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FAST BREEDER REACTOR
STATIC PHYSICS METHODS DEVELOPMENT
AND ANALYSIS PROJECT

— Quarterly Technical Report —

October - December 1968

Babcock & Wilcox

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1. INTRODUCTION

In March 1967, Babcock & Wilcox (B&W) initiated a program of analytical methods development applicable to the physics design of fast breeder reactors. One phase of this effort has as its goal the development and utilization of a design-oriented, one-dimensional criticality and depletion code applicable to the physics analysis of fast reactors. This phase of the methods development effort is under full sponsorship of the U.S. Atomic Energy Commission (AEC). Utilization of the code will consist of an investigation in which the design code FARED will be used to relate the sensitivity of certain fast reactor design parameters to the complexity of the physics model used to evaluate them. Finally, several fast reactor critical experiments will be analyzed to verify the applicability of the code and its cross-section libraries. Future topics of study under the FARED project include (1) extension of the criticality and depletion segments to two dimensions with provision for complex fuel management studies, and (2) study of the importance of generating multigroup cross sections using space-dependent spectrum weighting.

In April 1968, a sensitivity study relating to burnup and fuel management in fast reactors was initiated as Task 4 of the FARED project. The objectives of this study are described in the third quarterly progress report (BAW-3867-3).¹

This sixth quarterly report for the FARED project covers work done during the period October - December 1968. Major accomplishments during this period may be summarized as follows:

1. Programming and debugging of various portions of the FARED code continued; with completion of the RAIM routine and final coupling of all segments of the REGA routine were completed. The RAIM routine now contains the depletion calculation as a secondary overlay.
2. Detailed specification of the control logic has been made and is ready for programming.

3. The burnup studies (Task 04) are complete, and a topical report will be issued late in January.

2. FARED CODE DEVELOPMENT

2.1. Programming Status

RETAP — The basic structure of files on the RETAP-generated tape has been modified to eliminate multiple passes by the REGA code. Group cross sections and the transfer matrix for all nuclides have been combined into file five.

A full edit and a contents edit of files one through seven are now possible. It is also possible to update RETAP tape files two through six with the directives Deletion, Insertion, and Substitution by nuclides.

INPUT — The input overlay is now able to process the required input directives with associated data and create an abbreviated RETAP tape. The coding will be completed when we complete the two additional subroutines now being developed.

REGA — The REGA overlay is functioning to the extent that it is possible to run the test case of one reactor block through the computation of resolved resonance integrals and unresolved resonance integrals.

RAIM — The RAIM code now compiles in overlay form in less than 70K (octal) memory locations. It is now possible to compute macroscopic cross sections, flux distributions, and eigenvalues. The depletion overlay has been coded for a minor time step.

2.2. FARED Control

Control of the FARED program is maintained by the operational directives previously described in reports BAW-3867-4² and BAW-3867-5³. These directives provide program control by specifying the sequence of computations to be performed by the code. Program EXEC, Overlay (0,0), provides the overall program control, but does not directly perform any calculations. This program directs control to one of the three primary overlays, INPUT, REGA Control or RAIM Control, which provide control for the various computational modules. The

control routines for each primary overlay, as well as for the main overlay, are described in the following sections.

2.2.1. Overlay (0,0) — EXEC

The basic program control provided by EXEC is illustrated in Figure 1. The first directive is read and interpreted by this program. The "READ WORD" operation indicates that a complete word is read from a data card, and the "INTERPRET WORD" operation specifies the transfer of control according to the word interpretation. Acceptable directives, which are enclosed by quotation marks, determine subsequent program control. When a directive that cannot be interpreted is encountered by EXEC, execution is terminated and an ERROR is indicated. Whenever a directive cannot be interpreted by a lower-order overlay, control is returned to the next higher-order overlay for interpretation.

2.2.2. Overlay (1,0) — INPUT

INPUT is the control routine for reading input data and setting up the initial storage requirements. This program is called from EXEC after interpreting a CONFIGURATION directive. INPUT then reads and interprets a series of directives which define specific reactor data. Each of these directives initiates a call to a subroutine which reads and interprets the appropriate reactor data. Control is returned to EXEC when a directive that cannot be interpreted by INPUT is encountered. Figure 2 outlines INPUT control and lists the acceptable directives for interpretation by this routine.

2.2.3. Overlay (2,0) — REGA Control

REGA Control, as diagramed in Figure 3, is the control routine for the calculation of broad-group microscopic cross-section sets. This program is called from EXEC upon the interpretation of a REGA directive. Only two directives are interpreted by REGA Control. REGRES and REGMICRO indicate that resonance data and microscopic cross-section edits, respectively, are to be performed. REGA Control then reads fine-group microscopic cross sections from the RETAP library tape and prepares the composition data for each reactor block. Secondary overlays STRIP, UNRES and BGMCS are then called to

calculate the broad-group microscopic cross sections and perform the spectrum calculations. A fourth overlay, EDIT, is called if either the REGRES or REGMICRO edits have been specified. Control is returned to EXEC upon completion of these calculations.

