOUR PEND
/*
// EXEC SPDASCR
//SYSIN DD *
      T.JRW00000.NSTARR.NETS1.U232.PROB1A
//BURN EXEC BOLDFOUR,
// NB1=1,NB2=1,B1=3520,B2=7200,N1=10,N2=60,N3=20,N4=10,N5=30,N6=10,
// N7=10,N8=10,N9=10,N10=10,N11=10,
// N12=10,N13=10,N14=10,N15=10,NX=20,NS=30,N16=10,
// GOSIZE=384K
//GO.FT11F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.GRUPXS.DPT.NSAMPLE,
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT55F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT56F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)

```

Table 4.4 (Contd.)

```

//GO.FT57F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT58F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.NSTARR.NETS1.U232.PROB1A,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT61F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT62F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT63F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT85F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.RZFLUX.NALL
//GO.FT86F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.ZNATDN.NALL
//GO.FT87F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.RTFLUX.NALL
//GO.FT88F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.ATFLUX.NALL
//GO.FT89F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.PERTUB.NALL
//GO.SYSIN DD *
=CONTROL1
  DPT SAMPLE PROB #1A  SINGLE TIME STEP ADJ  CALC FOR U232 INVENTORY
025000                                1                                1
  99  2  2  1 99 99  7 99
    GRUPXS
  END
  SUBMRG
    5 -1
  RZFLUX    56 85  5  5
  ZNATDN    57 86  5  5
  RTFLUX    61 87  5  5
  ATFLUX    62 88  5  5
  PERTUB    63 89  5  5
  END
  DVENTR
001
                                1000.0+06                                1.0                                1.0
                                1.0-04                                5.0-04

  -1  3      2                                1      40
    1  0  0  0  1  0  0  0  2  0  0  0      2  2  2      6  2
003
    3  1  2
004
    16 26.2133 16 26.2133 16 26.2133 10 22.2350 10 22.2350
005
    1  2  3  4  5

```

Table 4.4 (Contd.)

```

012
  0
  1 3 1 1
  4 5 2 2
  0
013
  26
  26
TH228CTH232CPA231CPA233CU-232CU-233CU-234CU-235CU-236CU-238CNP237CNP239C
PU238CPU239CPU240CPU241CPU242CAM241CAM243CCM244CSS  CNA  CO-16 CCHAN C
CTLKDCFP  C
  26
TH228RTH232RPA231RPA233RU-232RU-233RU-234RU-235RU-236RU-238RNP237RNP239R
PU238RPU239RPU240RPU241RPU242RAM241RAM243RCM244RSS  RNA  RO-16 RCHAN R
CTLRDRFP  R
020  -1  1          0.0
END
DUTLIN
EXPINS          0  1  0 40
      91.3125
      0  1      0  1          1      0  0
              1      1      0      0  0
BLANK
END
INPUT PROCESSOR
0V EXPOSE
1D /  FILE REFERENCE INFORMATION
0 24 0 1 0 20 1 20 0 0 0 28 0 8R
2D /  TITLE AND NUCLIDE NAMES
*      DEPLETION MODULE WITH 20 HM 1 FP 3 OTHER NUCLIDES      *
*TH228 * *TH232 * *PA231 * *PA233 * *U 232 * *U 233 * *U 234 * *U 235 *
*U 236 * *U 238 * *NP237 * *NP239 * *PU238 * *PU239 * *PU240 * *PU241 *
*PU242 * *AM241 * *AM243 * *CM244 * *FP RL * *NA      * *SS COR* *0 16 *
3D /  REFERENCE DATA
0.0 /
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 /
21 /
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 /
4D /  DECAY DATA
1.156-08 1.580-18 6.312-13 2.971-07 2.968-10 1.360-13 8.860-14 3.080-17
9.150-16 4.870-18 9.980-15 3.414-06 2.540-10 9.000-13 3.340-12 1.560-09
5.780-14 4.800-11 2.750-12 1.220-09
5D /  FISSION PRODUCT YIELD DATA
1.0 20R
6D /  CHAIN DATA FOR MATRIX EXPONENTIAL
2 4 2  2 3 5  3 5 2  4 5 5  4 6 1  4 7 2  5 1 1  5 6 2  6 5 5  6 7 2
7 8 2  8 9 2  9 11 2  10 11 5  10 12 2  11 13 2  12 14 1  13 14 2
14 15 2  15 16 2  16 17 2  16 18 1  17 19 2  19 20 2
  21 21  2  22 22 2  23 23 2  24 24 2
STOP
END

```


Table 4.4 (Contd.)

CHARGE

133 0 0 0 0 0 0 0 0 0 1 F0 T

3533 0 1 8 24 1 5 68 1 1 9

3633 0 1 1 0 3 -2 0 0 0 0 T

37** 4R0.0 0.38525 19R0.0 4Q24 T

END

DEPTH

0

0

END

DEPTH

0

0

END

//

Table 4.5
SELECTED OUTPUT FROM SAMPLE PROBLEM #1

*** MODULE *SUBMRG* VERSION 1 (12/22/80) IS BEING ACCESSED ***

IPLIE = 4 NOPT = -1

RZFLUX IP(I) = 56 85 5 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
ORDER IN WHICH RZFLUX FILES WERE STACKED ON UNIT # 56
KEFF = 1.0116129 0.0 DAYS EXPOSURE

ZMATDN IP(I) = 57 86 5 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
ORDER IN WHICH ZMATDN FILES WERE STACKED ON UNIT # 57
CYCLE # 1 0.0 DAYS EXPOSURE

RTFLUX IP(I) = 61 87 5 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
ORDER IN WHICH RTFLUX FILES WERE STACKED ON UNIT # 61
KEFF = 1.0116129 NGROUP = 9 NDIM = 1

ATFLUX IP(I) = 62 88 5 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
ORDER IN WHICH ATFLUX FILES WERE STACKED ON UNIT # 62
KEFF = 1.0116129 NGROUP = 9 NDIM = 1

*** MODULE *SUBMRG* IS FINISHED ***

*** MODULE *CHARGE* VERSION 1 (12/22/80) IS BEING ACCESSED ***

1\$ ARRAY 10 ENTRIES READ

OT

35\$ ARRAY 10 ENTRIES READ

36\$ ARRAY 10 ENTRIES READ

OT

37\$ ARRAY 120 ENTRIES READ

OT

INTERFACE FILE *DATAIN* WAS WRITTEN ON UNIT # 55

*** MODULE *CHARGE* IS FINISHED ***

*** MODULE *DEPTH* VERSION 1 (12/22/80) IS BEING ACCESSED ***

*** INITIAL ADJOINT DENSITY VECTORS BY REGION FOR TIME STEP # 1 ***

TH228	0.0	0.0	0.0	0.0	0.0
TH232	0.0	0.0	0.0	0.0	0.0
PA231	0.0	0.0	0.0	0.0	0.0
PA233	0.0	0.0	0.0	0.0	0.0
UU232	3.8525E-01	3.8525E-01	3.8525E-01	3.8525E-01	3.8525E-01
UU233	0.0	0.0	0.0	0.0	0.0
UU234	0.0	0.0	0.0	0.0	0.0
UU235	0.0	0.0	0.0	0.0	0.0
UU236	0.0	0.0	0.0	0.0	0.0
UU238	0.0	0.0	0.0	0.0	0.0
NP237	0.0	0.0	0.0	0.0	0.0
NP239	0.0	0.0	0.0	0.0	0.0
PO238	0.0	0.0	0.0	0.0	0.0
PO239	0.0	0.0	0.0	0.0	0.0
PO240	0.0	0.0	0.0	0.0	0.0
PO241	0.0	0.0	0.0	0.0	0.0
PO242	0.0	0.0	0.0	0.0	0.0
AM241	0.0	0.0	0.0	0.0	0.0
AM243	0.0	0.0	0.0	0.0	0.0
CM244	0.0	0.0	0.0	0.0	0.0
FP RL	0.0	0.0	0.0	0.0	0.0
NA	0.0	0.0	0.0	0.0	0.0
SS COR	0.0	0.0	0.0	0.0	0.0
O 16	0.0	0.0	0.0	0.0	0.0

*** ALPHA FOR TIMESTEP # 1 IS 1.4195E 22 ***

*** END OF TIME STEP DENSITIES FOR REGION # 1 ***									
1.6661D-10	2.6871D-03	7.4954D-07	2.8645D-05	1.5776D-07	6.8333D-04	1.6064D-05	5.4665D-06	2.4933D-07	4.0841D-03
1.0891D-06	3.4318D-06	7.9293D-08	2.1286D-04	1.4999D-05	6.7625D-07	2.7540D-08	2.8027D-09	7.8990D-10	2.1182D-11
2.2092D-04	8.5936D-03	1.4757D-02	1.6959D-02						

*** END OF TIME STEP DENSITIES FOR REGION # 2 ***									
1.2156D-10	2.7061D-03	5.8074D-07	2.1982D-05	1.1360D-07	7.1388D-04	1.2418D-05	5.5770D-06	1.9354D-07	4.1110D-03
8.4618D-07	2.6283D-06	4.7031D-08	2.0022D-04	1.3314D-05	5.7563D-07	2.2489D-08	2.9200D-09	5.3649D-10	1.1404D-11
1.6993D-04	8.5936D-03	1.4757D-02	1.6959D-02						

*** END OF TIME STEP DENSITIES FOR REGION # 3 ***									
5.6733D-11	2.7347D-03	2.9789D-07	1.1802D-05	5.1768D-08	7.6340D-04	6.7524D-06	5.8334D-06	1.0679D-07	4.1516D-03
4.3600D-07	1.4105D-06	1.2792D-08	1.8006D-04	1.1013D-05	4.4679D-07	1.6382D-08	3.2496D-09	2.4479D-10	2.9792D-12
9.0434D-05	8.5936D-03	1.4757D-02	1.6959D-02						

*** END OF TIME STEP DENSITIES FOR REGION # 4 ***									
2.8439D-12	1.4424D-02	2.0267D-07	1.9290D-05	3.1396D-09	1.8995D-04	5.7291D-07	1.7124D-09	3.3172D-12	0.0
4.7670D-15	0.0	1.9641D-17	2.4589D-20	2.0976D-23	1.7057D-26	9.4666D-30	2.2543D-29	6.3576D-33	6.1215D-36
5.3060D-06	7.0091D-01	0.0	2.3358D-02						

*** END OF TIME STEP DENSITIES FOR REGION # 5 ***									
1.2070D-13	1.4467D-02	1.5741D-08	2.8868D-06	1.1385D-10	1.6812D-04	6.9749D-08	3.4172D-11	1.0479D-14	0.0
2.3596D-18	0.0	1.5333D-21	3.1482D-25	4.3244D-29	5.7552D-33	4.9568D-37	7.8280D-36	5.4174D-41	8.5489D-45
6.8840D-07	7.0091D-03	0.0	2.3358D-02						

*** N*N SUMM'D OVER REGIONS AT END OF TIME STEP # 1 FOR RESPONSE # 1 IS 5.91791E-02 ***

PSTAR BY RESPONSE FOR TIME STEP # 1 SUBSTEP # 1
6.8992E-11

*** ADJOINT SOURCE VECTORS BY ZONE FOR TIME STEP # 1 ***

1.5885E 01	-1.5063E 01	-1.3791E 01	6.4017E 00	2.9478E 00
-1.1504E-01	-1.1342E-01	-1.1115E-01	-4.2227E-02	-4.3118E-02
-5.2105E-02	-5.2158E-02	-5.2553E-02	-6.3552E-03	-8.6479E-03
-5.0199E-02	-5.2799E-02	-5.7314E-02	-5.551E-03	-1.0596E-02
-6.6003E-02	-7.3513E-02	-8.6604E-02	-5.3297E-03	-1.7821E-02
-1.0744E-01	-1.2329E-01	-1.5107E-01	-5.4242E-03	-3.0864E-02
-1.4894E-01	-1.7648E-01	-2.2508E-01	-8.6526E-04	-5.2911E-02
-1.0061E 00	-1.0392E 00	-1.1172E 00	-3.1377E-02	-2.7706E-01
-1.2991E 02	-1.2814E 02	-1.2498E 02	-2.3366E 01	-2.4119E 01

INTEGRAL OF (S*(R,E) * GFLX(R,E)) FOR RESPONSE # 1 IS 1.4575E-07

*** NSTAR EFFECT BY REGION FOR TIME STEP # 1 SUBSTEP # 1 ***

TH228	0.0	0.0	0.0	0.0	0.0
TH232	7.3411E-06	4.4361E-06	1.2074E-06	5.2902E-08	6.3114E-10
PA231	4.3597E-02	3.4025E-02	1.8826E-02	6.6132E-03	1.0323E-03
PA233	6.0386E-05	4.7032E-05	2.4373E-05	3.2087E-06	2.4978E-07
U 232	1.5585E-01	1.6250E-01	1.7217E-01	3.8048E-01	1.8177E-01
U 233	4.8482E-05	3.8249E-05	2.0167E-05	2.7024E-06	2.1144E-07
U 234	0.0	0.0	0.0	0.0	0.0
U 235	0.0	0.0	0.0	0.0	0.0
U 236	0.0	0.0	0.0	0.0	0.0
U 238	0.0	0.0	0.0	0.0	0.0
NP237	0.0	0.0	0.0	0.0	0.0
NP239	0.0	0.0	0.0	0.0	0.0
PU238	0.0	0.0	0.0	0.0	0.0
PU239	0.0	0.0	0.0	0.0	0.0
PU240	0.0	0.0	0.0	0.0	0.0
PU241	0.0	0.0	0.0	0.0	0.0
PU242	0.0	0.0	0.0	0.0	0.0
AM241	0.0	0.0	0.0	0.0	0.0
AM243	0.0	0.0	0.0	0.0	0.0
CM244	0.0	0.0	0.0	0.0	0.0
FP RL	0.0	0.0	0.0	0.0	0.0
NA	0.0	0.0	0.0	0.0	0.0
SS COR	0.0	0.0	0.0	0.0	0.0
O 16	0.0	0.0	0.0	0.0	0.0

VENTURE - NEUTRONICS MODULE -VERS 3- JANUARY 1,1981 --- QUALITY ASSURANCE LEVEL 1

RUN TITLE - DPT SAMPLE PROB #1 SINGLE TIME STEP ADJ CALC FOR U232 INVENTORY

STORAGE REQUIRED FOR CROSS SECTION CHECK 948 WORDS

TITLE OF THE LATEST VERSION CROSS SECTION FILE
ANISN TO CITATION MODULE - 9 GROUP URANIUM RUN

CROSS SECTION CHECK COMPLETED NORMALLY

REFERENCE REAL TIME FROM ZNATCH INTERFACE FILE = 0.0 DAYS

SOLUTION BY FINITE-DIFFERENCE DIFFUSION THEORY

FIXED SOURCE ADJOINT PROBLEM

PERTURBATION RESULTS ARE REQUESTED

GEOMETRY NO. 3 1-D SPHERE

NUMBER OF ENERGY GROUPS

9

NUMBER OF UPSCATTER GROUPS (MAX)

0

NUMBER OF DOWNSCATTER GROUPS (MAX)

8

NUMBER OF INTERVALS IN DIMENSION 1 (COLUMNS)

68

NUMBER OF INTERVALS IN DIMENSION 2 (ROWS)

1

NUMBER OF INTERVALS IN DIMENSION 3 (PLANES)

1

NUMBER OF ZONES

5

NUMBER OF REGIONS

5

NUMBER OF BLACK ABSORBER ZONES

0

BOUNDARY INDICATORS- LEFT 1 RIGHT 2

MEMORY REQUIREMENTS FOR DATA STORAGE

	TOTAL		A	B	C	D
	MINIMUM	MAXIMUM				
STORAGE AVAILABLE	60000					
MACRO CALCULATION	1900					
EQUATION CONSTANTS CALCULATION						
CORE CONTAINED OR SPACE STORED	1134	1134				
PLANE STORED	1270	1270				
ROW STORED	928	928				
MULTI-LEVEL PLANE STORED	1270	1270				
INITIAL FLUX						
CORE CONTAINED OR SPACE STORED	1806	1806				
OTHER NODES	1806	1806				
ITERATIVE PROCESS						
CORE CONTAINED	9367		6000	2529	632	206
SPACE STORED	3436		750	2529	157	0
1 PLANE STORED	3713		1027	2529	157	0
1 PLANE STORED	3713		1027	2529	157	0
1 ROWS STORED	3708		1022	2529	157	0
1 ROW STORED	2686		0	2529	157	0
1 MULTI-LEVEL PLANES STORED	3985		408	2529	157	891
PERTURBATION CALCULATION	2483					

DATA WILL BE STORED FOR ALL GROUPS, ALL SPACE

MEMORY LOCATIONS RESERVED FOR DATA STORAGE--- 60000

MAX MEMORY LOCATIONS REQUIRED FOR THIS PROB-- 9367

MEMORY LOCATIONS NOT USED----- 50633

SPECIAL SCRATCH DATASET REQUIREMENTS

MAXIMUM PHYSICAL RECORD IS 7200 WORDS

RITE CONTAINER ARRAYS, CONTROL		36 DATA	50587						
FILE 24 DEFAULTS TO CORE - NO.RECS,	REC.LNTH,	TOT.LNTH,	START LOC,	CORE LEFT.	9	136	1224	1	49363
FILE 27 DEFAULTS TO CORE - NO.RECS,	REC.LNTH,	TOT.LNTH,	START LOC,	CORE LEFT.	9	136	1224	1225	48139
FILE 28 DEFAULTS TO CORE - NO.RECS,	REC.LNTH,	TOT.LNTH,	START LOC,	CORE LEFT.	9	136	1224	2449	46915
FILE 40 DEFAULTS TO CORE - NO.RECS,	REC.LNTH,	TOT.LNTH,	START LOC,	CORE LEFT.	9	205	1845	3673	45069
DIRECT ACCESS FILE 23 REQUIRES		9 RECORDS	341 WORDS IN LENGTH						

DD PARAMETERS FOLLOW FOR B1 = 3520 AND B2 = 2176
N2= 2 N3= 8 N4= 1 N5= 12 N6= 10 N7= 1 N8= 1 N9= 1 N10= 1 N11= 1 N12= 1 N13= 1 N14= 1 N15= 10
N16= 2 (NOTE THAT IF THE FLUXES ARE TO BE EXPANDED FROM EXISTING RTFLUX, N10= 2)

REQUIRED DISK STORAGE SPACE FOR FLUX(UNITS 24,27,28) IS 7040 BYTES.
FOR CONSTANTS(UNIT 40) IS-- 26112 BYTES.
FOR CONSTANTS(UNIT 23) IS-- 28160 BYTES.
REQUIRED TOTAL DISK STORAGE SPACE IS----- 5451904 BYTES.

FOR THE ASSIGNED DATA STORAGE, THE REQUIRED REGION SIZE IS APPROXIMATELY 570K BYTES

MAXIMUM STORAGE USED FOR MACROSCOPIC CROSS SECTION CALCULATION 1899 WORDS

THE MAXIMUM AND MINIMUM DIFFUSION COEFFICIENTS ARE 4.00782E 00 6.71699E-02

FINE MESH DESCRIPTION - POINT IS LOCATED AT THE CENTROID OF THE VOLUME ELEMENT

DISTANCE TO POINT - DIMENSION 1 (LEFT TO RIGHT)															
1	8.2567	2	11.9082	3	14.1187	4	15.7944	5	17.1746	6	18.3627	7	19.4142	8	20.3627
9	21.2302	10	22.0321	11	22.7795	12	23.4809	13	24.1427	14	24.7700	15	25.3671	16	25.9374
17	26.0001	18	31.0144	19	33.5349	20	35.7245	21	37.6744	22	39.4409	23	41.0620	24	42.5643
25	43.9674	26	45.2862	27	46.5325	28	47.7153	29	48.8422	30	49.9194	31	50.9520	32	51.9443
33	53.6928	34	56.0600	35	58.2426	36	60.2728	37	62.1748	38	63.9670	39	65.6641	40	67.2776
41	68.8173	42	70.2911	43	71.7054	44	73.0661	45	74.3779	46	75.6450	47	76.8711	48	78.0592
49	80.0695	50	82.7848	51	85.3327	52	87.7370	53	90.0162	54	92.1856	55	94.2574	56	96.2419
57	98.1477	58	99.9823	59	102.2314	60	104.8413	61	107.3274	62	109.7034	63	111.9806	64	114.1689
65	116.2763	66	118.3100	67	120.2760	68	122.1798								

MAXIMUM STORAGE USED FOR CALCULATING INITIAL PARAMETERS WAS 574

INITIAL FLUX IS CONSTANT

INTEGRAL (REGULAR SOURCE) TIMES (ADJOINT SOURCE) FOR CORRECTION IS 2.6872484D-13

TOTAL CORE REQUIRED FOR DATA STORAGE IS 9363 WORDS

FIXED SOURCE - TOTAL, MAXIMUM, MINIMUM ARE -3.45587D 08 1.97692E 07 -1.79161E 08

NEGATIVE FIXED SOURCE TERM(S) REQUIRE ALLOWING NEGATIVE FLUX

ABS FIXED SOURCE VOLUME INTEGRAL 4.42171E 01

THE INITIAL FLUX IS EQUAL TO THE FIXED SOURCE
ELAPSED CPU AND CLOCK MINUTES ARE 0.023 0.427

FIXED SOURCE ADJOINT PROBLEM FOLLOWS

*****THIS IS THE HIGHER ORDER HARMONIC PROBLEM - NOT THE FUNDAMENTAL*****

***CAUTION - THE SPECIFIED FLUX CHANGE GREATER THAN 0.0001 MAY NOT EFFECT ADEQUATE CONVERGENCE FOR RESULTS TO BE RELIABLE.

1 INNERS MIN, 1 INNERS MAX - NO CHERICHEV BETA

PROCEDURE=0,1,2,3,4-NORMAL, CHERICHEV, SEMEX, DENEX, SEMEXP.

ITER	PROC	ICVR	OCVR	FLUX CHANGE	NO-BAR	OTHER-MU	SEM-IND	ACCELERATION	PARAMETERS	K-USED	D.F.-CALC	D.F.-USED
1	0	0	0	-3.50693D-03	0.0	0.0	1.00000	0.0	0.0	1.0116129	1.00000D-00	1.00000D-00
2	0	0	0	-5.28405D-00	-2.62053	0.0	1.00000	1.00000	0.0	1.0116129	1.03052D-00	1.00000D-01
3	0	0	0	-2.08063D-01	0.14371	0.0	1.00000	0.16783	0.0	1.0116129	1.01126D-00	1.00000D-01
4	0	0	0	7.09570D-02	0.39780	0.0	1.00000	0.23691	0.04282	1.0116129	1.00515D-00	1.00000D-01

FORCED EXTRAPOLATION LAMDA

0.57275

2.70736D-01	4.72692D-01	7.42856D-01	0.0	5.72754D-01	3.64452D-01	5.73446D-01	9.97172D-01	2.82760D-03
5	4	0	4.56570D-02	0.57275	0.0	1.00000	0.48820	0.0
6	1	1	1.30922D-02	0.0	0.0	1.00000	0.40130	0.0
7	1	0	-1.64359D-03	0.0	0.0	1.00000	0.52401	0.08757
8	1	0	7.10756D-04	0.43356	0.43356	1.00000	0.46547	0.04579
9	1	0	-6.76391E-05	0.37472	0.07000	1.00000	0.46289	0.04395

ESTIMATED ABSOLUTE POINT FLUX RELATIVE ERROR 9.06749D-05

MULTIPLICATION RELIABILITY ESTIMATORS

BY THE SUM OF THE SQUARES OF THE RESIDUES-----

1.0115912

UPPER AND LOWER BOUNDS ESTIMATES BY MAX REL FLUX CHANGE-----

1.0116814

1.0115445

UPPER AND LOWER BOUNDS ESTIMATES OVER ALL SIGNIFICANT POINTS-----

1.0117692

1.0113233

NUMBER OF INNER ITERATIONS, OUTER ITERATION ERROR EIGENVALUE, AND OVERRELAXATION COEFFICIENTS

1 5.72754D-01

1.00000 1.00000 1.00000 1.00000 1.00000 1.00000 1.00000 1.00000 1.00000

CPU AND CLOCK MINUTES REQUIRED FOR THIS EIGENVALUE PROBLEM ARE 0.013 0.220

ADJOINT FLUX ENERGY SPECTRUM BY GROUP, 1 TO MAX, (SUMMED OVER SPACE)

8.98452D-01 -4.38301D-00 -3.54651D-00 -3.39114D-00 -2.90763D-00 -2.87765D-00 -2.89335D-00 -5.54581D-00 -1.49416D-01

ADJOINT FLUX SPACE FUNCTION BY ZONE (SUMMED OVER ENERGY)

1.19915D-02 1.11615D-02 9.59796D-01 6.03391D-01 1.24185D-01

ZONE AVERAGE ADJOINT FLUXES BY GROUP

GROUP 1
2.30732D-02 2.19175D-02 1.82487D-02 8.22580D-01 3.45059D-01

GROUP 2
-1.36324D-01 -1.24079D-01 -8.80586D-00 -3.70692D-00 -1.61091D-00

GROUP 3
-1.20784D-01 -1.11101D-01 -7.76780D-00 -2.76148D-00 -1.01138D-00

GROUP 4
-1.13973D-01 -1.07563D-01 -7.71455D-00 -2.39375D-00 -9.92106D-01

GROUP 5
-9.15797D-00 -9.26900D-00 -7.20976D-00 -1.47424D-00 -9.86310D-01

GROUP 6
-8.31038D-00 -8.89056D-00 -7.78921D-00 -6.88940D-01 -1.26378D-00

GROUP 7
-8.34678D-00 -8.93130D-00 -7.80807D-00 -6.99516D-01 -1.27730D-00

GROUP 8
-1.71997D-01 -1.69168D-01 -1.41545D-01 2.03657D-01 -3.77759D-00

GROUP 9
-3.06948D 01 -2.92779D 01 -2.52579D 01 -1.03976D 01 -1.11680D 01

PCINT ADJOINT FLUX INTERFACE FILE ATFLUX (VERSION 2) HAS BEEN WRITTEN ON UNIT NUMBER 19
DOPC FILE CLOSING DATA - UNIT, ARRAYS 24 26 5518
DOPC FILE CLOSING DATA - UNIT, ARRAYS 27 21 5518
DOPC FILE CLOSING DATA - UNIT, ARRAYS 28 16 5518

FILE 27 DEFAULTS TO CORE - NO.RECS, REC.LNTH, TOT.LNTH, START LOC, CORE LEFT. 9 136 1224 1 49363

FILE 28 DEFAULTS TO CORE - NO.RECS, REC.LNTH, TOT.LNTH, START LOC, CORE LEFT. 9 136 1224 1225 48139

SPECIAL SCRATCH DATASET REQUIREMENTS
MAXIMUM PHYSICAL RECORD IS 7200 WORDS

*****THE ADJOINT PROBLEM IS FIXED SOURCE.

-CAUTION- THE FLUXES BEING PROCESSED ARE SPECIAL, SO EDITED RESULTS HAVE A DIFFERENT INTERPRETION
THEN THE DOCUMENTING EDITS INDICATING REACTIVITY IMPORTANCE

'ENERGY PER UNIT FLUX' WEIGHTED REGULAR FLUX TIMES ADJOINT FLUX BY GROUP. SUM = -2.57528E-06
9.28408E-07 -6.31048E-07 -3.40187E-07 -1.37464E-06 -7.74028E-07 -8.79329E-09 -3.69744E-07 -5.24571E-09 -3.75809E-12

FIXED SOURCE ADJOINT FLUXES HAVE ALREADY BEEN CORRECTED FOR REGULAR ADJOINT CONTAMINATION

REGULAR, FIXED SOURCE ADJOINT FLUX INTEGRALS - NOT NORMALIZED (MULTIPLIED) BY BID DADDY = 3.983595D-16

PERTURBATION INTERFACE FILE PERTUB HAS BEEN WRITTEN ON NEW UNIT NUMBER 20

DOPC USE OF CONTAINER ARRAYS, CONTROL 21, MAX DATA 5517

TOTAL CPU MINUTES USED 0.050 TOTAL CLOCK MINUTES USED 0.831 TOTAL I/O USED 0

*** MODULE *DEPTH * VERSION 1 (12/22/80) IS BEING ACCESSED ***
*** GAMMA* EFFECT FOR TIME STEP # 1 ***

*** REGION # 1 ***

NUCLIDE	LEAKAGE	REMOVAL	INSCATTER	FISSION	TOTAL
TH228	0.0	0.0	0.0	0.0	0.0
TR232	-4.38354E-10	3.36686E-06	-3.00769E-06	-2.48240E-08	3.33912E-07
PA231	-3.23728E-10	1.45301E-05	-3.61641E-06	-5.45792E-07	1.03676E-05
PA233	-4.42762E-10	7.60712E-06	-3.60706E-06	-5.45792E-07	3.45383E-06
U 232	-1.20430E-10	7.20827E-06	-2.17631E-06	-9.84857E-07	4.04698E-06
U 233	1.89786E-11	2.31332E-05	-2.13735E-06	-6.24947E-06	1.47464E-05
U 238	-6.06340E-10	7.75165E-06	-2.80739E-06	-8.13538E-07	4.13012E-06
U 235	-6.38754E-10	1.91667E-05	-2.33259E-06	-4.22169E-06	1.26118E-05
U 236	-2.91875E-10	5.70888E-06	-3.06914E-06	-2.74480E-07	2.33476E-06
U 238	-5.09638E-10	3.20485E-06	-3.06307E-06	-1.27200E-07	1.40721E-08
NP237	9.27404E-11	1.77190E-05	-4.52807E-06	-1.04409E-06	1.23469E-05
NP239	-1.02097E-10	1.47971E-05	-4.12458E-06	-9.43384E-07	9.33208E-06
PU238	-2.23733E-10	1.29027E-05	-7.45019E-07	-3.18945E-06	8.91849E-06
PU239	-6.16434E-10	7.80922E-05	-2.18064E-06	-8.86727E-06	1.10837E-05
PU240	-5.85645E-10	7.12650E-06	-2.06262E-06	-1.16704E-06	3.89549E-06
PU241	-1.77658E-10	2.25341E-05	-2.83876E-06	-6.63724E-06	1.0579E-05
PU242	2.24209E-10	6.27892E-06	-1.74161E-06	-9.03214E-07	3.63433E-06
AM241	5.07302E-09	1.82025E-04	-5.07628E-06	-8.45371E-07	1.76109E-04
AM243	-9.61503E-10	1.05612E-05	-4.62066E-06	-6.91721E-07	5.24787E-06
CM244	3.80409E-10	7.78680E-06	-1.14129E-06	-1.99400E-06	4.65189E-06
FP RL	-2.13346E-09	4.01721E-06	-3.96945E-06	0.0	4.56303E-08
NA	-5.73507E-10	1.91988E-06	-2.58891E-06	0.0	-6.69608E-07
SS COR	1.75762E-10	4.37532E-08	-1.16097E-06	0.0	-1.11704E-06
O 16	-8.82792E-10	1.49718E-06	-1.73681E-06	0.0	-2.40514E-07

*** REGION # 2 ***

NUCLIDE	LEAKAGE
TH228	0.0
TH232	-2.8355E-08
PA231	-3.1846E-08
PA233	-2.9846E-08
U 232	-2.3716E-08
U 233	-2.7513E-08
U 234	-3.5879E-08
U 235	-3.2376E-08
U 236	-3.3910E-08
U 238	-3.1737E-08
MP237	-3.3672E-08
MP239	-2.9090E-08
PU238	-2.9531E-08
PU239	-3.2227E-08
PU240	-3.1649E-08
PU241	-3.2153E-08
PU242	-2.9876E-08
AM241	-5.1669E-08
AM243	-3.1515E-08
CM244	-2.8775E-08
FP RL	-6.3506E-08
NA	-1.5054E-08
SS COR	-1.4262E-08
O 16	-1.5231E-08

REMOVAL

0.0
4.8140E-06
1.0689E-06
5.5405E-06
5.4322E-06
1.7001E-05
5.5684E-06
1.4144E-05
4.1183E-06
2.2769E-06
1.3032E-05
1.0935E-05
9.5127E-06
1.3253E-05
5.1591E-06
1.6613E-05
4.6175E-06
1.3841E-04
7.6963E-06
5.6555E-06
2.9178E-06
1.4200E-06
1.3785E-06
1.0537E-06

INSCATTER

0.0
-1.1578E-06
-1.5949E-06
-2.3877E-06
-1.3616E-06
-1.5374E-06
-2.0163E-06
-1.6750E-05
-2.2267E-06
-2.1954E-06
-3.2723E-06
-2.9586E-06
-5.8248E-07
-1.5391E-06
-1.4884E-06
-2.0876E-06
-1.2625E-06
-3.6709E-06
3.3265E-06
-8.3803E-07
-2.8337E-06
-1.9533E-06
-8.4386E-07
-1.2733E-06

FISSION

0.0
-1.2116E-08
-2.6632E-07
-2.6632E-07
-4.0862E-07
-3.0823E-06
-3.6955E-07
-2.0620E-06
-1.3395E-07
-6.2082E-08
-5.0946E-07
-6.6030E-07
-1.5571E-06
-2.3766E-06
-5.6491E-07
-3.2818E-06
-4.4074E-07
-4.1253E-07
-3.3755E-07
-9.7316E-07
0.0
0.0
0.0
0.0

TOTAL

0.0
4.1606E-07
7.1964E-06
2.6570E-06
1.1663E-06
1.2383E-06
3.1192E-06
1.0375E-05
1.7236E-06
1.2272E-08
9.2171E-06
7.4871E-06
7.3435E-06
9.3051E-06
3.0733E-06
1.1291E-05
2.8847E-06
1.3427E-04
4.0007E-06
3.8255E-06
2.0556E-08
0.0
-5.5140E-07
-6.4434E-07
-2.3473E-07

*** REGION # 3 ***

NUCLIDE	LEAKAGE
TH228	0.0
TH232	-9.0997E-08
PA231	-1.0294E-07
PA233	-9.3110E-08
U 232	-7.3002E-08
U 233	-9.0561E-08
U 234	-1.1665E-07
U 235	-1.1048E-07
U 236	-1.1148E-07
U 238	-1.0389E-07
MP237	-1.0262E-07
MP239	-8.8509E-08
PU238	-1.0115E-07
PU239	-1.0634E-07
PU240	-1.0515E-07
PU241	-1.0647E-07
PU242	-1.0111E-07
AM241	-2.5217E-07
AM243	-1.0148E-07
CM244	-9.9684E-08
FP RL	-1.8253E-07
NA	-5.0803E-08
SS COR	-4.9602E-08
O 16	-5.0600E-08

REMOVAL

0.0
8.8730E-07
4.3309E-06
2.1929E-06
2.0525E-06
6.8856E-06
2.1292E-06
5.7828E-06
1.5753E-06
8.1732E-07
5.2658E-06
4.8665E-06
5.8730E-06
3.3181E-06
2.0073E-06
6.7679E-06
1.8544E-06
5.9861E-05
3.0696E-06
2.2209E-06
1.0995E-06
5.7004E-07
3.7489E-08
3.8351E-07

INSCATTER

0.0
-8.1860E-07
-9.8290E-07
-9.7983E-07
-5.9208E-07
-5.8506E-07
-7.6532E-07
-6.3670E-07
-8.4542E-07
-8.3113E-07
-1.2559E-06
-1.1215E-06
-2.2952E-07
-2.8622E-07
-3.6638E-07
-7.8349E-07
-4.8738E-07
-1.4089E-06
-1.2668E-06
-3.2060E-07
-1.0673E-06
-8.3472E-07
-3.2942E-07
-5.0330E-07

FISSION

0.0
8.8199E-09
1.0662E-07
1.0662E-07
1.9618E-07
1.3263E-06
1.6023E-07
8.9782E-07
5.3390E-08
2.4703E-08
2.0536E-07
1.8822E-07
6.5765E-07
1.0198E-06
2.1167E-06
1.4107E-06
1.7769E-07
1.6484E-07
1.3491E-07
3.9929E-07
0.0
0.0
0.0
0.0

TOTAL

0.0
-1.7474E-08
3.3517E-06
1.2266E-06
1.5836E-06
7.5363E-06
1.4074E-06
5.9335E-06
6.7180E-07
-9.2997E-08
4.1126E-06
3.4417E-06
4.2000E-06
5.6656E-06
1.5674E-06
7.2887E-06
1.4436E-06
5.8365E-05
1.3431E-07
2.1999E-06
-1.5031E-07
-3.1508E-07
-4.1651E-07
-1.7038E-07

*** REGION # 4 ***
 NUCLIDE LEAKAGE
 TH228 0.0
 TH232 -2.69812E-08
 PA231 -3.07981E-08
 PA233 -2.72119E-08
 U232 -2.09669E-08
 U233 -2.70315E-08
 U234 -3.46633E-08
 U235 -3.38184E-08
 U236 -3.33194E-08
 U238 -1.07595E-08
 NP237 -2.95601E-08
 NP239 -2.51768E-08
 PU238 -1.09349E-08
 PU239 -1.20305E-08
 PU240 -1.13482E-08
 PU241 -1.18552E-08
 PU242 -1.07019E-08
 AM241 -8.95005E-08
 AM243 -2.97216E-08
 CM244 -3.03423E-08
 FP RL -4.97644E-08
 NA -1.54313E-08
 SS COR 0.0
 O 16 -1.46301E-08

REMOVAL
 0.0
 7.94908E-08
 3.42767E-07
 1.58422E-07
 1.63422E-07
 5.57171E-07
 1.68758E-07
 4.67297E-07
 1.28376E-07
 7.04607E-08
 4.27125E-07
 3.47784E-07
 2.97572E-07
 4.29075E-07
 1.58170E-07
 5.50207E-07
 1.39291E-07
 4.98545E-06
 2.31410E-07
 1.71433E-07
 9.18047E-08
 5.69792E-08
 0.0
 4.23795E-08

INSCATTER
 0.0
 -2.26685E-08
 -6.19214E-08
 -6.16637E-08
 -3.78363E-08
 -3.70384E-08
 -4.79394E-08
 -4.21566E-08
 -5.32319E-08
 -5.28772E-08
 -8.32241E-08
 -7.06647E-08
 -1.64459E-08
 -3.79643E-08
 -3.76492E-08
 -3.35111E-08
 -3.35199E-08
 -8.33081E-08
 -8.00911E-08
 -2.23637E-08
 -6.66162E-08
 -5.72911E-08
 0.0
 -3.90476E-08

FISSION
 0.0
 7.59836E-10
 1.89443E-08
 1.89443E-08
 4.25514E-08
 4.48713E-07
 3.09881E-08
 3.11090E-07
 8.82551E-09
 3.93890E-09
 3.95092E-08
 3.45821E-08
 1.83706E-07
 3.25081E-07
 4.80114E-08
 4.90683E-07
 3.37149E-08
 2.83810E-08
 2.30413E-08
 8.90823E-08
 0.0
 0.0
 0.0
 0.0

TOTAL
 0.0
 6.30944E-10
 2.68996E-07
 8.82926E-08
 1.46843E-07
 9.41816E-07
 1.17143E-07
 7.02413E-07
 5.06505E-08
 -9.23706E-09
 3.53850E-07
 2.86485E-07
 4.33897E-07
 6.84161E-07
 1.17184E-07
 9.55523E-07
 1.10005E-07
 4.83503E-06
 1.46638E-07
 2.07809E-07
 -2.48760E-07
 -1.57432E-08
 0.0
 -1.12983E-08

*** REGION # 5 ***
 NUCLIDE LEAKAGE
 TH228 0.0
 TH232 -9.97990E-10
 PA231 -1.11323E-09
 PA233 -9.87358E-10
 U232 -7.57075E-10
 U233 -9.85098E-10
 U234 -1.24951E-09
 U235 -1.18971E-09
 U236 -1.21173E-09
 U238 -1.14186E-09
 NP237 -1.09455E-09
 NP239 -9.02513E-10
 PU238 -1.09497E-09
 PU239 -1.13515E-09
 PU240 -1.10306E-09
 PU241 -1.14848E-09
 PU242 -1.08860E-09
 AM241 -2.98939E-09
 AM243 -1.02648E-09
 CM244 -1.05906E-09
 FP RL -1.81318E-09
 NA -5.31950E-10
 SS COR 0.0
 O 16 -5.12318E-10

REMOVAL
 0.0
 6.54545E-09
 3.38959E-08
 2.02282E-08
 2.04196E-08
 4.76597E-08
 1.48684E-08
 4.20364E-08
 1.22151E-08
 5.51334E-09
 4.24367E-08
 3.67415E-08
 2.79213E-08
 3.82646E-08
 1.85969E-08
 5.02992E-08
 1.55754E-08
 4.78226E-07
 2.75191E-08
 1.85680E-08
 1.03996E-08
 5.96316E-09
 0.0
 2.15680E-09

INSCATTER
 0.0
 -2.12535E-09
 -2.36448E-09
 -2.34094E-09
 -1.44823E-09
 -1.52048E-09
 -1.90245E-09
 -1.74032E-09
 -2.11275E-09
 -3.74088E-09
 -3.67304E-09
 -2.71762E-09
 -9.38195E-10
 -1.59643E-09
 -1.62068E-09
 -2.30273E-09
 -1.53526E-09
 -3.80762E-09
 -3.17318E-09
 -1.11676E-09
 -2.60928E-09
 -6.69090E-09
 0.0
 -2.30921E-09

FISSION
 0.0
 2.74906E-11
 7.45560E-10
 7.45560E-10
 2.08902E-09
 2.83874E-08
 1.31980E-09
 1.98284E-08
 3.27797E-10
 1.43091E-10
 1.68552E-09
 1.42747E-09
 1.06049E-08
 1.98840E-08
 2.21393E-09
 3.12993E-08
 1.43176E-09
 1.09319E-09
 8.86537E-10
 4.42339E-09
 0.0
 0.0
 0.0
 0.0

TOTAL
 0.0
 3.44960E-09
 3.11638E-08
 1.76455E-08
 2.02173E-08
 7.35414E-08
 1.30362E-08
 5.89348E-08
 9.21844E-09
 2.34049E-09
 3.93544E-08
 3.45488E-08
 2.64930E-08
 5.84170E-08
 1.80871E-08
 7.81416E-08
 1.3852E-08
 4.72523E-07
 2.42060E-08
 2.08156E-08
 5.97711E-09
 -1.25970E-09
 0.0
 -6.64734E-10

*** INITIAL ADJOINT DENSITY*VOL VECTORS BY REGION FOR TIME STEP # 2 ***

TH228	0.0	0.0	0.0	0.0	0.0
TH232	5.752E-01	2.356E-00	1.5706E-00	9.2302E-02	1.0812E-02
PA231	1.2898E-03	1.7972E-04	2.6990E-04	1.4963E-04	1.0812E-03
PA233	4.4632E-00	2.8366E-01	3.4083E-01	6.8481E-00	8.3768E-01
U232	2.6848E-04	1.9148E-05	5.3438E-05	8.6086E-05	1.2493E-06
U233	1.7754E-01	2.3243E-00	4.9545E-00	7.635E-00	2.2684E-00
U234	-2.8658E-01	-1.5280E-00	-2.3044E-00	-8.6384E-01	-1.2040E-01
U235	-2.2714E-00	-1.1656E-01	-1.5927E-01	-9.8780E-00	-2.3950E-00
U236	-1.5019E-02	-1.0472E-01	-4.0861E-01	-1.9116E-01	-6.2522E-03
U238	-8.5296E-02	-4.6507E-01	-7.5248E-01	-1.5409E-01	-8.1921E-03
NP237	2.1813E-01	1.1607E-00	8.5178E-01	-5.1773E-01	-5.6943E-02
NP239	5.7372E-02	3.6113E-01	5.2228E-02	-5.8415E-01	-5.3902E-02
PU238	-1.5165E-00	-7.7545E-00	-1.0263E-01	-5.1786E-00	-1.1311E-00
PU239	-2.3708E-00	-1.2129E-01	-1.5963E-01	-8.8453E-00	-2.0629E-00
PU240	-4.2712E-01	-2.2052E-00	-2.9884E-00	-1.1588E-00	-1.7288E-01
PU241	-3.3729E-00	-1.7207E-01	-2.2575E-01	-1.3386E-01	-3.2552E-00
PU242	-3.0298E-01	-1.5407E-00	-2.0996E-00	-8.2105E-01	-1.0696E-01
AM241	1.2807E-01	6.8367E-01	8.0218E-01	1.0138E-01	1.5557E-00
AM243	-5.0335E-03	-1.5890E-02	-4.4901E-01	-3.322E-01	-2.2983E-03
CH244	-7.8085E-01	-3.9899E-00	-2.1134E-00	-2.0327E-00	-3.6340E-01
PP RL	-3.4428E-03	1.0857E-02	-2.1548E-01	-5.5605E-02	2.1015E-02
NA	-5.0521E-02	-2.9122E-01	-4.5169E-01	-3.5620E-02	-4.8291E-03
SS COR	-8.4280E-02	-4.4593E-01	-5.9708E-01	0.0	0.0
O 16	-1.8147E-02	-1.2398E-01	-2.4426E-01	-2.5563E-02	-2.3372E-03

*** INITIAL ADJOINT DENSITY VECTORS BY REGION FOR TIME STEP # 2 ***

TH228	0.0	0.0	0.0	0.0	0.0
TH232	7.6249E-06	4.4625E-06	1.0956E-06	4.0795E-08	3.0750E-09
PA231	4.3603E-02	3.4029E-02	1.8827E-02	6.6132E-03	1.0329E-03
PA233	5.9155E-05	4.6136E-05	2.3776E-05	3.0267E-06	2.4394E-07
U232	3.5584E-01	3.6250E-01	3.7277E-01	3.8048E-01	3.8377E-01
U233	-3.3531E-06	-4.8608E-06	-3.4562E-06	-3.3748E-06	-7.3049E-07
U234	-3.7983E-06	-2.8931E-06	-1.6075E-06	-3.8180E-07	-3.4242E-08
U235	-3.0106E-05	-2.2070E-05	-1.1110E-05	-4.3658E-06	-6.8117E-07
U236	-1.9906E-07	-1.4828E-07	-2.8504E-07	-8.4489E-08	-1.7782E-09
U238	-1.1305E-06	-8.8057E-07	-5.2491E-07	-6.8105E-08	-2.3300E-09
NP237	2.8911E-06	2.1978E-06	5.9418E-07	-2.2882E-07	-1.6195E-08
NP239	7.6041E-07	6.8376E-07	3.6433E-08	-2.5818E-07	-1.5330E-08
PU238	-2.0100E-05	-1.4683E-05	-7.1591E-06	-2.2888E-06	-3.2171E-07
PU239	-3.1422E-05	-2.2966E-05	-1.1135E-05	-3.9094E-06	-5.8672E-07
PU240	-5.6610E-06	-4.1753E-06	-2.0846E-06	-5.1215E-07	-4.9169E-08
PU241	-4.4704E-05	-3.2580E-05	-1.5748E-05	-5.9165E-06	-9.2582E-07
PU242	-4.0157E-06	-2.9172E-06	-1.4646E-06	-3.6288E-07	-3.0421E-08
AM241	1.6974E-04	1.2945E-04	5.5958E-05	4.4880E-06	4.4248E-07
AM243	-6.6714E-08	-3.0086E-08	-1.7370E-07	-1.4684E-07	-6.5368E-10
CH244	-1.0349E-05	-7.5546E-06	-1.5670E-06	-8.9840E-07	-1.0336E-07
PP RL	-4.5630E-08	-2.0556E-08	-1.5032E-07	-2.4576E-08	5.9771E-09
NA	-6.6961E-07	-5.1514E-07	-3.1509E-07	-1.5743E-08	-1.2597E-09
SS COR	-1.1170E-06	-8.4434E-07	-4.1651E-07	0.0	0.0
O 16	-2.4051E-07	-2.3474E-07	-1.7039E-07	-1.1298E-08	-6.6473E-10

*** MODULE *DEPTH * IS FINISHED ***

TABLE 4.6

INPUT FOR SAMPLE PROBLEM #2

