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Development Report

**Knolls
Atomic Power
Laboratory**

**CUREBO: A Generalized Two-Space-Dimensional
Coding with Cross-Section and
Depletion Calculations for the IBM 704**

J. A. Archibald, Jr.

April, 1959

Operated for the
United States Atomic
Energy Commission by

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UC-34, Physics and Mathematics
(TID-4500, 14th Edition)

CUREBO: A GENERALIZED TWO-SPACE-DIMENSIONAL
CODING WITH CROSS-SECTION AND DEPLETION
CALCULATIONS FOR THE IBM 704

J. A. Archibald, Jr.

April 30, 1959

D. B. MacMillan

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KNOLLS ATOMIC POWER LABORATORY
Schenectady, New York
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ABSTRACT

The CUREBO code for the IBM 704 consists of three major parts:

1. The calculation of nuclear cross sections of the various physical components of a reactor (WOX7).
2. The solution of the multigroup diffusion equations in two-space dimensions in order to find neutron fluxes and sources for an operating reactor containing these components (CURE).
3. The calculation of fuel and poison depletion as a result of operating this reactor under steady-state conditions (BO2).

All three parts are completely described (including input and output) as they exist in the latest (C series) CURE tapes.

CUREBO: A GENERALIZED TWO-SPACE-DIMENSIONAL CODING
WITH CROSS-SECTION AND DEPLETION CALCULATIONS
FOR THE IBM 704

I. INTRODUCTION

The original CURE code was written by the Computer Usage Company in New York City and the National Bureau of Standards in Washington, D. C. according to specifications supplied by the Knolls Atomic Power Laboratory in Schenectady, New York.

During the past two years the code has been extensively modified by members of the KAPL Staff. These changes, which include both revisions and additions, have made it necessary to issue a new, complete report on CUREBO. The original CURE manual (KAPL-1724, "CURE: A Generalized Two-Space-Dimension Multigroup Coding for the IBM-704," E. L. Wachspress, April 30, 1957) should be consulted for theoretical descriptions of the CURE code. (See Chapter II and the appendices of KAPL-1724.) These theoretical discussions will not be repeated here. The descriptions in the other parts of KAPL-1724 are at least partially obsolete and are superceded by the information contained herein.

The modifications performed at KAPL are independent of work done by the Computer Usage Company since June, 1957. The CURE code subsequently developed by them for the Aircraft Nuclear Propulsion Department of the General Electric Company and the CURE code developed at KAPL should be thought of as being two different codes with the same general purpose.

Some of the modifications (designed to decrease program running time) are not sufficiently general to be used in all problems. They limit certain options. This has necessitated the keeping of CURE tapes in quintuplicate. The five current versions of CURE are as follows. All versions require a 32K 704.

CURE 1CT	Does not use drums and contains slow Peaceman-Rachford flux calculation. Has no restrictions. (The maximum number of points is 3294.)
CURE 1C	Uses drums for certain internal data and contains slow Peaceman-Rachford flux calculation. Its only restriction is to 2046 points.

- CURE 2CT Does not use drums and contains fast Peaceman-Rachford flux calculation. Is limited to full rectangular meshes in x-y or r-z geometry with 3236 or fewer points.
- CURE 2C Uses drums for certain internal data and contains fast Peaceman-Rachford flux calculation. Is limited to full rectangular meshes in x-y or r-z geometry with 2046 or fewer points.
- CURE 3CT Does periodic x-y problems only. Handles a maximum of 3249 points.

II. CUREBO INPUT

The complete input to CUREBO is a deck of cards (known as the Problem Deck) consisting of decimal and binary cards. The entire deck is read by the machine during the early part of the program, and the necessary information is stored internally and on tape for later use.

The binary cards are read by MDBCL1 and the decimal cards by UADBC2 and UACSH2. These are both standard SHARE routines and will not be described further.

The input for a sample problem is included as Appendix B.

A. The CUREBO Problem Deck

The CUREBO problem deck consists of the following cards. The cards themselves will be described in the remainder of this section.

1. Clear and load tape card (GKCLT2) with CURE merge calling card or CURE loader.
2. 8000 card, problem identification.
3. Binary input deck for WOX7 and BQ2, if any.
4. Decimal input for WOX7 and BQ2, if any.
5. Decimal input for CURE.
6. TRA 2,4...
7. Precalculated cross sections, if any.
8. TRA 2,4 used if and only if precalculated cross sections exist.

B. The CURE Loader and the Merge Calling Card

The CURE loader consists of six cards. It is used for individual CURE tapes on tape unit 9. The cards are:

1. Clear card, UAZCS2
- 2,3 Binary loader, MDBCL1
- 4,5 Tape 9 loader
- 6 Binary transfer to 23420_8 (10000_{10}).

If a merge of several CURE tapes is used on tape unit 1, the loader is replaced by the following two cards:

1. Clear and load tape card, GKCLT2

2. CUREBO calling card (has the number of the CURE code on the merge, in binary, in the 9 left word, and otherwise is blank).

C. The 8000 Card, Problem Identification

The problem identification is one word of not more than six characters supplied as a standard piece of BCD input:

Columns 3-6	Columns 8-10	Columns 12-18
8000	BCD	1 SICK

D. Binary Input for WOX7 and B02

The binary input exists if and only if it is desired to perform calculations based upon the results of a preceding depletion calculation. The binary deck itself is B02 card output, and hence, is not key-punched. The binary deck is preceded by a decimal "TRA 4" card and ends with a binary transfer card to 36667₈ (15799₁₀). Both transfer cards must be key-punched. The information starts loading at location 41150₈ (17000₁₀). These cards exist only for core materials. A core material is one containing both fuel and burnable poison. (All core materials must contain both fuel and poison.) The items supplied are given below. All values, except the first, are floating point numbers.

1. ℓ The material index
2. $\frac{P_{\ell}}{P}$ The power fraction for all regions containing this material
3. M_t^A The actual mass of the fuel after depletion
4. B_t^A The actual mass of the poison after depletion
5. M_{t-1}^A The actual mass of the fuel before depletion
6. B_{t-1}^A The actual mass of the poison before depletion
7. $\frac{P_{dt}}{P_t}$ The fraction of poison contained in discrete substances after depletion
8. $\frac{P_{dt-1}}{P_{t-1}}$ The fraction of poison contained in discrete substances before depletion
9. V_{cc} The volume occupied by material ℓ , in cubic centimeters.

E. Decimal Input for WOX7 and B02

Items 1 through 5 of the decimal input to WOX7 and B02 exist if and only if WOX7 is to be used for the calculation of cross sections. Items 6 and 7 may exist without items 1 through 5 if and only if the precalculated cross sections supplied for these materials contain all of the information listed under G. Precalculated Cross Sections on page 20.

The decimal input to WOX7 and B02 consists of the following parts:

1. General temperature (in floating point) if any:
8001 DEC general temperature in degrees F
2. Material-dependent WOX7 input
3. WOX7 control card, if any
4. WOX7 special purpose tables, if any
5. Self-shielding parameters
6. B02 control card if depletion is to be calculated
7. Material-dependent depletion input if depletion is to be calculated.

Material-Dependent WOX7 and B02 Input

Material-dependent WOX7 and B02 input is supplied if and only if WOX7 cross sections are desired for the material concerned. The input for each material consists of an even number of words (between 18 and 38). The input starts at 8002₁₀ and must not exceed 1998 words. (The maximum number of materials is 57.)

If S is the location of the material identification (the ℓ value), then the entries for each ℓ are as follows. All entries are floating point unless indicated otherwise.

TABLE 1. Material-Dependent WOX7 and B02 Input

<u>Location</u>	<u>Contents</u>
S	Index for material m , ℓ ; $1 \leq \ell \leq 57$ (fixed point)
$S + 1$	Volume occupied by material m (in cubic centimeters), V
$S + 2$	Initial discrete poison ratio, $P_{do}/P_o = P_{do}$ (material-dependent; the actual mass of burnable poison subject to self-shielding different from the fuel self-shielding divided by the total actual mass of burnable poison at the beginning of life)

Location	Contents
S + 3	Temperature option 0 Use general actual temperature Not 0 Use this value for specific actual temperature
S + 4	Age option (fixed point) 1 Use given values of τ_1 and τ_2 2 Calculate values of τ_1 and τ_2
S + 5	τ_1 if given, otherwise 0
S + 6	$\mathcal{F}$ -factor option (fixed point) 1 Apply $\mathcal{F}$'s to A's 2 Apply $\mathcal{F}$'s to E's 3 Do not use $\mathcal{F}$'s
S + 7	τ_2 if given, otherwise 0
S + 8	Xenon option (fixed point) 1 No xenon 2 Steady-state xenon 3 Peak xenon 4 Transient xenon
S + 9	Reactor operating power in megawatts, P
S + 10	Thin-region option Use 0. Thin-region calculations are not currently available.
S + 11	Boron equivalent of nonburnable poisons in grams, B^M
S + 12	$\mathcal{F}_2$ if it is to be used, 0 otherwise
S + 13	$\mathcal{F}_3$ if it is to be used, 0 otherwise
S + 14*	U^{235} sentinel (fixed point) 1 if core material, omit otherwise
S + 15*	Actual mass of U^{235} (in grams) in material if core material, omit otherwise
S + 16*	B^{10} sentinel (fixed point) 12 if core material, omit otherwise
S + 17*	Actual mass of burnable B^{10} (in grams) in material if core material, omit otherwise
S + 18*	Water sentinel (fixed point) 21 if material contains water, omit otherwise
S + 19*	Volume fraction of water if material contains water, omit otherwise

*The actual numbers starting at S + 14 are meaningless. However, they do indicate relative order. This is due to the possibility of omitting pairs of words.

Location	Contents
S + 20*	Zirconium sentinel (fixed point) 22 if material contains zirconium, omit otherwise
S + 21*	Volume fraction of zirconium if material contains zirconium, omit otherwise
S + 22*	Aluminum sentinel (fixed point) 23 if material contains aluminum, omit otherwise
S + 23*	Volume fraction of aluminum if material contains aluminum, omit otherwise
S + 24*	Iron sentinel (fixed point) 24 if material contains iron, omit otherwise
S + 25*	Volume fraction of iron if material contains iron, omit otherwise
S + 26*	Stainless steel sentinel (fixed point) 25 if material contains stainless steel, omit otherwise
S + 27*	Volume fraction of stainless steel if material contains stainless steel, omit otherwise
S + 28*	Zircaloy sentinel (fixed point) 26 if material contains Zircaloy, omit otherwise
S + 29*	Volume fraction of Zircaloy if material contains Zircaloy, omit otherwise
S + 30*	Void sentinel (fixed point) 27 if sum of other volume fractions is less than unity, omit if sum is unity
S + 31*	$\left(1 - \sum_s V_s\right)$, where $\sum_s V_s$ is the sum of other volume fractions, if $\sum_s V_s$ is not 1; omit if sum is 1
S + 32*	Ethylene sentinel (fixed point) 28 if material contains ethylene
S + 33*	Volume fraction of ethylene if material contains ethylene, omit otherwise
S + 34*	Inconel sentinel (fixed point) 29 if material contains Inconel, omit otherwise
S + 35*	Volume fraction of Inconel if material contains Inconel, omit otherwise

*The actual numbers starting at S + 14 are meaningless. However, they do indicate relative order. This is due to the possibility of omitting pairs of words.

Location	Contents
S + 36*	Ending sentinel (fixed point) 75 New region starts in S + 38* 77 This is last region
S + 37*	Specific moderator density Use this value for moderator density if the general value is not used.

*The actual numbers starting at S + 14 are meaningless. However, they do indicate relative order. This is due to the possibility of omitting pairs of words.

The material-dependent WOX7 input may be condensed as described below. However, the limit of 1998 words applies to the equivalent uncondensed input.

Materials with the same composition and sequential material indices may be lumped together under the lowest of the indices. The lumped input will be split into materials according to option specifications described below.

Input to materials not to be split is normal WOX7 input, and input for lumped materials is normal WOX7 input except for the quantities V, P, mass of fuel, and mass of poison, each of which is the total for the lumped material. The splitting of each lumped material is controlled by a block of input consisting of a 79, then one or more triples of numbers (each triple being two material indices and a floating point number), and then a 79. These blocks follow the moderator density following the 77 which signifies the end of WOX7 decimal input.

If the materials which have been lumped together are all of the same volume, specifications for manufactured data are as follows:

$$79, l_i, l_m, f, 79 \quad ,$$

where l_i is the material index for the lumped material, l_m is the material index for the last material to be manufactured from the lumped material data, and f is the number obtained by dividing the volume for one of the manufactured materials by the volume of the lumped material.