2.2.4. Overlay (3,0) — RAIM Control

RAIM Control is called from EXEC by a RAIM, EDIT, or DEplete directive. In addition, the directive "SEARCH" is interpreted by this routine. Figure 4 illustrates the basic flow of control according to directive interpretation. The directive "RAIM" initiates a call to the secondary overlay RAIM which computes the macroscopic cross sections and performs the flux and eigenvalue calculation. Control is then returned to RAIM Control for interpretation of the next directive.

RAIM Control also reads and interprets the list of edits following an EDIT directive. The EDIT overlay that executes the desired edits is then called. The EDIT directive may be read from either the EXEC or RAIM Control routine.

Interpretation of the SEARCH directive transfers control to the search control portion of RAIM Control. The directive defining the type of search, and subsequent search data, is then read and interpreted. Overlay CRIT, which performs one search iteration, and overlay RAIM are then executed in sequence until the convergence criterion is achieved. The entire search iteration control procedure is diagrammed in Figure 5.

The depletion control portion of RAIM Control is outlined in Figure 6. This control point is reached when a DEplete directive is encountered. Specific data defining the depletion sequencing and the desired edits are then read. The next directive may be "TEST", in which case the particular test directives and associated data are read.

The depletion sequence starts by initializing various depletion parameters. Overlay REDEP, which performs the depletion calculation for one major time step, and overlay RAIM are then called. If a CONTROL directive has been encountered, a criticality search will be performed until the convergence criterion is met. The EDIT overlay is then called to perform the desired edits. Other tests, as indicated

by the appropriate directives, are then performed. The zone-material compositions are then updated for burnup, and depletion continues for another time step. The depletion sequence is terminated if any test fails, or after the final time step.

The foregoing description of the control routines is designed to indicate the logical flow through the FARED code according to directive interpretation. Additional program control occurs within each overlay and subroutine according to various options and conditions.

2.3. Criticality Searches

Four types of criticality searches have been established for the FARED code. These include a zone-material composition search, a transverse buckling search, and two types of dimension searches. The dimension searches differ as to whether the outer reactor dimension is fixed or variable. The general method for criticality searches and a detailed description of each particular search are presented in the following sections. The program CRIT, which performs one iteration of the criticality search, is also outlined.

2.3.1. General Method for Criticality Searches

Consider the search quantity P which may be a matrix, vector or a single variable. The value of P after the n th iteration is P_n , where P_0 is the value of P at the beginning of the criticality search. Also, let K_n be the eigenvalue corresponding to the search quantity P_n . The calculation of K_n can be expressed in functional notation by $K_n = f(P_n)$. The function f represents a series of calculations employing the MACRO, CONS and FLUX subprograms of the RAIM overlay.

Consider, also, the iteration parameter X_n where $X_0 = 0$. The relationship used to determine the value of P_n from the value of the iteration parameter is

$$P_n = (1 + X_n)P_0. \quad (1)$$

Further, let it be assumed that the value of X_1 is known (either as a standard guess or by some simple approximation). Then, the first approximations for P and K are given by the following equations:

$$P_1 = (1 + X_1)P_0 \quad (2)$$

and

$$K_1 = f(P_1). \quad (3)$$

In order to approximate the value of X_2 , consider the following graph:

Assuming linear interpolation (or extrapolation) between the coordinates (X_0, K_0) and (X_1, K_1) , the value of X_2 is approximated by

$$X_2 = X_1 \left[1 - \frac{K_1 - \bar{K}}{K_1 - K_0} \right] \quad (4)$$

where $\bar{K}$ is the desired value of the eigenvalue. The eigenvalue corresponding to X_2 is actually

$$K_2 = f(P_2) \quad (5)$$

where

$$P_2 = (1 + X_2)P_0. \quad (6)$$

The entire iterative procedure for the n th iteration can be expressed by the following set of equations:

$$X_n = X_{n-1} + \frac{(X_{n-1} - X_{n-2})(\bar{K} - K_{n-1})}{(K_{n-1} - K_{n-2})} \quad (7)$$

$$P_n = (1 + X_n)P_0. \quad (8)$$

$$K_n = f(P_n). \quad (9)$$

To eliminate the storage of P_0 , equation 8 can be rewritten as

$$P_n = \frac{1 + X_n}{1 + X_{n-1}} P_{n-1}. \quad (10)$$

The iterative procedure is terminated when

$$\left| \frac{K_n - \bar{K}}{\bar{K}} \right| \leq \epsilon_0 \quad (11)$$

where ϵ_0 is the specified convergence criterion.