```

//JRWPROB2 JOB (19934,108),'JR WHITE UNIV LOWELL',TIME=(1,40)
/*JOBPARM LINES=10
/*ROUTE PRINT RMT162
//BOLDFOUR PROC GOSIZE=384K,GOTIME=,MODULE=SCALE,
// NB1=1,NB2=1,B1=3520,B2=32000,NX=2,NS=50,N1=100,
// N2=1,N3=1,N4=1,N5=1,N6=1,N7=1,N8=1,N9=1,N10=1,N11=1,N12=1,N13=1,
// N14=1,N15=1,N16=1
//GO EXEC PGM=MODULE,
// REGION=MODULE,GOSIZE=,TIME=,MODULE=
//STEPLIB DD UNIT=3330V,VOL=SER=VLFS01,DISP=SHR,
// DSN=JLL.BVFOUR.LOADM
// DD UNIT=3330-1,VOL=SER=NE3330,DISP=SHR,DSN=E.LMP00000.SCALE.PGMS
//PRINT DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//FT01F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT02F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT03F001 DD UNIT=SYSDA,SPACE=(80,(10)),
// DCB=(RECFM=F,BLKSIZE=80)
//FT04F001 DD UNIT=SYSDA,SPACE=(3200,(N1,NX)),
// DCB=(RECFM=FBS,LRECL=80,BLKSIZE=3200)
//FT05F001 DD UNIT=SYSDA,SPACE=(3120,(200,100)),
// DCB=(RECFM=FB,BUFNO=1,LRECL=80,BLKSIZE=3120)
//FT06F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//FT07F001 DD SYSOUT=B,DCB=(RECFM=F,BLKSIZE=80)
//FT08F001 DD UNIT=SYSDA,SPACE=(B1,(N1,2)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT09F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT10F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT11F001 DD UNIT=SYSDA,SPACE=(B1,(N1,NX)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT12F001 DD UNIT=SYSDA,SPACE=(B1,(N1,NX)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT13F001 DD UNIT=SYSDA,SPACE=(B1,(N1,2)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT14F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT15F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT16F001 DD UNIT=SYSDA,SPACE=(B1,(N1,NX)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT17F001 DD UNIT=SYSDA,SPACE=(B1,(N16)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT18F001 DD UNIT=SYSDA,SPACE=(B1,(N16)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)

```

Table 4.6 (Contd.)

```

//FT19F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT20F001 DD UNIT=SYSDA,SPACE=(#B1,(#N13)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT21F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT22F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT23F001 DD UNIT=SYSDA,SPACE=(#B1,(#N3)),
//          DCB=(RECFM=FI,BUFNO=#NB1)
//FT24F001 DD UNIT=SYSDA,SPACE=(#B1,(#N2)),
//          DCB=(RECFM=FT,BUFNO=#NB2)
//FT25F001 DD UNIT=SYSDA,SPACE=(#B1,(#N12)),
//          DCB=(RECFM=FT,BUFNO=#NB1)
//FT26F001 DD UNIT=SYSDA,SPACE=(#B1,(#N12)),
//          DCB=(RECFM=FT,BUFNO=#NB1)
//FT27F001 DD UNIT=SYSDA,SPACE=(#B1,(#N2)),
//          DCB=(RECFM=FT,BUFNO=#NB2)
//FT28F001 DD UNIT=SYSDA,SPACE=(#B1,(#N2)),
//          DCB=(RECFM=FT,BUFNO=#NB2)
//FT29F001 DD UNIT=SYSDA,SPACE=(#B1,(#N14)),
//          DCB=(RECFM=FT,BUFNO=#NB2)
//FT30F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT31F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,#NX)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT32F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT33F001 DD UNIT=SYSDA,SPACE=(#B1,(#N4)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT34F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,#NX)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT35F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT36F001 DD UNIT=SYSDA,SPACE=(#B1,(#N6,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT37F001 DD UNIT=SYSDA,SPACE=(#B1,(#N15,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT38F001 DD UNIT=SYSDA,SPACE=(#B1,(#N15,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT39F001 DD UNIT=SYSDA,SPACE=(#B1,(#N15,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT40F001 DD UNIT=SYSDA,SPACE=(#B2,(#N5)),
//          DCB=(RECFM=FT,BUFNO=#NB2)
//FT41F001 DD UNIT=SYSDA,SPACE=(#B1,(#N4)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT42F001 DD UNIT=SYSDA,SPACE=(#B2,(#N7)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB2,BLKSIZE=#B2)
//FT43F001 DD UNIT=SYSDA,SPACE=(#B2,(#N8)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB2,BLKSIZE=#B2)

```

Table 4.6 (Contd.)

```

//FT44F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT45F001 DD UNIT=SYSDA,SPACE=(#B1,(#N9)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT46F001 DD UNIT=SYSDA,SPACE=(#B1,(#N10)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT47F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT48F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT49F001 DD UNIT=SYSDA,SPACE=(#B1,(#N11)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT50F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT51F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT52F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT53F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT54F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT55F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT56F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT96F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT97F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT98F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT99F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//BOLDFOUR PEND
/*
// EXEC SPDASCR
//SYSIN DD *
      T.JRW00000.NSTARR.BOC1KEFF.PROB2
      T.JRW00000.DRDATA.BOC1KEFF.PROB2
      T.JRW00000.TDSENS.BOC1KEFF.PROB2
//BURN EXEC BOLDFOUR,
// NB1=1,NB2=1,B1=3520,B2=7200,N1=10,N2=60,N3=20,N4=10,N5=30,N6=10,
// N7=10,N8=10,N9=10,N10=10,N11=10,
// N12=100,N13=10,N14=10,N15=10,NX=20,NS=30,N16=10,
// GOSIZE=500K
//GO.FT11F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.GRUPXS.DPT.NSAMPLE,
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)

```


Table 4.6 (Contd.)