If the lumped materials are not all of the same volume, then specifications for manufactured data are as follows:

$$79, l, l_m, f_1, l_{m+1}, l_k, f_2, \dots 79 \quad ,$$

where ℓ_m is the material index for the last material to be manufactured using f_1 , f_1 is a number found as above, ℓ_{m+1} is 1 greater than ℓ_m and is the material index for the first material to be manufactured using f_2 , ℓ_k is the material index for the last material to be manufactured using f_2 , and f_2 is a number found as above.

If the sum of the fractions into which a lumped material is split does not approximate 1.0, notice to this effect will be printed on-line (the tolerance is ± 0.01). If a calculation is not to be followed by a depletion calculation, it is not important that the sum approximate 1.0.

The code manufactures input to WOX7 for the materials into which the lumped material is to be split. The input for each of the manufactured materials is identical to the lumped input except for the material index and for the quantities V, P, mass of fuel, and mass of poison, each of which is given the value of the product of its lumped value by the appropriate f .

The splitting of the lumped materials is done before the coding associated with the self-shielding calculations is executed. Thus, splitting of lumped materials is done before fuel and poison masses are transcribed from a preceding depletion calculation, whereas criticality search region-splitting is done after this transcription.

Example:

```

77
 $\rho_{H_2O}$       moderator density for final  $\ell_n$ 
79, $\ell_i,\ell_j,f,79$ 
79, $\ell_k,\ell_m,f_1,\ell_{m+1},\ell_p,f_2,79$  .

```

The WOX7 Control Card

The WOX7 control card is used to indicate the generalized xenon option, if any, the reactor operating power to be used with the xenon option, if appropriate, the control on the use of the special purpose tables, and the general moderator density, if any. The card is of the form

14400 DEC Xe, P, T, D ,

and the values supplied are interpreted as follows.

1. The general xenon option, Xe, (fixed point):

- 0 Use material-dependent xenon options and power in all materials.
- 1 Change xenon options in all materials to 1 and power in all materials to 0. Use depleted masses on binary cards as the input actual masses.

- 2 Change xenon options in all core materials to 2 and all values of power to the product of the "new reactor operating power" (see 2 below) and the proper material-dependent power fraction on binary cards. Use depleted masses on binary cards as the actual masses.
 - 3 Change xenon options in all core materials to 3 and all values of power to the product of the "new reactor operating power" and the proper material-dependent power fraction on binary cards. Use undepleted masses on binary cards as the actual masses.
 - 4 Change xenon options in all core materials to 4 and all values of power to the number of xenon atoms in the material ($\times 10^{-18}$). (This number must be supplied as an overlay over the power fractions on the binary cards.) Use depleted masses on binary cards as the actual masses.
2. The new reactor operating power, P: The uses of this floating point number are described under the general xenon option above.
 3. Special purpose table control word, T, (fixed point): There are three special purpose tables available for use with WOX7. (See below.) The sum of the numbers of the tables to be used is the entry for this control word (i.e., 5 indicates that tables 1 and 4 only are to be used, etc).
 4. General moderator density, D, (floating point): If a nonzero value is used here, it becomes the moderator density in all regions. If any of the densities are different, then all must be supplied to the 8002 table, and this entry must be zero.

WOX7 Special Purpose Tables

The three WOX7 special purpose tables are used to facilitate criticality searches. These are table 1 (region-splitting table), table 2 ($\mathcal{F}$ -factor option changing table), and table 4 ($\mathcal{F}$ -factor changing table.) These tables start at 14404₁₀. The input supplied in these tables is acted upon as part of the calculation of effective masses.

Regions formed by table 1 can be modified by tables 2 and 4.

Table 1 — Region-Splitting Table. The region splitting input is of the form

DEC $l_{01}, l_{n1}, l_{02}, l_{n2}, \dots, l_{oi}, l_{ni}, \dots 0$.

This will cause the code to generate for all i in the table WOXY7 decimal input for a new material, l_{ni} , that will be exactly the same as the input supplied for material l_{oi} , and then to change the $\mathcal{F}$ -factor option in material l_{oi} to a 3. The table may consist of just the terminal zero, which indicates that no regions are to be split.

Table 2 — $\mathcal{F}$ -Factor Option-Changing Table. The input for table 2 is of the form,

$$\text{DEC } l_1, f_1, l_2, f_2, \dots, l_i, f_i, \dots, 58, l_{n1}, l_{m1}, \\ f_{n1}, l_{n2}, l_{m2}, f_{n2}, \dots, l_{nj}, l_{mj}, f_{nj}, \dots, 0 .$$

This table may consist of just the terminal zero, just the material up to the 58 and the terminal zero, or just the material starting with the 58.

The input before the 58 will cause the code to change the $\mathcal{F}$ -factor option in material l_i to f_i for all i in the table.

The input after the 58 will cause the code to change the $\mathcal{F}$ -factor option in all materials l such that $l_{nj} \leq l \leq l_{mj}$.

The new $\mathcal{F}$ -factor option is f_{nj} . The changes are made for all l in the 8002 table such that $l_{nj} \leq l \leq l_{mj}$ for some j .

Table 4 — $\mathcal{F}$ -Factor-Changing Table. The input for table 4 is of the form,

$$\text{DEC } l_{n1}, l_{m1}, F_{21}, F_{31}, l_{n2}, l_{m2}, F_{22}, F_{32}, \\ \dots, l_{nj}, l_{mj}, F_{2j}, F_{3j}, \dots, 0 .$$

This input will cause the code to change the values of the $\mathcal{F}$ -factors to F_{2j} and F_{3j} in all materials l such that $l_{nj} \leq l \leq l_{mj}$. The changes are made for all l in the 8002 table such that $l_{nj} \leq l \leq l_{mj}$ for some j .

Self-Shielding Parameters

Before the cross sections can be calculated by WOXY7, the actual masses of fuel and poison supplied as input must be converted to effective masses. In order to do this, self-shielding parameters must be supplied for each material in the core. This is done in the 18000₁₀ table. Each entry consists of twelve words:

$$\text{DEC } l_n, l_m, K_{u2}, K_{u3}, \gamma_{u2}, \gamma_{u3}, K_{p2}, K_{p3}, \gamma_{pd2}, \gamma_{pd3}, \gamma_{ph2}, \gamma_{ph3} .$$

The code will calculate self-shielding factors from the ten parameters

following l_m for all l such that $l_n \leq l \leq l_m$. The numerical subscripts indicate group numbers, and the letters are u for fuel, pd for discrete poison, and ph for homogeneous poison. Zeros must be supplied for non-existent parameters. The table ends with a zero.

The calculation of effective masses is described in Chapter III on WOX7.

These self-shielding parameters are also used in the depletion calculation.

If no parameters are supplied for a particular core material, then the following assumptions will be made: (1) the masses supplied are effective masses and (2) the poison in the material is all homogeneous.

B02 Control Card

The B02 control card, when used, is of the following form:

19000 DEC $v_{crit}, \Delta v_{crit}, \Delta F$.

If depletion is desired, then the code will calculate new fuel and poison concentrations based upon a total fuel depletion of ΔF if and only if the value of v calculated by CURE is such that

$$v_{crit} - \Delta v_{crit} \leq v \leq v_{crit} + \Delta v_{crit}.$$

If depletion is not desired, this card may be omitted.

The B02 control card should not be confused with the 1032 card of the general mesh input. It is the 1032 card that determines whether or not depletion is to be attempted.

Material-Dependent Depletion Input

The material-dependent depletion input is located in a table starting at 19003₁₀. The entries may consist of three or nine values each. The table ends with a zero.

If the fuel in a region is U^{235} and the poison is a $1/v$ absorber, the input is three words:

$$l_n, l_m, A.$$

This is interpreted as follows: For all l such that $l_n \leq l \leq l_m$, the value of $A = \sigma_u^3 / \sigma_p^3$ is the word following l_m .

If the fuel is not U^{235} or if the poison is not a $1/v$ absorber, the input is nine words:

$$l_n, l_m, A, g_{ua}, g_{ub}, g_{uc}, g_{pa}, g_{pb}, g_{pc}.$$

The interpretation is as follows: For all l such that $l_n \leq l \leq l_m$, the values of Q and the various g 's are the seven words following l_m . Zeros must be supplied for missing numbers.

The use of these parameters will be shown in the chapter on EO2.

F. Decimal Input for CURE

The various parts of the CURE decimal input are as follows:

1. 1000_{10} table, general mesh input.
2. 22000_{10} table or 2000_{10} table, geometry input.
3. 25000_{10} table or 3000_{10} table, increment input.

Note that the geometry and increment tables must be located at 22000 and 25000 or at 2000 and 3000. Combinations are not permitted.

The increment input is followed by a TRA 2,4 card.

General Mesh Input

The general mesh input consists of certain individual entries to the general mesh table that must be supplied by the requester. The minimum input consists of words 1007 and 1010. The option of supplying certain other words does exist. The complete table of general mesh data follows.

TABLE 2. CURE General Mesh Table (1000 Table)

<u>Location</u>	<u>Symbol</u>	<u>Description</u>	<u>How Supplied</u>
1000	I	Maximum value of i in mesh	By program
1001	J	Maximum value of j in mesh	By program
1002	D	Total number of points in collapsed mesh	By program
1003	$4(D'/N)$	Maximum number of words in each record of K mesh	By program
1004	$5(D'/N)$	Maximum number of words in each record of coefficient mesh	By program
1005	P	Periodic index	By program
1006	N	Number of records in K and coefficient meshes	By program
1007	G	Total number of lethargy groups	Decimal input
1008	ID	Problem identification	By program
1009	-	(Vacant)	
1010	δ_1	Type of geometry	BCD input
1011	δ_2	Type of geometry	By program

Location	Symbol	Description	How Supplied
1012	SFG	Source flux guess option	Optional decimal input
1013	)S(	Location of first word of S mesh	By program
1014	α	$t_{\max}$ multiplier	Optional decimal input
1015	t_1	Initial $t_{\max}$ } $t_p = \alpha^{p-1} t_1$	Optional decimal input
1016	B^2	Perpendicular buckling	Optional decimal input
1017	-	(Vacant)	-
1018	a_s	Source acceleration parameter	Optional decimal input
1019	(G^1-1)	Number of groups for which $\sum_l F_l^g = 0$	By program
1020	ϵ	Source convergence error criterion	Optional decimal input
1021	Σ	Cross-section option	Optional decimal input
1022	L^1	Largest l such that $\sum_g F_l^g \neq 0$	By program
1023	PF	Fraction of steady-state power for WOX7 (also temporary storage in SSRM).	By program
1024	$D_{\max}$	Maximum number of points in problem	By program
1025	SSRM	SSRM option	Optional decimal input
1026	b	Peaceman-Rachford parameter	Optional decimal input
1027	-	(Vacant)	-
1028	w_1	Peaceman-Rachford parameter	Optional decimal input
1029	x	Peaceman-Rachford parameter	Optional decimal input
1030	$1/\epsilon$	Peaceman-Rachford error criterion	Optional decimal input
1031	-	Temporary storage, SSRM	-

<u>Location</u>	<u>Symbol</u>	<u>Description</u>	<u>How Supplied</u>
1032	BO	Burnout option	Optional decimal input
1033	EO	Coefficient edit option	Optional decimal input
1034	C	"Semicell" option	By program
1035	-	(Vacant)	-
1036	-	(Vacant)	-
1037	-	Temporary storage, SSRM	-
1038	-	Temporary storage, SSRM	-
1039	AID	Supplementary identification	Optional BCD input
1040	ν_c	Number of neutrons per fission, reactivity	By program
1041	V_c	Core volume	By program
1042	-	Source extrapolation block index	By program
1043	T_{p-2}	Chebyshev factor for power iteration $p - 2$	By program
1044	T_{p-1}	Chebyshev factor for power iteration $p - 1$	By program
1045	E_{p-1}	Last error	By program
1046	t	Flux iteration index	By program
1047	g	Group index	By program
1048	p	Power iteration index	By program
1049	-	(Vacant)	-

REMARKS

(The below assumes that a clear card precedes the loading deck.)

- 1000 through 1006 are supplied from information in the 2000 or 22000 table. D' is the smallest integer such that $D' \geq D$ and D'/N is an integer.
- 1007 MUST be supplied as follows: 1007 DEC G , where G is a fixed point constant. Note that $1 \leq |G| \leq 5$ and that -3 indicates that a 3-group adjoint problem is to be done.
- The contents of 1008 are made identical to the contents of 8000 (WOX7 problem identification).