All criticality searches employ the foregoing method, where P represents a different set of quantities for each type of search. Also, the series of calculations represented by the function f may be different for each type of criticality search.

2.3.2. Buckling Search

The buckling search iterates on the group-dependent transverse buckling in specified reactor zones. In this case

$$P = (B_{ij}^2) \quad (12)$$

where B_{ij}^2 is the transverse buckling for group j and search zones i .

Therefore, the buckling values in the search zones for the n th iteration are given according to equation 10 as

$$\left(B_{ij}^2\right)_n = \frac{1 + X_n}{1 + X_{n-1}} \left(B_{ij}^2\right)_{n-1} \quad (13)$$

The transverse buckling values in the non-search zones do not change during the iteration procedure. The corrected buckling values are used to calculate new values for the total removal cross section, $\sum T_j^i$, for the zones in which a buckling search is specified. Therefore, the function f must include the recalculation of the $\sum T_j^i$, the corresponding changes in the flux coefficients, and the new group fluxes and system eigenvalue.

2.3.3. Composition Search

The composition search iterates on the concentrations of FUEL nuclides in specified zone materials, with an option to vary DILUENT nuclide concentrations to maintain a constant FUEL-DILUENT volume in each zone material. For this case

$$P = \left(N_{f_j}^i\right) \quad (14)$$

where $N_{f_j}^i$ is the concentration of the j th nuclide labeled FUEL in the i th search zone material. After the n th iteration, the concentrations are given by

$$\left(N_{f_j}^i\right)_n = \frac{1 + X_n}{1 + X_{n-1}} \left(N_{f_j}^i\right)_{n-1} \quad (15)$$

If DILUENT nuclides are present in the i th search zone material, and the parameter R_i has been properly specified, then the DILUENT nuclide concentrations, $N_{d_j}^i$, are computed according to

$$\left(N_{d,j}^i\right)_n = \frac{1 - X_n R_i}{1 - X_{n-1} R_i} \left(N_{d,j}^i\right)_{n-1} \quad (16)$$

for each DILUENT nuclide j in search zone material i . If no R_i values are specified, the DILUENT nuclide concentrations remain unchanged. The concentrations of the nuclides labeled MIX, as well as those not labeled, are not altered during the composition search.

In order to perform a composition search, at least one FUEL or DILUENT nuclide must initially have a non-zero concentration. A composition search may be performed for a zone material containing only DILUENT nuclides provided that a non-zero value of R_i is specified.

The new nuclide concentrations are used to recalculate the zone and group-dependent macroscopic cross sections. Consequently, the function f must include the recalculation of all macroscopic cross sections and flux coefficients for the zones in which search zone materials are present, and compute the new group fluxes and eigenvalue.

The values of R_i are calculated according to

$$R_i = \frac{\sum_j \frac{N_{f,j}^i A_{f,j}}{\rho_{f,j}}}{\sum_j \frac{N_{d,j}^i A_{d,j}}{\rho_{d,j}}} \quad (17)$$

2.3.4. Dimension Search - Variable Outer Dimension

This dimension search varies the widths of specified zones to achieve criticality. The outer dimension of the reactor is variable. In this case

$$P = (\Delta R_i) \quad (18)$$

where ΔR_i is the width of search zone i. Therefore,

$$(\Delta R_i)_n = \frac{1 + X_n}{1 + X_{n-1}} (\Delta R_i)_{n-1} \quad (19)$$

where i specifies a search zone. For zones j in which a search is not specified

$$(\Delta R_j)_n = (\Delta R_j)_{n-1} \quad (20)$$

2.3.5. Dimension Search — Fixed Outer Dimension

This search is similar to the variable dimension search except that the outer boundary of the zones adjacent to the search zones, as well as the outer dimension of the reactor, is kept fixed. Hence, the last reactor zone cannot be a search zone. The widths of the search zones i are given by equation 19. Equation 20 applies to zones j which are not search zones nor immediately to the right of a search zone. However, when zone j is not a search zone but is immediately to the right of one or more adjacent search zones, the following equation applies:

$$(\Delta R_j)_n = \frac{(\Delta R_j)_{n-1}}{1 + X_{n-1}} - \frac{X_n}{1 + X_n} \sum_{i=m}^{j-1} (\Delta R_i)_n \quad (21)$$

where m is the first of the adjacent search zones immediately to the left of zone j.

For both dimension searches, the outer radius, R_i , of each reactor zone is computed according to

$$(R_i)_n = (R_{i-1})_n + (\Delta R_i)_n \quad (22)$$

The mesh spacing within each zone, SR_i , is given by the following equation:

$$\left(SR_i \right)_n = \frac{\left(\Delta R_i \right)_n}{M_i} \quad (23)$$

where M_i is the number of mesh intervals in zone i .