```

// GO.FT55F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT56F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT57F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT58F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.NSTARR.BOC1KEFF.PROB2,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT61F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT62F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT63F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT65F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.DRDATA.BOC1KEFF.PROB2,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT66F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.TDSENS.BOC1KEFF.PROB2,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT85F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.RZFLUX.NALL
//GO.FT86F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.ZNATDN.NALL
//GO.FT87F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.RTFLUX.NALL
//GO.FT88F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.ATFLUX.NALL
//GO.FT89F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.PERTUB.NALL
//GO.SYSIN DD *
=CONTROL1
DPT SAMPLE PROB #2 BOC STATIC SENSITIVITY CALC. KEFF RESPONSE
060000 1 1
99 2 2 1 99 99 99 99
GRUPXS
END
SUBMRG
5 -1
RZFLUX 56 85 5 5
ZNATDN 57 86 5 5
RTFLUX 61 87 5 5
ATFLUX 62 88 5 5
PERTUB 63 89 5 5
END

```

Table 4.6 (Contd.)

DVENTR

001

1000.0+06

1.0
1.0-041.0
5.0-04

-1 3 2 1 40

1 0 0 0 1 0 0 0 2 0 0 0 2 2 2 6 2

003

3 1 2

004

16 26.2133 16 26.2133 16 26.2133 10 22.2350 10 22.2350

005

1 2 3 4 5

012

0

1 3 1 1

4 5 2 2

0

013

26

26

TH228CTH232CPA231CPA233CU-232CU-233CU-234CU-235CU-236CU-238CNP237CNP239C
 PU238CPU239CPU240CPU241CPU242CAM241CAM243CCM244CSS CNA CO-16 CCHAN C
 CTLRDCFP C

26

TH228RTH232RPA231RPA233RU-232RU-233RU-234RU-235RU-236RU-238RNP237RNP239R
 PU238RPU239RPU240RPU241RPU242RAM241RAM243RCH244RSS RNA RO-16 RCHAN R
 CTLRDRFP R

020 -1 1 0.0

END

DUTLIN

EXPINS 0 1 0 40

0.001

0 1 0 1 1 0 0
 1 1 0 0

BLANK

END

INPUT PROCESSOR

0V EXPOSE

1D / FILE REFERENCE INFORMATION

0 24 0 1 0 0 0 0 0 0 1 0 8R

2D / TITLE AND NUCLIDE NAMES

* SAMPLE DUMMY EXPOSE FOR STATIC CALC *

*TH228 * *TH232 * *PA231 * *PA233 * *U 232 * *U 233 * *U 234 * *U 235 *
 *U 236 * *U 238 * *NP237 * *NP239 * *PU238 * *PU239 * *PU240 * *PU241 *
 *PU242 * *AM241 * *AM243 * *CM244 * *FP RL * *NA * *SS COR* *0 16 *

3D / REFERENCE DATA

0.0

6D / CHAIN DATA FOR MATRIX EXPONENTIAL

1 1 2

STOP

END

Table 4.6 (Contd.)

CHARGE

1\$\$\$ C 0 0 0 0 0 0 0 0 0 0 1 F0 T

35\$\$\$ 0 1 0 24 1 5 68 1 1 9

36\$\$\$ 0 1 1 0 1 1 0 0 1 0 T

37** F0.0 T

END

DEPTH

0

0

END

DEPTH

0

0

END

CHARGE

1\$\$\$ 0 0 0 0 0 0 0 0 1 4 0 F0 T

26\$\$\$ 0 0 3 1 0 0 F0

27** 1.011613 3.9037E+09 T

END

//

TABLE 4.7
SELECTED OUTPUT FROM SAMPLE PROBLEM #2

*** MODULE *SUBMRG* VERSION 1 (12/22/80) IS BEING ACCESSED ***

IPLIE = 5 NOPT = -1

```

RZFLUX  IP(I) = 56.85  5 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
ORDER IN WHICH RZFLUX FILES WERE STACKED ON UNIT # 56
KEFF = 1.0116129 0.0 DAYS EXPOSURE

ZWATDN  IP(I) = 57.86  5 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
ORDER IN WHICH ZWATDN FILES WERE STACKED ON UNIT # 57
CYCLE # 1 0.0 DAYS EXPOSURE

RTFLUX  IP(I) = 61.87  5 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
ORDER IN WHICH RTFLUX FILES WERE STACKED ON UNIT # 61
KEFF = 1.0116129 NGROUP = 9 NDIM = 1

ATFLUX  IP(I) = 62.88  5 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
ORDER IN WHICH ATFLUX FILES WERE STACKED ON UNIT # 62
KEFF = 1.0116129 NGROUP = 9 NDIM = 1

PERTUB  IP(I) = 63.89  5 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
ORDER IN WHICH PERTUB FILES WERE STACKED ON UNIT # 63
BIG-DAD = 0.27185E-12 KEFF = 1.0116129 NGROUP = 9

```

*** MODULE *SUBMRG* IS FINISHED ***

*** MODULE *CHARGE* VERSION 1 (12/22/80) IS BEING ACCESSED ***

```

1$ ARRAY 10 ENTRIES READ
0T
35$ ARRAY 10 ENTRIES READ
36$ ARRAY 10 ENTRIES READ
0T
37$ ARRAY 120 ENTRIES READ
0T
INTERFACE FILE *DATAIN* WAS WRITTEN ON UNIT # 55

```

*** MODULE *CHARGE* IS FINISHED ***

*** MODULE *DEPTH* VERSION 1 (12/22/80) IS BEING ACCESSED ***

```

*** INITIAL ADJOINT DENSITY*VOL VECTORS BY REGION FOR TIME STEP # 1 ***
TH228      0.0      0.0      0.0      0.0      0.0
TH232      0.0      0.0      0.0      0.0      0.0
PA231      0.0      0.0      0.0      0.0      0.0
PA233      0.0      0.0      0.0      0.0      0.0
UU232      0.0      0.0      0.0      0.0      0.0
UU233      0.0      0.0      0.0      0.0      0.0
UU234      0.0      0.0      0.0      0.0      0.0
UU235      0.0      0.0      0.0      0.0      0.0
UU236      0.0      0.0      0.0      0.0      0.0
UU238      0.0      0.0      0.0      0.0      0.0
NP237      0.0      0.0      0.0      0.0      0.0
NP239      0.0      0.0      0.0      0.0      0.0
PU238      0.0      0.0      0.0      0.0      0.0
PU239      0.0      0.0      0.0      0.0      0.0
PU240      0.0      0.0      0.0      0.0      0.0
PU241      0.0      0.0      0.0      0.0      0.0
PU242      0.0      0.0      0.0      0.0      0.0
AM241      0.0      0.0      0.0      0.0      0.0
AM243      0.0      0.0      0.0      0.0      0.0
CM244      0.0      0.0      0.0      0.0      0.0
WE RL      0.0      0.0      0.0      0.0      0.0
NA      0.0      0.0      0.0      0.0      0.0
SS COR     0.0      0.0      0.0      0.0      0.0
O 16      0.0      0.0      0.0      0.0      0.0

```

*** ALPHA FOR TIMESTEP # 1 IS 1.4195E 22 ***

*** N*N SUMMED OVER REGIONS AT END OF TIME STEP # 1 FOR RESPONSE # 1 IS 0.0 ***

PSTAR BY RESPONSE FOR TIME STEP # 1 SUBSTEP # 1

0.0

```

*** ADJOINT SOURCE VECTORS BY ZONE FOR TIME STEP # 1 ***
0.0      0.0      0.0      0.0      0.0
0.0      0.0      0.0      0.0      0.0
0.0      0.0      0.0      0.0      0.0
0.0      0.0      0.0      0.0      0.0
0.0      0.0      0.0      0.0      0.0
0.0      0.0      0.0      0.0      0.0
0.0      0.0      0.0      0.0      0.0
0.0      0.0      0.0      0.0      0.0
0.0      0.0      0.0      0.0      0.0
0.0      0.0      0.0      0.0      0.0

```

INTEGRAL OF (S*(R,E) * GPLX(R,E)) FOR RESPONSE # 1 IS 0.0

*** MODULE *DEPTH * IS FINISHED ***

*** MODULE *DEPTH * VERSION 1 (12/22/80) IS BEING ACCESSED ***

*** INITIAL ADJOINT DENSITY*VOL VECTORS BY REGION FOR TIME STEP # 2 ***

TH228	0.0	0.0	0.0	0.0	0.0
TH232	-1.3623E-09	-5.3381E-09	-3.376E-09	-1.3680E-10	-1.7306E-12
PA231	-4.6880E-09	-1.8925E-08	-1.3870E-08	-1.3088E-09	-3.1316E-11
PA233	-2.3996E-10	-3.6198E-09	-2.1838E-09	-3.5002E-10	-5.0314E-12
U232	7.2218E-10	3.2681E-09	3.0579E-09	3.5800E-10	1.2905E-11
U233	1.7118E-08	7.0344E-08	5.6963E-08	9.2557E-09	4.0511E-10
U234	9.6777E-12	3.2628E-10	1.0884E-09	2.4340E-10	7.8658E-12
U235	9.8590E-09	4.0649E-08	3.3561E-08	6.2226E-09	2.7602E-10
U236	-1.4285E-09	-5.5621E-09	-3.4421E-09	-1.6865E-10	-2.8332E-12
U238	-7.8835E-10	-2.9649E-09	-1.4821E-09	-6.2743E-11	-3.1369E-12
MP237	-4.2071E-09	-1.6936E-08	-1.2332E-08	-1.2310E-09	-2.9303E-11
MP239	-3.1536E-09	-1.2680E-08	-9.2267E-09	-9.2422E-10	-2.1942E-11
PD238	7.4468E-09	3.0726E-08	2.4934E-08	3.6504E-09	1.4276E-10
PD239	1.3411E-08	5.5154E-08	4.4452E-08	6.9502E-09	2.0111E-10
PD240	1.6882E-09	7.1544E-09	6.2149E-09	6.7333E-10	1.9885E-11
PD241	1.9319E-08	7.9382E-08	6.4170E-08	1.0847E-08	4.5749E-10
PD242	6.2170E-10	2.7864E-09	2.8118E-09	3.8983E-10	1.1360E-11
AN241	-9.9495E-08	-4.0661E-07	-3.1215E-07	-3.1288E-08	-7.2787E-10
AN243	-9.8778E-10	-3.8132E-09	-2.3864E-09	-3.4298E-10	-1.0981E-11
CH244	-4.8523E-09	-2.0093E-08	-1.6210E-08	-1.7759E-09	-5.5392E-11
FF241	-1.9064E-09	-4.1002E-09	-3.9999E-09	6.5646E-11	3.1342E-12
MA	-4.1438E-13	1.1579E-10	4.5178E-10	8.8366E-11	2.2725E-12
SS COR	-8.2045E-11	-2.0678E-10	2.5119E-10	0.0	0.0
O 16	-1.4126E-11	5.2618E-11	3.7515E-10	8.6371E-11	1.9923E-12

*** MODULE *DEPTH * IS FINISHED ***

*** MODULE *CHARGE* VERSION 1 (12/22/80) IS BEING ACCESSED ***

1\$ ARRAY 10 ENTRIES READ
 0T
 26\$ ARRAY 10 ENTRIES READ
 27* ARRAY 2 ENTRIES READ
 0T

ENERGY AND XSEC SET INTEGRATED CAPTURE SECS. COEFF. FOR TIME STEP 0 1 (BEFORE TRANSPORT CORR.)

NUCLIDE	T2A	T2AD	T4AD
U238	0.0	0.0	0.0
U235	-1.4640E-01	0.0	0.0
Pa233	0.0	0.0	0.0
Th232	0.0	0.0	0.0
U233	-2.0	0.0	0.0
U234	-7.524E-02	0.0	0.0
U236	-4.3878E-04	0.0	0.0
U238	-1.5044E-01	0.0	0.0
U237	0.0	0.0	0.0
U238	0.0	0.0	0.0
U239	-9.7127E-03	0.0	0.0
U240	-5.5847E-02	0.0	0.0
U241	-1.5922E-01	0.0	0.0
U242	-1.79598E-01	0.0	0.0
U243	0.0	0.0	0.0
U244	0.0	0.0	0.0
U245	0.0	0.0	0.0
U246	0.0	0.0	0.0
U247	0.0	0.0	0.0
U248	0.0	0.0	0.0
U249	0.0	0.0	0.0
U250	0.0	0.0	0.0
U251	0.0	0.0	0.0
U252	0.0	0.0	0.0
U253	0.0	0.0	0.0
U254	0.0	0.0	0.0
U255	0.0	0.0	0.0
U256	0.0	0.0	0.0
U257	0.0	0.0	0.0
U258	0.0	0.0	0.0
U259	0.0	0.0	0.0
U260	0.0	0.0	0.0
U261	0.0	0.0	0.0
U262	0.0	0.0	0.0
U263	0.0	0.0	0.0
U264	0.0	0.0	0.0
U265	0.0	0.0	0.0
U266	0.0	0.0	0.0
U267	0.0	0.0	0.0
U268	0.0	0.0	0.0
U269	0.0	0.0	0.0
U270	0.0	0.0	0.0
U271	0.0	0.0	0.0
U272	0.0	0.0	0.0
U273	0.0	0.0	0.0
U274	0.0	0.0	0.0
U275	0.0	0.0	0.0
U276	0.0	0.0	0.0
U277	0.0	0.0	0.0
U278	0.0	0.0	0.0
U279	0.0	0.0	0.0
U280	0.0	0.0	0.0
U281	0.0	0.0	0.0
U282	0.0	0.0	0.0
U283	0.0	0.0	0.0
U284	0.0	0.0	0.0
U285	0.0	0.0	0.0
U286	0.0	0.0	0.0
U287	0.0	0.0	0.0
U288	0.0	0.0	0.0
U289	0.0	0.0	0.0
U290	0.0	0.0	0.0
U291	0.0	0.0	0.0
U292	0.0	0.0	0.0
U293	0.0	0.0	0.0
U294	0.0	0.0	0.0
U295	0.0	0.0	0.0
U296	0.0	0.0	0.0
U297	0.0	0.0	0.0
U298	0.0	0.0	0.0
U299	0.0	0.0	0.0
U300	0.0	0.0	0.0
U301	0.0	0.0	0.0
U302	0.0	0.0	0.0
U303	0.0	0.0	0.0
U304	0.0	0.0	0.0
U305	0.0	0.0	0.0
U306	0.0	0.0	0.0
U307	0.0	0.0	0.0
U308	0.0	0.0	0.0
U309	0.0	0.0	0.0
U310	0.0	0.0	0.0
U311	0.0	0.0	0.0
U312	0.0	0.0	0.0
U313	0.0	0.0	0.0
U314	0.0	0.0	0.0
U315	0.0	0.0	0.0
U316	0.0	0.0	0.0

ENERGY AND XSEC SET INTEGRATED FISSION SECS. COEFF. FOR TIME STEP 0 1 (BEFORE TRANSPORT CORR.)

NUCLIDE	T2A	T2F	T3F	T4AD	T4AD
U238	0.0	0.0	0.0	0.0	0.0
U235	-5.2090E-03	0.0	0.0	0.0	0.0
Pa233	0.0	0.0	0.0	0.0	0.0
Th232	0.0	0.0	0.0	0.0	0.0
U233	-2.0	0.0	0.0	0.0	0.0
U234	-9.965E-01	0.0	0.0	0.0	0.0
U236	-1.5696E-03	0.0	0.0	0.0	0.0
U238	-2.0	0.0	0.0	0.0	0.0
U237	-9.9753E-02	0.0	0.0	0.0	0.0
U238	0.0	0.0	0.0	0.0	0.0
U239	0.0	0.0	0.0	0.0	0.0
U240	0.0	0.0	0.0	0.0	0.0
U241	0.0	0.0	0.0	0.0	0.0
U242	0.0	0.0	0.0	0.0	0.0
U243	0.0	0.0	0.0	0.0	0.0
U244	0.0	0.0	0.0	0.0	0.0
U245	0.0	0.0	0.0	0.0	0.0
U246	0.0	0.0	0.0	0.0	0.0
U247	0.0	0.0	0.0	0.0	0.0
U248	0.0	0.0	0.0	0.0	0.0
U249	0.0	0.0	0.0	0.0	0.0
U250	0.0	0.0	0.0	0.0	0.0
U251	0.0	0.0	0.0	0.0	0.0
U252	0.0	0.0	0.0	0.0	0.0
U253	0.0	0.0	0.0	0.0	0.0
U254	0.0	0.0	0.0	0.0	0.0
U255	0.0	0.0	0.0	0.0	0.0
U256	0.0	0.0	0.0	0.0	0.0
U257	0.0	0.0	0.0	0.0	0.0
U258	0.0	0.0	0.0	0.0	0.0
U259	0.0	0.0	0.0	0.0	0.0
U260	0.0	0.0	0.0	0.0	0.0
U261	0.0	0.0	0.0	0.0	0.0
U262	0.0	0.0	0.0	0.0	0.0
U263	0.0	0.0	0.0	0.0	0.0
U264	0.0	0.0	0.0	0.0	0.0
U265	0.0	0.0	0.0	0.0	0.0
U266	0.0	0.0	0.0	0.0	0.0
U267	0.0	0.0	0.0	0.0	0.0
U268	0.0	0.0	0.0	0.0	0.0
U269	0.0	0.0	0.0	0.0	0.0
U270	0.0	0.0	0.0	0.0	0.0
U271	0.0	0.0	0.0	0.0	0.0
U272	0.0	0.0	0.0	0.0	0.0
U273	0.0	0.0	0.0	0.0	0.0
U274	0.0	0.0	0.0	0.0	0.0
U275	0.0	0.0	0.0	0.0	0.0
U276	0.0	0.0	0.0	0.0	0.0
U277	0.0	0.0	0.0	0.0	0.0
U278	0.0	0.0	0.0	0.0	0.0
U279	0.0	0.0	0.0	0.0	0.0
U280	0.0	0.0	0.0	0.0	0.0
U281	0.0	0.0	0.0	0.0	0.0
U282	0.0	0.0	0.0	0.0	0.0
U283	0.0	0.0	0.0	0.0	0.0
U284	0.0	0.0	0.0	0.0	0.0
U285	0.0	0.0	0.0	0.0	0.0
U286	0.0	0.0	0.0	0.0	0.0
U287	0.0	0.0	0.0	0.0	0.0
U288	0.0	0.0	0.0	0.0	0.0
U289	0.0	0.0	0.0	0.0	0.0
U290	0.0	0.0	0.0	0.0	0.0
U291	0.0	0.0	0.0	0.0	0.0
U292	0.0	0.0	0.0	0.0	0.0
U293	0.0	0.0	0.0	0.0	0.0
U294	0.0	0.0	0.0	0.0	0.0
U295	0.0	0.0	0.0	0.0	0.0
U296	0.0	0.0	0.0	0.0	0.0
U297	0.0	0.0	0.0	0.0	0.0
U298	0.0	0.0	0.0	0.0	0.0
U299	0.0	0.0	0.0	0.0	0.0
U300	0.0	0.0	0.0	0.0	0.0
U301	0.0	0.0	0.0	0.0	0.0
U302	0.0	0.0	0.0	0.0	0.0
U303	0.0	0.0	0.0	0.0	0.0
U304	0.0	0.0	0.0	0.0	0.0
U305	0.0	0.0	0.0	0.0	0.0
U306	0.0	0.0	0.0	0.0	0.0
U307	0.0	0.0	0.0	0.0	0.0
U308	0.0	0.0	0.0	0.0	0.0
U309	0.0	0.0	0.0	0.0	0.0
U310	0.0	0.0	0.0	0.0	0.0
U311	0.0	0.0	0.0	0.0	0.0
U312	0.0	0.0	0.0	0.0	0.0
U313	0.0	0.0	0.0	0.0	0.0
U314	0.0	0.0	0.0	0.0	0.0
U315	0.0	0.0	0.0	0.0	0.0
U316	0.0	0.0	0.0	0.0	0.0

*** TIME-DEPENDENT (REVERSE TIME ORDER) DATA SENSITIVITY COEFFS FOR TIME STEP 1 ***

	CAPTURE -- CAP (WISOE,NISIT) SUMMED OVER ENERGY	
TH228	0.0	0.0
TH232	-1.2155E-01	-2.3802E-02
PA231	0.0	0.0
PA233	0.0	0.0
U 232	0.0	0.0
U 233	-2.7217E-02	-2.1094E-04
U 234	0.0	0.0
U 235	-4.3750E-04	0.0
U 236	0.0	0.0
U 238	-1.4994E-01	0.0
WP237	0.0	0.0
WP239	0.0	0.0
PO238	0.0	0.0
PO239	-9.6906E-03	0.0
PO240	-5.5694E-04	0.0
PO241	-1.8864E-05	0.0
PO242	-7.9430E-07	0.0
AM241	0.0	0.0
AM243	0.0	0.0
CM244	0.0	0.0
FP RL	0.0	0.0
NA	-2.7213E-03	-7.0325E-05
SS COR	-3.1436E-02	0.0
O 16	-3.0P56E-03	-8.9550E-05

	FISSION -- FIS (WISOE,NISIT) SUMMED OVER ENERGY	
TH228	0.0	0.0
TH232	5.8046E-03	8.9014E-04
PA231	0.0	0.0
PA233	0.0	0.0
U 232	0.0	0.0
U 233	4.8431E-01	6.4053E-03
U 234	0.0	0.0
U 235	2.4474E-03	0.0
U 236	0.0	0.0
U 238	5.0506E-02	0.0
WP237	0.0	0.0
WP239	0.0	0.0
PO238	0.0	0.0
PO239	7.6693E-02	0.0
PO240	1.0291E-03	0.0
PO241	2.2325E-04	0.0
PO242	1.0165E-06	0.0
AM241	0.0	0.0
AM243	0.0	0.0
CM244	0.0	0.0
FP RL	0.0	0.0
NA	0.0	0.0
SS COR	0.0	0.0
O 16	0.0	0.0

	NU	--	INU(NISOE,NXSET)	SUMMED OVER ENERGY
TR228	0.0		0.0	
TR232	1.0254E-02		1.4504E-03	
PA231	0.0		0.0	
PA233	0.0		0.0	
U232	0.0		0.0	
U233	7.8030E-01		8.5757E-03	
U234	0.0		0.0	
U235	4.0097E-03		0.0	
U236	0.0		0.0	
U238	7.9699E-02		0.0	
NP237	0.0		0.0	
NP239	0.0		0.0	
PU238	0.0		0.0	
PC239	1.1388E-01		0.0	
PO240	1.5079E-03		0.0	
PO241	3.2924E-04		0.0	
PO242	1.4999E-06		0.0	
AM241	0.0		0.0	
AM243	0.0		0.0	
CM244	0.0		0.0	
YF EL	0.0		0.0	
MA EL	0.0		0.0	
SS COR	0.0		0.0	
O 16	0.0		0.0	

	TRANSPORT --	TR(NISOE,NXSET)	SUMMED OVER ENERGY
TR228	0.0		0.0
TR232	1.4267E-02		2.0187E-02
PA231	0.0		0.0
PA233	0.0		0.0
U232	0.0		0.0
U233	4.3116E-03		2.3402E-04
U234	0.0		0.0
U235	3.6182E-05		0.0
U236	0.0		0.0
U238	2.4110E-02		0.0
NP237	0.0		0.0
NP239	0.0		0.0
PU238	0.0		0.0
PC239	8.9335E-04		0.0
PO240	4.9165E-05		0.0
PO241	1.9604E-06		0.0
PO242	6.3327E-08		0.0
AM241	0.0		0.0
AM243	0.0		0.0
CM244	0.0		0.0
YF EL	0.0		0.0
MA EL	2.1796E-02		4.8414E-03
SS COR	4.1344E-02		0.0
O 16	4.0708E-02		1.4490E-02

[illegible]

ITEM	QTY	UNIT	PRICE	AMOUNT	TAX	TOTAL	DATE	TIME	USER	REMARKS
1	1	EA	100.00	100.00	0.00	100.00	2023-10-27	10:00	ADMIN	ITEM 1
2	1	EA	200.00	200.00	0.00	200.00	2023-10-27	10:00	ADMIN	ITEM 2
3	1	EA	300.00	300.00	0.00	300.00	2023-10-27	10:00	ADMIN	ITEM 3
4	1	EA	400.00	400.00	0.00	400.00	2023-10-27	10:00	ADMIN	ITEM 4
5	1	EA	500.00	500.00	0.00	500.00	2023-10-27	10:00	ADMIN	ITEM 5
6	1	EA	600.00	600.00	0.00	600.00	2023-10-27	10:00	ADMIN	ITEM 6
7	1	EA	700.00	700.00	0.00	700.00	2023-10-27	10:00	ADMIN	ITEM 7
8	1	EA	800.00	800.00	0.00	800.00	2023-10-27	10:00	ADMIN	ITEM 8
9	1	EA	900.00	900.00	0.00	900.00	2023-10-27	10:00	ADMIN	ITEM 9
10	1	EA	1000.00	1000.00	0.00	1000.00	2023-10-27	10:00	ADMIN	ITEM 10
11	1	EA	1100.00	1100.00	0.00	1100.00	2023-10-27	10:00	ADMIN	ITEM 11
12	1	EA	1200.00	1200.00	0.00	1200.00	2023-10-27	10:00	ADMIN	ITEM 12
13	1	EA	1300.00	1300.00	0.00	1300.00	2023-10-27	10:00	ADMIN	ITEM 13
14	1	EA	1400.00	1400.00	0.00	1400.00	2023-10-27	10:00	ADMIN	ITEM 14
15	1	EA	1500.00	1500.00	0.00	1500.00	2023-10-27	10:00	ADMIN	ITEM 15
16	1	EA	1600.00	1600.00	0.00	1600.00	2023-10-27	10:00	ADMIN	ITEM 16
17	1	EA	1700.00	1700.00	0.00	1700.00	2023-10-27	10:00	ADMIN	ITEM 17
18	1	EA	1800.00	1800.00	0.00	1800.00	2023-10-27	10:00	ADMIN	ITEM 18
19	1	EA	1900.00	1900.00	0.00	1900.00	2023-10-27	10:00	ADMIN	ITEM 19
20	1	EA	2000.00	2000.00	0.00	2000.00	2023-10-27	10:00	ADMIN	ITEM 20
21	1	EA	2100.00	2100.00	0.00	2100.00	2023-10-27	10:00	ADMIN	ITEM 21
22	1	EA	2200.00	2200.00	0.00	2200.00	2023-10-27	10:00	ADMIN	ITEM 22
23	1	EA	2300.00	2300.00	0.00	2300.00	2023-10-27	10:00	ADMIN	ITEM 23
24	1	EA	2400.00	2400.00	0.00	2400.00	2023-10-27	10:00	ADMIN	ITEM 24
25	1	EA	2500.00	2500.00	0.00	2500.00	2023-10-27	10:00	ADMIN	ITEM 25
26	1	EA	2600.00	2600.00	0.00	2600.00	2023-10-27	10:00	ADMIN	ITEM 26
27	1	EA	2700.00	2700.00	0.00	2700.00	2023-10-27	10:00	ADMIN	ITEM 27
28	1	EA	2800.00	2800.00	0.00	2800.00	2023-10-27	10:00	ADMIN	ITEM 28
29	1	EA	2900.00	2900.00	0.00	2900.00	2023-10-27	10:00	ADMIN	ITEM 29
30	1	EA	3000.00	3000.00	0.00	3000.00	2023-10-27	10:00	ADMIN	ITEM 30
31	1	EA	3100.00	3100.00	0.00	3100.00	2023-10-27	10:00	ADMIN	ITEM 31
32	1	EA	3200.00	3200.00	0.00	3200.00	2023-10-27	10:00	ADMIN	ITEM 32
33	1	EA	3300.00	3300.00	0.00	3300.00	2023-10-27	10:00	ADMIN	ITEM 33
34	1									

[illegible]

*** MODULE CHANGE IS FINISHED ***

TABLE 4.8

INPUT FOR SAMPLE PROBLEM #3

```

//JRWPROB3 JOB (19934,I08),'JR WHITE UNIV LOWELL',TIME=(1,40)
/*JOBPARM LINES=10
/*ROUTE PRINT RMT162
//BOLDFOUR PROC GOSIZE=384K,GOTIME=,MODULE=SCALE,
// NB1=1,NB2=1,B1=3520,B2=32000,NX=2,NS=50,N1=100,
// N2=1,N3=1,N4=1,N5=1,N6=1,N7=1,N8=1,N9=1,N10=1,N11=1,N12=1,N13=1,
// N14=1,N15=1,N16=1
//GO      EXEC  PGM=MODULE,
//          REGION=MODULE,GOSIZE=,TIME=,GOTIME=
//STEPLIB DD UNIT=333CV,VOL=SER=VLFS01,DISP=SHR,
//          DSN=JLL.BVFOUR.LOADM
// DD UNIT=3330-1,VOL=SER=NE3330,DISP=SHR,DSN=E.LMP00000.SCALE.PGMS
//PRINT   DD  SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//FT01F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT02F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT03F001 DD UNIT=SYSDA,SPACE=(80,(10)),
//          DCB=(RECFM=F,BLKSIZE=80)
//FT04F001 DD UNIT=SYSDA,SPACE=(3200,(N1,NX)),
//          DCB=(RECFM=FBS,LRECL=80,BLKSIZE=3200)
//FT05F001 DD UNIT=SYSDA,SPACE=(3120,(200,100)),
//          DCB=(RECFM=FB,BUFNO=1,LRECL=80,BLKSIZE=3120)
//FT06F001 DD  SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//FT07F001 DD  SYSOUT=B,DCB=(RECFM=F,BLKSIZE=80)
//FT08F001 DD UNIT=SYSDA,SPACE=(B1,(N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT09F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT10F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT11F001 DD UNIT=SYSDA,SPACE=(B1,(N1,NX)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT12F001 DD UNIT=SYSDA,SPACE=(B1,(N1,NX)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT13F001 DD UNIT=SYSDA,SPACE=(B1,(N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT14F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT15F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT16F001 DD UNIT=SYSDA,SPACE=(B1,(N1,NX)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT17F001 DD UNIT=SYSDA,SPACE=(B1,(N16)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)

```

Table 4.8 (Contd.)