4. The type of geometry is supplied as follows:

	1010 BCD IRZ	r-z geometry
or		
	1010 BCD LXY	x-y geometry
or		
	1010 BCD 1RTHETA	r- θ geometry (permitted in CUREL only)

If no entry is supplied, the geometry will be assumed to be x-y.

5. 1010 and 1011 are assigned values, according to the type of geometry, as follows:

	<u>r-z</u>	<u>x-y</u>	<u>r-θ</u>
1010	1	0	1
1011	1	0	0

6. Input to 1012 is one of the following:

	1012 DEC 0	No guess available
or		
	1012 DEC 1	Tape guess, continuing old problem; commence extrapolation on first iteration.
or		
	1012 DEC 2	Tape guess, starting new problem; commence extrapolation on second iteration.

If no entry is supplied, it will be assumed that no guess is available. Conversely, if no guess is available, the card should be omitted.

7. The value 3120 is supplied to 1013.

8. The maximum number of flux iterations per group is dependent upon p,

$$t_p = \alpha^{p-1} t_1 ,$$

where α (1014) and t_1 (1015) are to be floating point numbers supplied as follows:

1014 DEC α, t_1

If either or both are supplied as 0 or not supplied at all, the following values will be used:

α	= 1.0	in all cases
t_1	= 1.0	in r-z geometry
t_1	= 8.0	in r- θ geometry
t_1	= 20.0	in x-y geometry .

9. 1016, 1020, and 1023 should be supplied as floating point numbers if and only if nonzero values are needed.
10. 1018 should be supplied as a floating point number. If the card is omitted, the value 2.5 is assumed.
11. 1019 and 1022 are supplied from the cross sections by the WOX7 code.
12. 1021 need only be input when the cross sections are partly precalculated and partly to be calculated by WOX7. This condition is indicated as follows:

1021 DEC 2 .

13. The value 3294 is supplied to 1024.
14. Values supplied for Peaceman-Rachford iteration parameters are as follows:

	CURE1			CURE2	CURE3	Symbol
	x-y	r-z	r- θ			
1026	1.0	2.0	0.05	Calculated	2.0	b
1028	0.00001	0.0021	0.006	by program	0.00002	w ₁
1029	0.1	0.1	0.1	Same as	0.1	x
1030	100.0	10.0	10.0	CURE1	100.0	1/t

If other values are desired, they should be supplied as floating point input.

15. 1025 (SSRM option), 1032 (burnout option), and 1033 (coefficient edit option) should be supplied as follows:

DEC 1 do the option or DEC 0 omit the option.

If no entry is supplied, the option will be omitted. Conversely, if the option is not desired, the card should be omitted.

16. 1034 is supplied by the program. A semicell problem has a mesh on which both the left and right boundaries have a zero current condition. This occurs in CURE2 only.
17. 1039 is a word of BCD input:

1039 BCD 11D .

This prints after the iteration number on iteration summaries. If the entry is omitted, a word of blanks is inserted.

18. 1040 through 1048 are supplied by the machine and are self-explanatory.

Geometry Input

The geometry input to CURE may begin at either 2000₁₀ or 22000₁₀. The limits in these cases are 1000 and 2000 words, respectively. The input consists of two mandatory tables and up to four optional tables. Each table is identified by the sentinel which precedes and follows it:

1. 990 table. Boundary and boundary condition specification (mandatory) (see below).
2. 991 table. Horizontal point deletions (optional).
3. 992 table. Vertical point deletions (optional).
4. 993 table. Material specifications (mandatory) (see below).
5. 994 table. Special configurations (optional).
6. 995 table. Special configuration identification (optional).

When optional tables are not used, they are completely omitted. A 999 sentinel is the last word of the geometry input.

It is suggested that none of the optional geometry input be used. The 991 and 992 tables involve point deletion. The rules for this are quite complicated, and the results obtained are of questionable value. The rules and input are completely described in KAPL-1724. Note that the zeros immediately preceding and following the 991 and 992 sentinels are not necessary.

The 994 and 995 tables involve the specifications of materials by contours rather than by geometric coordinates. They can be just as conveniently specified by coordinates in the 993 table. The 994 and 995 tables were designed specifically for "thin regions" but are not restricted to them. If either of these tables is used, the other must also be used. The clearest known description of their contents is in APEX-452.* Note that the zeros immediately preceding and following the 994 and 995 sentinels are not necessary.

The 990 Table. Boundary and Boundary Condition Specification

Entries within the 990 table describe the boundary and the conditions placed upon the boundary. Each entry consists of three words: i, j, z.

The origin is defined as the point with coordinates (1,1). Consider a path traced around the boundary in a clockwise direction (inside to the right). The first triplet is the i and j values of the initial point and the boundary condition (z) along the segment leading to the initial point. The initial point is the point with smallest i on the row j = 1. (For a full rectangular mesh, as required by CURE2, the initial point is the origin.)

*APEX-452, "CURE: A Two-Space-Dimension, Multi-group Code for the IBM-704," F. M. Trantham, Jr., August 12, 1958.

The next triplet pertains to the first point on the path where the boundary condition changes or the first corner point, whichever comes first. The entries are the i and j coordinates of this point and the boundary condition (z) leading to this point. The successive triplets pertain to the successive boundary condition change points or corner points in the order in which they occur. The last triplet is identical to the first triplet.

The boundary conditions (z values) are interpreted as follows:

62	Flux zero
58	Current zero or x-y periodic
60	Periodic boundary ($r-\theta$)
1-57	Gradient condition with respect to material z .

The 993 Table. Material Specifications

The mesh is divided up physically into several regions, and each of these regions contains a material. The specification of regions and materials is done in the 993 table. Any material may occur in several different regions.

The materials in the region bounded by row $j = 1$ are supplied first. On row 1 we specify the i boundaries (left and right) of the regions and the materials found therein. Beyond the first row, only rows with horizontal region boundaries are mentioned (i.e., tops or bottoms). First the row concerned is listed, and then the new left and right boundaries and materials are mentioned. Each row is identified only once. When there is no change from the previous row, no input is used. Upper region boundaries that coincide with outer boundaries of the mesh are not mentioned. Specifications for different rows are separated by single zeros, and the rows themselves must be listed in order. In any specification the column numbers (i 's) must be given in order.

The input is of the form:

$$j_1, i_{1n1}, i_{1m1}, l_{11}, i_{1n2}, i_{1m2}, l_{12}, \dots, i_{1nq}, i_{1mq}, l_{1q}, 0$$

$$j_2, i_{2n1}, i_{2m1}, l_{21}, \dots$$

The interpretation is: The region bounded by columns $i = i_{1n1}$ and i_{1m1} lying above row j_1 contains material l_{11} ; the next specification of these i values will indicate the top of the region, etc. Note that row $j = 1$ must be specified completely.

Increment Input

The increment input starts at 3000_{10} when the geometry starts at 2000_{10} and at 25000_{10} when the geometry starts at 22000_{10} . The maximum number of words in either case is 800.

The increment input is contained in the 996 and 997 tables. These are identical in form. The 996 table is used for horizontal increments and the 997 table for vertical increments.

The entries are in triplets of the form: c_1, c_2, d_1 , which is interpreted as follows. The increment between any two successive columns (or rows) is d_1 for all i (or j) such that $c_1 \leq i \leq c_2$ (or $c_1 \leq j \leq c_2$). The c 's are fixed point numbers and the d 's are floating point.

G. Precalculated Cross Sections

The WOX7 cross-section code calculates cross sections for three groups based upon the prescription of R. W. Deutsch and described in the article "Computing 3-Group Constants for Neutron Diffusion," Nucleonics 15 (January 1957). It computes both flux and adjoint cross sections.

If any other method of computing cross sections is desired or if the problem is other than a 3-group problem, the cross sections must be supplied as input. In any particular problem all the cross sections may be supplied by WOX7, all supplied as input, or some each way. (In the mixed case a 1021 DEC 2 card must be supplied with the general mesh input.)

For all materials, l , in problems that do not involve depletion and for noncore materials (i.e., materials without fuel and burnable poison) in problems that involve depletion, the following input cards must be supplied for all groups, g , in the problem:

2600+875($g+1$)+15($l+1$) DEC $D_l^g, E_l^{g-1}, A_l^g, F_l^g, 0, Z_l^g$,

where D_l^g is the diffusion coefficient for material l in group g

E_l^{g-1} is the slowing-down cross section for material l out of group $g-1$

A_l^g is the total removal cross section for material l in group g

F_l^g is the fission cross section for material l in group g , and

Z_l^g is the boundary constant for material l in group g

$$Z_l^g = \sqrt{A_l^g D_l^g}.$$

Whenever it is desired to deplete a region possessing precalculated cross sections, the precalculated cross sections must include all depletion input.

The data required are dependent upon the poisons in the material. The quantity P_{dt}/P_t is the ratio of the mass of poison in discrete substances of the material to the total mass of poison in each material. This number defines the poison option, as follows. (t indicates time step. Note that the option is determined for all t by the value of P_{do}/P_o .)

- 1 $\frac{P_{dt}}{P_t} = 1$ All poison is in discrete substances (i.e., discrete from fuel). This means that all of the burnable poison is subject to a self-shielding factor that is different from the self-shielding factor to which the fuel is subject.
- 2 $\frac{P_{dt}}{P_t} = 0$ All poison is in homogeneous substances (with the fuel). This means that all of the burnable poison is subject to the same self-shielding factor as the fuel.
- 3 $0 < \frac{P_{dt}}{P_t} < 1$ Some poison is discrete, some is homogeneous. This means that some of the burnable poison ($1 - P_{dt}/P_t = P_{ht}/P_t$ of it) is subject to the fuel self-shielding, and the rest of it (P_{dt}/P_t of it) is subject to a different self-shielding.

Data Required — Discrete Poison

The data required in case 1 above for region l are supplied as follows. (All data are floating point.)

2600+15(l-1) DEC $D^1, O, A^1, F^1, Te, Z^1, Q, M_O^A, B_O^A, U_t, P_t, O, X^1, 1., 1.$

3475+15(l-1) DEC $D^2, E^1, A^2, F^2, g_{ua}, Z^2, \gamma_u^2, \gamma_{pd}^2, K_u^2, K_p^2, g_{ub}, g_{uc}, X^2, 1., M_t^A$

4350+15(l-1) DEC $D^3, E^2, A^3, F^3, g_{pa}, Z^3, \gamma_u^3, \gamma_{pd}^3, K_u^3, K_p^3, g_{pb}, g_{pc}, X^3, 1., B_t^A$

Data Required — Homogeneous Poison

The data required in case 2 above for region l are supplied as follows. (All data are floating point.)

2600+15(l-1) DEC $D^1, O, A^1, F^1, Te, Z^1, Q, M_O^A, B_O^A, U_t, P_t, O, X^1, 1., 0.$

3475+15(ℓ -1) DEC $D^2, E^1, A^2, F^2, g_{ua}, Z^2, \gamma_u^2, \gamma_{ph}^2, K_u^2, 0, g_{ub}, g_{uc}, X^2, 1., M_t^A$.

4350+15(ℓ -1) DEC $D^3, E^2, A^3, F^3, g_{pa}, Z^3, \gamma_u^3, \gamma_{ph}^3, K_u^3, 1., g_{pb}, g_{pc}, X^3, 1., B_t^A$.

Data Required — Combination Poison

The data required in case 3 above for region ℓ are supplied as follows.
(All data are floating point.)

2600+15(ℓ -1) DEC $D^1, 0, A^1, F^1, Te, Z^1, Q, M_o^A, B_o^A, U_t, P_t, 0, X^1, 1., P_{dt}/P_t$.

3475+15(ℓ -1) DEC $D^2, E^1, A^2, F^2, g_{ua}, Z^2, \gamma_u^3, \gamma_{pd}^3, K_u^3, K_p^3, g_{ub}, g_{uc}, X^2, 1., M_t^A$.

4350+15(ℓ -1) DEC $D^3, E^2, A^3, F^3, g_{pa}, Z^3, P_{do}/P_o, \gamma_{ph}^3, 0, P_{ho}/P_o, g_{pb}, g_{pc}, X^3, 1., B_t^A$.

Remarks

Values of X^g (the appropriate fission spectrum) are supplied only when they differ from the standard values. The standard values are:

$$(\text{flux problems}) \quad X^1 = 1., X^2 = X^3 = 0$$

$$(\text{adjoint problems}) \quad X^1 = 1., X^2 = F^2/F^3, X^3 = F^1/F^3.$$

Zeros may be used in place of standard values.