For either dimension search, the function f includes only the recalculation of flux coefficients, group fluxes, and the eigenvalue.

2.3.6. Overlay CRIT

Overlay CRIT performs one complete iteration of the criticality search. Initialization of the search parameters, calculation of X_n , and the convergence check are performed in the search control portion of RAIM Control. CRIT calculates the search quantity P_n for a given X_n , and then updates the value of P with P_n .

2.4. Adjoint and Perturbation Calculations

Adjoint fluxes may be calculated for use in perturbation calculations or for direct output. In either case, the adjoint flux calculations will be initiated by an ADJOINT directive. Following the interpretation of the directive by overlays EXEC or RAIM Control, a program is called which stores the real fluxes on a disc file and inverts the cross sections and group structure. Program RAIM, which calculates the adjoint fluxes, is then called. The adjoint fluxes are then stored on a disc file, and the real fluxes are returned to the program COMMON storage.

The adjoint fluxes may be printed by specifying an ADJOINT Edit. This edit simply prints the contents of the appropriate disc file. The user must assume the responsibility for ensuring that the proper adjoint fluxes have been previously computed. In addition, a perturbation edit may be specified at any time by a PERT Edit directive. This edit also assumes that the appropriate adjoint fluxes have been previously computed.

All perturbation calculations are performed by edits. The basic program to be used for this purpose is the DEL code.⁴ This code determines the fractional change in k_{eff} due to a perturbation in macroscopic cross sections and/or in the transverse buckling. Changes in the macroscopic cross sections may result from perturbations in either microscopic cross sections or zone material nuclide concentrations.

The only modifications needed in the DEL code for incorporation into the FARED code involve the specification of the perturbed quantities. In its present form, the DEL code requires the user to specify the concentration perturbations in terms of the nuclides in a particular zone. For use in the FARED code, this specification must be compatible with the definition of zone materials. Hence, FARED perturbations will be defined in terms of zone materials instead of particular nuclides in a zone.

A further change must be made in the specification of microscopic cross section perturbations. At present, these changes are input by cards to DEL, which allows for only one microscopic cross section library. For the FARED code, the perturbed microscopic cross sections will be specified on a new REGA library tape for the cross-section blocks being perturbed. With the exception of the input specification changes, the DEL program will be used for the perturbation edits in the FARED code.

2.5. Fuel Management

Fuel movement, with respect to the FARED code, will consist entirely of reassigning zone materials to the desired zones. There will be no automated fuel management capability in the basic FARED code. However, any fuel management scheme, which can be described by the movement of individual zone materials from one zone to another, can be achieved by CONFIGURATION directives. Zone materials may be moved from zone to zone or removed from the reactor entirely. In addition, new zone materials may be introduced into the reactor at any time.

Edits will be provided to record the history of each zone material. For a depletion problem, this edit will record the length of time that a zone material resides in each zone and will compute the cumulative burnup of each zone material. Additional edits will compute parameters associated with each zone; i.e., for all zone materials in that zone. These edits will provide the data necessary for analysis of fuel management problems.

Although very complicated fuel management schemes can be accommodated by this method, the user is responsible for correctly

setting up the problem. Zone materials to be introduced into the reactor during depletion must be specified at the beginning of the problem, and data pertaining to those removed from the reactor must be recorded.

Figure 1. EXEC Control Overlay (0,0)

Figure 2. INPUT Control Overlay (1,0)

Figure 3. REGA Control Overlay (2,0)

Figure 4. RAIM Control Overlay (3,0)

Figure 5. Search Control Portion of RAIM Control Overlay (3,0)

Figure 6. Depletion Control Portion of RAIM Control Overlay (3, 0)

3. BURNUP STUDIES

3.1. Summary

The following items were to be obtained at equilibrium fuel cycle conditions (except as noted) according to contract requirements.

1. The total fission product reactivity worth at the beginning and end of cycle, and the contribution to fission product worth resulting from capture.
2. For the two reference cases only: A comparison of the fission product scattering contribution to worth with the worth of the scattering contribution of fissioned heavy atoms, at both beginning and end of cycle.
3. The worth, separately, of ^{238}U , ^{239}Pu , ^{240}Pu , and ^{241}Pu inventory changes between the beginning and end of cycle.
4. The worth of blanket plutonium inventory buildup from cycle beginning to end.
5. A representative sodium void decrement at cycle beginning and end. In addition, the effect of substituting the start-of-cycle fission product inventory and the start-of-cycle blanket plutonium inventory on the end-of-cycle sodium void decrement will be determined.
6. Isothermal Doppler coefficients at cycle beginning and end.
7. In-core and total coefficients at cycle beginning and end.
8. Power peak-to-average values at cycle beginning and end.