```

//FT18F001 DD UNIT=SYSDA,SPACE=(qB1,(qN16)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT19F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT20F001 DD UNIT=SYSDA,SPACE=(qB1,(qN13)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT21F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT22F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT23F001 DD UNIT=SYSDA,SPACE=(qB1,(qN3)),
//          DCB=(RECFM=FT,BUFNO=qNB1)
//FT24F001 DD UNIT=SYSDA,SPACE=(qB1,(qN2)),
//          DCB=(RECFM=FT,BUFNO=qNB2)
//FT25F001 DD UNIT=SYSDA,SPACE=(qB1,(qN12)),
//          DCB=(RECFM=FT,BUFNO=qNB1)
//FT26F001 DD UNIT=SYSDA,SPACE=(qB1,(qN12)),
//          DCB=(RECFM=FT,BUFNO=qNB1)
//FT27F001 DD UNIT=SYSDA,SPACE=(qB1,(qN2)),
//          DCB=(RECFM=FT,BUFNO=qNB2)
//FT28F001 DD UNIT=SYSDA,SPACE=(qB1,(qN2)),
//          DCB=(RECFM=FT,BUFNO=qNB2)
//FT29F001 DD UNIT=SYSDA,SPACE=(qB1,(qN14)),
//          DCB=(RECFM=FT,BUFNO=qNB2)
//FT30F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT31F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,qNX)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT32F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT33F001 DD UNIT=SYSDA,SPACE=(qB1,(qN4)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT34F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,qNX)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT35F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT36F001 DD UNIT=SYSDA,SPACE=(qB1,(qN6,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT37F001 DD UNIT=SYSDA,SPACE=(qB1,(qN15,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT38F001 DD UNIT=SYSDA,SPACE=(qB1,(qN15,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT39F001 DD UNIT=SYSDA,SPACE=(qB1,(qN15,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT40F001 DD UNIT=SYSDA,SPACE=(qB2,(qN5)),
//          DCB=(RECFM=FT,BUFNO=qNB2)
//FT41F001 DD UNIT=SYSDA,SPACE=(qB1,(qN4)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT42F001 DD UNIT=SYSDA,SPACE=(qB2,(qN7)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB2,BLKSIZE=qB2)

```

Table 4.8 (Contd.)

```

//FT43F001 DD UNIT=SYSDA,SPACE=(#B2,(#N8)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB2,BLKSIZE=#B2)
//FT44F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT45F001 DD UNIT=SYSDA,SPACE=(#B1,(#N9)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT46F001 DD UNIT=SYSDA,SPACE=(#B1,(#N10)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT47F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT48F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT49F001 DD UNIT=SYSDA,SPACE=(#B1,(#N11)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT50F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT51F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT52F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT53F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT54F001 DD UNIT=SYSDA,SPACE=(#B1,(#N1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT55F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT56F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT96F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT97F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT98F001 DD UNIT=SYSDA,SPACE=(#B1,(#NS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=#NB1,BLKSIZE=#B1)
//FT99F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//BOLDFOUR PEND
/*
// EXEC SPDASCR
//SYSIN DD *
      T.JRW00000.NSTARR.BOC2BR.PROB3
      T.JRW00000.DRDATA.BOC2BR.PROB3
      T.JRW00000.TDSENS.BOC2BR.PROB3
// EXEC BOLDFOUR,
// NB1=1,NB2=1,B1=3520,B2=7200,N1=10,N2=60,N3=20,N4=10,N5=30,N6=10,
// N7=10,N8=10,N9=10,N10=10,N11=10,
// N12=100,N13=10,N14=10,N15=10,NX=20,NS=30,N16=10,
// GOSIZE=500K
//GO.FT11F001 DD UNIT=SPDA,DISP=SMR,
// DSN=T.JRW00000.GRUPXS.DPT.NSAMPLE,
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)

```

Table 4.8 (Contd.)

```

//GO.FT55F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT56F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT57F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT58F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.NSTARR.BOC2BR.PROB3,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT61F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT62F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT63F001 DD UNIT=SYSDA,SPACE=(3520,(10,5)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT65F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.DRDATA.BOC2BR.PROB3,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT66F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.TDSENS.BOC2BR.PROB3,
// SPACE=(3520,(10,5),RLSE),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=1,BLKSIZE=3520)
//GO.FT85F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.RZFLUX.NALL
//GO.FT86F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.ZNATDN.NALL
//GO.FT87F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.RTFLUX.NALL
//GO.FT88F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.ATFLUX.NALL
//GO.SYSIN DD *
=CONTROL1
DPT SAMPLE PROB #3 BOC2 'STATIC' B.R. RESPONSE FULL MULTICYCLE ADJ C
060000 1 1
99 2 2 1 1 99 99 7 2 99 7 99 7 99 7 99 99
GRUPXS
END
SUBMRG
4 -1
RZFLUX 56 85 5 1 3 4 5
ZNATDN 57 86 5 1 3 4 5
RTFLUX 61 87 5 1 3 4 5
ATFLUX 62 88 5 1 3 4 5
END

```

Table 4.8 (Contd.)

DVENTR

001

1000.0+06

1.0
1.0-041.0
5.0-04

-1 3 2 1 40
1 0 0 0 1 0 0 0 2 0 0 0

2 2 2

6 2

003

3 1 2

004

16 26.2133 16 26.2133 16 26.2133 10 22.2350 10 22.2350

005

1 2 3 4 5

012

0

1 3 1 1

4 5 2 2

0

013

26

26

TH228CTH232CPA231CPA233CU-232CU-233CU-234CU-235CU-236CU-238CNP237CNP239C
PU238CPU239CPU240CPU241CPU242CAM241CAM243CCM244CSS CNA CO-16 CCHAN C
CTLRDCFP C

26

TH228RTH232RPA231RPA233RU-232RU-233RU-234RU-235RU-236RU-238RNP237RNP239R
PU238RPU239RPU240RPU241RPU242RAM241RAM243RCM244RSS RNA RO-16 RCHAN R
CTLRDRFP R

020

-1 1 0.0

END

DUTLIN

EXPINS 0 1 0 40

0.001

0 1 0 1 1 0 0
1 1 0 0

BLANK

END

INPUT PROCESSOR

0V EXPOSE

1D / FILE REFERENCE INFORMATION

0 24 0 1 0 20 1 20 0 0 0 28 0 8R

2D / TITLE AND NUCLIDE NAMES

* DEPLETION MODULE WITH 20 HM 1 FP & 3 OTHER NUCLIDES *

*TH228 * *TH232 * *PA231 * *PA233 * *U 232 * *U 233 * *U 234 * *U 235 *
*U 236 * *U 238 * *NP237 * *NP239 * *PU238 * *PU239 * *PU240 * *PU241 *
*PU242 * *AM241 * *AM243 * *CM244 * *FP RL * *NA * *SS COR* *0 16 *

Table 4.8 (Contd.)

```

3D / REFERENCE DATA
  0.0 /
  1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 /
  21 /
  1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 /
4D / DECAY DATA
1.156-08 1.580-18 6.312-13 2.971-07 2.968-10 1.360-13 8.860-14 3.080-17
9.150-16 4.870-18 9.980-15 3.414-06 2.540-10 9.000-13 3.340-12 1.560-09
5.780-14 4.800-11 2.750-12 1.270-09
5D / FISSION PRODUCT YIELD DATA
1.0 20R
6D / CHAIN DATA FOR MATRIX EXPONENTIAL
  2 4 2  2 3 5  3 5 2  4 5 5  4 6 1  4 7 2  5 1 1  5 6 2  6 5 5  6 7 2
  7 8 2  8 9 2  9 11 2  10 11 5  10 12 2  11 13 2  12 14 1  13 14 2
 14 15 2  15 16 2  16 17 2  16 18 1  17 19 2  19 20 2
  21 21 2  22 22 2  23 23 2  24 24 2
STOP
END
INPUT PROCESSOR
0V REFUEL
1D 0 0 24 0 0  0 0 0 2 11  1 0 1 24 2  0 5R
2D
*TH228 * *TH232 * *PA231 * *PA233 * *U 232 * *U 233 * *U 234 * *U 235 *
*U 236 * *U 238 * *NP237 * *NP239 * *PU238 * *PU239 * *PU240 * *PU241 *
*PU242 * *AM241 * *AM243 * *CM244 * *FP RL * *NA  * *SS COR* *0 16 *
  0.0 24R  0.0 24R  0.0 24R  0.0 24R
4D
  2 6 8 10 14 15 16 17 22 23 24
  2 6 8 10 14 15 16 17 22 23 24
  2.7669-3  8.2324-4  6.2594-6  4.1970-3  1.5467-4  8.6224-6
  3.2695-7  1.1106-8  8.5936-3  1.4757-2  1.6959-2
  2.4902-3  8.2324-4  6.2594-6  4.4736-3  1.5467-4  8.6224-6
  3.2695-7  1.1106-8  8.5936-3  1.4757-2  1.6959-2
5D
  1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
6D 0.0 0
7D 1 1 0  0 17R /REF FUEL MANG EOC1
8D 1 0 0 1 0  3
7D 1 1 0  0 17R /EXCHANGE 10% TH232 WITH U238 IN FEED (PERT #1)
8D 2 0 0 1 0  3
STOP
END
CHARGE
1$$$ 0 0 0 0 0  1 0 1 0 -1  F0  T
11$$$ 1 1 3 1 2  0 F0  T
12** 0.0 1.0 2R0.0 1.0 0.0 1.0 2R0.0 1.0 2R0.0 1.0 0.0 1.0 9R0.0
      3R0.0 1.0 0.0 1.0 0.0 1.0 5R0.0 1.0 0.0 1.0 8R0.0
13** F1.0

```


Table 4.8 (Contd.)

```

14$$$ F1
15$$$ 1 2 T
35$$$ 0 4 0 24 1 5 68 1 1 9
36$$$ 0 1 1 1 1 2 6 0 1 0 T
END
DEPTH
0
0
END
DUTLIN
EXPINS 0 1 0 40
91.3125
0 1 0 1 1 0 0
1 1 0 0 0
BLANK
END
DEPTH
1
1 0 8 1 1 1 0 0
END
DEPTH
0
0
END
DEPTH
0
0
END
DEPTH
0
0
END
CHARGE
1$$$ 0 0 0 0 1 1 0 1 4 0 F0 T
2$$$ 0 1 5 1 2 F0
6** 1.32313 1.0 T
3$$$ 4 T
4$$$ 3I1 5
5** F1.0 T
11$$$ 1 1 3 1 2 1 F0 T
12** 0.0 1.0 2R0.0 1.0 0.0 1.0 2R0.0 1.0 2R0.0 1.0 0.0 1.0 9R0.0
3R0.0 1.0 0.0 1.0 0.0 1.0 5R0.0 1.0 0.0 1.0 8R0.0
13** F1.0
14$$$ F1
15$$$ 1 2 T
26$$$ 2 4 0 1 0 -1 F0
27** 1.32313 1.0 T
28$$$ 1 2
29$$$ 1 2 3 4 T
END
//

```

TABLE 4.9

SELECTED OUTPUT FROM SAMPLE PROBLEM #3

*** MODULE *SUBMRG* VERSION 1 (12/22/80) IS BEING ACCESSED ***

IFLIE = 4 NOPT = -1

RZFLUX ORDER IP(I) = 56 85 5 1 3 4 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 ORDER IN WHICH RZFLUX FILES WERE STACKED ON UNIT 56
 KEPP = 0.9517500 273.9373 DAYS EXPOSURE
 KEPP = 0.9856577 182.6250 DAYS EXPOSURE
 KEPP = 0.9714870 91.3125 DAYS EXPOSURE
 KEPP = 1.0116129 0.0 DAYS EXPOSURE

ZMATDN ORDER IP(I) = 57 86 5 1 3 4 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 ORDER IN WHICH ZMATDN FILES WERE STACKED ON UNIT 57
 CYCLE 0 2 273.9373 DAYS EXPOSURE
 CYCLE 0 1 182.6250 DAYS EXPOSURE
 CYCLE 0 1 91.3125 DAYS EXPOSURE
 CYCLE 0 1 0.0 DAYS EXPOSURE

RTFLUX ORDER IP(I) = 61 87 5 1 3 4 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 ORDER IN WHICH RTFLUX FILES WERE STACKED ON UNIT 61
 KEPP = 0.9517500 WGROUP = 9 NDIN = 1
 KEPP = 0.9856577 WGROUP = 9 NDIN = 1
 KEPP = 0.9714870 WGROUP = 9 NDIN = 1
 KEPP = 1.0116129 WGROUP = 9 NDIN = 1

ATFLUX ORDER IP(I) = 62 88 5 1 3 4 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 ORDER IN WHICH ATFLUX FILES WERE STACKED ON UNIT 62
 KEPP = 0.9517500 WGROUP = 9 NDIN = 1
 KEPP = 0.9856577 WGROUP = 9 NDIN = 1
 KEPP = 0.9714870 WGROUP = 9 NDIN = 1
 KEPP = 1.0116129 WGROUP = 9 NDIN = 1

*** MODULE *SUBMRG* IS FINISHED ***

*** MODULE *CHANGE* VERSION 1 (12/22/80) IS BEING ACCESSED ***

18 ARRAY 10 ENTRIES READ
 0T
 118 ARRAY 10 ENTRIES READ
 0T

	***	NORMALIZED	FLUX	SHAPE	BY	GROUP	AND	ZONE	***
2.8812E-09	2.8812E-09	2.8812E-09	2.8812E-09	2.8812E-09	2.8812E-09	2.8812E-09	2.8812E-09	2.8812E-09	2.8812E-09
8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08
8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08	8.8833E-08
3.1172E-07	3.1172E-07	3.1172E-07	3.1172E-07	3.1172E-07	3.1172E-07	3.1172E-07	3.1172E-07	3.1172E-07	3.1172E-07
1.1115E-07	1.1115E-07	1.1115E-07	1.1115E-07	1.1115E-07	1.1115E-07	1.1115E-07	1.1115E-07	1.1115E-07	1.1115E-07
8.1144E-10	8.1144E-10	8.1144E-10	8.1144E-10	8.1144E-10	8.1144E-10	8.1144E-10	8.1144E-10	8.1144E-10	8.1144E-10
2.2691E-08	2.2691E-08	2.2691E-08	2.2691E-08	2.2691E-08	2.2691E-08	2.2691E-08	2.2691E-08	2.2691E-08	2.2691E-08
2.8905E-11	2.8905E-11	2.8905E-11	2.8905E-11	2.8905E-11	2.8905E-11	2.8905E-11	2.8905E-11	2.8905E-11	2.8905E-11
4.4774E-18	4.4774E-18	4.4774E-18	4.4774E-18	4.4774E-18	4.4774E-18	4.4774E-18	4.4774E-18	4.4774E-18	4.4774E-18

*** ALPHA = 1.50854E 22 ***

12* ARRAY 48 ENTRIES READ
 13* ARRAY 18 ENTRIES READ
 14* ARRAY 10 ENTRIES READ
 15* ARRAY 2 ENTRIES READ
 0T

*** CALCULATED RESPONSE DURING N*(TPINAL) CALC. ***

R = R(1)/R(2) = 1.32313E 00 R(1) = 4.40154E 19 R(2) = 3.32662E 19

*** DELTA R/DELTA N FOR EACH EXPOSURE NUCLIDE BY REGION - N*(TPINAL) - ***

TH228	0.0	0.0	0.0	0.0	0.0
TH232	9.9063E-05	7.9915E-05	4.6080E-05	1.5306E-05	2.8801E-06
PA231	0.0	0.0	0.0	0.0	0.0
PA233	-3.1575E-04	-2.5663E-04	-1.8972E-04	-5.2254E-05	-8.7694E-06
NU232	-1.5011E-04	-1.2065E-04	-6.9883E-05	-3.2164E-05	-5.7466E-06
NU233	-1.1558E-03	-9.3627E-04	-5.8113E-04	-1.7051E-04	-2.6932E-05
U234	1.6344E-04	1.3178E-04	7.6143E-05	2.7854E-05	4.6924E-06
U235	-9.8246E-04	-7.6227E-04	-4.4045E-04	-1.4481E-04	-2.3291E-05
U236	0.0	0.0	0.0	0.0	0.0
U238	8.0836E-05	6.5137E-05	3.7562E-05	1.2067E-05	1.9633E-06
NP237	0.0	0.0	0.0	0.0	0.0
NP239	0.0	0.0	0.0	0.0	0.0
PO238	1.7633E-04	1.4124E-04	8.1541E-05	3.2660E-05	5.1643E-06
PU238	-8.8833E-04	-7.1775E-04	-4.2366E-04	-1.5208E-04	-2.4905E-05
PU240	-1.4343E-04	-1.1697E-04	-6.7265E-05	-2.7484E-05	-4.2905E-06
PU242	-1.7422E-03	-9.0098E-04	-5.2260E-04	-1.7217E-04	-2.1619E-05
PU244	0.0	0.0	0.0	0.0	0.0
AM241	0.0	0.0	0.0	0.0	0.0
AM243	0.0	0.0	0.0	0.0	0.0
CH244	0.0	0.0	0.0	0.0	0.0
FP RI	0.0	0.0	0.0	0.0	0.0
NA	0.0	0.0	0.0	0.0	0.0
SS COR	0.0	0.0	0.0	0.0	0.0
O 16	0.0	0.0	0.0	0.0	0.0

*** CALCULATED RESPONSE DURING DRDS(TPINAL) CALC. ***

R = R(1)/R(2) = 1.32313E 00 R(1) = 4.40153E 19 R(2) = 3.32660E 19

*** DELTA R/DELTA FLUX FOR EACH ENERGY GROUP BY ZONE - DRDS(TPINAL) - ***

-1.1697E 00	-1.2008E 00	-1.3649E 00	-3.4936E-01	-1.8857E-01
-7.5383E-01	-7.7447E-01	-8.8972E-01	1.6122E-01	2.8860E-01
-5.1281E-01	-5.3576E-01	-6.6375E-01	7.9443E-01	4.2928E-01
-8.9412E-01	-5.3060E-01	-7.2888E-01	1.2850E 00	1.4182E 00
-9.2690E-02	-1.4940E-01	-4.7695E-01	3.3966E 00	1.6960E 00
-3.0881E-01	-2.5214E-01	-1.8392E-01	7.7799E 00	3.1490E 00
-1.4444E 00	-1.5537E 00	-2.2213E 00	8.3465E 00	3.1123E 00
-2.4444E 00	-2.3006E 01	-2.4028E 01	-4.0444E 00	1.7864E 00
-1.7511E 03	-1.8959E 03	-2.6081E 03	-6.1365E 02	-2.9725E 02

*** DELTA R/DELTA ALPHA = 0.0 ***

TH 228
TH 232
TPA 231
PA 233
U 232
U 233
U 234
U 235
U 236
U 238
U 237
MP 239
PU 238
PU 239
PU 240
PU 241
PU 242
PA 241
CH 243
CF 244
NS RL
O COR
16

```
0.0  
0.0  
-1.2000E-05  
-4.4188E-04  
-2.9768E-06  
0.0  
0.0  
0.0  
0.0  
-5.447E-05  
-1.0029E-06  
0.0  
0.0  
0.0  
0.0  
0.0
```

368 ARRAY 10 ENTRIES READ

INTERFACE FILE *DATAIN* WAS WRITTEN ON UNIT # 55

*** MODULE *DEPTH * VERSION 1 (12/22/80) IS BEING ACCESSED ***

VENTURE - NEUTRONICS MODULE -VERS 3- JANUARY 1, 1981 --- QUALITY ASSURANCE LEVEL 1

RUN TITLE - DNT SAMPLE PROB #3 BOC2 'STATIC' B.R. RESPONSE FULL MULTICYCLE ADJ C

STORAGE REQUIRED FOR CROSS SECTION CHECK 948 WORDS

TITLE OF THE LATEST VERSION CROSS SECTION FILE
AMISH TO CITATION MODULE - 9 GROUP URANIUM RUN

CROSS SECTION CHECK COMPLETED NORMALLY

REFERENCE REAL TIME FROM ZWATDN INTERFACE FILE = 2.73937E 02 DAYS

SOLUTION BY FINITE-DIFFERENCE DIFFUSION THEORY

FIXED SOURCE ADJOINT PROBLEM

PERTURBATION RESULTS ARE REQUESTED

GEOMETRY NO. 3 1-D SPHERE

NUMBER OF ENERGY GROUPS 9

NUMBER OF UPSCATTER GROUPS (MAX) 0

NUMBER OF DOWNSCATTER GROUPS (MAX) 8

NUMBER OF INTERVALS IN DIMENSION 1 (COLUMNS) 68

NUMBER OF INTERVALS IN DIMENSION 2 (ROWS) 1

NUMBER OF INTERVALS IN DIMENSION 3 (PLANES) 1

NUMBER OF ZONES 5

NUMBER OF REGIONS 5

NUMBER OF BLACK ABSORBER ZONES 0

BOUNDARY INDICATORS- LEFT 1 RIGHT 2

MEMORY REQUIREMENTS FOR DATA STORAGE

	TOTAL		A	B	C	D
	MINIMUM	MAXIMUM				
STORAGE AVAILABLE	60000					
MACRO CALCULATION	1900					
EQUATION CONSTANTS CALCULATION						
CORE CONTAINED OR SPACE STORED	1134	1134				
PLANE STORED	1270	1270				
ROW STORED	928	923				
MULTI-LEVEL PLANE STORED	1270	1270				
INITIAL FLUX						
CORE CONTAINED OR SPACE STORED	1806	1806				
OTHER NODES	1806	1806				
ITERATIVE PROCESS						
CORE CONTAINED	9367		6000	2529	632	206
SPACE STORED	3436		750	2529	157	0
1 PLANE STORED	1713		1027	2529	157	0
1 PLANE STORED	1713		1027	2529	157	0
1 PLANE STORED	1713		1027	2529	157	0
1 ROW STORED	3708		1027	2529	157	0
1 ROW STORED	2686		0	2529	157	0
1 MULTI-LEVEL PLANES STORED	3985		408	2529	157	891
PERTURBATION CALCULATION	2483					

DATA WILL BE STORED FOR ALL GROUPS, ALL SPACE

MEMORY LOCATIONS RESERVED FOR DATA STORAGE--- 60000

MAX MEMORY LOCATIONS REQUIRED FOR THIS PROB-- 9367

MEMORY LOCATIONS NOT USED----- 50633

GROUP 8
-6.21463D 02 -4.83543D 02 -2.11556D 02 1.08344D 02 1.10468D 02

GROUP 9
-1.16199D 03 -8.70314D 02 -3.75252D 02 1.15781D 02 5.34659D 01

PCINT ADJOINT FLUX INTERFACE FILE ATFLUX (VERSION 2) HAS BEEN WRITTEN ON UNIT NUMBER 20

DOPC FILE CLOSING DATA - UNIT, ARRAYS	24	26	5518
DOPC FILE CLOSING DATA - UNIT, ARRAYS	27	21	5518
DOPC FILE CLOSING DATA - UNIT, ARRAYS	28	16	5518

FILE 27 DEFAULTS TO CORE - NO.RECS, REC.LNTH, TOT.LNTH, START LOC, CORE LEFT. 9 136 1224 1 49363

FILE 28 DEFAULTS TO CORE - NO.RECS, REC.LNTH, TOT.LNTH, START LOC, CORE LEFT. 9 136 1224 1225 48139

SPECIAL SCRATCH DATASET REQUIREMENTS
MAXIMUM PHYSICAL RECORD IS 7200 WORDS

*****THE ADJOINT PROBLEM IS FIXED SOURCE.

-CAUTION- THE FLUXES BEING PROCESSED ARE SPECIAL, SO EDITED RESULTS HAVE A DIFFERENT INTERPRETION
THAN THE DOCUMENTING EDITS INDICATING REACTIVITY IMPORTANCE

'ENERGY PER UNIT FLUX' WEIGHTED REGULAR FLUX TIMES ADJOINT FLUX BY GROUP. SUM = 2.76948E-07
-7.83072E-10 1.65484E-07 1.00521E-07 2.11161E-07 -6.05050E-07 3.77366E-09 3.84640E-07 1.72145E-08 -1.34822E-11

FIXED SOURCE ADJOINT FLUXES HAVE ALREADY BEEN CORRECTED FOR REGULAR ADJOINT CONTAMINATION

REGULAR, FIXED SOURCE ADJOINT FLUX INTEGRALS - NOT NORMALIZED (MULTIPLIED) BY BID DADDY = -1.264388D-16

PERTURBATION INTERFACE FILE PERTUB HAS BEEN WRITTEN ON NEW UNIT NUMBER 30

DOPC USE OF CONTAINER ARRAYS, CONTROL 21, MAX DATA 5517

TOTAL CPU MINUTES USED 0.053 TOTAL CLOCK MINUTES USED 1.019 TOTAL I/O USED 0

*** MODULE *DEPTH * VERSION 1 (12/22/80) IS BEING ACCESSED ***

*** ADJOINT SOURCE VECTORS BY ZONE FOR TIME STEP # 2 ***

3.2287E-01	1.6210E-01	-9.2280E-02	-1.2611E-01	-7.2640E-02
1.9827E-01	1.1206E-01	-5.0954E-02	-3.2478E-02	-2.2866E-02
1.4602E-01	9.1297E-02	-2.4221E-02	-2.6829E-02	-8.6645E-03
1.8000E-01	8.9108E-02	-2.7828E-02	-3.8916E-02	-1.3853E-02
-2.5170E-02	-2.5287E-02	-4.3707E-02	-9.4117E-02	-2.5578E-02
-2.4788E-01	-1.9073E-01	-7.9021E-02	-2.0474E-01	-5.2151E-02
3.0388E-01	1.7628E-01	-1.2125E-01	-2.4304E-01	-6.9732E-02
6.6043E-00	4.2999E-00	-5.5683E-01	-2.3565E-01	-1.7433E-01
6.1051E-02	4.1911E-02	-5.1011E-01	-1.1288E-01	-1.1809E-01

INTEGRAL OF (S*(B,E) * GPLX(B,E)) FOR RESPONSE # 1 IS 8.1491E-08

*** MODULE *DEPTH * IS FINISHED ***

Output From Time Steps 3 and 4 Have Been Omitted Here

*** MODULE *DEPTH * VERSION 1 (12/22/80) IS BEING ACCESSED ***

[illegible]