Values of Z are necessary only for those values of ℓ which appear in the 990 table as boundary conditions. Zeros may be used for nonboundary materials.

Entries in the 8002₁₀, 14404₁₀, 18000₁₀, 19003₁₀, and 41150₈ tables will be ignored for regions with precalculated cross sections.

The quantities $Q, g_{ua}, g_{ub}, g_{uc}, g_{pa}, g_{pd}$, and g_{pc} are depletion input and are described in Chapter V on B023.

The quantities $M_o^A, B_o^A, U_t, P_t, P_{dt}/P_t, P_{ht}/P_t, P_{do}/P_o, K_u^g, K_p^g, \gamma_{pd}^g, \gamma_{ph}^g, \gamma_u^g, M_t^A$, and B_t^A are described in Chapter III on W0X7.

III. CROSS-SECTION CALCULATIONS — WOX7

WOX7 calculates neutron cross sections based upon the prescription of R. W. Deutsch, as described in "Computing 3-Group Constants for Neutron Diffusion," *Nucleonics* 15 (January 1957). Cross sections may be calculated for use in either a flux problem or an adjoint problem. It is assumed that the fuel is U^{235} and the burnable poison B^{10} .

The various parts of the WOX7 calculation are as follows:

1. Expansion of lumped material-dependent input (i.e., expansion of "79" tables).
2. Calculation of effective masses of fuel and poison from actual masses and self-shielding parameters in core materials (i.e., materials containing fuel and burnable poison). (See section A, below.)
3. Execution of instructions provided in WOX7 special purpose tables (i.e., region splitting, β -factor option changing, and β -factor changing).
4. Actual cross-section calculations (see sections B through F):
 - a. Precalculations
 - b. Calculation of cross sections in the thermal group (group 3).
 - c. Calculation of cross sections in the epithermal group (group 2).
 - d. Calculation of cross sections in the fast group (group 1).
 - e. Optional calculations.
5. Edit of WOX7 input.

Items 1 and 3 above are interpretations of input supplied as described in the chapter on input. The output provided by items 4 and 5 is self-explanatory. Coding details are beyond the scope of this report. The equations used in items 2 and 4 are listed in the following sections.

A. Calculation of Effective Masses

Effective masses of fuel and poison in core materials must be calculated from actual masses before any cross-section calculations are performed. This calculation involves the self-shielding of the actual masses

and is group-dependent. There are five steps: (1) calculation of thermal self-shielding factors from thermal self-shielding parameters supplied as input, (2) calculation of thermal effective masses, (3) calculation of epithermal self-shielding factors from epithermal self-shielding parameters supplied as input, (4) calculation of epithermal unself-shielding factors from thermal and epithermal self-shielding factors, and (5) unself-shielding the contribution to epithermal cross sections that involve thermal effective masses.

The reason for this procedure is that thermal cross sections (based upon thermal masses) are calculated first, and epithermal cross sections are calculated directly from thermal cross sections rather than from epithermal masses. The first four steps are performed prior to the actual cross-section calculation, and the fifth step as part of the WOX7 routine.

The remainder of this chapter and the WOX glossary, found at the end of this chapter, should be consulted for undefined symbols.

1. The thermal self-shielding factors are as follows:

$$f_{us} = \frac{K_{u3}}{1 + \gamma_{u3}U_t + \gamma_{ph3}P_{ht}} = f_{ph3}$$

$$f_{pds} = \frac{K_{p3}}{1 + \gamma_{pd3}P_{dt}}$$

2. Thermal effective masses are calculated as follows:

$$M_{t3}^E = M_{ot}^A f_{us}$$

$$B_{t3}^E = B_{odt}^A f_{pds} + B_{oh3}^A f_{ph3} + M_{ot}^A f(1-U_t) f_{ph3} + B^M$$

3. Epithermal self-shielding factors are calculated as follows:

$$f_{u2} = \frac{K_{u2}}{1 + \gamma_{u2}U_t + \gamma_{ph2}P_{ht}} = f_{ph2}$$

$$f_{pd2} = \frac{K_{p2}}{1 + \gamma_{pd2}P_{dt}}$$

4. Epithermal unself-shielding factors are calculated as follows:

$$K_f = K_{ph} = \frac{f_{u2}}{f_{u3}} - 1$$

$$K_{pd} = \frac{f_{pd2}}{f_{pd3}} - 1$$

5. Epithermal fission and absorption cross sections are unself-shielded as follows (primes indicate values before epithermal unself-shielding):

$$F^2 = F'^2(1 + K_f)$$

$$A^2 = A'^2 + K_a \left[K_f (\sigma_{af}^3 + 0.93\sigma_{apr}^3 + 0.93\sigma_{aph}^3) + 0.93K_{pd}\sigma_{apd}^3 \right]$$

Note that no unself-shielding is performed if the poison is partially discrete and partially homogeneous. The function $f(1-U_t)$, appearing in the effective poison mass calculation, is determined from the following table (linear interpolation is used for intermediate values). This function represents the B^{10} equivalent of fission-product concentration corresponding to the fuel concentration.

TABLE 3. Values of $f(1-U_t)$

$(1 - U_t)$	$f(1-U_t)$
0.0	0
0.01	$6.56 (10^{-5})$
0.025	$9.70 (10^{-5})$
0.05	$1.206 (10^{-4})$
0.125	$1.534 (10^{-4})$
0.26	$1.967 (10^{-4})$
0.47	$2.544 (10^{-4})$
0.68	$3.016 (10^{-4})$
0.76	$3.147 (10^{-4})$
0.835	$3.189 (10^{-4})$
1.0	$3.168 (10^{-4})$

B. WOX7 Precalculations

The following calculations are performed for each material before the cross-section routine is initiated.

Effective Neutron Temperature

The effective neutron temperature (in degrees F), which is a function of the "spectrum hardening effect," is calculated as follows (the result

in degrees F, is provided as output):

$$T_e = \left[1 + \frac{0.75 \Sigma_a^3(T)}{\xi \Sigma_s} \right]^2 (T + 460^\circ) - 460^\circ ,$$

where the thermal absorption cross section is

$$\Sigma_a^3(T) = \frac{M_{t3}^E \sigma_{aU_{235}}^3 + B_{t3}^E \sigma_{aB_{10}}^3(T)}{V} + \rho V_{H_2O} \sigma_{aH_2O}^3(T) + \sum_m \sigma_{am}^3(T) V_m + \gamma \frac{P}{V} ,$$

and

$$\xi \Sigma_s = \rho \xi \sigma_{sH_2O} V_{H_2O} + \sum_m \xi \sigma_{sm} V_m$$

and where

$$\sigma_{aU_{235}} = \frac{2.7769(10^{23}) \text{ barns}}{(10^{24}) \sqrt{T} \text{ (ev)}}$$

P	is the reactor operating power
ρ	is the moderator density
γ	will be described in the discussion of xenon option
V	when not subscripted, is volume (in cubic centimeters) occupied by the material; when subscripted, V is the fraction (a pure number) of the material volume which is occupied by the substance specified by the subscript
T(ev)	is actual temperature in electron volts
$\xi \sigma_{sH_2O}$	are microscopic slowing-down and absorption cross sections found in Table 4; "m" indicates structural substances other than water.
$\xi \sigma_{sm}$	
$\sigma_{aB_{10}}^3(T)$	
$\sigma_{aH_2O}^3(T)$	
$\sigma_{am}^3(T)$	

Thermal Cutoff

The cutoff lethargy (between thermal and epithermal groups) is calculated as follows:

$$K_a = \frac{1}{0.93(U_c - 4)}$$

$$K_f = 0.877K_a ,$$

where $U_c = 24.68 - \ln (Te + 460)$ (i.e., in degrees R).

Age Factors

Age factors may be either supplied as input or calculated through groups 1 and 2, respectively, as follows:

$$\tau_1 = \frac{24}{\left(\rho_{H_2O} V_{H_2O} + \sum_m e_m V_m \right) \left(\rho_{H_2O} V_{H_2O} + \sum_m f_m V_m \right)}$$

$$\tau_2 = \frac{0.44U_c}{\left(\rho_{H_2O} V_{H_2O} + \sum_m g_m V_m \right) \left(\rho_{H_2O} V_{H_2O} + \sum_m h_m V_m \right)} ,$$

where e_m , f_m , g_m , and h_m are age equivalence factors found in Table 4.

Fission Spectra

The fission spectrum in each group, χ^g , is supplied as follows:

$$\chi^1 = 1.0$$

$$\chi^2 = \chi^3 = 0 .$$

C. Cross Sections, Thermal Group

The following equations are solved in order to calculate cross sections in the thermal group:

$$\Sigma_{aU_{235}}^3 = \frac{M_{t3}^E \left\{ 2.5617(10^{21}) \left[(108.6) - (410.4)\sqrt{Te} + (2926)\sqrt{Te^3} \right] \right\}}{V(10^{24})} ,$$

where T_e is effective temperature in ev,

$$\Sigma_{a_{B_{10}}}^3 = \frac{0.93 B_{t3}^E \sigma_{a_{B_{10}}}^3(T)}{V}$$

$$\Sigma_{a_s}^3 = 0.93 \left[\rho V_{H_2O} \sigma_{a_{H_2O}}^3(T) + \sum_m V_m \sigma_{a_m}^3(T) \right]$$

$$A^3 = \Sigma_{a_{U_{235}}}^3 + \Sigma_{a_{B_{10}}}^3 + \Sigma_{a_s}^3 + \Sigma_{a_{Xe}}^3 + D^3 B^2$$

$$F^3 = \frac{\Sigma_{a_{U_{235}}}^3}{1.184}$$

$$\Sigma_{tr}^3 = \Sigma_{a_{U_{235}}}^3 + \Sigma_{a_{B_{10}}}^3 + \Sigma_{a_s}^3 + \gamma \frac{P}{V} + \sum_m (V_m \sigma_{tr_m}^3) + \frac{\rho \sigma_{tr}^3 V_{H_2O}}{\sqrt{T_e}},$$

where T_e is in degrees R and σ_{tr}^3 is found in Table 4,

$$D^3 = \frac{1}{3 \Sigma_{tr}^3}$$

$$E^3 = \sqrt{D^3 A^3}$$

The terms $\Sigma_{a_{Xe}}^3$ and $D^3 B^2$ in the expression for A^3 are described in section F on options.

D. Cross Sections, Epithermal Group

The following equations are solved in order to calculate cross sections in the epithermal group:

$$\Sigma_{tr}^2 = \rho V_{H_2O} \sigma_{tr_{H_2O}}^2 + \sum_m (V_m \sigma_{tr_m}^2)$$

$$D^2 = \frac{1}{3 \Sigma_{tr}^2}$$

$$E^2 = \frac{D^2}{\tau_2}$$

$$A^2 = E^2 + D^2 B^2 + K_a \left\{ K_f \left[\Sigma_{a_{U_{235}}}^3 + 0.93 \left(\Sigma_{a_{pr}}^3 + \Sigma_{a_{B_{10h}}}^3 \right) \right. \right. \\ \left. \left. + 0.93 K_p \Sigma_{a_{B_{10d}}}^3 + \left(A^3 - \Sigma_{a_{Xe}} \right) \right] \right\} ,$$

where $D^2 B^2$ will be described in section F on options, and the subscripts a_{pr} , $a_{B_{10h}}$, and $a_{B_{10d}}$ refer to effective poisons which are due to fission products, homogeneous B_{10} , and discrete B_{10} , respectively,

$$F^2 = F^3 K_f (1 + K_f)$$

$$Z^2 = \sqrt{A^2 D^2} .$$

E. Cross Sections, Fast Group

The following equations are solved in order to calculate cross sections in the fast group:

$$\Sigma_{tr}^1 = \rho V_{H_2O} \sigma_{H_2O}^1 + \sum_m \left(\sigma_{tr_m}^1 v_m \right)$$

$$D^1 = \frac{1}{3 \Sigma_{tr}^1}$$

$$E^1 = \frac{D^1}{\tau_1}$$

$$A^1 = E^1 + D^1 B^2$$

$$Z^1 = \sqrt{A^1 D^1} .$$

F. Optional Calculations

Rod Representation

In r-z geometry it is frequently desirable to represent the presence or absence of control rods. The two most common types of r-z models are the "cylindrical shell" model and the "window shade" model. In the former the rods are discrete regions, and, hence, no geometric difficulties arise. In the latter the presence of the rods is shown by modifying the removal or the slowing-down cross sections in the core regions containing the rods.