All items except 2 and a portion of 7 have been completed. It was not possible to obtain item 2 since the as-stipulated ENDF/B set used for lumped plutonium fission fragments contains no scattering matrix.

As to item 7, both in-core and total worths were obtained in all instances, where applicable, except for the Doppler coefficient. In this case, the in-core Doppler coefficients only were calculated. This procedure was adopted for two reasons. First, owing to the nature of the axial and radial blanket representation in spherical geometry (alternating radial and axial spherical shell regions), difficulties are introduced in attempting to ascertain a meaningful average blanket fuel temperature change for a given core fuel temperature change. Second, past experience with standard B&W LMFBR calculations (oxide-fueled) has indicated that even when larger average blanket fuel temperature changes (relative to a given core fuel temperature change) than would normally be considered are used, the error introduced in the Doppler coefficient by considering only a change in the average core fuel temperature is at most very small (<3%).

All the worth calculations were performed using the one-dimensional perturbation worth compiler of the multigroup, diffusion theory SCRAMBLE code. Doppler coefficients were determined using SCRAMBLE with Doppler-broadened cross-section sets from BWIG.

All the worths presented are indicative of reactivity associated with the addition of the particular isotope(s) or effect (Doppler) relative to an absence of the isotope (void) or effect. Each worth presented is determined based on the zonal concentration of the isotope(s) in question in the region designated; i.e., core and blankets. Thus, the worths presented are for 100% of the isotope(s) in question. They should therefore be used only for comparison since accuracy can only be expected for small perturbations using perturbation theory.

3.2. Final Results

Tables 1 and 2 show the total fission product reactivity worth and the contribution to fission product worth resulting from capture for all cases at BOEC and EOEC, and also the percentage change observed when using the FF and plutonium libraries. As can be seen, for all cases the total fission product worth consists almost entirely of the capture component, since the leakage term is small and the scattering cross sections are missing. The use of the FF library increases the fission product worth from 40 to 50% for both core sizes at both BOEC

and EOEC. The use of the plutonium library decreases the core and core plus blanket fission product worth from 10 to 15% for both core sizes at both BOEC and EOEC. The blanket fission product worth, however, increases for the small core at BOEC and EOEC, but decreases for the large core at BOEC and EOEC.

Tables 3 through 7 show isotopic worths at BOEC and EOEC for ^{238}U , ^{239}Pu , ^{241}Pu , and ^{242}Pu for all cases considered and the percentage change between BOEC and EOEC worths. Also given is the percentage change in worth relative to the reference cross-section set when using the FF or plutonium sets. From these tables one could examine the effect of using the FF or plutonium sets on the worth of isotopic inventory changes for the isotopes in question. Also, the effect of using the altered sets on the BOEC and EOEC worths individually can easily be compared. Since the tables are self-explanatory, no attempt is made to discuss the various comparisons.

Table 8 shows the worth of the total blanket plutonium inventory at BOEC and EOEC for all cases and the difference in BOEC and EOEC values in terms of a percentage change. Also, the percentage change due to using the FF and plutonium sets is given. In general, the changes in blanket plutonium inventory buildup from BOEC to EOEC and also BOEC and EOEC values individually are affected more by the plutonium set than by the FF set.

Table 9 gives sodium worths at BOEC and EOEC and the effect of using the FF and plutonium sets on the sodium worths in terms of a percentage difference. With no specifics being mentioned, it can be seen from the table that the effect of the plutonium set on the sodium worth both at BOEC and EOEC is greater than the corresponding effect of the FF set.

Table 10 reflects the effect of substituting the BOEC fission product inventory and, separately, the BOEC blanket plutonium inventory on the EOEC sodium worth. The percentage change due to each of these substitutions is also given. The BOEC fission product inventory substitution affects the EOEC sodium worth by decreasing the in-core and total worth from 4 to 10% and decreasing the blanket sodium worth from 1 to 3% for all cases. The substitution of blanket plutonium increases

the in-core and total EOEC sodium worth, but only very slightly. The effect on the blanket sodium worth is a decrease from 4 to 12%.

Table 11 gives BOEC and EOEC in-core Doppler coefficients for all cases and the percentage changes relative to the reference cases. As would be expected with the plutonium set, the effect of the substitutions is greater than with the FF set.

A topical report presenting results for the entire task has been written and is ready for processing by the report group.