```

*** MODULE *DEPTH * IS FINISHED ***
*** MODULE *CHARGE* VERSION 1 (12/22/80) IS BEING ACCESSED ***

1$ ARRAY      10 ENTRIES READ
0T

2$ ARRAY      10 ENTRIES READ
6$ ARRAY      2 ENTRIES READ
0T

3$ ARRAY      1 ENTRIES READ
0T

4$ ARRAY      5 ENTRIES READ
5$ ARRAY      120 ENTRIES READ
0T

```

*** CHANGE IN RESPONSES FOR PERTURBATION # 1 TIME STEP # 4 AND RESPONSE # 1 ***

CHANGE IN RESPONSE BY NUCLIDE FOR REGION # 1									
TH228	0.0	TH232	6.78357E-05	PA231	0.0	PA233	0.0	U 232	0.0
U 233	-8.62555E-04	U 238	0.0	U 235	-3.07486E-06	U 236	0.0	U 238	-8.16235E-05
NP237	0.0	NP239	0.0	PU238	0.0	PU239	-8.17423E-05	PU240	-4.14058E-07
PU241	-1.82320E-07	PU242	-7.41090E-11	AN241	0.0	AN243	0.0	CH244	0.0
FP RL	0.0	NA	-1.08566E-06	SS COR	2.69226E-05	O 16	5.37721E-06		
TOTAL CHANGE IN RESPONSE IN REGION # 1 IS									

CHANGE IN RESPONSE BY NUCLIDE FOR REGION # 2									
TH228	0.0	TH232	5.75146E-04	PA231	0.0	PA233	0.0	U 232	0.0
U 233	-2.89951E-03	U 238	0.0	U 235	-1.87931E-05	U 236	0.0	U 238	-6.97778E-04
NP237	0.0	NP239	0.0	PU238	0.0	PU239	-8.80659E-04	PU240	-2.41028E-07
PU241	-1.12376E-06	PU242	-3.12570E-10	AN241	0.0	AN243	0.0	CH244	0.0
FP RL	0.0	NA	-9.26737E-05	SS COR	1.17115E-05	O 16	-9.62380E-05		
TOTAL CHANGE IN RESPONSE IN REGION # 2 IS									

CHANGE IN RESPONSE BY NUCLIDE FOR REGION # 3									
TH228	0.0	TH232	8.38902E-05	PA231	0.0	PA233	0.0	U 232	0.0
U 233	-4.54408E-04	U 238	0.0	U 235	-2.16872E-06	U 236	0.0	U 238	-6.72389E-05
NP237	0.0	NP239	0.0	PU238	0.0	PU239	-6.46426E-05	PU240	-6.15829E-07
PU241	-1.81775E-07	PU242	-3.00736E-10	AN241	0.0	AN243	0.0	CH244	0.0
FP RL	0.0	NA	1.65545E-05	SS COR	6.73573E-05	O 16	2.47191E-05		
TOTAL CHANGE IN RESPONSE IN REGION # 3 IS									

CHANGE IN RESPONSE BY NUCLIDE FOR REGION # 4									
TH228	0.0	TH232	1.57722E-03	PA231	0.0	PA233	0.0	U 232	0.0
U 233	-1.38548E-04	U 238	0.0	U 235	0.0	U 236	0.0	U 238	0.0
NP237	0.0	NP239	0.0	PU238	0.0	PU239	0.0	PU240	0.0
PU241	0.0	PU242	0.0	AN241	0.0	AN243	0.0	CH244	0.0
FP RL	0.0	NA	-7.85946E-05	SS COR	0.0	O 16	-1.19845E-04		
TOTAL CHANGE IN RESPONSE IN REGION # 4 IS									

CHANGE IN RESPONSE BY NUCLIDE FOR REGION # 5									
TH228	0.0	TH232	7.18749E-04	PA231	0.0	PA233	0.0	U 232	0.0
U 233	-9.86252E-05	U 238	0.0	U 235	0.0	U 236	0.0	U 238	0.0
NP237	0.0	NP239	0.0	PU238	0.0	PU239	0.0	PU240	0.0
PU241	0.0	PU242	0.0	AN241	0.0	AN243	0.0	CH244	0.0
FP RL	0.0	NA	6.15187E-05	SS COR	8.69156E-04	O 16	1.87513E-04		
TOTAL CHANGE IN RESPONSE IN REGION # 5 IS									

TOTAL CHANGE IN RESPONSE BY NUCLIDE									
TH228	0.0	TH232	3.02284E-03	PA231	0.0	PA233	0.0	U 232	0.0
U 233	-8.25365E-03	U 238	0.0	U 235	-2.40367E-05	U 236	0.0	U 238	-8.46640E-04
NP237	0.0	NP239	0.0	PU238	0.0	PU239	-6.27044E-04	PU240	-1.27091E-06
PU241	-1.88786E-06	PU242	-8.87416E-10	AN241	0.0	AN243	0.0	CH244	0.0
FP RL	0.0	NA	-9.42809E-05	SS COR	1.05991E-04	O 16	1.52682E-06		

*** TOTAL CHANGE IN RESPONSE FOR PERTURBATION # 1 TIME STEP # 4 AND RESPONSE # 1 IS -1.02477E-03 ***

*** TOTAL PERTURBED RESPONSE FOR PERTURBATION # 1 TIME STEP # 4 AND RESPONSE # 1 IS 1.32210E 00 ***

11% ARRAY 10 ENTRIES READ

OT

*** NORMALIZED FLUX SHAPE BY GROUP AND ZONE ***				
2.8812E-09	2.4422E-09	1.8492E-09	2.4277E-10	2.1686E-11
8.6883E-08	7.7653E-08	3.4872E-08	9.0066E-09	3.5029E-10
8.4863E-08	7.3771E-08	8.4374E-08	9.7896E-09	3.0168E-11
3.1172E-07	2.6917E-07	1.1339E-07	2.2386E-08	8.8337E-09
1.3152E-07	1.0693E-07	6.1123E-08	2.2386E-08	3.1867E-10
8.3184E-10	6.6193E-10	3.8310E-10	3.1559E-10	4.1867E-11
2.2691E-08	1.8103E-08	1.0879E-08	3.7822E-09	7.1215E-10
2.8905E-11	2.3788E-11	2.0508E-11	3.0195E-11	9.8882E-12
4.4778E-18	3.4350E-18	2.2051E-18	5.5939E-16	1.6909E-16

*** ALPHA = 1.50854E 22 ***

12* ARRAY 48 ENTRIES READ

13* ARRAY 18 ENTRIES READ

14* ARRAY 10 ENTRIES READ

15* ARRAY 2 ENTRIES READ

OT

CAP(NISOB,NISBT)

[illegible]

PIS(NISOZ,NXSET)