The cross-section modification formulas involve factors (called $\mathcal{F}$ -factors, $\mathcal{F}_2$ and $\mathcal{F}_3$) which must be supplied as WOX input. The way

these factors are used is determined by the $\mathcal{F}$ -factor option (which is also part of the input), as follows:

$$\text{Option 1: } A^2 = \frac{A^{2'}}{\mathcal{F}_2}$$

$$A^3 = \frac{A^{3'}}{\mathcal{F}_3}$$

$$\text{Option 2: } E^1 = E^{1'} \mathcal{F}_2$$

$$E^2 = E^{2'} \mathcal{F}_3$$

Option 3: Ignore $\mathcal{F}$ -factors .

Primes indicate unmodified cross sections. The $\mathcal{F}$ -factors may be defined as unity minus the ratio of rod absorption area to total fissionable area.

Xenon Option

There are four xenon options, one of which is specified for each material. They are (1) no xenon, (2) steady-state xenon, (3) peak xenon, and (4) transient xenon.

Option 1: No Xenon. In no xenon materials the terms Σ_{aXe}^s and γ in the expressions for A^3 and $\Sigma_a(T)$, respectively, are set equal to zero. This option must be used for all noncore materials.

Option 2: Steady-State Xenon. In materials with steady-state xenon we calculate the xenon contribution to A^3 as follows:

$$\Sigma_{aXe}^s = \frac{P \bar{\sigma}_{Xe} (2.0 \times 10^{-3})}{V (0.2092 \times 10^{-4} + \phi^3 \bar{\sigma}_{Xe})},$$

where
$$\phi^3 = \frac{(3.125 \times 10^{-2}) P \cdot \bar{F}}{F^3 V}$$

$$\bar{F} = \frac{1}{1 + \frac{F^2 A^3}{F^3 A^2}}, \text{ and}$$

$$\bar{\sigma}_{Xe} = \frac{(0.5101 - 0.162Te - 12.08Te^2)10^6}{\sqrt{Te}} \text{ barns}.$$

Te is the effective neutron temperature in electron volts. In materials

with steady-state xenon we also set γ in the expression for $\Sigma_a^3(T)$ equal to zero.

Option 3: Peak Xenon. In materials with peak xenon the xenon contribution is calculated as follows:

$$\Sigma_{aXe}^3 = \frac{95.6 P \bar{\sigma}_{Xe} B}{V}$$

B can be calculated for fractional power reductions where the reactor power has been lowered to a fraction f of the steady-state power. This f must be specified as part of the input. The decay constants to be used are

$$\lambda_{Xe} = 2.092 \times 10^{-5} \text{ sec}^{-1}$$

$$\lambda_I = 2.874 \times 10^{-5} \text{ sec}^{-1}$$

The formula for B follows: ($\bar{\sigma}_{Xe}$ and ϕ^3 are as shown in option 2):

$$B = B(f, \bar{\sigma}_{Xe}^3 \phi^3) = \frac{\lambda_{Xe}}{\lambda_{Xe} + \bar{\sigma}_{Xe}^3 \phi^3} \left\{ \frac{f(\lambda_{Xe} + \bar{\sigma}_{Xe}^3 \phi^3)}{\lambda_{Xe} + f\bar{\sigma}_{Xe}^3 \phi^3} + \left[1 - \frac{f(\lambda_{Xe} + \bar{\sigma}_{Xe}^3 \phi^3)}{\lambda_{Xe} + f\bar{\sigma}_{Xe}^3 \phi^3} \right] \frac{\lambda_{Xe} + f\bar{\sigma}_{Xe}^3 \phi^3}{\lambda_I - \lambda_{Xe} - f\bar{\sigma}_{Xe}^3 \phi^3} \right. \\ \left. - \frac{(\lambda_{Xe} + \bar{\sigma}_{Xe}^3 \phi^3)(1-f)}{\lambda_{Xe} + f\bar{\sigma}_{Xe}^3 \phi^3 - \lambda_I} \left[\frac{\lambda_{Xe}(\lambda_I + \bar{\sigma}_{Xe}^3 \phi^3) + f(\bar{\sigma}_{Xe}^3 \phi^3)^2}{\lambda_I(\lambda_{Xe} + \bar{\sigma}_{Xe}^3 \phi^3)} \right] \frac{\lambda_{Xe} + f\bar{\sigma}_{Xe}^3 \phi^3}{\lambda_I - \lambda_{Xe} - f\bar{\sigma}_{Xe}^3 \phi^3} \right. \\ \left. + \frac{(\lambda_{Xe} + \bar{\sigma}_{Xe}^3 \phi^3)(1-f)}{\lambda_{Xe} + f\bar{\sigma}_{Xe}^3 \phi^3 - \lambda_I} \left[\frac{\lambda_{Xe}(\lambda_I + \bar{\sigma}_{Xe}^3 \phi^3) + f(\bar{\sigma}_{Xe}^3 \phi^3)^2}{\lambda_I(\lambda_{Xe} + \bar{\sigma}_{Xe}^3 \phi^3)} \right] \frac{\lambda_I}{\lambda_I - \lambda_{Xe} - f\bar{\sigma}_{Xe}^3 \phi^3} \right\}$$

The value of γ used in the calculation of the effective neutron temperature and in the calculation of the thermal group transport cross section is linearly interpolated depending upon f . For $f = 1.0$, $\gamma = 20.0$, and for $f = 0.0$, $\gamma = 72.9$. The fraction f of steady-state power is put into the general mesh data, 1023. If it is omitted, zero is used.

Option 4: Transient Xenon. In materials with transient xenon the input must contain the number of xenon atoms in the material (times 10^{-18}) in place of the power in megawatts. The macroscopic xenon cross section is

$$\Sigma_{aXe}^3 = \bar{\sigma}_{Xe}^3 \frac{N_{Xe}}{V_{cc}} \times 10^{-18},$$

where $\bar{\sigma}_{\text{Xe}}^3$ is the hardened thermal xenon cross section in megabarns, calculated as in option 2, and N_{Xe} is the number of xenon atoms. N.B. Because $\bar{\sigma}_{\text{Xe}}^3$ is in megabarns, the input must be the number of xenon atoms times 10^{-18} .

With option 4 the value of γ used in the calculation of the effective neutron temperature and in the calculation of the thermal group transport cross section is 1.8.

Perpendicular Buckling

In x-y or r- θ problems perpendicular buckling, B^2 , is used (if and only if supplied) to account for leakage in the z direction. When used, it yields the $D^2 B^2$ contribution to the absorption cross sections.

Adjoint Cross Section

If it is desired to calculate adjoints rather than fluxes, the following cross-section transformations are made by WOX7 in each region in adjoint problems. (Superscripts refer to group numbers.)

$$\text{Adjoint } D^1 = \text{flux } D^3$$

$$\text{Adjoint } A^1 = \text{flux } A^3$$

$$\text{Adjoint } F^1 = 0$$

$$\text{Adjoint } D^2 = \text{flux } D^2$$

$$\text{Adjoint } E^1 = \text{flux } E^2$$

$$\text{Adjoint } A^2 = \text{flux } A^2$$

$$\text{Adjoint } F^2 = 0$$

$$\text{Adjoint } D^3 = \text{flux } D^1$$

$$\text{Adjoint } E^2 = \text{flux } E^1$$

$$\text{Adjoint } A^3 = \text{flux } A^1$$

$$\text{Adjoint } F^3 = \text{flux } F^3$$

$$\text{Adjoint } x^1 = 1.0$$

$$\begin{aligned} \text{Adjoint } x^2 &= \text{flux } F^2 / \text{flux } F^3 \text{ if flux } F^3 \neq 0, \text{ or} \\ &= 0 \text{ if flux } F^3 = 0 \end{aligned}$$

$$\begin{aligned} \text{Adjoint } x^3 &= \text{flux } F^1 / \text{flux } F^3 \text{ if flux } F^3 \neq 0, \text{ or} \\ &= 0 \text{ if flux } F^3 = 0 \end{aligned}$$

Note that x^2 and x^3 are region-dependent, and that if any precalculated cross sections are supplied, they must be flux cross sections rather than adjoint cross sections. The control for this is the 1007 card. Three-group adjoint cross sections are supplied if -3 is the value on this card. The CURE adjoint calculation controls are also set by WOX7.

TABLE 4. Microscopic Cross Sections and
Age Equivalence Factors

<u>Substance Index</u>		<u>Substance</u>	<u>$\sigma_a^3(T)$</u>	<u>$\xi\sigma_s$</u>
12		B ¹⁰	5270.0	-
21		H ₂ O	0.5078	1.354
22		Zirconium	0.1769	0.0074
23		Aluminum	0.3194	0.0061
24		Iron	4.929	0.0330
25		Stainless steel	5.664	0.0330
26		Zircaloy	0.2060	0.0074
27		Void	0	0
28		C ₂ H ₄	0.6055	1.609
29		Inconel	8.70	0.0440

<u>Index</u>	<u>e</u>	<u>f</u>	<u>g</u>	<u>h</u>	<u>σ_{tr}^1</u>	<u>σ_{tr}^2</u>	<u>$\sigma_{tr}^3(Te)$</u>
12	-	-	-	-	-	-	-
21	0	0	0	0	0.2016	0.5496	$53.19/\sqrt{T(R^{\circ})}$
22	0.109	1.33	0.005	0.547	0.2650	0.2993	0.262
23	0.103	0.922	0.006	0.195	0.1859	0.1074	0.0845
24	0.186	1.20	0.021	1.39	0.2425	0.7573	0.967
25	0.186	1.20	0.021	1.39	0.2425	0.7573	0.967
26	0.109	1.33	0.005	0.547	0.2650	0.2993	0.262
27	0	0	0	0	0	0	0
28	1.19	1.06	1.19	1.23	0.2137	0.6782	$\frac{62.13}{\sqrt{T(R^{\circ})}} + 0.1778$
29	0.209	1.53	0.034	2.30	0.309	1.26	1.28

G. WOX7 Glossary

<u>Symbol</u>	<u>Definition</u>
A	Superscript - actual
A_{ℓ}^g	Total removal cross section, material ℓ , group g
D	Peak xenon burnout reduction factor; mass of poison
B^2	Buckling
B^M	Boron equivalent of structural substances not appearing in the WOX7 cross-section tables
D_{ℓ}^g	Diffusion coefficient, material ℓ , group g
E	Superscript - effective

Symbol	Definition
E_{ℓ}^g	Slowing-down cross section, material ℓ , group g
ev	Electron volts
e,f,g,h	Age equivalence factors
F	Superscript - contribution from original fissionable material
f	Self-shielding factor
F_{ℓ}^g	Fission cross section, material ℓ , group g
β_2, β_3	β -factors (control rod equivalence factors)
g	Group index
K	Self-shielding parameter
K_a, K_f	Thermal cutoff constants
K_f, K_p	Unself-shielding factors
ℓ	Material index
M	Mass of fuel
m	Substance index for structural substance (i.e., substance other than U^{235} , B^{10} , or water)
o	Subscript - initial value
$^{\circ}F$	Degrees Fahrenheit
$^{\circ}R$	Degrees Rankine
P	Power; poison concentration (ratio of poison mass now to original poison mass)
P	Superscript - contribution from fission products
P	Subscript - poison only
P_{ℓ}/P	Power fraction in material ℓ
pr	Subscript - pertains to fission products
T	Actual temperature (degrees F)
t	Time step index
Te	Effective neutron temperature (ev, degrees F, or degrees R)
U	Fuel concentration (ratio of fuel mass now to original fuel mass)

Symbol	Definition
u	Subscript - fuel only
V	Volume associated with material index; volume fraction of a substance in a material
Z_{ℓ}^g	Boundary constant, material ℓ , group g
γ	First-approximation xenon cross-section factor; (with subscript) self-shielding parameter
ρ	Moderator density
$\Sigma_a, \Sigma_{tr}, \Sigma_s$	Macroscopic group-averaged cross sections (absorption, transport, slowing down)
$\sigma_a, \sigma_{tr}, \sigma_s$	"Microscopic" cross sections. (These are not what is ordinarily meant by microscopic cross sections. They do not all have the same units. Their significances may be inferred from the formulas in which they appear.)
$\sum_m$	Sum over all substance indices for structural substances.