Table 1. Total Fission Product Reactivity Worth^(a) and the Contribution to Fission Product Worth Resulting From Capture at BOEC

		Capture	Total	% change
SR	Core	-0.00850	-0.00850	--
	Blkt	-0.00022	-0.00022	--
	Total	-0.00872	-0.00872	--
SFF	Core	-0.01194	-0.01195	+41
	Blkt	-0.00033	-0.00033	+50
	Total	-0.01228	-0.01228	+41
SPU	Core	-0.00711	-0.00711	-16
	Blkt	-0.00049	-0.00050	+127
	Total	-0.00760	-0.00760	-13
LR	Core	-0.00931	-0.00931	--
	Blkt	-0.00016	-0.00016	--
	Total	-0.00947	-0.00947	--
LFF	Core	-0.01360	-0.01360	+46
	Blkt	-0.00022	-0.00022	+38
	Total	-0.01383	-0.01383	+46
LPU	Core	-0.00810	-0.00810	-13
	Blkt	-0.00013	-0.00013	-19
	Total	-0.00823	-0.00823	-13

^(a) $\Delta k/k$ relative to a void.

Table 2. Total Fission Product Reactivity Worth^(a) and the Contribution to Fission Product Worth Resulting From Capture at EOEC

		Capture	Total	% change
SR	Core	-0.02414	-0.02415	--
	Blkt	-0.00045	-0.00045	--
	Total	-0.02459	-0.02460	--
SFF	Core	-0.03300	-0.03301	+37
	Blkt	-0.00067	-0.00067	+49
	Total	-0.03368	-0.03369	+37
SPU	Core	0.02060	-0.02060	-15
	Blkt	-0.00070	-0.00071	+58
	Total	-0.02130	-0.02131	-13
LR	Core	-0.02644	-0.02644	--
	Blkt	-0.00028	-0.00029	--
	Total	-0.02672	0.02673	--
LFF	Core	-0.03740	-0.03741	+41
	Blkt	-0.00041	-0.00041	+41
	Total	-0.03781	-0.03782	+41
LPU	Core	-0.02343	-0.02343	-11
	Blkt	-0.00025	-0.00025	-14
	Total	-0.02368	-0.02368	-11

(a) $\Delta k/k$ relative to a void.

Table 3. Worth^(a) of ²³⁸U Inventory Change Between Beginning and End of Equilibrium Cycle

		BOEC	Library % change	EOEC	Library % change	BOEC & EOEC % change
SR	Core	-0.19810	--	-0.18436	--	-6.9
	Blkt	-0.04139	--	-0.04383	--	+5.9
	Total	-0.23948	--	-0.22819	--	-4.7
SFF	Core	-0.19371	-2.2	-0.17766	-3.6	-8.3
	Blkt	-0.04287	+3.6	-0.04455	+1.6	+3.9
	Total	-0.23658	-1.2	-0.22221	-2.6	-6.1
SPU	Core	-0.17851	-9.9	-0.16889	-8.4	-5.4
	Blkt	-0.03971	-4.1	-0.04206	-4.0	+5.9
	Total	-0.21822	-8.9	-0.21095	-7.6	-3.3
LR	Core	-0.24988	--	-0.23696	--	-5.2
	Blkt	-0.02879	--	-0.03125	--	+8.5
	Total	-0.27867	--	-0.26821	--	-3.7
LFF	Core	-0.24553	-1.7	-0.22729	-4.1	-7.4
	Blkt	-0.02860	-0.7	-0.02639	-15.6	-7.7
	Total	-0.27413	-1.6	-0.25368	-5.4	-7.5
LPU	Core	-0.22870	-8.5	-0.21800	-8.0	-4.7
	Blkt	-0.02653	-7.8	-0.02525	-19.2	-4.8
	Total	-0.25523	-8.4	-0.24325	-9.3	-4.7

(a) $\Delta k/k$ relative to a void.

Table 4. Worth^(a) of ²³⁹Pu Inventory Change Between Beginning and End of Equilibrium Cycle

		<u>BOEC</u>	<u>Library % change</u>	<u>EOEC</u>	<u>Library % change</u>	<u>BOEC & EOEC % change</u>
SR	Core	+0.48747	--	+0.48524	--	-0.5
	Blkt	+0.01225	--	+0.02153	--	+75.6
	Total	+0.49972	--	+0.50677	--	+1.4
SFF	Core	+0.48821	+0.2	+0.48971	+0.9	+0.3
	Blkt	+0.01242	+1.4	+0.02180	+1.2	+75.5
	Total	+0.50063	+0.2	+0.51150	+0.9	+2.2
SPU	Core	+0.47072	-3.4	+0.46907	-3.3	-0.4
	Blkt	+0.01078	-1.2	+0.01928	-10.4	+78.8
	Total	+0.48150	-3.6	+0.48835	-3.6	+1.4
LR	Core	+0.49611	--	+0.49636	--	+0.1
	Blkt	+0.00910	--	+0.01315	--	+44.5
	Total	+0.50521	--	+0.50950	--	+8.5
LFF	Core	+0.49717	+0.2	+0.50068	+0.9	+7.1
	Blkt	+0.00897	-1.4	+0.01336	+1.6	+48.9
	Total	+0.50614	+0.2	+0.51404	+0.9	+1.6
LPU	Core	+0.47922	-3.4	+0.47847	-3.6	-0.2
	Blkt	+0.00797	-12.4	+0.01223	-7.0	+53.5
	Total	+0.48719	-3.6	+0.49070	-3.7	+0.7

(a) $\Delta k/k$ relative to a void.