```

      223132333556677889900111213141516
      T H A E E E E E E E E E E E E E E E E
      P I S S I O N  -- 1
      0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      - 1 0 471E-03
      - 0 549E-01
      - 0 951E-03
      0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
      - 1 2089E-01
      - 0 7116E-04
      0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

```


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APPENDIX A

Derivation of Adjoint Equations

The purpose of this Appendix is to derive the equations programmed into the DEPTH module. An approach similar to that utilized by Williams¹³ will be taken. The main difference, other than slight variations in notation and the use of discrete variables where possible, is the treatment of nuclide discontinuities at the time-step and cycle boundaries. This additional feature in the present work allows for nuclide recharges and multicycle refueling operations during the forward depletion calculation. Such operations are necessary for realistic multicycle depletion analyses.

The notation for the complete set of forward quasi-static depletion equations utilized in this study is given as follows:

1. Nuclide Density Equation:

$$\frac{d}{dt} \underline{N}^{ijk}(\vec{r}, t) = [\underline{T}^{ijk}(\vec{r}) + \underline{D}] \underline{N}^{ijk}(\vec{r}, t) \quad (\text{A.1})$$

where $\underline{N}^{ijk}(\vec{r}, t)$ = Space-dependent nuclide density vector (NNUC isotopes) at time t within sub-step j, time step i, and cycle k.

$\underline{D}$ = Matrix (NNUC*NNUC) of nuclide decay constants.

$$\underline{T}^{ijk}(\vec{r}) = \alpha^{ijk} \underline{X}^{ik}(\vec{r}) \underline{\Psi}^{jk}(\vec{r}) \quad (\text{A.2})$$

with $\underline{T}^{ijk}(\vec{r})$ = Space-dependent transmutation matrix (NNUC*NNUC) for ijk interval. Diagonal terms represent loss mechanisms and off-diagonal terms represent production routes.

α^{ijk} = Flux normalization constant, held fixed during ijk interval.

$\underline{\Psi}^{jk}(\vec{r})$ = Space-dependent flux shape group vector (IGM) held constant during ik interval.

$\underline{X}^{ik}(\vec{r})$ = Space-dependent burnup operator. Consists of a matrix (NNUC*NNUC) of microscopic cross-section vectors (IGM) held constant during the ik interval.

2. Initial Condition of $\underline{N}(\vec{r}, t)$:

$$\underline{N}(\vec{r}, t)|_{t_{ik}} = \underline{C}^{ik}(\vec{r}) \quad (\text{A.3})$$

where $\underline{N}(\vec{r}, t_{ik})$ = Initial nuclide density vector (NNUC) for the ik time interval.

$$\underline{C}^{ik}(\vec{r}) = \underline{P}_{SD}^{ik}(\vec{r}) \underline{N}^{ik-}(\vec{r}) + \underline{M}^{ik}(\vec{r}) \quad (\text{A.4})$$

with $\underline{N}^{ik}(\vec{r})$ = Final nuclide density field vector (NNUC) for time step prior to the ik time interval.

$\underline{P}_{SD}^{ik}(\vec{r})$ = Shuffling/discharge operator for ik time interval.

$\underline{M}^{ik}(\vec{r})$ = Space-dependent nuclide vector (NNUC) specifying feed composition for the ik time interval.

3. Power Normalization Equation: (Defining equation for α^{ik})

$$P^{ik} = \alpha^{ik} \int_{all\ space} \underline{N}^{T\ ijk}(\vec{r}) \underline{E}_P \underline{\sigma}_f^{ik}(\vec{r}) \underline{\psi}^{ik}(\vec{r}) d\vec{r} \quad (A.5)$$

where P^{ik} = Specified reactor power for ijk time interval.

$\underline{E}_P$ = Diagonal matrix (NNUC*NNUC) of nuclide-dependent energy per fission conversion factors.

$\underline{\sigma}_f^{ik}(\vec{r})$ = Space-dependent microscopic fission cross-section matrix (NNUC*IGM) held constant during ik interval.

4. Flux Shape Equation: (Time-independent diffusion equation)

$$(\underline{L} - \lambda \underline{F}) \underline{\psi}^{ik}(\vec{r}) = 0 \quad (A.6)$$

where $\underline{L}$ = Leakage, removal and inscatter operator.

$\underline{F}$ = Fission source operator.

$$\lambda = \frac{1}{K_{eff}}$$

5. Flux Shape Normalization:

$$\int_{all\ space} (\underline{\psi}^{ik}(\vec{r}) \cdot \underline{1}) d\vec{r} = 1 \quad (A.7)$$

where the inner product of $\underline{\psi}^{ik}(\vec{r})$ and $\underline{1}$ represent an integration over the discrete energy variable.

Now using Eqns. (A.1)-(A.7) as constraints on the desired response as described in Ref. 13, one can define the following K-functional,

$$K(\underline{N}, \alpha, \underline{\psi}, \lambda, \beta, P, \underline{C}) = R(\underline{N}, \alpha, \underline{\psi}) \quad (A.8)$$

$$\begin{aligned} & - \sum_k \sum_i \int_{all\ space} d\vec{r} [\underline{\Gamma}^{*T}(\vec{r})(\underline{L} - \lambda \underline{F}) \underline{\psi}(\vec{r})]^{ik} \\ & + \sum_k \sum_i \sum_j P^{*ijk} [P^{ijk} - \alpha^{ijk} \int_{all\ space} d\vec{r} \underline{N}^{T\ ijk}(\vec{r}) \underline{E}_P \underline{\sigma}_f^{ik}(\vec{r}) \underline{\psi}^{ik}(\vec{r})] \end{aligned}$$

$$\begin{aligned}
& - \sum_k \sum_i \sum_j \int_{all\ space} d\vec{r} \int_{substep\ j} dt \underline{N}^{*T_{ik}}(\vec{r}, t) \left[\frac{d}{dt} \underline{N}^{ijk}(\vec{r}, t) - (\underline{T}^{ijk}(\vec{r}) + \underline{D}) \underline{N}^{ijk}(\vec{r}, t) \right] \\
& - \sum_k \sum_i \int_{all\ space} d\vec{r} \int_{timestep\ i} dt \underline{N}^{*T_{ik}}(\vec{r}, t) [\underline{N}^{ik}(\vec{r}, t) - \underline{C}^{ik}(\vec{r}, t)] \delta(t - t_{ik}) \\
& - \sum_k \sum_i A^{*ik} \left[\int_{all\ space} d\vec{r} (\underline{\psi}^{jk}(\vec{r}) \cdot \underline{1}) - 1 \right] ,
\end{aligned}$$

where $\underline{\Gamma}^{*ik}(\vec{r})$, P^{*ijk} , $\underline{N}^{ijk}(\vec{r}, t)$, and A^{*ik} are Lagrange multipliers. The desired adjoint depletion equations defining these Lagrange multipliers are derived by forcing the functional derivative of the K-functional with respect to $\underline{\psi}^{jk}(\vec{r})$, α^{ijk} , $\underline{N}^{ijk}(\vec{r}, t)$, and λ^{ik} to vanish. Taking one term at a time, one has,

1. Setting $\partial K / \partial \underline{\psi}^{jk}(\vec{r})$ to Zero:

$$(\underline{L} - \underline{\lambda F})^{T_{ik}} \underline{\Gamma}^{*ik}(\vec{r}) = \underline{S}^{*ik}(\vec{r}) \quad (A.9)$$

$$\text{with } \underline{S}^{*ik}(\vec{r}) = \frac{\partial R}{\partial \underline{\psi}^{jk}(\vec{r})} - (A^{*ik} \cdot \underline{1})$$

$$+ \sum_j \int_{substep\ j} dt \underline{N}^{*T_{ijk}}(\vec{r}, t) \frac{\partial}{\partial \underline{\psi}^{jk}(\vec{r})} (\underline{T}^{ijk}(\vec{r}) \underline{N}^{ijk}(\vec{r}, t)) \quad (A.10)$$

$$+ \sum_j P^{*ijk} \alpha^{ijk} \underline{N}^{T_{ijk}}(\vec{r}) \underline{E}_p \underline{\sigma}_f^{jk}(\vec{r})$$

2. Setting $\partial K / \partial \alpha^{ijk}$ to Zero:

$$P^{*ijk} = \frac{1}{p^{ijk}} \left[\left(\alpha \frac{\partial R}{\partial \alpha} \right)^{ijk} \right] \quad (A.11)$$

$$+ \alpha^{ijk} \int_{all\ space} d\vec{r} \int_{substep\ j} dt \underline{N}^{*T_{ijk}}(\vec{r}, t) \underline{X}^{ik}(\vec{r}) \underline{\psi}^{jk}(\vec{r}) \underline{N}^{ijk}(\vec{r}, t)$$

3. Taking Variation with Respect to $\underline{N}^{ijk}(\vec{r}, t)$:

Before taking the variation with respect to $\underline{N}^{ijk}(\vec{r}, t)$, one must rewrite the fourth term on the right-hand side of Eqn. (A.8). Integration in the forward time direction yields,

$$\begin{aligned}
\text{4th term of (A.8)} = & - \sum_k \sum_i \sum_j \int_{\text{all space}} d\vec{r} \left[\underline{N}^{*T}(\vec{r}, t) \underline{N}(\vec{r}, t) \right]_{i,jk+1} \\
& - \underline{N}^{*T}(\vec{r}, t) \underline{N}(\vec{r}, t) \Big|_{i,jk} \\
& + \int_{t_{ijk+1}}^{t_{ijk}} dt \underline{N}^{Tijk}(\vec{r}, t) \left(\frac{d}{dt} \underline{N}^{*ijk}(\vec{r}, t) + (\underline{T}^{ijk}(\vec{r}) + \underline{D})^T \underline{N}^{*ijk}(\vec{r}, t) \right)
\end{aligned} \tag{A.12}$$

Now substituting (A.12) into (A.8) and taking the variation with respect to $\underline{N}^{ijk}(\vec{r}, t)$ gives,

$$\begin{aligned}
\int d\vec{r} \int dt \frac{\partial K}{\partial \underline{N}(\vec{r}, t)} \delta \underline{N}(\vec{r}, t) &= 0 = \int d\vec{r} \int dt \frac{\partial R}{\partial \underline{N}(\vec{r}, t)} \delta \underline{N}(\vec{r}, t) \\
&- \sum_k \sum_i \int d\vec{r} \left[\underline{N}^{*T}(\vec{r}) \frac{\partial}{\partial \underline{N}(\vec{r})} [(\underline{L} - \lambda \underline{F}) \underline{\psi}(\vec{r})] \delta \underline{N}(\vec{r}) \right]^{ik+} \\
&- \sum_k \sum_i \sum_j \int d\vec{r} P^{*ijk+} \alpha^{ijk+} \underline{E}_p \underline{\sigma}_f^{jk+}(\vec{r}) \underline{\psi}^{jk+}(\vec{r}) \delta \underline{N}^{ijk+}(\vec{r}) \\
&- \sum_k \sum_i \sum_j \int d\vec{r} [\underline{N}^{*T}(\vec{r}) \delta \underline{N}(\vec{r})]^{(ijk+1)} \\
&+ \sum_k \sum_i \sum_j \int d\vec{r} [\underline{N}^{*T}(\vec{r}) \delta \underline{N}(\vec{r})]^{ijk+} \\
&- \sum_k \sum_i \sum_j \int d\vec{r} \int_{t_{ijk+1}}^{t_{ijk}} dt \left[\frac{d}{dt} \underline{N}^{*ijk}(\vec{r}, t) + (\underline{T}^{ijk}(\vec{r}) + \underline{D})^T \underline{N}^{*ijk}(\vec{r}, t) \right] \delta \underline{N}^{ijk}(\vec{r}, t) \\
&- \sum_k \sum_i \int d\vec{r} [(\underline{N}^{*Tik}(\vec{r}) \delta \underline{N}^{ik}(\vec{r})) - (\underline{N}^{*Tik}(\vec{r}) \underline{P}_{SD}^{ik}(\vec{r}) \delta \underline{N}^{ik}(\vec{r}))]
\end{aligned} \tag{A.13}$$

Equating similar integrands, noting that

$$\delta \underline{N}^{ik+}(\vec{r}) = \delta \underline{N}^{ik}(\vec{r}) = \underline{P}_{SD}(\vec{r}) \delta \underline{N}^{ik}(\vec{r}) , \tag{A.14}$$

and defining (restricted to final time responses)

$$\frac{\partial R}{\partial \underline{N}(\vec{r}, t)} = \underline{N}^*(\vec{r}, t_f) , \tag{A.15}$$

one obtains the following adjoint equations,

$$\frac{d}{dt} \underline{N}^{*ijk}(\vec{r}, t) + (\underline{T}^{ijk}(\vec{r}) + \underline{D})^T \underline{N}^{*ijk}(\vec{r}, t) = 0 \quad (\text{A.16})$$

and

$$\underline{N}^{*ijk}(\vec{r}) = \underline{N}^{*ijk*}(\vec{r}) + \underline{\Gamma}^{*ijk}(\vec{r})_{\text{effect}} + \underline{P}^{*ijk}(\vec{r})_{\text{effect}} \quad (\text{A.17})$$

where

$$\underline{\Gamma}^{*ijk}(\vec{r})_{\text{effect}} = - \underline{\Gamma}^{*Tik}(\vec{r}) \frac{\partial}{\partial \underline{N}^{ik}(\vec{r})} [(\underline{L} - \lambda \underline{F}) \underline{\psi}^{jk}(\vec{r})] \text{ for } j = 1$$

$$\underline{\Gamma}^{*ijk}(\vec{r})_{\text{effect}} = 0 \text{ for } j \neq 1 \quad (\text{A.18})$$

$$\underline{P}^{*ijk}(\vec{r})_{\text{effect}} = - P^{*ijk} \alpha^{ijk} \underline{E}_P \underline{\sigma}_f^{jk}(\vec{r}) \underline{\psi}^{jk}(\vec{r}) \quad (\text{A.19})$$

and

$$\underline{N}^{*ijk*}(\vec{r}) = \underline{P}_{SD}^{*ijk}(\vec{r}) \underline{N}^{*ijk}(\vec{r}) \quad (\text{A.20})$$

where $\underline{P}_{SD}^{*ijk}(\vec{r})$ is the adjoint operator to $\underline{P}_{SD}^{ik}(\vec{r})$.

4. Setting $\partial K / \partial \lambda^{ik}$ to Zero:

$$\int_{\text{all space}} \underline{\Gamma}^{*Tik}(\vec{r}) \underline{F} \underline{\psi}^{jk}(\vec{r}) d\vec{r} = 0 \quad (\text{A.21})$$

5. Additional Relationships:

From Eqn. (A.9) one has

$$\int_{\text{all space}} d\vec{r} \underline{\psi}_z^{Tik}(\vec{r}) \underline{\Sigma}^{*ik}(\vec{r}) = 0. \quad (\text{A.22})$$

Using this result and Eqn. (A.9) multiplied by $\underline{\psi}^{jk}(\vec{r})$ and integrated over all space along with Eqn. (A.10) gives the following definition for A^{*ik} :

$$A^{*ik} = \int_{\text{all space}} d\vec{r} \underline{\psi}^{jk}(\vec{r}) \frac{\partial R}{\partial \underline{\psi}^{jk}(\vec{r})} - \sum_j (\alpha \frac{\partial R}{\partial \alpha})^{ijk}. \quad (\text{A.23})$$

Equations (A.9)-(A.10) and (A.15)-(A.23) define a consistent set of space-continuous burnup equations adjoint to the forward quasi-static depletion formulation described in Eqns. (A.1)-(A.7). The meaning and use of these adjoint equations are described in the main text of this report.

The above derivation was performed with the dependent variables as continuous functions of space. In realistic depletion problems, zone- or subzone-averaged quantities are almost always used. The zone-averaged flux is calculated and used in the transmutation matrix to produce zone/subzone-averaged nuclide density fields. In problems with subzones it is assumed that the following relationships are true.

$$\underline{N}_z(t) = \frac{1}{V_z} \sum_s \underline{N}_{sz}(t) V_{sz} \quad (\text{A.24})$$

where

$$V_z = \sum_s V_{sz} \quad (\text{A.25})$$

and

$$\underline{\psi}_z = \frac{1}{V_z} \int_{V_z} \underline{\psi}(\vec{r}) d\vec{r} = \underline{\psi}_{sz} \quad (\text{A.26})$$

where $\underline{N}_z(t)$ = zone-averaged nuclide vector (NNUC)

$\underline{N}_{sz}$ = subzone-averaged nuclide vector (NNUC)

$\underline{\psi}_z = \underline{\psi}_{sz}$ = zone-averaged flux vector (IGM)

V_z = volume of zone z

V_{sz} = volume of subzone s in zone z.

Using these definitions, a straightforward averaging of the space-continuous adjoint depletion equations can be performed with the following results.

1. Space-Averaged Nuclide Adjoint Equations:

Nuclide adjoint equation:

$$\frac{d}{dt} \underline{N}_{sz}^{ijk}(t) + (\underline{T}_{sz}^{ijk} + \underline{D})^T \underline{N}_{sz}^{ijk}(t) = 0 \quad (\text{A.27})$$

where

$$\underline{T}_{sz}^{ijk} = \alpha^{ijk} \underline{X}_{sz}^{lk} \underline{\psi}_z^{jk} \quad (\text{A.28})$$

and final condition

$$\underline{N}_{\underline{x}}^*(t_f) = \frac{\partial R}{\partial \underline{N}_{\underline{x}}}(t)|_{t_f} = \frac{1}{V_{\underline{x}}} \int_{V_{\underline{x}}} \frac{\partial R}{\partial \underline{N}(\vec{r}, t)}|_{t_f} d\vec{r} \quad (\text{A.29})$$

and jump condition

$$\underline{N}_{\underline{x}}^{*ijk} = \underline{N}_{\underline{x}}^{*ijk+} + \underline{\Gamma}_{\underline{x}}^{*ijk+} \text{ effect} + \underline{P}_{\underline{x}}^{*ijk+} \text{ effect} \quad (\text{A.30})$$

with

$$\underline{\Gamma}_{\underline{x}}^{*ijk+} \text{ effect} = - \frac{1}{v_z} \int_{V_z} d\vec{r} \underline{\Gamma}^{*Tik}(\vec{r}) \frac{\partial}{\partial \underline{N}_{\underline{x}}^{ik}} [(\underline{L} - \lambda \underline{F})^{ik} \underline{\psi}^{ik}(\vec{r})] \text{ for } j = 1$$

$$\underline{\Gamma}_{\underline{x}}^{*ijk+} \text{ effect} = 0 \text{ for } j \neq 1. \quad (\text{A.31})$$

[See Appendix B for details of Eqn. (A.31).]

$$\underline{P}_{\underline{x}}^{*ijk+} \text{ effect} = - \underline{P}^{*ijk} \alpha^{ijk} \underline{E}_p \sigma_{f\underline{x}}^{ik} \underline{\psi}^{ik} \quad (\text{A.32})$$

and adjoint refueling discontinuity condition

$$\underline{Z}^{*ijk-} = \underline{P}_{SD}^{*Tijk} \underline{Z}^{*ijk} \quad (\text{A.33})$$

with

$$\underline{Z}^{*ijk} = \begin{bmatrix} \underline{N}_{\underline{x}}^* \\ \underline{N}_{\underline{x}}^* \\ \vdots \\ \underline{N}_{NREG}^* \end{bmatrix} = \text{Vector (NREG) of region-averaged adjoint nuclide vectors (NNUC).}$$

$\underline{P}_{SD}^{*ijk}$ = Shuffling/discharge matrix (NREG*NREG) consisting of the identity matrix (NNUC*NNUC) in various locations so as to represent the desired nuclide discontinuity.

Note when $j \neq 1$

$$\underline{P}_{SD}^{ijk} = \begin{bmatrix} \underline{I} & & \\ & \ddots & \\ & & \underline{I} \end{bmatrix} \quad \text{with } \underline{I} = \begin{bmatrix} 1 & & \\ & \ddots & \\ & & 1 \end{bmatrix}$$

(NREG*NREG) (NNUC*NNUC)

2. Space-Averaged Power Normalization Adjoint Equation:

$$P^{ijk} = \frac{1}{P^{ijk}} \left[\left(\alpha \frac{\partial R}{\partial \alpha} \right)^{ijk} + \alpha^{ijk} \sum_i \sum_j v_{xz} \int_{substep_j} dt \underline{N}_{xz}^{*Tijk}(t) \underline{X}_{xz}^{ik} \underline{\psi}_{xz}^{jk} \underline{N}_{xz}^{ijk}(t) \right] \quad (\text{A.34})$$

3. Space-Averaged Generalized Adjoint Shape Equation:

$$(\underline{L} - \lambda \underline{F})^{Tik} \underline{\Gamma}^{*ik}(\vec{r}) = \underline{S}_i^{*ik} \quad (\text{A.35})$$

where

$$\begin{aligned} \underline{S}_i^{*ik} &= \frac{\partial R}{\partial \underline{\psi}_i^{jk}} - (A^{*ik} * 1) \\ &+ \sum_j \frac{\alpha^{ijk}}{v_z} \sum_x v_{xz} \int_{substep_j} dt \underline{N}_{xz}^{*Tijk}(t) \underline{X}_{xz}^{ik} \underline{N}_{xz}^{ijk}(t) \\ &- \sum_j \frac{1}{v_z} \sum_x v_{xz} P^{*ijk} \alpha^{ijk} \underline{N}_{xz}^{Tijk} \underline{E}_p \underline{\sigma}_{f_{xz}}^{jk} \end{aligned} \quad (\text{A.36})$$

4. Space-Averaged Auxiliary Equations:

$$\int_{all\ space} [\underline{\Gamma}^{*T}(\vec{r}) \underline{F} \underline{\psi}(\vec{r})]^{ik} d\vec{r} = 0 \quad (\text{A.37})$$

$$\sum_i v_z (\underline{\psi}_i^T \underline{S}_i^*)^{ik} = 0 \quad (\text{A.38})$$

$$A^{*ijk} = \int_{all\ space} d\vec{r} \underline{\psi}^{jk}(\vec{r}) \frac{\partial R}{\partial \underline{\psi}^{jk}(\vec{r})} - \sum_j \left(\alpha \frac{\partial R}{\partial \alpha} \right)^{ijk} \quad (\text{A.39})$$

Equations (A.27)-(A.39) represent the depletion perturbation formulation programmed into the DEPTH module. Although the detailed notation has been somewhat cumbersome, these adjoint burnup equations look quite similar to the FORTRAN equations in DEPTH and thus allow a fairly easy understanding of the coding within the new module.

APPENDIX B

Evaluation of the Γ^* Effect Integral

The purpose of this Appendix is to evaluate the nuclide adjoint jump condition term involving the generalized adjoint shape function, $\underline{\Gamma}^*(\vec{r})$. In addition, it will be shown that the resultant volume integrals are equivalent to the perturbation integrals calculated within the VENTURE modular system and stored in the PERTUB interface file.

The first goal is to evaluate the following integral expression,

$$\underline{I}_x = \int_{V_x} d\vec{r} \left[\underline{\Gamma}^{*T}(\vec{r}) \frac{\partial}{\partial N_x} [(\underline{L} - \lambda \underline{F}) \underline{\psi}(\vec{r})] \right] \quad (\text{B.1})$$

where the term in the $[\]$ is just the time-independent multigroup diffusion equation written using operator notation. The form of the diffusion equation solved by VENTURE is,

$$\begin{aligned} & - D_{r,g} \nabla^2 \psi_{r,g} + [\Sigma_{a,r,g} + \sum_n \Sigma_{s,r,g \rightarrow n} + D_{r,g} B_g^2] \psi_{r,g} \\ & = \sum_n [\Sigma_{s,r,n \rightarrow g} + \frac{1}{K_{eff}} \chi_{r,g} (\nu \Sigma)_{f,r,n}] \psi_{r,n} \end{aligned} \quad (\text{B.2})$$

where r refers to the space variable, g and n refer to the energy variable and D , Σ_a , Σ_s , $(\nu \Sigma_f)$ and χ are the diffusion coefficient, macroscopic absorption, scattering, and neutron production cross sections, and distribution function for fission neutrons, respectively.

Rewriting Eqn. (B.2) in matrix form and assuming that the cross sections are constant within subzone s in zone z , one has

$$\begin{aligned} & - \underline{D}_{zz} \nabla^2 \underline{\psi}(\vec{r}) + [\underline{\Sigma}_a + \underline{\Sigma}_s^O + \underline{DB}^2]_{zz} \underline{\psi}(\vec{r}) \\ & - [\underline{\Sigma}_s^I + \frac{1}{K_{eff}} \underline{\chi} \underline{\nu \Sigma}_f]_{zz} \underline{\psi}(\vec{r}) = 0 \end{aligned} \quad (\text{B.3})$$

where $\underline{\Sigma}_s^O$ and $\underline{\Sigma}_s^I$ are the outscatter and inscatter terms, respectively. Now taking the derivative of (B.3) with respect to $\underline{N}_{zz}$, one has (neglecting the $\underline{DB}^2$ term),

$$\left[\underline{\underline{\sigma}}_a \nabla^2 + \underline{\underline{\sigma}}_R - \underline{\underline{\sigma}}_S - \frac{1}{K_{eff}} \underline{\underline{\chi}} \underline{\underline{v}} \underline{\underline{\sigma}}_f \right] \psi(\vec{r}) = 0 \quad (\text{B.4})$$

where

$$\underline{\underline{\sigma}}_a = - \frac{d}{dN} D = \begin{bmatrix} 3D^2 \underline{\underline{\sigma}}_{a1} & & 0 \\ & \ddots & \\ 0 & & 3D^2 \underline{\underline{\sigma}}_{aIGM} \end{bmatrix}_{IGM \times IGM}$$

$$\underline{\underline{\sigma}}_R = \frac{d}{dN} (\underline{\underline{\Sigma}}_a + \underline{\underline{\Sigma}}_r^0) = \begin{bmatrix} \underline{\underline{\sigma}}_{a1} + \sum_{\substack{n \\ n \neq 1}} \underline{\underline{\sigma}}_{r,1 \rightarrow n} & & 0 \\ & \ddots & \\ 0 & & \underline{\underline{\sigma}}_{aIGM} + \sum_{\substack{n \\ n \neq IGM}} \underline{\underline{\sigma}}_{r,IGM \rightarrow n} \end{bmatrix}_{IGM \times IGM}$$

$$\underline{\underline{\sigma}}_S = \frac{d}{dN} \underline{\underline{\Sigma}}_s^I = \begin{bmatrix} 0 & \underline{\underline{\sigma}}_s^{2 \rightarrow 1} & \underline{\underline{\sigma}}_s^{3 \rightarrow 1} & \dots & \underline{\underline{\sigma}}_s^{IGM \rightarrow 1} \\ \underline{\underline{\sigma}}_s^{1 \rightarrow 2} & 0 & & & \\ \vdots & & \ddots & & \\ \underline{\underline{\sigma}}_s^{1 \rightarrow IGM} & & & & 0 \end{bmatrix}_{IGM \times IGM}$$

$$\underline{\underline{v}} \underline{\underline{\sigma}}_f = \frac{d}{dN} \underline{\underline{v}} \underline{\underline{\Sigma}}_f = \begin{bmatrix} \underline{\underline{v}} \underline{\underline{\sigma}}_{f1} & \underline{\underline{v}} \underline{\underline{\sigma}}_{f2} & \dots & \dots & \dots \\ \underline{\underline{v}} \underline{\underline{\sigma}}_{f1} & \underline{\underline{v}} \underline{\underline{\sigma}}_{f2} & & & \\ \vdots & & \ddots & & \\ \underline{\underline{v}} \underline{\underline{\sigma}}_{f1} & \underline{\underline{v}} \underline{\underline{\sigma}}_{f2} & & & \underline{\underline{v}} \underline{\underline{\sigma}}_{fIGM} \end{bmatrix}_{IGM \times IGM}$$

and

$$\underline{X} = \begin{bmatrix} X_1 & & & 0 \\ & X_2 & & \\ & & \ddots & \\ 0 & & & X_{JGM} \end{bmatrix} \quad IGM * IGM$$

with the microscopic cross-section vectors (NNUC) within the matrices now representing the nuclide dependence of the cross sections.

Now substituting Eqn. (B.4) into (B.1), one obtains the following relations:

$$\underline{L}_{sz} = [\underline{L}_1 + \underline{L}_2 + \underline{L}_3 + \underline{L}_4]_{sz} \quad (B.5)$$

with

$$\underline{L}_1 = \int_{V_i} d\vec{r} \underline{\Gamma}^{*T}(\vec{r}) \underline{\sigma}_{lr} \nabla^2 \underline{\psi}(\vec{r}) \quad (B.6)$$

$$\underline{L}_2 = \int_{V_i} d\vec{r} \underline{\Gamma}^{*T}(\vec{r}) \underline{\sigma}_R \underline{\psi}(\vec{r}) \quad (B.7)$$

$$\underline{L}_3 = - \int_{V_i} d\vec{r} \underline{\Gamma}^{*T}(\vec{r}) \underline{\sigma}_s \underline{\psi}(\vec{r}) \quad (B.8)$$

$$\underline{L}_4 = - \frac{1}{K_{eff}} \int_{V_i} d\vec{r} \underline{\Gamma}^{*T}(\vec{r}) \underline{\chi} \underline{\nu} \underline{\sigma}_f \underline{\psi}(\vec{r}) . \quad (B.9)$$

Equations (B.6)-(B.9) can also be written using summation notation as follows:

$$\underline{L}_{1sz} = \sum_g (3D_g^2 \underline{\sigma}_{lg})_{sz} \int_{V_i} \Gamma_g^*(\vec{r}) \nabla^2 \psi_g(\vec{r}) d\vec{r} , \quad (B.10)$$

$$\underline{L}_{2sz} = \sum_g (\underline{\sigma}_{ag} + \sum_{n \neq g} \underline{\sigma}_{ng \rightarrow n})_{sz} \int_{V_i} \Gamma_g^*(\vec{r}) \psi_g(\vec{r}) d\vec{r} , \quad (B.11)$$

$$\underline{L}_{3sz} = - \sum_g \sum_{n \neq g} (\underline{\sigma}_{n \rightarrow g})_{sz} \int_{V_i} \Gamma_g^*(\vec{r}) \psi_n(\vec{r}) d\vec{r} , \quad (B.12)$$

$$\underline{L}_{4sz} = - \frac{1}{K_{eff}} \sum_g (\underline{\nu} \underline{\sigma}_{fg})_{sz} \int_{V_i} \left(\sum_n \chi_n \Gamma_n^*(\vec{r}) \right) \psi_g(\vec{r}) d\vec{r} . \quad (B.13)$$

Using this last set of equations, a numerical result can be obtained for $\underline{I}_{xx}$ and the Γ_{xx}^* effect jump condition. The volume integrals in the above equations are stored in the PERTUB interface file as the following quantities:

(2D RECORD)

$$T_{i,g} = \frac{1}{K_{eff}} \sum_{i\alpha} v_i \psi_{i,g} \sum_n \chi_n \Gamma_{i,n}^* \quad (\text{B.14})$$

(3D RECORD)

$$S_{i,n,g} = \sum_{i\alpha} v_i \Gamma_{i,g}^* \psi_{i,n} \quad (\text{B.15})$$

(4D RECORD)

$$W_{i,g} = \sum_{i\alpha} v_i \Gamma_{i,g}^* \nabla^2 \psi_{i,g} \quad (\text{B.16})$$

Finally, using (B.10)-(B.16), the expression in Eqn. (B.1) can be written as:

$$\begin{aligned} \underline{I}_{xx} = & \sum_g (3D_g^2 \underline{\sigma}_{xx})_{xx} W_{i,g} \\ & + \sum_g (\sigma_{ag} + \sum_{n \neq g} \underline{\sigma}_{g \rightarrow n})_{xx} S_{i,g,g} \\ & - \sum_g \sum_{n \neq g} (\underline{\sigma}_{n \rightarrow g})_{xx} S_{i,n,g} \\ & - \sum_g (\underline{v}\sigma_{fg})_{xx} T_{i,g} \end{aligned} \quad (\text{B.17})$$

It is Eqn. (B.17) that is evaluated within the DEPTH module.

APPENDIX C

Details of Time-Dependent Data Sensitivity Theory

The purpose of this Appendix is to precisely define the terms appearing in the definition of the time-dependent derivative of the response of interest with respect to a data parameter β , and to provide the exact equations programmed within the DEPTH-CHARGE system. These equations will define the data saved in the DRDATA and TDSENS interface files whose specifications are given in Appendix E.

Using the notation in Appendix A, the time-dependent derivative of a specified response with respect to the cross-section or burnup data parameter β is,

$$\begin{aligned} \frac{dR(t_f)}{d\beta(t_{ik})} &= \frac{dR(t_f)}{d\beta^{ik}} \delta(t_{ik} - t_f) \\ &- \int d\vec{r} \underline{\Gamma}^{*Tik}(\vec{r}) \frac{\partial}{\partial \beta^{ik}} [(\underline{L} - \underline{\lambda F}) \underline{\Psi}(\vec{r})]^{ik} \\ &- P^{*ik} \alpha^{ik} \int d\vec{r} \frac{\partial}{\partial \beta^{ik}} [\underline{N}^{Tik}(\vec{r}) \underline{E}_{\sigma_f^{ik}}(\vec{r}) \underline{\Psi}^{ik}(\vec{r})] \\ &+ \int d\vec{r} \int_{t_i}^{t_{i+1}} dt \underline{N}^{*T}(\vec{r}, t) \frac{\partial}{\partial \beta^{ik}} [(\underline{T}^{ik}(\vec{r}) + \underline{D}) \underline{N}(\vec{r}, t)] \end{aligned} \quad (C.1)$$

where $\partial R(t_f)/\partial \beta(t_{ik})$ is defined as the rate of change of some final-time response with respect to the data utilized during time step i and cycle k in the reference burnup calculation.

Although Eqn. (C.1) is rather lengthy, it is easily interpretable. The first term on the right-hand side (RHS) is just the static derivative of the final-time response functional with respect to the data utilized at that time. This is typically the quantity obtained from static sensitivity analyses and is the sum of both the "direct" and "indirect" effects. The remaining three terms on the RHS of Eqn. (C.1), therefore, represent the effect of a data variation during the burnup process on the response of interest. The first of these accounts for perturbations to the spectral and spatial shape of the neutron flux resulting from a variation in the data parameter. The second term reflects the importance due to the flux normalization changes (assuming constant power) brought about by a data variation. Lastly, the term containing the time-dependent nuclide adjoint density vector, $\underline{N}^*(\vec{r}, t)$, accounts for variations in the time-dependent nuclide field due to nuclide transmutation and decay processes. It is the combination of these latter three terms that allows the determination of data sensitivity coefficients in realistic reactor depletion studies.

Before discussing the last three terms in Eqn. (C.1) in detail, it is important to note that relative sensitivity coefficients can be obtained from Eqn. (C.1) by simply multiplying by β^{ik}/R and integrating over time. This procedure gives

$$S_\beta = \frac{\beta}{R} \left. \frac{dR}{d\beta} \right|_{t_f} + \sum_k \sum_i \frac{\beta^{ik}}{R} \frac{dR}{d\beta^{ik}} \quad (C.2)$$

Thus, the percent change in response R due to a 1% variation in the data utilized in a depletion calculation is just the sum of the static sensitivity coefficient at t_f and the "indirect" burnup sensitivities integrated over time.

The above formulation has been implemented within the DEPTH-CHARGE Depletion Perturbation Theory System. The DEPTH module calculates the time-dependent derivatives in Eqn. (C.1) and the CHARGE code combines the various derivatives into time-dependent (or time-integrated) relative data sensitivity coefficients. The derivatives from DEPTH are output on the DRDATA interface file and the sensitivity coefficients from CHARGE are saved in the TDSSENS file. This additional capability of the DEPTH-CHARGE system has significantly enhanced presently available static data sensitivity analysis capability. In fact, static analyses are now just a subset of the more general time-dependent capability available with the DEPTH-CHARGE system.

To understand more fully the meaning and usefulness of the time-dependent data sensitivity formulation, we will discuss each of the three burnup effects separately. These effects, from Eqn. (C.1), will be denoted as T2, T3, and T4, indicating the respective derivative terms in Eqn. (C.1).

1st Burnup Effect: "T^{*} effect"

$$T2^{ik}(\vec{r}) = - \frac{\partial}{\partial \beta^{ik}} \int d\vec{r} \{ \Gamma^* T(\vec{r}) \{ (L - \lambda F) \Psi(\vec{r}) \}^{ik} \} \quad (C.3)$$

where the term in { } is just the time-dependent diffusion equation written in operator notation. The form of the diffusion equation solved by VENTURE is (assuming that the cross sections are constant within subzone s in zone z),

$$- \underline{D}_{zz} \nabla^2 \underline{\Psi}(\vec{r}) + [\underline{\Sigma}_a + \underline{\Sigma}_f^0 + \underline{DB}^2]_{zz} \underline{\Psi}(\vec{r})$$

$$- [\underline{\Sigma}_f^I + \frac{1}{K_{eff}} \underline{\chi} \nu \underline{\Sigma}_f]_{zz} \underline{\Psi}(\vec{r}) = 0$$

where $\underline{\Sigma}_f^0$ and $\underline{\Sigma}_f^I$ are the outscatter and inscatter terms, respectively, and the $\underline{DB}^2$ contribution is assumed negligible. The microscopic data parameters of interest in this equation are $\underline{\sigma}_s, \nu, \underline{\chi}$,

$$\underline{\sigma}_a \rightarrow \underline{\sigma}_a = \underline{\sigma}_c + \underline{\sigma}_f + \underline{\sigma}_{n,n} + \underline{\sigma}_{n,p} + \underline{\sigma}_{n,D} + \underline{\sigma}_{n,T} - \underline{\sigma}_{n,2n} ,$$

and

$$\underline{\sigma}_{tr} \rightarrow \underline{D} = (3N^T \underline{\sigma}_{tr})^{-1} ,$$

where the matrix notation indicates dependence on energy and nuclide. The fission spectrum presently is assumed to be nuclide-independent, hence a matrix dependence on energy only.

1. If β^{ik} is one of the terms comprising $\underline{\sigma}_a$, the only nonzero term in T2 (except for the $\nu \underline{\Sigma}_f$ term) is,

$$T2A_{I,g,n}^{ik} = - \frac{1}{\alpha} \sum_{j \neq n} N_{I,j} S_{I,g,g} \frac{V_{jj}}{V_I} \quad (C.4)$$

where $T2A_{I,g,n} =$ derivative of the removal term's contribution to R with respect to absorption-like processes, $\sigma_{I,g,n}^{ik}$,

$\sigma_{x_{l,g,n}}^{ik}$ = microscopic removal cross section x for nuclide l , group g , and cross-section set n at time step i and cycle k ,

$N_{l,sz}$ = density of nuclide l in subzone s and zone z at t_{ik} ,

V_{sz} = volume of subzone s in zone z ,

V_z = volume of zone z ,

and

$$S_{z,g,g} = \alpha \sum_{isz} v_i \Gamma_{i,g}^* \Psi_{i,g} \quad (C.5)$$

The last integrals, $S_{z,g,g}$, are the flux-adjoint flux integrals stored in the 3D record of the PERTUB interface file. The derivative given by Eqn. (C.4) is appropriate for β equal to $\underline{\sigma_x} = \underline{\sigma_c}, \underline{\sigma_f}, \underline{\sigma_{n,n}}, \underline{\sigma_{n,p}}, \underline{\sigma_{n,D}},$ or $\underline{\sigma_{n,T}}$, and the negative of Eqn. (C.4) is valid for $\underline{\beta} = \underline{\sigma_{n,2n}}$.

2. If β^{ik} is $\underline{\sigma_f}$, another term in Eqn. (C.3) is also nonzero. The derivative arising from the term containing $\nu \Sigma_f$ is,

$$T2F_{l,g,n}^{ik} = \frac{1}{\alpha} \sum_{szn} N_{l,sz} v_{l,g,n} T_{z,g} \frac{V_{sz}}{V_z} \quad (C.6)$$

where $T2F_{l,g,n}^{ik}$ = derivative of the fission source term's contribution to R with respect to the fission cross section, $\sigma_{f_{l,g,n}}^{ik}$,

and

$$T_{z,g} = \frac{\alpha}{k_{eff}} \sum_{szn} v_i \Psi_{i,g} \sum_g x_g \Gamma_{i,g}^* \quad (C.7)$$

The $T_{z,g}$ integrals are stored in the 2D record of the PERTUB interface file.

3. If β^{ik} is $\underline{\nu}$, then

$$T2NU_{l,g,n}^{ik} = \frac{1}{\alpha} \sum_{szn} N_{l,sz} \sigma_{f_{l,g,n}} T_{z,g} \frac{V_{sz}}{V_z} \quad (C.8)$$

where $T2NU_{l,g,n}^{ik}$ = derivative of the fission source term's contribution to R with respect to $\nu_{l,g,n}^{ik}$.

4. If β^{ik} is $\underline{x}$, then

$$T2X_g^{ik} = \frac{1}{\alpha k_{eff}} \sum_{sz} \frac{V_{sz}}{V_z} \sum_{g'} \sum_l N_{l,sz} v_{l,g',sz} \sigma_{f_{l,g',n}} S_{z,g',g} \quad (C.9)$$

where $T2X_g^{ik}$ = derivative of the fission source term's contribution to R with respect to the reactor fission spectrum,

and

$$S_{z,g,g'} = \alpha \sum_{i \in \alpha} V_i \Gamma_{i,g}^* \Psi_{i,g'} \quad (C.10)$$

The $S_{z,g,g'}$ are the off-diagonal integrals stored in the 3D records of the PERTUB file.

5. If β^{ik} is $\underline{\sigma}_v$, then

$$T2D_{l,g,n}^{ik} = -\frac{3.0}{\alpha} \sum_{z \in \alpha} D_{z,n}^2 N_{l,n} W_{z,g} \frac{V_n}{V_z} \quad (C.11)$$

where $T2D_{l,g,n}^{ik}$ = derivative of the leakage term's contribution to R with respect to the transport cross section, $\sigma_{v,l,g,n}^{ik}$,

$$D_{l,n} = \text{diffusion coefficient} = (3N^T \underline{\sigma}_{trg})_n^{-1}$$

and

$$W_{z,g} = \alpha \sum_{i \in \alpha} V_i \Gamma_{i,g}^* \nabla^2 \Psi_{i,g} \quad (C.12)$$

The $W_{z,g}$ integrals are stored in the 4D record of the PERTUB file.

6. If β^{ik} is an element of the scatter matrix,

$$T2S_{l,g,g',n}^{ik} = -\frac{1}{\alpha} \sum_{z \in \alpha} N_{l,n} (S_{z,g,g'} - S_{z,g',g}) \frac{V_n}{V_z} \quad (C.13)$$

where $T2S_{l,g,g',n}^{ik}$ = derivative of the outscatter and inscatter contributions to R with respect to $\sigma_{l,g \rightarrow g',n}^{ik}$

and

$$S_{z,g,g'} = \alpha \sum_{i \in \alpha} V_i \Gamma_{i,g'}^* \Psi_{i,g}$$

These six time-dependent derivative terms, T2A, T2F, T2NU, T2X, T2D, and T2S, describe the rate of change of the final-time response with respect to a variation in the respective data parameter due to the spectral and spatial redistribution of the flux (neutron source strength) caused by the variation at $t_{ik} < t_f$. These terms only represent the first of the burnup effects noted in Eqn. (C.1) and will be termed the "P* effect." These derivative terms are stored under the names given above in the DRDATA interface file.

2nd Burnup Effect: "P* effect"

$$T3F^{ik}(\vec{r}) = \frac{-\partial}{\partial \beta^{ik}} \int d\vec{r} [P^* \{ \alpha \underline{N}^T(\vec{r}) \underline{E}_p \sigma_f(\vec{r}) \underline{\Psi}(\vec{r}) \}]^{ik} \quad (C.14)$$

where the term in the $\{ \}$ is just an expression for the reactor power at t_i . The data parameters of interest in Eqn. (C.14) are the energy/fission conversion factor, $\underline{E}_p$, and the microscopic fission cross section.

1. If β^{ik} is $\sigma_{f,sg}$ then

$$T3F_{f,sg}^{ik} = - \sum_j (P^* \alpha)^{ijk} \sum_{sz \in n} N_{f,sz}^{ijk} e_l \Psi_{f,sg}^{ik} V_{sz} \quad (C.15)$$

where $T3F_{f,sg}^{ik}$ = derivative of the normalization term's contribution to R with respect to $\sigma_{f,sg}$.

2. If β^{ik} is an element of the diagonal matrix $\underline{E}_p$, then

$$T3E_l^{ik} = - \sum_j (P^* \alpha)^{ijk} \sum_{sz} N_{f,sz}^{ijk} V_{sz} \sum_g (\sigma_{f,sg} \Psi_{zg}) \quad (C.16)$$

where $T3E_l^{ik}$ = derivative of the normalization term's contribution to R with respect to the nuclide-dependent energy/fission factor, e_l .

These two derivative terms, T3F and T3E, represent the importance of flux normalization changes (assuming constant power) brought about by the respective data variations. The sum over the j superscript in Eqns. (C.15) and (C.16) indicate that the power normalization constraint is applied at the beginning of each substep j within time step i . These derivatives represent the contribution of the second burnup effect in Eqn. (C.1) and will be termed the "P* effect." These time-dependent terms are also stored in the DRDATA file.

3rd Burnup Effect: "N* effect"

$$T4^{ik}(\vec{r}) = \frac{\partial}{\partial \beta^{ik}} \sum_j \int d\vec{r} \int_{substep j} dt [\underline{N}^{*Tijk}(\vec{r}, t) \{ (\underline{T}^{ijk}(\vec{r}) + \underline{D}) \underline{N}^{ijk}(\vec{r}, t) \}] \quad (C.17)$$

where the term in $\{ \}$ is an expression for the rate of change of the nuclide density field at time t , with the matrices $\underline{T}$ and $\underline{D}$ describing the nuclide transmutation and decay processes, respectively.

1. If β^{ik} is an absorption-like cross section along the diagonal of the transmutation matrix, then

$$T4AD_{f,sg}^{ik} = - \sum_j \alpha^{ijk} \sum_{sz \in n} \Psi_{f,sg} V_{sz} \int_{substep j} dt (N_l^* N_l)_{sz}^{ijk} \quad (C.18)$$

where $T4AD_{f,sg}^{ik}$ = derivative of the transmutation term's contribution to R with respect to an absorption-like cross section, $\sigma_{x,l,mg}$, along the diagonal of the burnup matrix ($l=m$),

and $\sigma_{x,l,mg}$ = microscopic production (or destruction) cross section for reaction x of nuclide l by nuclide m for group g .

(note: $m \rightarrow$ parent, $l \rightarrow$ daughter, $x \rightarrow$ process)

2. If β^{ik} is an absorption-like cross section in the off-diagonal elements, then

$$T4AOD_{ma, n}^{ik} = \sum_j \alpha^{ik} \sum_{zz} \Psi_{z, g} V_{zz} \int_{substep j} dt (N_i^* N_m)_{zz}^{ijk} \quad (C.19)$$

and

$$IPDS_{ma} = m$$

$$IDDS_{ma} = 1$$

$$IPRDS_{ma} = x$$

where $T4AOD_{i, g, n}^{ik}$ = derivative of the nuclide transmutation term's contribution to R with respect to absorption-like cross sections in the off-diagonal elements of the burnup matrix, with the three vectors, IPDS, IDDS, IPRDS, describing the parent, daughter, and process occurring in each nonzero element of the matrix.

The derivatives given in Eqns. (C.18) and (C.19) are appropriate for β equal to

$$\sigma_x = \sigma_c, \sigma_f, \sigma_{n, p}, \sigma_{n, D}, \sigma_{n, T}, \text{ and } \sigma_{n, 2n}.$$

In addition, if the process is fission with yield to some fission product, then T4AOD must be multiplied by the yield fraction $Y_{m, l}$.

3. If β^{ik} is an energy-independent fission product yield, then

$$T4Y_{m, l}^{ik} = \sum_j \alpha^{ik} \sum_{zz} V_{zz} \sum_g \sigma_{f, m, g, zz} \Psi_{z, g} \int_{substep j} dt (N_i^* N_m)_{zz}^{ijk} \quad (C.20)$$

where $T4Y_{m, l}^{ik}$ = derivative of the nuclide transmutation term's contribution to R with respect to the fission product yield ($Y_{m, l}$) of fissioning nuclide m producing fission product l.

4. If β^{ik} is a decay constant along the diagonal of $\underline{D}$, then

$$T4LD_l^{ik} = - \sum_j \sum_{zz} V_{zz} \int_{substep j} dt (N_i^* N_l)_{zz}^{ik} \quad (C.21)$$

where $T4LD_l^{ik}$ = derivative of the nuclide decay term's contribution to R with respect to the decay constant of nuclide l.

5. If β^{ik} is an off-diagonal decay constant, then

$$T4LOD_{ma}^{ik} = \sum_j \sum_{zz} V_{zz} \int dt (N_i^* N_m)_{zz}^{ik} \quad (C.22)$$

where $T4LOD_{ma}^{ik}$ = derivative of the nuclide decay term's contribution to R with respect to the decay constant (λ_m) of nuclide m decaying to nuclide l, with the vectors IPDS_{ma} and IDDS_{ma} describing the parent-daughter relationships for each nonzero element of D.

These five derivatives, T4AD, T4AOD, T4Y, T4LD, and T4LOD, account for the effect of variations in the time-dependent nuclide field due to data variations affecting the nuclide transmutation and decay processes. These represent the contribution of the third burnup effect in Eqn. (C.1) and will be called the "N* effect." As before, the T4 derivatives are saved in the DRDATA file.

At this point, it should be noted that a static data sensitivity calculation in DEPTH proceeds exactly as would an adjoint depletion calculation. However, a static case is one that has only one depletion time step with the time interval typically on the order of 0.001 days. This methodology allows the same coding in DEPTH to be used for both static and time-dependent problems. In static problems, the T3 and T4 data derivatives are typically zero and the T2 derivatives are the familiar "indirect" effects of static generalized sensitivity theory.

The next step in the calculation of data sensitivity coefficients is to combine the various "indirect" static and time-dependent derivatives from the DRDATA file into relative data sensitivity coefficients (time-dependent or time-integrated). The CHARGE module performs this task as well as the calculation and addition of the "direct" static sensitivity coefficients for a large variety of response functionals. Finally, the total relative data sensitivity coefficients are edited and output on the TDSSENS file.

The equations programmed into CHARGE and the data appearing in the TDSSENS file are as follows:

1. Capture Sensitivity

$$CAP_{I,g,n}^k = \frac{\sigma_{cI,g,n}}{R} [(T2A + T4AD)_{I,g,n} + T4AOD_{m-I,g,n}]^k \quad (C.23)$$

2. Fission Sensitivity

$$FIS_{I,g,n}^k = \frac{\sigma_{fI,g,n}}{R} [(T2A + T2F + T3F + T4AD)_{I,g,n} + T4AOD_{m-I,g,n}]^k \quad (C.24)$$

3. Nu Sensitivity

$$XNU_{I,g,n}^k = \frac{\nu_{I,g,n}}{R} [T2NU]_{I,g,n}^k \quad (C.25)$$

4. Transport Sensitivity

$$TR_{I,g,n}^k = \frac{\sigma_{trI,g,n}}{R} [T2D]_{I,g,n}^k \quad (C.26)$$

5. Total Scatter Sensitivity

$$SCAT_{I,g,n}^k = \sum_{g'} \frac{\sigma_{sI,g \rightarrow g',n}}{R} [T2S]_{I,g,g',n}^k \quad (C.27)$$

6. Chi Sensitivity

$$CHI_{\epsilon}^{ik} = \frac{X_{\epsilon}}{R} [T2CHI]_{\epsilon}^{ik} \quad (C.28)$$

7. N, α Sensitivity

$$XNA_{I,g,n}^{ik} = \frac{\sigma_{n,\alpha I,g,n}}{R} [(T2A + T4AD)_{I,g,n} + T4AOD_{m-I,g,n}]^{ik} \quad (C.29)$$

8. N,P Sensitivity

$$XNP_{I,g,n}^{ik} = \frac{\sigma_{n,P I,g,n}}{R} [(T2A + T4AD)_{I,g,n} + T4AOD_{m-I,g,n}]^{ik} \quad (C.30)$$

9. N,2N Sensitivity

$$XN2N_{I,g,n}^{ik} = \frac{\sigma_{n,2n I,g,n}}{R} [(-T2A + T4AD)_{I,g,n} + T4AOD_{m-I,g,n}]^{ik} \quad (C.31)$$

10. N,D Sensitivity

$$XND_{I,g,n}^{ik} = \frac{\sigma_{n,d I,g,n}}{R} [(T2A + T4AD)_{I,g,n} + T4AOD_{m-I,g,n}]^{ik} \quad (C.32)$$

11. N,T Sensitivity

$$XNT_{I,g,n}^{ik} = \frac{\sigma_{n,t I,g,n}}{R} [(T2A + T4AD)_{I,g,n} + T4AOD_{m-I,g,n}]^{ik} \quad (C.33)$$

12. Energy/Fission Sensitivity

$$EF_I^{ik} = \frac{e_I}{R} [T3E]_I^{ik} \quad (C.34)$$

13. Decay Constant Sensitivity

$$DCY_I^{ik} = \frac{\lambda_I}{R} [T4LD_I + T4LOD_{m-I}]^{ik} \quad (C.35)$$

14. Fission Product Yield Sensitivity

$$YLD_{m,I}^{ik} = \frac{Y_{m,I}}{R} [T4Y]_{m,I}^{ik} \quad (C.36)$$

15. 2-D Scattering Sensitivity

$$SCAT2_{l,g,n}^k = \frac{\sigma_{s_{l,g \rightarrow g'},n}}{R} \{T2S_{l,g,g',n}^k\} \quad (C.37)$$

where SCAT2 is looped over g' energy groups.

The above 15 data sensitivity coefficients are stored in the TDSSENS file exactly as indicated above. In the current version of CHARGE, sensitivity data for elastic and inelastic scattering are also calculated and stored similar to the total scatter sensitivities, if the appropriate cross-section data are available in the GRUPXS file or supplied by optional input. If time-dependent sensitivities are to be saved, the above files are repeated NLOOP = NTOT (number of time steps) times. If the sensitivities are summed over time, NLOOP = 1 and the data contains the time-integrated values. In addition, if "direct" static sensitivities are incorporated into the file, they are added to the static "indirect" coefficients and just summed as usual if a time-integration is performed.

One final explanation is necessary to fully define the data sensitivity coefficients calculated in CHARGE and stored in the TDSSENS interface file. It has been implicitly assumed up to now that the derivatives of the leakage term in Eqn. (C.3) with respect to the partial cross sections making up the transport cross section were zero. However, since

$$\sigma_{tr_{l,g,n}} = \sigma_{a_{l,g,n}} + \sigma_{s_{l,g,n}} (1 - \bar{\mu}_g), \quad (C.38)$$

we see that the derivatives with respect to σ_s and the components of σ_a are typically nonzero. Therefore, the following default "transport corrections" are made unless instructed otherwise.

1. "Transport Correction" for absorption-like reactions:

$$\frac{\sigma_{x_g}}{R} \frac{dR}{d\sigma_{x_g}} = \frac{\sigma_{x_g}}{R} \frac{\partial R}{\partial \sigma_{x_g}} + \frac{\sigma_{x_g}}{R} \frac{\partial R}{\partial \sigma_{tr_g}} \frac{\partial \sigma_{tr_g}}{\partial \sigma_{x_g}} \quad (C.39)$$

but from Eqn. (C.38), $\partial \sigma_{tr_g} / \partial \sigma_{x_g} = 1$ (except for $\partial \sigma_{tr_g} / \partial \sigma_{n,2n_g} = -1$); therefore,

$$S_{x_{l,g,n}}^{tr} = S_{x_{l,g,n}} + \left[\frac{\sigma_x}{\sigma_{tr}} \right]_{l,g,n} S_{tr_{l,g,n}} \quad (C.40)$$

where $S_{x_{l,g,n}}$ and $S_{x_{l,g,n}}^{tr}$ are the sensitivity coefficients for nuclide l , reaction x , and cross-section set n before and after the transport correction, respectively, and $S_{tr_{l,g,n}}$ is the transport cross-section sensitivity ($TR_{l,g,n}$) mentioned previously.

2. "Transport Correction" for scattering reactions:

$$S_{s_{g \rightarrow g'}}^{tr} = S_{s_{g \rightarrow g'}} + \frac{\sigma_{s_{g \rightarrow g'}}}{R} \frac{\partial R}{\partial \sigma_{tr_g}} \frac{\partial \sigma_{tr_g}}{\partial \sigma_{s_g}} \frac{\partial \sigma_{s_g}}{\partial \sigma_{s_{g \rightarrow g'}}} \quad (C.41)$$

but

$$\frac{\partial \sigma_{tr}}{\partial \sigma_{s_t}} = 1 - \bar{\mu}_t = \frac{1}{\sigma_{s_t}} (\sigma_{tr} - \sigma_{a_t}) \quad (\text{C.42})$$

and

$$\frac{\partial \sigma_{s_t}}{\partial \sigma_{s_t}} = 1. \quad (\text{C.43})$$

Therefore,

$$S_{s_{l,s} \rightarrow t}^{tr} = S_{s_{l,s} \rightarrow t} + \left[\frac{\sigma_{tr} - \sigma_a}{\sigma_{tr}} \right]_{l,s} \left[\frac{\sigma_{s_t \rightarrow t'}}{\sigma_{s_t}} \right]_{l,s} S_{tr_{l,s}}. \quad (\text{C.44})$$

Equations (C.40) and (C.44) define the so-called "transport corrections" and thus complete the detailed description of the time-dependent data sensitivity capability of the DEPTH-CHARGE system.

APPENDIX D

Treatment of Equilibrium Nuclides

The purpose of this Appendix is to present the methodology utilized for treating large terms within the transmutation matrix for the matrix exponential solution technique. The procedure used here is similar to that utilized in the BURNER¹⁹ code, with some slight extensions. The extensions are applied in the adjoint problem only when very large values of $N_i^*(t_f)$ are encountered for isotope i having a large loss term in the transmutation matrix.

Consider a system of linear first-order equations given by

$$\frac{d}{dt} \underline{N}(t) = \underline{A} \underline{N}(t) \quad (D.1)$$

The solution to Eqn. (D.1) is

$$\underline{N}(t + \Delta t) = \underline{B} \underline{N}(t) \quad (D.2)$$

with

$$\begin{aligned} \underline{B} &= \exp[\underline{A}\Delta t] \\ &= \underline{I} + \underline{A}\Delta t + \frac{1}{2!} (\underline{A}\Delta t)^2 + \dots \end{aligned} \quad (D.3)$$

Thus, for a given Δt (calculated by DEPTH), the matrix exponential, $\underline{B}$, can be easily calculated with convergence limits set by user input. Once $\underline{B}$ has been determined, successive matrix multiplications are performed using Eqn. (D.2) to obtain the nuclide density vector at various time points.

As discussed in Ref. 19, if an entry in the $\underline{A}\Delta t$ matrix exceeds some value, the results of Eqn. (D.3) will not have adequate significance due to subtraction of numbers of nearly the same magnitude. The simplest way to alleviate the problem is to reduce the value of Δt , thereby reducing the elements of $\underline{A}\Delta t$. This procedure is done automatically within DEPTH. However, for nuclides such as ¹³⁵Xe whose coefficients are very large, this procedure becomes quite expensive in most cases and completely impractical when coupled with an extremely large initial concentration (or importance) for this nuclide. This latter situation is encountered in the adjoint case where values as large as $10^5 - 10^6$ have been observed for the initial importance, $N^*(t_f)$, for ¹³⁵Xe.

In simple situations it is reasonable to assume that a nuclide having a large value along the diagonal of $\underline{A}$, a_{nn} , will take on the end-of-exposure steady-state solution very rapidly. In this case for all nuclides m having coupling ($m \rightarrow n$) and all nuclides l having coupling ($n \rightarrow l$), we simply replace the coupling ($n \rightarrow l$) with coefficients

$$a_{m,l} = a_{m,n} \frac{a_{n,l}}{a_{n,n}} \quad (D.4)$$

and set the concentration of equilibrium nuclide n to its equilibrium value (determined by setting $dN_n/dt = 0$). This simple procedure is utilized for the calculation of both $N(t)$ and $N^*(t)$ when equilibrium nuclides are present.

However, as mentioned above, in the adjoint case the initial value t_f of the importance function can be very large. In order to conserve this importance over some depletion step [$N^*(t)N(t) = \text{constant}$], one must account for the production of daughters during the approach to equilibrium. The procedure utilized in DEPTH to account for production during the approach to equilibrium will be illustrated with the following simple example.

Consider a three-nuclide decay chain where nuclide A is produced from B and nuclide C is produced from A. This scheme can be described in equation form as

$$\frac{d}{dt} \begin{bmatrix} A \\ B \\ C \end{bmatrix} = \begin{bmatrix} -a_{11} & a_{12} & 0 \\ 0 & -a_{22} & 0 \\ a_{31} & 0 & -a_{33} \end{bmatrix} \begin{bmatrix} A \\ B \\ C \end{bmatrix} \quad (\text{D.5})$$

Now assume that a_{11} is large, causing nuclide A to go into equilibrium very rapidly. The equilibrium value of A is found by setting $dA/dt = 0$, giving

$$A_e(t) = a_{12} \frac{B(t)}{a_{11}} \quad (\text{D.6})$$

If we also assume that the initial value of A is large (say $A_I > 5A_e$), we have for $t \approx 0$

$$\frac{dA}{dt} = -a_{11} A + a_{12} B \approx -a_{11} A \quad (\text{D.7})$$

Therefore, during the approach to equilibrium (actually a value of $2A_e$ is used in DEPTH), we have

$$A(t) \approx A_I e^{-a_{11}t} \quad (\text{D.8})$$

with the time required to reach $2A_e$ given by

$$T_{2e} \approx -\frac{1}{a_{11}} \ln \frac{2A_e}{A_I} \quad (\text{D.9})$$

From Eqn. (D.8), we can obtain the average value of $A(t)$ during its approach to equilibrium,

$$A_{ave} = \frac{1}{T_{2e}} \int_0^{T_{2e}} A(t) dt = \frac{A_I}{a_{11} T_{2e}} [1 - e^{-a_{11} T_{2e}}] \quad (\text{D.10})$$

Thus, the integral of $A(t)$ over T_{2e} is

$$A_{int} = A_{ave} T_{2e} . \quad (D.11)$$

Finally, to account for the production to some daughter nuclide during the approach to equilibrium, we simply integrate the production rate over T_{2e} , giving for the present example,

$$\begin{array}{l} \text{Production of C from A during} \\ \text{approach to equilibrium} \end{array} = a_{31} A_{ave} T_{2e} \quad (D.12)$$

Thus the initial value of nuclide C can be adjusted to reflect this production, giving

$$C'_I = C_I + a_{31} A_{ave} T_{2e} \quad (D.13)$$

If we now also set the initial value of A to $A'_I = A_e$, we will have conserved (approximately) the total importance in the system.

With the time dependence of the daughter nuclide adjoint densities properly taken into account, we still need to account for the contribution of the equilibrium nuclide during its approach to equilibrium in the P^* and S^* integrals of Depletion Perturbation Theory (DPT). In these expressions, we have terms of the form

$$I_i = \int N_i^*(t) \sigma_{xi} N_i(t) dt \quad (D.14)$$

However, over the small time interval $0 \leq t \leq T_{2e}$,

$$N_i(t) \approx \text{Constant} = N_i(t_f) . \quad (D.15)$$

Equation (D.13) now becomes

$$I_i = \sigma_x N_i(t_f) \int_0^{T_{2e}} N^*(t) dt \quad (D.16)$$

where the integral is calculated using expressions analogous to Eqs. (D.9) and (D.10). Thus, the correction term I_i needs to be added to the P^* and S^* integrals (see Appendix A) and to the time-integrals in the data sensitivity formulation (see Appendix C) for all equilibrium nuclides i.

The above treatment of equilibrium nuclides is implemented as default within the DEPTH module, and this is the suggested mode of operation. However, control of the formulation can be accomplished with the IX(40) parameter in the EXPINS file and the IKEY(8) parameter in DEPTH.

Lastly, it should be noted that although the above methodology is not very rigorous, extremely good results have been obtained in a few sample problems that included the equilibrium nuclide ^{135}Xe . In fact, in the problems examined, the direct approach of subdividing the depletion step into many sub-intervals did not give converged results for the P^* and S^* integrals even for $\Delta t = 0.5$ days. Thus, the approximate method presented here appears to be the only acceptable method. However, the user should also be cautioned that only a few problems requiring this formulation have been treated to date; and therefore, one should exercise care in evaluating DPT analyses requiring the equilibrium assumption.

APPENDIX E

NSTARR, DRDATA, and TDSSENS Interface File Specifications

The purpose of this Appendix is to provide specifications for three new interface files created by the DEPTH-CHARGE system. Although other files are produced (most notably the DATAIN file), only the major output files will be described here, since these are probably the only files of real interest to the user. The files described in Tables E.1 - E.3 are:

1. NSTARR - contains time-dependent partial derivatives of some specified response with respect to the nuclide density field within the reactor model.
2. DRDATA - contains time-dependent partial derivatives of some specified response with respect to cross sections and burnup data.
3. TDSSENS - contains time-dependent (or time-integrated) relative sensitivity coefficients of some specified response to cross sections and burnup data.

The NSTARR and DRDATA files are created in DEPTH and used in CHARGE, while TDSSENS is produced in CHARGE from the DRDATA file.

In addition to the above data, it should be noted that a utility module exists (see Appendix F) that converts the TDSSENS formatted sensitivity data into a SENPRO³² file for use in the FORSS³³ Sensitivity and Uncertainty Analysis System. Thus the DEPTH-CHARGE system described here can be directly coupled to the FORSS system, greatly enhancing ORNL's overall sensitivity and uncertainty analysis capabilities.

TABLE E.1

NSTARR INTERFACE FILE SPECIFICATIONS