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IV. MULTIGROUP CALCULATIONS — CURE

By the multigroup calculation we mean the calculation of criticality, of spatial distribution of neutron flux in each group, and of spatial distribution of fission source. If one construes the word "multigroup" more strictly and distinguishes between multi-group and few-group calculations, then one will say that CURE (in the versions we are discussing here) is capable only of few-group calculations.

(A version of CURE with provisions for inelastic scattering and for Selengut-Goertzel hydrogen scattering but without the provisions for depletion calculations of the codes described here has been completed recently by Computer Usage Company of New York City for KAPL. It is named CUREM. It is written for the 704 and is available through IBM.)

The system of equations which govern the eigenvalue and the neutron flux distribution, written as a partial differential equation spatially but as a difference equation (on a very crude mesh) in the energy direction, is:

$$-\nabla \cdot D^g \nabla \phi^g + A^g \phi^g = \chi^g P + E^{g-1} \phi^{g-1}$$

$$P = v \sum_g F^g \phi^g \quad g = 1, 2, \dots, G$$

$$E^0 = \phi^0 = 0$$

$$\int_{\text{core}} dV = \int_{\text{core}} P dV \text{ (normalization) } .$$

The passage from this system of equations to a system of finite difference equations and the methods used to solve the difference equations are discussed in KAPL-1724.

The present CURE handles the following types of problems, which could not be handled in CURE as described in KAPL-1724: (1) χ^g may be region-dependent, and (2) the right and top boundaries of an x-y problem may be identified by a 90-deg periodic boundary condition.

An optional variation of the source iteration process, devised by

E. L. Wachspress, has been incorporated in the present CURE. It is called SSRM and is described in Appendix A. In CURE2 the flux iteration process has been modified (see sections A, C, and D below and Appendix A). In CURE3 a very specialized version of the Peaceman-Rachford flux iteration process is used to handle the 90-deg periodic x-y problem. With these exceptions, the solution methods used in the present CURE are essentially those described in KAPL-1724.

The boundary conditions may be one of the following:

1. Flux equals zero ($\phi^g = 0$)
2. Current equals zero ($D^g \nabla \phi^g = 0$)
3. Current condition
$$\left(- \frac{D^g \frac{d\phi^g}{dn}}{\phi^g} = Z^g \right)$$
4. The top and bottom boundaries in r- θ may be periodic (CURE1 only).
5. The right and top boundaries in x-y may be periodic if a special version of CURE (i.e., CURE3) is in use.

A. Coefficient Calculation

The coefficient calculation is unchanged from that described in KAPL-1724, except for CURE2, in which the coefficients at each point are normalized by dividing them by $\int_{\text{mesh box } ij} D^g dV$ for that point, and in which γ_{ij}^g is calculated and written on tape in place of $\gamma_{ij}^g/2$.

B. Source and Flux Guesses

It is necessary to have a source guess and a group-dependent flux guess during every outer iteration. After the first iteration, CURE uses the preceding results for guesses. The options for initial guesses are as follows.

- 0 (No guess supplied, input contains either no 1012 card or 1012 DEC 0 card.) A "flat source guess" is generated. At each point the source density is assumed to be unity where there are fissions and zero elsewhere. The effect of the unities used is weighted by the volume surrounding the point. The flux guess in group 1 is assumed to be zero all over. The other groups use the final flux in the previous group as a guess. The source extrapolation scheme starts at the beginning.

- 1 (Source and flux guess supplied on tape. A 1012 DEC 1 card is included in the input.) The tape on unit 5 is assumed to be the flux and source for the previous iteration of this problem. They are used as a guess, and the source extrapolation scheme is resumed right where it is. (The behavior is the same as for iterations beyond the first of all problems.)
- 2 (Source and flux guess supplied on tape. A 1012 DEC 2 card is included in the input.) The tape on unit 5 is assumed to be the final flux and source of a similar problem. They are used as a guess, and the source extrapolation scheme starts at the beginning.

C. Pregroup Source Calculation

The group source corresponds to the right-hand member of the first of the system of equations given on page 37.

$$x^g p + \phi^{g-1} \phi^{g-1}$$

The group source for the finite difference equation is the integral of the above over a mesh box:

$$S_{ij}^g = \int_{\text{mesh box}} x^g p \, dV + \phi_{ij}^{g-1} \int_{\text{mesh box}} \phi^{g-1} \, dV$$

For the normal case, in which x^g is not space-dependent, this is equivalent to the formula actually used in the code:

$$S_{ij}^g = x^g \int_{ij} + \phi_{ij}^{g-1} \int_{\text{mesh box}} \phi^{g-1} \, dV$$

For problems (in particular, adjoint calculations) in which x^g is not a constant, the following approximation is used in the code:

$$S_{ij}^g = \frac{\int_{\text{mesh box}} x^g \, dV}{\int_{\text{mesh box}} dV} \int_{ij} + \phi_{ij}^{g-1} \int_{\text{mesh box}} \phi^{g-1} \, dV$$

In either case CURE2 (but not CURE1 or CURE3) normalizes S_{ij}^g by

dividing by $\int_{\text{mesh box}} D^g dV$ at each point.

D. Flux Calculations in CURE1 and CURE2

The flux calculation is a generalization of the Peaceman-Rachford technique. Theoretical discussions are available in KAPL-1724.

Peaceman-Rachford Technique in CURE1

Parameters Used. In CURE1 there is no provision for automatic calculation of parameters. There are standard values for these numbers, which are used unless special values are supplied in the general mesh input. The standard values are given in Table 5.

TABLE 5. Peaceman-Rachford Iteration Parameters

<u>Location</u>	<u>Symbol</u>	<u>Value</u>		
		<u>r-z</u>	<u>x-y</u>	<u>r-θ</u>
1014	α	1.0	1.0	1.0
1015	t_1	1.0	20.0	8.0
1026	b	2.0	1.0	0.05
1028	w_1	0	0.00001	0.006
1029	x	0.1	0.1	0.1
1030	$1/\xi$	10.0	100.0	10.0

Iterations and Extrapolation. During the first Peaceman-Rachford double sweep, the extrapolation number used is w_1 . The next double sweep uses $w_2 = w_1/x$, and the next $w_3 = w_2/x$, and so forth, until the first w_k such that $w_k \geq b$. w_k is used on the k^{th} double sweep, but on the $(k+1)^{\text{th}}$, w_1 is used, and on the $(k+2)^{\text{th}}$, w_2 . The cycle of extrapolation numbers is repeated for each group of k double sweeps.

Flux Convergence. The fluxes are said to be converged after the k^{th} iteration (i.e., double sweep) if and only if

$$\frac{\sum_{ij} \left[\left| \phi^1 - \phi^{\frac{1}{2}} \right| + \left| \phi^{\frac{1}{2}} - \phi^0 \right| \right]_{ij}}{\sum_{ij} \left[\left| \phi^k - \phi^{k-\frac{1}{2}} \right| + \left| \phi^{k-\frac{1}{2}} - \phi^{k-1} \right| \right]_{ij}} > \frac{1}{\xi},$$

where one-half superscripts indicate half of double sweeps, or single sweeps. Superscript 0 indicates the flux guess used.

Early Termination of Flux Iterations. If the number of double sweeps performed, t_p , exceeds the maximum for the p^{th} outer iteration (i.e., if $t_p > \alpha^{p-1} t_1$), then the flux iterations will terminate.

Peaceman-Rachford Technique in CURE2

Parameters. The values of b and w_1 in CURE2 are calculated for each problem by the coding. The coefficients are the input for this calculation. A theoretical discussion appears in Appendix A. Special values may be supplied for all parameters. If special values are supplied for b or w_1 , they will be used and the parameter calculation will be bypassed.

The general parameters are:

Location	Symbol	Value	
		r-z	x-y
1014	α	1.0	1.0
1015	t_1	1.0	20.0
1029	x	0.1	0.1
1030	$1/\epsilon$	10.0	100.0

Iterations and Extrapolation. Extrapolation numbers for the first k flux double sweeps in CURE2 are the same as in CURE1. The flux iteration terminates after the k^{th} double sweep.

Flux Convergence. The fluxes are said to be converged after the k^{th} iteration (i.e., double sweep) if and only if:

$$\frac{\sum_{ij} |\phi^1 - \phi^0|_{ij}}{\sum_{ij} |\phi^k - \phi^{k-1}|_{ij}} > \frac{1}{\epsilon}$$

Superscript 0 indicates the flux guess used.

Early Termination of Flux Iterations. If the number of double sweeps in the p^{th} outer iteration, t_p , satisfies $t_p > \alpha^{p-1} t_1$, then the flux iterations are terminated. They are also terminated after the iteration in which $w_k \geq b$.

E. Flux Calculation in CURE3

CURE3 is the special tape for x-y periodic problems. Its flux calculation is a modified line inversion technique rather than the Peaceman-Rachford technique.

The parameters used are:

<u>Location</u>	<u>Symbol</u>	<u>Value</u>
1014	α	1.0
1015	t_1	20.0
1026	b	2.0
1028	w_1	0.00002
1029	x	0.1
1030	$1/\xi$	100.0

In other respects, the CURE3 calculation resembles the CURE1 calculation except that the flux convergence criterion is treated as it is in CURE2.

F. Source Calculation and Extrapolation

The source extrapolation is based upon the Stiefel "Best Strategy" method. The theory appears in KAPL-1724. The extrapolation is based upon the current unextrapolated source and the last two extrapolated sources when they are available.

The extrapolation parameter, a_s , is supplied a standard value of 2.5. A different value may be supplied as part of the general mesh input. The source extrapolation in the t^{th} time step is as follows ($\mathcal{J}$ indicates unextrapolated source):

$$\mathcal{J}_{ij}^p = \mathcal{J}_{ij}^{p-1} + \alpha_p (\mathcal{J}_{ij}^p - \mathcal{J}_{ij}^{p-1}) + \beta_p (\mathcal{J}_{ij}^{p-1} - \mathcal{J}_{ij}^{p-2}),$$

where

$$\alpha_1 = 1.0$$

$$\beta_1 = 0$$

$$\alpha_2 = \frac{a_s}{a_s - 1}$$

$$\beta_2 = 0$$

$$\alpha_{k+2} = 2a_s \frac{\cosh k [\text{arc cosh } (a_s - 1)]}{\cosh (k+1) [\text{arc cosh } (a_s - 1)]}$$

$$\beta_{k+2} = \frac{\cosh (k-1) [\text{arc cosh } (a_s - 1)]}{\cosh (k+1) [\text{arc cosh } (a_s - 1)]}$$

$$\lim_{p \rightarrow \infty} \alpha_p = 2a_s e^{-\text{arccosh}(a_s-1)}$$

$$\lim_{p \rightarrow \infty} \beta_p = e^{-2 \text{arc cosh } (a_s-1)}$$

Theoretically, the value of a_s used should be

$$a_s = 2 \frac{\lambda_0}{\lambda_1},$$

where $\lambda_0 > \lambda_1$, and λ_0 and λ_1 are the two largest real eigenvalues of the matrix, $\mathcal{J}$, defined by

$$\mathcal{J}^p = \nu^p \mathcal{J} \mathcal{J}^{p-1},$$

where ν^p is the reactivity eigenvalue of the p^{th} outer iteration. As a practical matter, the value of a_s cannot be calculated in advance and so must be guessed at. The claim that this is a "Best Strategy" method is based upon proper selection of a_s .

In order to eliminate the effects of an improper a_s , the sum square residual minimization method (SSRM) was developed. A theoretical discussion of this appears in Appendix A. It is available as an option and is obtained by using a 1025 DEC 1 card as part of the general mesh input.