Table 5. Worth^(a) of ²⁴⁰Pu Inventory Change Between Beginning and End of Equilibrium Cycle

		<u>BOEC</u>	<u>Library % change</u>	<u>EOEC</u>	<u>Library % change</u>	<u>BOEC & EOEC % change</u>
SR	Core	+0.01344	--	+0.01606	--	+19.5
	Blkt	+0.00002	--	+0.00004	--	+100
	Total	+0.01346	--	+0.01610	--	+19.6
SFF	Core	+0.01310	-2.5	+0.01633	+1.7	+24.7
	Blkt	+0.00002	--	+0.00005	+25	+150
	Total	+0.01312	-2.5	+0.01637	+1.7	24.8
SPU	Core	+0.01571	+17	+0.01991	+24	+26.7
	Blkt	+0.00003	+50	+0.00007	+75	+133
	Total	+0.01573	+17	+0.01997	+24	+27.0
LR	Core	+0.00999	--	+0.01150	--	+15.1
	Blkt	+0.00001	--	+0.00002	--	+100
	Total	+0.01000	--	+0.01152	--	+15.2
LFF	Core	+0.01033	+3.4	+0.01272	+11	+23.1
	Blkt	+0.00001	--	+0.00002	--	+100
	Total	+0.01034	+3.4	+0.01274	+11	+23.2
LPU	Core	+0.01297	+30	+0.01621	+41	+25.0
	Blkt	+0.00002	+100	+0.00004	+100	+100
	Total	+0.01299	+30	+0.01625	+41	+25.1

(a) $\Delta k/k$ relative to a void.

Table 6. Worth^(a) of ²⁴¹Pu Inventory Change Between
Beginning and End of Equilibrium Cycle

		<u>BOEC</u>	<u>Library % change</u>	<u>EOEC</u>	<u>Library % change</u>	<u>BOEC & EOEC % change</u>
SR	Core	+0.03561	--	+0.03629	--	+1.9
	Blkt	+0.00002	--	+0.00004	--	+100
	Total	+0.03562	--	+0.03633	--	+2.0
SFF	Core	+0.03463	-2.8	+0.03499	-3.6	+1.0
	Blkt	+0.00002	--	+0.00004	--	+100
	Total	+0.03464	-2.8	+0.03503	-3.6	+1.1
SPU	Core	+0.03520	-1.2	+0.03689	+1.7	+4.8
	Blkt	+0.00002	--	+0.00005	+25	+150
	Total	+0.03522	-1.1	+0.03694	+1.7	+4.9
LR	Core	+0.03560	--	+0.03468	--	-2.6
	Blkt	+0.00001	--	+0.00003	--	+200
	Total	+0.03561	--	+0.03471	--	-2.5
LFF	Core	+0.03562	+0.1	+0.03487	+0.5	-2.1
	Blkt	+0.00001	--	+0.00003	--	+200
	Total	+0.03563	+0.1	+0.03490	+0.5	-2.0
LPU	Core	+0.03646	+2.4	+0.03738	+7.8	+2.5
	Blkt	+0.00002	+100	+0.00004	+33	+100
	Total	+0.03648	+2.4	+0.03742	+7.8	+2.6

(a) $\Delta k/k$ relative to a void.

Table 7. Worth^(a) of ²⁴²Pu Inventory Change Between
Beginning and End of Equilibrium Cycle

		<u>BOEC</u>	<u>Library % change</u>	<u>EOEC</u>	<u>Library % change</u>	<u>BOEC & EOEC % change</u>
SR	Core	+0.00056	--	+0.00066	--	+17.9
	Blkt	~0	--	~0	--	--
	Total	+0.00056	--	+0.00066	--	+17.9
SFF	Core	+0.00057	+1.8	+0.00072	+9.1	+26.3
	Blkt	~0	--	~0	--	--
	Total	+0.00057	+1.8	+0.00072	+9.1	+26.3
SPU	Core	+0.00070	+25	+0.00082	+24	+17.1
	Blkt	~0	--	~0	--	--
	Total	+0.00070	+25	+0.00082	+24	+17.1
LR	Core	+0.00038	--	+0.00040	--	5.3
	Blkt	~0	--	~0	--	--
	Total	+0.00038	--	+0.00040	--	5.3
LFF	Core	+0.00040	5.3	+0.00048	+20	+20
	Blkt	~0	--	~0	--	--
	Total	+0.00040	5.3	+0.00048	+20	+20
LPU	Core	+0.00052	+37	+0.00058	+45	+11.5
	Blkt	~0	--	~0	--	--
	Total	+0.00052	+37	+0.00058	+45	+11.5

(a) $\Delta k/k$ relative to a void.