```

C*****
C
CF      NSTARR          (7/28/80)
C
CN      INTERFACE FILE CONTAINING PARTIAL DERIVATIVES OF SOME SPECIFIED
CN      RESPONSE WITH RESPECT TO THE NUCLIDE DENSITY FIELD WITHIN THE
CN      REACTOR MODEL.  THE DERIVATIVES ARE CALCULATED VERSUS REVERSE
CN      TIME IN THE 'DEPTH' DEPLETION PERTURBATION THEORY MODULE.
C
C*****

C-----
CS      FILE STRUCTURE
CS
CS      RECORD TYPE
CS      -----
CS      FILE IDENTIFICATION
CS      FILE REFERENCE INFORMATION
CS ***** LOOP OVER NTOT1 TIME STEPS
CS #
CS #   NUCLIDE DERIVATIVES -- N*(T)
CS #
CS *****
C
C-----

C-----
CR      FILE IDENTIFICATION
C
CL      HNAME
C
CW      1*MULT
C
CD      HNAME          FILE NAME (A6) 'NSTARR'
C
CN      MULT           1 FOR LONG WORD, 2 FOR SHORT WORD MACHINES
C
C-----

C-----
CR      1D FILE REFERENCE INFORMATION
C
CL      NTOT1,NISOE,NREG,NR,NPARM5
C
CW      5
C
CD      NTOT1          TOTAL NUMBER OF TIME STEPS PLUS 1
CD      NISOE          NUMBER OF NUCLIDES

```

TABLE E.1 (contd.)

CD	NREG	NUMBER OF REGIONS IN PROBLEM	-
CD		IF NSZ.EQ.0 NREG = NZONE	-
CD		IF NSZ.GT.0 NREG = NSZ	-
CD	NR	NUMBER OF RESPONSES (SEE INPUT TC DEPTH MODULE)	-
CD	NPARAM5	NOT USED	-
C			-
C	-----		
C	-----		
CR	2D	NUCLIDE DERIVATIVES -- N*(T)	-
C			-
CW	NISOE*NREG*NR		-
C			-
CD	XNSTAR(I,J,K)	DERIVATIVE OF RESPONSE K WITH RESPECT TO	-
CD		NUCLIDE I IN REGION J	-
C			-
C	-----		
C	*****		
C			-
CEOF	NSTARR		-
C			-
C	*****		

TABLE E.2

DRDATA INTERFACE FILE SPECIFICATIONS

```

C*****
C
CF      DRDATA      (7/14/80)
C
CN      INTERFACE FILE CONTAINING PARTIAL DERIVATIVES OF SOME SPECIFIED
CN      RESPONSE WITH RESPECT TO CROSS SECTIONS AND BURNUP DATA.
CN      THE DERIVATIVES ARE CALCULATED VERSUS REVERSE TIME IN THE
CN      'DEPTH' DEPLETION PERTURBATION THEORY MODULE.
C
C*****

C-----
CS      FILE STRUCTURE
CS
CS      RECORD TYPE
CS      -----
CS      FILE IDENTIFICATION
CS      FILE REF INFO
CS      NUCLIDE NAMES
CS      CROSS SECTION REF INFO
CS      REFERENCE DATA
CS      TRANSMUTATION INFO
CS      ***** LOOP OVER NTOT TIME STEPS
CS      *      TERM #3 DERIVATIVES
CS      *      TERM #4 DERIVATIVES
CS      *      TERM #2 DERIVATIVES
CS      *****
CS
CS      NOTE: ABOVE RECORDS ARE ALWAYS PHYSICALLY PRESENT. HOWEVER UPON
CS      READING, IF THE RECORD LENGTH IS ZERO, INCREMENT THE RECORD
CS      NUMBER BUT DO NOT ACTUALLY READ THAT RECORD.
C
C-----