G. Glossary

Symbol	Definition	Indexed by	
		Sub- scripts	Super- scripts
A	Macroscopic total removal cross section	ij,q	g
T,B,L,R	Subscripts for adjacent points in 5-point formula	-	-
a_s	$\frac{2}{\text{dominance ratio}} = 2 \frac{\lambda_0}{\lambda_1}, \lambda_0 > \lambda_1 \geq \lambda_K$	-	-
a,c,d,e	Indices for coefficients for adjacent points in 5-point formula	ij	g
B	Coefficient for a given point in 5-point difference formula	ij	g
B^2	Perpendicular buckling	-	-
b,w,x	Peaceman-Rachford iteration parameters	-	-
D	Diffusion coefficient	ij,q,l	g
E	Macroscopic slowing-down cross section	ij,q,l	g
F	Macroscopic fission cross section	ij,q,l	g
$\mathcal{J}$	Iteration matrix	-	-

Symbol	Definition	Indexed by	
		Sub- scripts	Super- scripts
g	Group index	-	-
G'	Lowest group index for which there are $F \neq 0$	-	-
G	Total number of groups	-	-
i, j	Indices for the x-y, r-z, or r- θ directions, respectively	-	-
I, J	Maximum values for i, j	-	-
I	Identity matrix	-	-
K	Quadrant volume	ij, q	-
K	Criticality	-	p
$K_{\max}, K_{\min}$	Pointwise maximum (minimum) of K	-	p
ℓ	Material index	-	-
L'	Maximum index for material with fuel	-	-
L	Total number of materials	-	-
D	Geometric contribution to difference equation coefficients	Various	-
D	Total number of points in mesh	-	-
p	Index for source (outer) iteration	-	-
q	Quadrant index	-	-
r	Radial coordinate (r- θ or r-z geometries)	-	-
$\mathcal{S}$	Source	ij	-
S	Group source	ij	g
t	Index for flux (inner) iteration	-	-
$T, t_{\max}$	Maximum number of inner iterations	p	-
V_c	Total core volume	-	-
w, x	Peaceman-Rachford iteration parameters	-	-
z	Axial coordinate (r-z geometry)	-	-
Z	Region-dependent gradient boundary condition	ℓ	g

Symbol	Definition	Indexed by	
		Sub- scripts	Super- scripts
α, β	Source extrapolation parameters (3-term system)	p	-
ϵ	Convergence criterion for $\Sigma(\Delta\phi)^2$	-	p
θ	Angular coordinate (r- θ geometry)	-	-
λ	Eigenvalue of the iteration matrix	-	-
$\lambda_{\max}, \lambda_{\min}$	Pointwise maximum (minimum) of λ	-	-
ξ	Ratio of present flux residual to first flux residual	t	-
ϕ	Flux value	ij	g, t, p
χ	Fission spectrum	ij, q, l	g
ν, ν_c	Inverse of eigenvalue of the iteration matrix	-	-
$\nu_{\max}, \nu_{\min}$	Pointwise maximum (minimum) of ν	-	-

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V. DEPLETION CALCULATION — B02*

The depletion calculation, B02, calculates the masses of fuel and poison remaining in each material as a result of steady-state operation of a critical reactor. If the reactor is not critical, the calculation is not performed. The depletion is based upon thermal and epithermal fluxes and absorption cross sections. The time steps are determined by the total amount of fuel to be burned up. The calculations may be one of three types, depending upon the location of the burnable poison in the material:

1. Discrete poison: All burnable poison in the material is located in discrete substances separate from the fuel. This means that all of the burnable poison is subject to a self-shielding factor different from the fuel self-shielding factor.
2. Homogeneous poison: All burnable poison in the material is located in homogeneous substances with the fuel. This means that all of the burnable poison is subject to the same self-shielding factor as the fuel.
3. Combination poison: Some of the burnable poison is in homogeneous substances, and the remaining burnable poison is in discrete substances. This means that some of the burnable poison is subject to the fuel self-shielding factor, and the remaining burnable poison is subject to a different self-shielding factor.

The location of the burnable poison may vary from material to material.

A. Depletion Calculation — Discrete Poison

Fuel Concentration

The concentration of fuel after the t^{th} time step, U_t , in each material is

$$U_t = U_{t-1} - \frac{P_L}{P} \frac{\Delta F}{M_O^A},$$

*The WOX glossary of Chapter IV applies to this chapter, also.

where U_0 is taken as 1, ΔF is the total fuel depletion (input), P_ℓ/P is the power fraction, and M_0^A is the initial mass of fuel.

The depleted mass of fuel is

$$M_t^A = U_t M_0^A.$$

Poison Concentration

The concentration of poison in the discrete case after the t^{th} time step, P_{dt} , in each material is found by solving the following implicit equation by using Newton's method:

$$\begin{aligned} & \frac{1}{(w\alpha K_{u u2} + K_{us})} \ln \frac{U_t}{U_{t-1}} - \frac{w\alpha K_{u u2} K_{us} (\gamma_{u2} - \gamma_{us})^2}{(w\alpha K_{u u2} + K_{us}) (w\alpha K_{u u2} \gamma_{us} + K_{us} \gamma_{u2})^2} \\ & \ln \frac{(w\alpha K_{u u2} + K_{us}) + U_{t-1} (w\alpha K_{u u2} \gamma_{us} + K_{us} \gamma_{u2})}{(w\alpha K_{u u2} + K_{us}) + U_t (w\alpha K_{u u2} \gamma_{us} + K_{us} \gamma_{u2})} \\ & + \frac{\gamma_{u2} \gamma_{us}}{w\alpha K_{u u2} \gamma_{us} + K_{us} \gamma_{u2}} (U_t - U_{t-1}) \\ & = \frac{\sigma_{us}}{\sigma_{ps}} \left\{ \frac{1}{w\alpha K_{p p2} + K_{ps}} \ln \frac{P_{dt}}{P_{dt-1}} \right. \\ & \quad - \frac{w\alpha K_{p p2} K_{ps} (\gamma_{pd2} - \gamma_{pds})^2}{(w\alpha K_{p p2} + K_{ps}) (w\alpha K_{p p2} \gamma_{pds} + K_{ps} \gamma_{pd2})^2} \\ & \quad \ln \frac{(w\alpha K_{p p2} + K_{ps}) + P_{dt-1} (w\alpha K_{p p2} \gamma_{pds} + K_{ps} \gamma_{pd2})}{(w\alpha K_{p p2} + K_{ps}) + P_{dt} (w\alpha K_{p p2} \gamma_{pds} + K_{ps} \gamma_{pd2})} \\ & \quad \left. + \frac{\gamma_{pd2} \gamma_{pds}}{w\alpha K_{p p2} \gamma_{pds} + K_{ps} \gamma_{pd2}} (P_{dt} - P_{dt-1}) \right\}, \end{aligned}$$

where
$$w = \frac{\int \phi_2 dE}{\int \phi_3 dE}$$

$$\alpha_u = \frac{\sigma_{u2}}{\sigma_{u3}}$$

$$\alpha_p = \frac{\sigma_{p2}}{\sigma_{p3}}$$

$$P_{do} = 1.0 ;$$

σ represents microscopic absorption cross sections, and K_{u2} , K_{u3} , K_{p2} , K_{p3} , γ_{u2} , γ_{u3} , γ_{p2} , and γ_{p3} are self-shielding parameters.

The following approximations are made in these calculations.

$$w\alpha_u \cong g_u = g_{ua} + g_{ub}Te + g_{uc}Te^2$$

and

$$w\alpha_p \cong g_p = g_{pa} + g_{pb}Te + g_{pc}Te^2 ,$$

where Te is the effective neutron temperature in electron volts and the various g 's are coefficients (supplied as input if the fuel is not U^{235} or the poison not a $1/v$ absorber).

If the fuel is U^{235} , the following values of g_{ua} , g_{ub} , and g_{uc} are assumed:

$$g_{ua} = 0.34633$$

$$g_{ub} = 1.62$$

$$g_{uc} = -9.333 .$$

If the poison is a $1/v$ absorber, the value of g_p is set as follows:

$$g_p = w\alpha_p \cong 0.355 .$$

The depleted mass of poison is:

$$B_t^A = P_{dt} B_o^A .$$

B. Depletion Calculation — Homogeneous Poison

Fuel Concentration

The calculations of U_t and M_t^A are the same in the homogeneous case as they are in the discrete case.

Poison Concentration

The concentration of poison in the homogeneous case is calculated as follows:

$$P_{ht} = U_t^\beta,$$

where $\beta = \frac{\sigma_{p3}(g_p + 1)}{\sigma_{u3}(g_u + 1)}$. The depleted mass of poison is $B_t^A = P_{ht} B_o^A$.

C. Depletion Calculation — Combination Poison

Fuel Concentration

The calculations of U_t and M_t^A are the same in the combination case as they are in the discrete case.

Poison Concentration

The poison concentration in the combination case, P_t , is composed of two components, a discrete component, P_{dt} , and a homogeneous component, P_{ht} , so that

$$P_t = P_{dt} + P_{ht}$$

or

$$1 = \frac{P_{dt}}{P_t} + \frac{P_{ht}}{P_t}.$$

Likewise, the mass consists of two parts:

$$B_t^A = B_{dt}^A + B_{ht}^A$$

and

$$B_{dt}^A = \frac{P_{dt}}{P_t} B_t^A$$

$$B_{ht}^A = \frac{P_{ht}}{P_t} B_t^A.$$

In this case, we assume that $P_o = 1.0$, $P_{do} \neq 1.0$, and $P_{ho} \neq 1.0$.

The calculations performed for the combination case are based upon thermal fluxes and absorption cross sections only.

Homogeneous Poison Concentration. The concentration of homogeneous poison in the combination case after the t^{th} time step is calculated as follows:

$$P_{ht} = U_t^\beta P_{ho},$$

where
$$\beta = \frac{\sigma_{ps}(g_p + 1)}{\sigma_{us}(g_u + 1)}.$$

This calculation precedes the discrete poison calculation.

Discrete Poison Concentration. The concentration of discrete poison in the combination case after the t^{th} time step is calculated from the following implicit equation by Newton's method:

$$\begin{aligned} \frac{K_{ps}\beta}{K_{us}} \left[\ln \frac{U_t}{U_{t-1}} + \gamma_{us}(U_t - U_{t-1}) + \frac{\gamma_{pha}(P_{ht} - P_{ht-1})}{\beta} \right] \\ = \ln \frac{P_{dt}}{P_{dt-1}} + \gamma_{pds}(P_{dt} - P_{dt-1}). \end{aligned}$$

New Mass of Poison. The new mass of poison after the t^{th} time step is calculated as follows:

$$B_t^A = P_{dt} B_o^A + P_{ht} B_o^A.$$

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VI. CUREBO OUTPUT

Most CUREBO output is self-explanatory. Only that output which requires explanation will be explained. A sample problem is included as Appendix B for an illustration.

A. Types of Output

The output may be one of several types. It may be on-line, off-line, or punched cards. It may be optional or nonoptional. Samples of on-line and off-line output are included in Appendix B. The punched card output, supplied by B02, is the binary input for WOX7. (See Chapter III, Sections A and D.) The optional output and controls are listed below.

1. Edit of coefficients, "A", "B" and "K" meshes, topological point edit, and topological point type edit: These are supplied if and only if a 1033 DEC 1 card is included with the input.
2. Plain source edit: This is supplied for each group in each power iteration if and only if sense switch 6 is depressed.
3. Plain flux edit: The final flux is supplied for each group in each power iteration if and only if sense switch 4 is depressed.
4. Plain power edit: The plain power edit (four values per point, unnormalized and unextrapolated) is supplied for each power iteration if and only if sense switch 3 is depressed.
5. WOX7 input edit: The WOX input edit is supplied if and only if there is some WOX decimal input.

The optional edits (except item 5) are not illustrated in Appendix B. They are described in KAPL-1724.

B. The On-Line Output

Iteration Summaries

The following items of the on-line iteration summaries are not self-explanatory.

1. Label: The label following the word CURE indicates which version of CURE (i.e., which code tape) is in use. The date is the date that this version became available for use.
2. S and J: S means source after extrapolation.
J means source before extrapolation.
3. K EFF: $K_{\text{eff}} = 2.46/v$.
4. MAX NU, MIN NU, and ERROR RATIO:

$$\max v = \frac{v}{\min_{i,j} \frac{\bar{J}_{ij}^t}{\bar{J}_{ij}^{t-1}}}$$

$$\min v = \frac{v}{\max_{i,j} \frac{\bar{J}_{ij}^t}{\bar{J}_{ij}^{t-1}}}$$

$$\text{error ratio} = \frac{\frac{v}{\min v} - \frac{v}{\max v}}{2}$$

5. Flux Convergence Summary: The entries are group-dependent and listed by groups as follows for as many groups as necessary.

group 1	group 2
group 3	group 4
group 5	
6. SWEEP: Sweep is the total number of double sweeps, k, performed in the group.
7. FLUX ERROR: The value printed is as follows:
 - a. CURE 1

$$\sum_{ij} \left[\left| \phi_{ij}^k - \phi_{ij}^{k-\frac{1}{2}} \right| + \left| \phi_{ij}^{k-\frac{1}{2}} - \phi_{ij}^{k-1} \right| \right],$$

where $\frac{1}{2}$ indicates half a double sweep (i.e., a single sweep).

b. CURE 2

If $k \leq \alpha^{p-1} t_1 = t_p$,

$$\sum_{ij} |\phi_{ij}^1 - \phi_{ij}^0| / \sum_{ij} |\phi_{ij}^k - \phi_{ij}^{k-1}| ;$$

otherwise

$$\sum_{ij} |\phi_{ij}^k - \phi_{ij}^{k-1}| .$$

8. W MIN (CURE 2 only): The value is the machine-calculated parameter, w_1 .

9. NEUTRON BALANCE (CURE 1 only): The value printed is

$$\frac{\text{total group source}}{\text{removals} + \text{leakage out of boundaries}} .$$

It should be close to unity.