Table 8. Worth^(a) of Blanket Plutonium Inventory
Buildup From Cycle Beginning to End

	<u>BOEC</u>	<u>Library % change</u>	<u>EOEC</u>	<u>Library % change</u>	<u>BOEC & EOEC % change</u>
SR	+0.01229	--	+0.02161	--	+75.8
SFF	+0.01246	+1.4	+0.02189	+1.3	+75.7
SPU	+0.01083	-12	+0.01940	-10	+79.1
LR	+0.00912	--	+0.01320	--	+44.7
LFF	+0.00899	-1.4	+0.01341	+1.6	+49.2
LPU	+0.00801	-12	+0.01231	-6.7	+53.7

(a) $\Delta k/k$ relative to a void.

Table 9. Sodium Worth^(a) at Cycle Beginning and End

		<u>BOEC</u>	<u>Library % change</u>	<u>EOEC</u>	<u>Library % change</u>
SR	Core	-0.02226	--	-0.02424	--
	Blkt	-0.00588	--	-0.00599	--
	Total	-0.02814	--	-0.03022	--
SFF	Core	-0.02243	+0.8	-0.02514	+3.7
	Blkt	-0.00615	+4.6	-0.00623	+4.0
	Total	-0.02858	+1.6	-0.03137	+3.8
SPU	Core	-0.02531	+14	-0.02700	+11
	Blkt	-0.00610	+3.7	-0.00626	+4.5
	Total	-0.03141	+12	-0.03326	+10
LR	Core	-0.02569	--	-0.02886	--
	Blkt	-0.00367	--	-0.00324	--
	Total	-0.02936	--	-0.03210	--
LFF	Core	-0.02621	+20	-0.03027	+4.9
	Blkt	-0.00368	+0.3	-0.00330	+1.9
	Total	-0.02989	+1.8	-0.03357	+4.6
LPU	Core	-0.02955	+15	-0.03231	+12
	Blkt	-0.00363	+1.1	-0.00334	+3.1
	Total	-0.03318	+13	-0.03565	+11

(a) $\Delta k/k$ relative to a void.

Table 10. Effect of Substituting Start-of-Cycle Fission Product Inventory and Start-of-Cycle Blanket Plutonium Inventory on End-of-Cycle Sodium Worth^(a)

		<u>Standard</u>	<u>BOEC FF subst</u>	<u>% change</u>	<u>BOEC blkt Pu subst</u>	<u>% change</u>
SR	Core	-0.02424	-0.02227	-8.1	-0.02452	+1.2
	Blkt	-0.00599	-0.00592	-1.2	-0.00571	-4.7
	Total	-0.03022	-0.02819	-6.7	-0.03023	+0.03
SFF	Core	-0.02514	-0.02256	-10.3	-0.02596	+3.2
	Blkt	-0.00623	-0.00614	-1.4	-0.00546	-12.4
	Total	-0.03138	-0.02870	-8.5	-0.03141	+0.1
SPU	Core	-0.02700	-0.02558	-5.3	-0.02730	+1.1
	Blkt	-0.00626	-0.00621	-0.8	-0.00599	-4.3
	Total	-0.03326	-0.03179	-4.4	-0.03328	+0.1
LR	Core	-0.02886	-0.02667	-7.6	-0.02918	+1.1
	Blkt	-0.00324	-0.00316	-2.4	-0.00300	-7.4
	Total	-0.03210	-0.02983	-7.1	-0.03218	+0.2
LFF	Core	-0.03027	-0.02725	-10	-0.03062	+1.2
	Blkt	-0.00330	-0.00319	-3.3	-0.00306	-7.3
	Total	-0.03357	-0.03044	-9.3	-0.03368	+0.3
LPU	Core	-0.03231	-0.03062	-5.2	-0.03264	+1.0
	Blkt	-0.00334	-0.00327	-2.1	-0.00309	-7.5
	Total	-0.03565	-0.03389	-4.9	-0.03573	+0.2

(a) $\Delta k/k$ relative to a void.

Table 11. In-Core Doppler Coefficient
 $(-T \frac{dk}{dT} \times 10^2)$

	<u>BOEC</u>	<u>% change</u>	<u>EOEC</u>	<u>% change</u>
SR	0.6760	--	0.5739	--
SFF	0.6315	-6.6	0.5091	-11
SPU	0.5197	-23	0.4572	-20
LR	0.9667	--	0.8503	--
LFF	0.9283	-4.0	0.7573	-11
LPU	0.7799	-19	0.6937	-18

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