C-----
CR      FILE IDENTIFICATION
C
CL      HNAME
C
CW      1*MULT
C
CD      HNAME      FILE NAME (A6) 'DRDATA'
C
CN      MULT      1 FOR LONG WORD, 2 FOR SHORT WORD MACHINES
C
C-----

```

TABLE E.2 (contd.)

C	-----		
CR	1D	FILE REF INFO	-
C			-
CL	NTOT,NISOE,NGROUP,NSN,NAOD,IAOD,NDCYR,NLOD,NFSLR,NFPR		-
C			-
CW	10		-
C			-
CD	NTOT	TOTAL NUMBER OF TIME STEPS IN PROBLEM	-
CD	NISOE	NUMBER OF NUCLIDES	-
CD	NGROUP	NUMBER OF ENERGY GROUPS	-
CD	NSN	NUMBER OF NUCLIDE SETS	-
CD	NAOD	MAXIMUM NUMBER OF OFF DIAGONAL TERMS IN BURNUP MATRIX	-
CD	IAOD	NUMBER OF OFF DIAGONAL TERMS FOR PRESENT PROBLEM	-
CD	NDCYR	NUMBER OF NUCLIDES THAT DECAY	-
CD	NLOD	NUMBER OF OFF DIAGONAL DECAY TERMS	-
CD	NFSLR	NUMBER OF FISSION NUCLIDES THAT YIELD FISSION PRODUCTS	-
CD	NFPR	NUMBER OF FISSION PRODUCTS HAVING YIELD	-
C			-
C	-----		
C	-----		
CR	2D	NUCLIDE NAMES	-
C			-
CL	HNUC(NISOE)		-
C			-
CW	NISOE*MULT		-
C			-
CD	HNUC(I)	NAME OF NUCLIDE ORDERED I IN LIST	-
C			-
C	-----		
C	-----		
CR	3D	CROSS SECTION REFERENCE INFO	-
C			-
CL	IXREF(NISOE,NSN)		-
C			-
CW	NISOE*NSN		-
C			-
CD	IXREF	POSITION IN GRUPXS OF EACH NUCLIDE BY NUCLIDE SET	-
C			-
C	-----		
C	-----		
CR	4D	REFERENCE DATA	-
C			-
CL	IFSLR(NFSLR),IFPR(NFPR),IDCYR(NDCYR)		-
C			-
CW	NFSLR+NFPR+NDCYR		-
C			-
CD	IFSLR	ORDER NUMBER OF NUCLIDES WHICH FISSION	-
CD	IFPR	ORDER NUMBER OF FISSION PRODUCTS	-
CD	IDCYR	ORDER NUMBER OF NUCLIDES WHICH DECAY	-
C			-
C	-----		

TABLE E.2 (contd.)

C	-----					
CR	5D	TRANSMUTATION INFORMATION				-
C						-
CL	1PDS(NAOD),	IDDS(NAOD),	IPRDS(NAOD)			-
C						-
CW	3*NAOD					-
C						-
CD	IPDS	PARENT NUCLIDE				-
CD	IDDS	DAUGHTER NUCLIDE				-
CD	IPRDS	TRANSMUTATION PROCESS	(SEE EXPOSE FILE SPECS)			-
C						-
C	-----					
C	-----					
CR	6D	TERM #3 DERIVATIVES				-
C						-
CL	T3F(NISOE,	NGROUP, NSN),	T3E(NISOE)			-
C						-
CW	NISOE*NGROUP*	NSN+NISOE				-
C						-
CD	T3F	FISSION				-
CD	T3E	ENERGY/FISSION				-
C						-
C	-----					
C	-----					
CR	7D	TERM #4 DERIVATIVES				-
C						-
CL	T4AD(NISOE,	NGROUP, NSN),	T4AOD(NAOD,	NGROUP, NSN)		-
C						-
CW	(NISOE+NAOD)*	NGROUP*NSN				-
C						-
CD	T4AD	DIAGONAL TERMS OF BURNUP MATRIX				-
CD	T4AOD	OFF DIAGONAL TERMS OF BURNUP MATRIX				-
C						-
C	-----					
C	-----					
CR	8D	TERM #4 DERIVATIVES				-
C						-
CL	T4LD(NDCYR),	T4LOD(NLOD)				-
C						-
CW	NDCYR+NLOD					-
C						-
CD	T4LD	DECAY CONSTANTS ALONG DIAGONAL				-
CD	T4LOD	DECAY CONSTANTS OFF DIAGONAL				-
C						-
C	-----					

TABLE E.2 (contd.)

C	-----					
CR	9D	TERM #4	DERIVATIVES			-
C						-
CL	T4Y	(NFSLR,NFPR)				-
C						-
CW		NFSLR*NFPR				-
C						-
CD	T4Y		FISSION PRODUCT YIELD DATA			-
C						-
C	-----					
C	-----					
CR	10D	TERM #2	DERIVATIVES (ABS-LIKE)			-
C						-
CL	T2A	(NISOE,NGROUP,NSN)				-
C						-
CW		NISOE*NGROUP*NSN				-
C						-
CD	T2A		ABSORPTION - LIKE DATA			-
C						-
C	-----					
C	-----					
CR	11D	TERM #2	DERIVATIVES (FIS)			-
C						-
CL	T2F	(NISOE,NGROUP,NSN)				-
C						-
CW		NISOE*NGROUP*NSN				-
C						-
CD	T2F		FISSION			-
C						-
C	-----					
C	-----					
CR	12D	TERM #2	DERIVATIVES (NU)			-
C						-
CL	T2NU	(NISOE,NGROUP,NSN)				-
C						-
CW		NISOE*NGROUP*NSN				-
C						-
CD	T2NU		NU			-
C						-
C	-----					

TABLE E.2 (contd.)

C	-----		
CR	13D TERM #2 DERIVATIVES (TRANSPORT)		-
C			-
CL	T2D(NISOE,NGROUP,NSN)		-
C			-
CW	NISOE*NGROUP*NSN		-
C			-
CD	T2D TRANSPORT		-
C			-
C	-----		
C	-----		
CR	14D TERM #2 DERIVATIVES (CHI)		-
C			-
CL	T2CHI(NGROUP)		-
C			-
CW	NGROUP		-
C			-
CD	T2CHI CHI FISSION SPECTRUM		-
C			-
C	-----		
C	-----		
CR	15D TERM #2 DERIVATIVES (SCATTER)		-
C			-
CL	T2S(NISOE,NGROUP,NSN) NGROUP RECORDS INDEX JJ		-
C			-
CW	NISOE*NGROUP*NSN (EACH RECORD)		-
C			-
CD	T2S(I,J,K) SCATTER FROM GROUP J TO GROUP JJ		-
C			-
C	-----		
C	*****		
C			-
CEOF	DRDATA		-
C			-
C	*****		

TABLE E.3

TDSSENS INTERFACE FILE SPECIFICATIONS

```

C*****
C
CF      TDSSENS      (7/14/80)
C
CN      INTERFACE FILE CONTAINING RELATIVE SENSITIVITY COEFFICIENTS
CN      OF SOME SPECIFIED RESPONSE TO CROSS SECTIONS AND BURNUP DATA.
C
C
CN      NOTE: A TDSSENS - TO - SENPRO TRANSLATOR IS AVAILABLE.
C
C*****

C-----
CS      FILE STRUCTURE
CS
CS      RECORD TYPE
CS-----
CS      FILE IDENTIFICATION
CS      FILE REFERENCE INFORMATION
CS      NUCLIDE NAMES
CS      CROSS SECTION REFERENCE INFORMATION
CS      REFERENCE DATA
CS      ENERGY BOUNDARIES
CS ***** LOOP OVER NLOOP TIME STEPS
CS *      PRIN XSEC SENS COEFF
CS *      OPTIONAL XSEC SENS COEFF (IF PRESENT)
CS *      BURNUP DATA SENS COEFF (IF PRESENT)
CS *      2-D SCATTER SENS COEFF (IF PRESENT)
CS *****
C-----
C-----

C-----
CR      FILE IDENTIFICATION
C
CL      HNAME
C
CW      1*MULT
C
CD      HNAME      FILE NAME (A6) 'TDSSENS'
C
CN      MULT      1 FOR LONG WORD, 2 FOR SHORT WORD MACHINES
C
C-----

```

TABLE E.3 (contd.)

C			
CR	1D	FILE REFERENCE INFORMATION	-
C			-
CL		NLOOP, NXSET, NOPT, NISOE, NSN, NFSLR, NFPR, NDCYR, NGROUP,	-
CL		IALF, INP, IN2N, IND, INT, IBLK	-
C			-
OW	15		-
C			-
OD	NLOOP	NUMBER OF TIME LOOPS	-
OD	NXSET	NUMBER OF LOOPS OVER NUCLIDE SETS	-
OD	NOPT	OPTION SPECIFYING WHICH SENS ARE PRESENT	-
OD		1 PRIN XSEC SENS	-
OD		2 ALSO OPTIONAL XSEC SENS	-
OD		3 ALSO BURNUP DATA SENS	-
OD		4 ALSO 2-D SCATTER SENS	-
OD	NISOE	NUMBER OF NUCLIDES	-
OD	NSN	TOTAL NUMBER OF NUCLIDE SETS	-
OD	NFSLR	NUMBER OF FISSILE NUCLIDES THAT YIELD FISS PRODUCTS	-
OD	NFPR	NUMBER OF FISSION PRODUCTS HAVING YIELD	-
OD	NDCYR	NUMBER OF NUCLIDES THAT DECAY	-
OD	NGROUP	NUMBER OF ENERGY GROUPS	-
OD	IALF	N, ALPHA CROSS SECTION FLAG	-
OD		0 NOT PRESENT	-
OD		1 PRESENT	-
OD	INP	N, P FLAG	-
OD	IN2N	N, 2N FLAG	-
OD	IND	N, D FLAG	-
OD	INT	N, T FLAG	-
OD	IKIND	SCATTERING PROCESS OPTION	-
OD		1 ONLY TOTAL SCATTER	-
OD		3 TOTAL, ELASTIC, AND INELASTIC SCATTER	-
C			-
C			-
C			-
CR	2D	NUCLIDE NAMES	-
C			-
CL		HNUC(NISOE)	-
C			-
OW		NISOE*MULT	-
C			-
OD	HNUC(I)	NAME OF NUCLIDE ORDERED I IN LIST	-
C			-
C			-

TABLE E.3 (contd.)

C			
CR	3D	CROSS SECTION REFERENCE INFORMATION	-
C			-
CL	LXREF	(NLSOE, NSN)	-
C			-
OW		NLSOE*NSN	-
C			-
CD	IXREF	POSITION IN GROUPS OF EACH NUCLIDE BY NUCLIDE SET	-
C			-
C			-
C			-
CR	4D	REFERENCE DATA	-
C			-
CL	IFSLR(NFSLR), IFPR(NFPR), IDCYR(NDCYR)		-
C			-
OW		NFSLR+NFPR+NDCYR	-
C			-
CD	IFSLR	ORDER NUMBER OF NUCLIDES THAT FISSION	-
CD	IFPR	ORDER NUMBER OF FISSION PRODUCTS	-
CD	IDCYR	ORDER NUMBER OF NUCLIDES WHICH DECAY	-
C			-
CN	NOTE: THIS RECORD IS ALWAYS PRESENT. HOWEVER UPON READING, IF THE		-
CN	RECORD LENGTH IS ZERO, INCREMENT THE RECORD NUMBER BUT DO NOT		-
CN	ACTUALLY READ THE RECORD.		-
C			-
C			-
C			-
CR	5D	ENERGY BOUNDARIES	-
C			-
CL	EBOUND	(NG1)	-
C			-
OW		NG1 = NGROUP+1	-
C			-
CD	EBOUND	ENERGY GROUP BOUNDARIES	-
C			-
C			-
C			-
CR	6D	CAPTURE	-
C			-
CL	CAP	(NLSOE, NGROUP, NXSET)	-
C			-
OW		LENG = NLSOE*NGROUP*NXSET	-
C			-
CL	CAP	SENS COEFF TO CAPTURE	-
C			-
C			-

TABLE E.3 (contd.)

C			
CR	7D	FISSION	-
C			-
CL	FIS	(NISOE,NGROUP,NXSET)	-
C			-
OW	LENG		-
C			-
CD	FIS	SENS COEFF TO FISSION	-
C			-
C			
C			
CR	8D	NU	-
C			-
CL	XNU	(NISOE,NGROUP,NXSET)	-
C			-
OW	LENG		-
C			-
CD	XNU	SENS COEFF TO NU	-
C			-
C			
C			
CR	9D	TRANSPORT	-
C			-
CL	TR	(NISOE,NGROUP,NXSET)	-
C			-
OW	LENG		-
C			-
CD	TR	SENS COEFF TO TRANSPORT XSEC	-
C			-
C			
C			
CR	10D	TOTAL SCATTER	-
C			-
CL	SCAT1	(NISOE,NGROUP,NXSET)	-
C			-
OW	LENG		-
C			-
CD	SCAT1	SENS COEFF TO TOTAL SCATTER	-
C			-
C			
C			

TABLE E.3 (contd.)

C					
CR	10D-A	ELASTIC SCATTER	PRESENT IF IKIND.GT.1		-
C					-
CL		SCATEL(NISOE,NGROUP,NXSET)			-
C					-
OW		LENG			-
C					-
CD		SCATEL	SENS COEFF TO ELASTIC SCATTER		-
C					-
C					-
C					-
CR	10D-B	INELASTIC SCATTER	PRESENT IF IKIND.GT.1		-
C					-
CL		SCATIN(NISOE,NGROUP,NXSET)			-
C					-
OW		LENG			-
C					-
CD		SCATIN	SENS COEFF TO INELASTIC SCATTER		-
C					-
C					-
C					-
CR	11D	CHI			-
C					-
CL		CHI(NGROUP)			-
C					-
OW		NGROUP			-
C					-
CD		CHI	SENS COEFF TO FISSION SPECTRUM		-
C					-
C					-
C					-
CR	12D	N,ALPHA	PRESENT IF NOPT.GE.2 AND IALF.NE.0		-
C					-
CL		XNA(NISOE,NGROUP,NXSET)			-
C					-
OW		LENG			-
C					-
CD		XNA	SENS COEFF TO N,ALPHA XSEC		-
C					-
C					-
C					-

TABLE E.3 (contd.)

C						
CR	13D	N,P	PRESENT IF NOPT.GE.2 AND INP.NE.0			-
C						-
CL			XNP(NISOE,NGROUP,NXSET)			-
C						-
OW			LENG			-
C						-
CD		XNP	SEN COEFF TO N,P XSEC			-
C						-
C						-
C						-
CR	14D	N,2N	PRESENT IF NOPT.GE.2 AND IN2N.NE.0			-
C						-
CL			XN2N(NISOE,NGROUP,NXSET)			-
C						-
OW			LENG			-
C						-
CD		XN2N	SENS COEFF TO N,2N XSEC			-
C						-
C						-
C						-
CR	15D	N,D	PRESENT IF NOPT.GE.2 AND IND.NE.0			-
C						-
CL			XND(NISOE,NGROUP,NXSET)			-
C						-
OW			LENG			-
C						-
CD		XND	SENS COEFF TO N,D XSEC			-
C						-
C						-
C						-
CR	16D	N,T	PRESENT IF NOPT.GE.2 AND INT.NE.0			-
C						-
OW			XNT(NISOF,NGROUP,NXSET)			-
C						-
OW			LENG			-
C						-
CD		XNT	SENS COEFF TO N,T XSEC			-
C						-
C						-
C						-


```

C-----
CR  17D  BURNUP DATA   PRESENT IF NOPT.GE.3      -
C                                           -
CL      EF(NISOE) ,DCY(NDCYR) ,YLD(NFSLR,NFPR)    -
C                                           -
OW      NISOE+NDCYR+NFSLR*NFPR                   -
C                                           -
CD      EF          SENS COEFF TO ENERGY/FISSION -
CD      DCY          SENS COEFF TO DECAY DATA     -
CD      YLD          SENS COEFF TO FISSION PRODUCT YIELD DATA -
C                                           -
C-----

C-----
CR  18D  2-D SCATTERING  PRESENT IF NOPT.GE.4      -
C                                           -
CL      SCAT2(NISOE,NGROUP,NXSET)      NGROUP RECORDS INDEX JJ -
C                                           -
OW      LENG      EACH RECORD           -
C                                           -
CD      SCAT2      2-D SCATTERING SENS COEFF INTO GROUP JJ -
C                                           -
C-----

C*****
C                                           -
CEOF  TDSSENS                                -
C                                           -

```

APPENDIX F

SENSEN - A TDSSENS to SENPRO Translator

TDSSENS is an interface file generated by the VENTURE-DEPTH-CHARGE system containing relative sensitivity coefficients of some specified response to cross sections and burnup data. The reaction types treated are delineated in the TDSSENS file specification, see Appendix E. In TDSSENS, the relative sensitivity coefficients are ordered by reaction type, energy group, and material.

SENPRO³² is an interface file implemented in the FORSS system³³ to make relative sensitivity coefficients available to the adjustment module UNCOVER via the data preparation module COVERS. The file structures of SENPRO and TDSSENS are quite different.

Relative to response, material, and reaction type, the content of a SENPRO file is not limited or defined by the file structure. Sensitivity profiles are placed in a SENPRO file in an unstructured, i.e., random, order. In this context a sensitivity profile is defined as a vector of relative, energy-dependent, sensitivity coefficients. The length of the vector is the number of energy groups. The first entry in the vector is the sensitivity coefficient for group 1, the highest energy group. Each profile has five numerical identifiers to enhance automated retrieval. These identifiers are:

1. Assembly
2. Primary response
3. Material
4. Reaction type
5. Secondary response

The numerical values assigned to the identifiers are somewhat arbitrary with the restriction that each profile must be uniquely identified. To avoid chaos, it is suggested that ENDF/B material identification numbers (MAT) and reaction-type identification numbers (MT) be used as a guide in assigning SENPRO profile material and reaction-type identifiers. Regarding the response identifiers, it is suggested that k effective be assigned a primary response of identifier 1 and a secondary response identifier of 0. All linear reaction rate ratio responses could be assigned a primary response identifier of 4 and the secondary response identifier could assume values from 1 to 999 999 999 to establish uniqueness.

This identification philosophy can be extended as needed or it may be partially or completely replaced by something more appealing. The only mandatory requirement is that each profile in a SENPRO file must be uniquely identified with five identification numbers.

This discussion of the SENPRO file will, hopefully, aid the user in defining the parameters IASB, IRESP, NTRN (see the 155 input array) and the MAT(s) material identifiers (see the 255 array).

The translator has internally established the following TDSSENS to SENPRO correspondence for reaction types:

<u>TDSSENS Reaction</u>	<u>SENPRO Identifier</u>
CAPTURE	102
FISSION	18
NU	452
TRANSPORT	9002
TOTAL SCATTERING	9001
CHI	1018
N, ALPHA	21
N, P	28
N, 2N	16
N, D	32
N, T	33

Hollerith nuclide (material) names are provided in the 2D record of TDSSENS. Since SENPRO requires numerical material identifiers, they must be provided by the user via the 2\$\$ array. A one-to-one correspondence is assumed between the nuclide names in the TDSSENS 2D record and the user entries in the 2\$\$ array. The entries in 2\$\$ also have an additional function. TDSSENS has one set of sensitivity coefficients to the fission spectrum. Since SENPRO must assign a material identifier to these fission spectrum sensitivities, the user designates which material by making the appropriate entry in the 2\$\$ array negative. Any, all, or none of the entries in the 2\$\$ array may be negative.

This version of the translator discards the TDSSENS burnup and 2-D scattering sensitivities. The translators will not place in SENPRO a sensitivity profile containing sensitivity coefficients which are all equal to zero.

Even after generating thousands of sensitivity profiles and placing them in one or more SENPRO files, the user is not locked into a particular identification procedure. The SENPRO Service module of the FORSS system can be used to change any identifier on a SENPRO file. The operation is very fast, inexpensive, and requires very little input preparation.

SENSEN Input Specifications

Card 1 - SENSEN in columns 1-6

Card 2 - Hollerith title for the assembly, use no more than 12 characters

Card 3 - Hollerith title for the response, use no more than 12 characters.

Card(s) type 4

1\$\$ Integer Parameters [8]

1. IASM - Assembly identification number
2. IRESP - Primary response identification number
3. NTRN - Secondary response identification number
4. IV - SENPRO file version number
5. NUNIT - Unit number of the TDSSENS file (default 20)

6. NPRO - Unit number of the SENPRO file (default 21)
7. NSS - Unit number of scratch device (default 22)
8. NEW - 0 convert elastic, inelastic, and total scattering sensitivity coefficients
(if present)
1 only total scattering sensitivity data are present

T

Card(s) type 5

2\$\$ Integer Parameters [NISOE]

Enter one material identifier for each nuclide specified in the TDSENS 2D record.

T

SENSEN SAMPLE INPUT LISTING

```

//JRWPROB4 JOB (19934,104),'JR WHITE UNIV LOWELL',TIME=(0,20)
/*JOBPARM LINES=10
/*ROUTE PRINT RMT162
//BOLDFOUR PROC GOSIZE=384K,GOTIME=,MODULE=SCALE,
// NB1=1,NB2=1,B1=3520,B2=32000,NX=2,NS=50,N1=100,
// N2=1,N3=1,N4=1,N5=1,N6=1,N7=1,N8=1,N9=1,N10=1,N11=1,N12=1,N13=1,
// N14=1,N15=1,N16=1
//GO EXEC PGM=MODULE,
// REGION=MODULE,GOSIZE,TIME=GOTIME
//STEPLIB DD UNIT=3330V,VOL=SER=VLFS01,DISP=SHR,
// DSN=JLL.BVFOUR.LOADM
// DD UNIT=3330-1,VOL=SER=NE3330,DISP=SHR,DSN=E.LMP00000.SCALE.PGMS
//PT INT DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//FT01F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT02F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT03F001 DD UNIT=SYSDA,SPACE=(80,(10)),
// DCB=(RECFM=F,BLKSIZE=80)
//FT04F001 DD UNIT=SYSDA,SPACE=(3200,(N1,NX)),
// DCB=(RECFM=FBS,LRECL=80,BLKSIZE=3200)
//FT05F001 DD UNIT=SYSDA,SPACE=(3120,(200,100)),
// DCB=(RECFM=FB,BUFNO=1,LRECL=80,BLKSIZE=3120)
//FT06F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//FT07F001 DD SYSOUT=B,DCB=(RECFM=F,BLKSIZE=80)
//FT08F001 DD UNIT=SYSDA,SPACE=(B1,(N1,2)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT09F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT10F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT11F001 DD UNIT=SYSDA,SPACE=(B1,(N1,NX)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT12F001 DD UNIT=SYSDA,SPACE=(B1,(N1,NX)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT13F001 DD UNIT=SYSDA,SPACE=(B1,(N1,2)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT14F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT15F001 DD UNIT=SYSDA,SPACE=(B1,(NS,1)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT16F001 DD UNIT=SYSDA,SPACE=(B1,(N1,NX)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT17F001 DD UNIT=SYSDA,SPACE=(B1,(N16)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)
//FT18F001 DD UNIT=SYSDA,SPACE=(B1,(N16)),
// DCB=(RECFM=VBST,LRECL=X,BUFNO=NB1,BLKSIZE=B1)

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//FT19F001 DD UNIT=SYSDA, SPACE=(#B1, (#NS, 1)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT20F001 DD UNIT=SYSDA, SPACE=(#B1, (#N13)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT21F001 DD UNIT=SYSDA, SPACE=(#B1, (#N1, 2)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT22F001 DD UNIT=SYSDA, SPACE=(#B1, (#N3, 1)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT23F001 DD UNIT=SYSDA, SPACE=(#B1, (#N3)),
//          DCB=(RECFM=FT, BUFNO=#NB1)
//FT24F001 DD UNIT=SYSDA, SPACE=(#B1, (#N2)),
//          DCB=(RECFM=FT, BUFNO=#NB2)
//FT25F001 DD UNIT=SYSDA, SPACE=(#B1, (#N12)),
//          DCB=(RECFM=FT, BUFNO=#NB1)
//FT26F001 DD UNIT=SYSDA, SPACE=(#B1, (#N12)),
//          DCB=(RECFM=FT, BUFNO=#NB1)
//FT27F001 DD UNIT=SYSDA, SPACE=(#B1, (#N2)),
//          DCB=(RECFM=FT, BUFNO=#NB2)
//FT28F001 DD UNIT=SYSDA, SPACE=(#B1, (#N2)),
//          DCB=(RECFM=FT, BUFNO=#NB2)
//FT29F001 DD UNIT=SYSDA, SPACE=(#B1, (#N14)),
//          DCB=(RECFM=FT, BUFNO=#NB2)
//FT30F001 DD UNIT=SYSDA, SPACE=(#B1, (#N1, 2)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT31F001 DD UNIT=SYSDA, SPACE=(#B1, (#N1, #NX)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT32F001 DD UNIT=SYSDA, SPACE=(#B1, (#N1, 2)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT33F001 DD UNIT=SYSDA, SPACE=(#B1, (#N4)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT34F001 DD UNIT=SYSDA, SPACE=(#B1, (#N1, #NX)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT35F001 DD UNIT=SYSDA, SPACE=(#B1, (#N1, 2)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT36F001 DD UNIT=SYSDA, SPACE=(#B1, (#N6, 2)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT37F001 DD UNIT=SYSDA, SPACE=(#B1, (#N15, 2)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT38F001 DD UNIT=SYSDA, SPACE=(#B1, (#N15, 2)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT39F001 DD UNIT=SYSDA, SPACE=(#B1, (#N15, 2)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT40F001 DD UNIT=SYSDA, SPACE=(#B2, (#N5)),
//          DCB=(RECFM=FT, BUFNO=#NB2)
//FT41F001 DD UNIT=SYSDA, SPACE=(#B1, (#N4)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB1, BLKSIZE=#B1)
//FT42F001 DD UNIT=SYSDA, SPACE=(#B2, (#N7)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB2, BLKSIZE=#B2)
//FT43F001 DD UNIT=SYSDA, SPACE=(#B2, (#N8)),
//          DCB=(RECFM=VBST, LRECL=X, BUFNO=#NB2, BLKSIZE=#B2)

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T44F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT45F001 DD UNIT=SYSDA,SPACE=(qB1,(qN9)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT46F001 DD UNIT=SYSDA,SPACE=(qB1,(qN10)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT47F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT48F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT49F001 DD UNIT=SYSDA,SPACE=(qB1,(qN11)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT50F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT51F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT52F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT53F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT54F001 DD UNIT=SYSDA,SPACE=(qB1,(qN1,2)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT55F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT56F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT96F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT97F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT98F001 DD UNIT=SYSDA,SPACE=(qB1,(qNS,1)),
//          DCB=(RECFM=VBST,LRECL=X,BUFNO=qNB1,BLKSIZE=qB1)
//FT99F001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=1100)
//BOLDFOUR PEND
/*
// EXEC SPDASCR
//SYSIN DD *
      T.JRW00000.SENP101.DPT.PROB4
// EXEC BOLDFOUR,GOSIZE=384K
//GO.FT66F001 DD UNIT=SPDA,DISP=SHR,
// DSN=T.JRW00000.TDSENS.BOC2BR.PROB3
//GO.FT67F001 DD UNIT=SPDA,DISP=(NEW,CATLG),
// DSN=T.JRW00000.SENP101.DPT.PROB4,
// SPACE=(TRK,(020,05),RLSE),
// DCB=(RECFM=VBS,LRECL=X,BLKSIZE=4088)
//GO.FT68F001 DD UNIT=SYSDA,SPACE=(TRK,(090,010)),

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// DCB=(RECFM=VBST,LRECL=X,BLKSIZE=3120)
//GO.SYSIN DD *
=CONTROL1
PROB4 CONVERT TDSSENS FORMAT TO SENPRO FORMAT
025000                                0
99
END
SENSEN
DPT PROB #4
BOC2 BR
1$$$ 101 2 0 101 66 67 68 0 T
2$$$ 9990 1390 9991 1391 9992 -1393 9394
      1395 1396 1398 1337 9993 1338 1399
      1380 1381 1342 1361 1363 1444 9994
      1311 9995 1276
T
END
//

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