10. FLUX ERROR 1 and FLUX ERROR T (CURE 3 only): The initial and final flux errors printed in CURE 3 are as follows:

a. FLUX ERROR 1 (Initial Error)

$$\sum_{ij} |\phi_{ij}^1 - \phi_{ij}^0|$$

b. FLUX ERROR T (Final Error)

$$\sum_{ij} |\phi_{ij}^k - \phi_{ij}^{k-1}| .$$

Machine Error Indicators

Tape and drum errors are printed on-line. They are for the benefit of maintenance personnel only.

C. The Off-Line Output

WOX Output

The three unidentified columns on the first page of WOX7 output are from left to right:

1. σ_u , the microscopic uranium cross section in material l .
2. $\bar{\sigma}_u^3$, the average absorption cross section in material l .
3. $\bar{\sigma}_{Xe}^3$, the xenon cross section in material l .

All temperatures are supplied in degrees Fahrenheit.

The version of WOX and the date that it was made available for use are listed as the label on a line above the problem identification on each page containing output cross sections.

For each l the cross sections are printed horizontally by the group in which they are used in CURE. Thus, the first line contains D^1 , A^1 , F^1 , and Z^1 , the second D^2 , E^1 , A^2 , F^2 , and Z^2 , etc. This also means that the cross sections are printed after inversion in adjoint problems.

The seven pages of WOX input edit are omitted if all of the cross sections are precalculated.

"Thinness" is the thickness of a thin region if the material forms a thin region, and zero otherwise.

"LO" is the material from which this material had been split for purposes of criticality search.

The columns labelled F1 and F2 contain the values of $\mathcal{F}_2$ and $\mathcal{F}_3$, respectively.

Topological Material Edit

Entries. This edit is not truly a "topological material" edit. Its entries are the materials located in the regions above and to the right of each point (i.e., in quadrant I from each point).

Pseudo-entries. The row and column of flag points are indicated in this edit. The entry "59" is used for flag points, pseudo points, top and right boundary points, bottom and left zero flux boundary points, and points next to top and right flux zero boundary points.

Iteration Summaries

Everything said for on-line iteration summaries also applies to off-line iteration summaries. (See pages 53 to 55.)

General Mesh Data

1. MAX. NO. FLUX ITER. FOR ANY GP./PW. ITER.: The actual maximum is the printed value if it is an integer. Otherwise, the actual maximum is the first integer greater than the printed value. The number printed is $\alpha^{p-1}t_1$ for the current value of p .

2. ARE SIGMAS MACHINE-CALCULATED: The entry is "NO" if any of the cross sections are precalculated.
3. IS SOURCE FLUX GUESS AVAILABLE: The entry is always "YES" if more than one power iteration is done,
4. B and W MINIMUM: The values are b and w_1 . When the machine-calculated parameters of CURE2 are in use, these parameters are group-dependent and are not printed with the general mesh data. The values printed are zero. The parameters are included, by group, with the topological flux edits.

Topological Power Edit

Flag and pseudo points are included with the topological power edit. (The power at these points is zero.) Note that four values per point are printed, which permits power discontinuities at material interfaces.

Topological Flux Edit

Flag and pseudo points are included with the topological flux edit. The fluxes at these points are zero. The value printed at $i = 1, j = 0$ (a flag point) is b for the group concerned. The value printed at $i = 2, j = 0$ (a flag point) is w_1 for the group concerned.

Integration

The vertical data columns are:

1. The material volume
2. The material-dependent flux integral, group 1
3. The material-dependent flux integral, group 2
4. The material-dependent flux integral, group 3
5. The material-dependent power fraction
6. The material-dependent power density.

Materials lying along zero flux boundaries have incorrect volumes. If there are fewer than three groups, garbage prints out for flux integrals in the unused groups. In 4- or 5-group problems only the flux integrals for the first three groups are printed.

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VII. OPERATING INSTRUCTIONS

A. CURE Program Tapes

The first step in running a CURE problem after preparing the input is to select the proper code tape. The various C series code tapes are as follows:

1. CURE 1CT: Permits x-y, r-z, r, θ , or r, θ periodic geometry, concave boundaries, deleted points, and a maximum of 3294 points (including flag points and pseudo points). Requires one code tape, one output tape, and four working tapes.
2. CURE 1C: Like 1CT except that it is limited to 2046 points and requires three logical drums in addition to the 1CT equipment.
3. CURE 2CT: Permits x-y or r-z geometry only. Requires full-rectangular boundary with a maximum of 3236 points. Requires one code tape, one output tape, and five working tapes.
4. CURE 2C: Like 2CT except that it is limited to 2046 points and requires three logical drums in addition to 2CT equipment.
5. CURE 3CT: Permits x-y periodic geometry only. Requires square mesh with a maximum of 3249 points. Requires the same equipment as 1CT.

Note that 3CT is not interchangeable with any of the others under any circumstances. When several tapes are usable on a problem, the most restrictive tape is the fastest.

The code tape itself may be an individual code tape to be mounted on tape unit 9 or a merge of several tapes to be mounted on tape unit 1. In the former case, a loading routine is the first part of the problem deck, and in the latter, a clear and load tape card followed by the appropriate calling card is the first part of the problem deck.

B. Preparation of the Machine

In addition to the code tape on units 1 or 9, the following other preparations must be made:

1. Output (tape unit 6) must be ready.
2. Blank working tapes must be mounted on units 2, 3, and 4.
3. For CURE2 a blank must also be mounted on 7.
4. The appropriate tapes 2 and 4 replace the blanks in re-starts of CURE3 problems.
5. The appropriate source guess tape is mounted on unit 5 if one exists. Otherwise a blank is mounted.
6. The problem deck is readied in the card reader.
7. The printer is readied. It should have a SHARE No. 1 or No. 2 board.
8. If depletion is to be calculated, the card punch should be readied.

C. The Start and the Finish

Starting

The problem is started by depressing "LOAD CARDS."

Source Convergence

The only automatic control on source convergence is the 1020 versus $\sum (\Delta J)^2$ control. The control is bypassed by not using a 1020 card in the input. When this is done, source convergence must be determined manually from one or more of the following measures:

1. The changes in successive values of NU
2. The value of $\sum (\Delta J)^2$
3. The value of maximum ΔJ
4. The value of $\sum (J - J)^2$
5. The value of maximum ΔJ
6. The value of the ERROR RATIO
7. The values of the FLUX ERRORS .

When a problem is considered converged, sense switch 2 is depressed. Depressing sense switch 5 will cause a normal stop at 6162_g so that the decision can be made before proceeding.

Stopping

The normal stop is at 265_g for all problems run with a tape 9 code tape. Problems run with the merge will end by reading the next problem deck if there is one, or if there is no next deck, stop at 0 with a select of the card reader.

If only the eigenvalue is desired (i.e., if powers, fluxes, depletions, etc. are not wanted), the problem may be considered finished at the final 6162_g stop with sense switch 5 depressed (i.e., the stop at 6162_g with the problem converged).

The following items should be removed and saved for future use:

1. The CURE code tape, unless another problem is to be done.
2. The latest source guess tape. (The tape printed in the last iteration summary; it will be 3 or 5.) This tape should be labelled.
3. The problem deck.
4. The punched deck in the card punch. This is the binary card B02 output. These cards are already labelled.
5. The on-line output.
6. Tape 4 if 1CT, 2CT, or 3CT was used and a perturbation (PSP) calculation is to be done.

D. Use of Sense Switches

Sense switches 2 and 5 are used for problem control. If sense switch 2 is down, the source is assumed converged, no new power iteration will be started, and the topological edits, integration, and depletion calculations will be initiated. If the problem is started with the switch down, one and only one power iteration is performed. If the switch is up, the control is on word 1020₁₀ and the value of $\sum(\Delta J)^2$.

Sense switch 5 is used to stop the machine after each power iteration. If it is down, the machine stops between the convergence test of word 1020₁₀ against $\sum(\Delta J)^2$ and the switch 2 test. If it is up, there will be no stop. The location of the stop is 6162₈.

Note that if the problem is converged on the basis of word 1020₁₀ and $\sum(\Delta J)^2$, neither sense switch is operative.

The use of sense switches 3, 4, and 6 for optional output is described in Chapter VI. Plain power, flux, or source edits are taken as often as editable material is available if the respective switch is down.

Sense switch 1 is inoperative in CUREBO itself. It must be down when a merge code tape (tape 1 version) is in use on a machine lacking the BSF (back-space file) instruction.

E. Reruns and Restarts

There are three ways of rerunning or restarting CURE problems. These are (1) the "internal restart," (2) the "rerun," and (3) the "3CT rerun."

Internal Restart

The internal restart, when it can be used, may save considerable re-starting time. It avoids unnecessary recalculations of cross sections, coefficients, and previous iterations.

Restrictions and Remedies. Before this restart routine is attempted,

it must be determined that the restart will work. If any of the following conditions is true, the internal restart will not work and should not be attempted:

1. Tape 2 is unreadable (because of damage or breakage).
2. Tape 4 is unreadable.
3. Tape 3 is unreadable during an even-numbered power iteration.
4. Tape 5 is unreadable during an odd-numbered power iteration.
5. Internal memory has been destroyed in any way. (This applies to cores and drums.)
6. The geometry and/or cross sections of the problem are to be changed in any way whatsoever.

In cases 1 and 2 the problem should be restarted from the beginning with a 1012 DEC 1 card in the general mesh data part of the input. (See Rerun, below.)

In cases 3 and 4 it will usually be necessary to restart from the beginning either without a 1012 card or with the 1012 card and the original guess, if it was saved. If the first group fluxes have not been written, case 3 may be treated like cases 1 and 2, and case 4 may be treated in the same way after the current tapes 3 and 5 are interchanged. This possibility may be detected by noting the position of tape 5 in case 3 or tape 3 in case 4. If it is already rewound, then the method for cases 1 and 2 may be used.

In cases 5 and 6 a restart from the beginning is absolutely necessary.

Operating Instructions for Internal Restart. If the internal restart is desired and none of the above conditions is violated, execute a manual transfer to 1400_g. One of three things will occur:

1. The machine will stop at 1441_g. This indicates that the problem has not entered the outer (or source) iterative loop. The problem should be started over from the beginning in the usual manner.
2. The problem will go back to the beginning of the current power iteration and run from there as if nothing had happened. This occurs if the initial stop was in the iterative loop. In this case sense light 4 is off.
3. The problem will go back to the beginning of the general mesh data edit and run from there as if nothing had happened. This occurs if the initial stop was after the exit from the iterative loop. In this case sense light 4 is on.

Continuing a Prematurely "Converged" Problem. If a problem is permitted to leave the outer iteration loop before it has converged, the loop may be re-entered in the following way:

1. Press "RESET"
2. If convergence is under control of 1020 card, execute manually

0 60000 0 01774 (STZ 1020) .

If control is under sense switch 2, this is unnecessary.

3. Execute manual transfer to 1400_a.

This will repeat the last-performed outer iteration and subsequent iterations until sense switch 2 is depressed. Step 1 above turns off sense light 4 and permits a return to the loop. If step 2 is necessary and omitted, the problem will redo the last iteration and leave the loop again.

Rerun

If it is necessary to rerun a problem, the appropriate one of the following procedures must be followed

1. If a useable source guess tape is available from the previous run of this problem,
 - a. Mount the latest source guess tape on unit 5.
(This is the source guess tape listed in the last complete on-line iteration summary and will be either 3 for odd iterations or 5 for even iterations.)
 - b. Insert the following card with the general mesh input of the problem deck

1012 DEC 1 .

The previous 1012 card, if any, should be removed.

- c. Proceed as in sections B and C above.
2. If no useable source guess tape is available from the previous run of this problem, follow exactly the procedures listed in sections B and C above.

The 3CT Rerun

The 3CT rerun accomplishes for 3CT what the internal rerun accomplishes for other versions of CUREBO. It has the same restrictions as does the internal restart except that it may be used when core memory has been destroyed. The appropriate tapes must be mounted on units 2 and 4 and the most recent good source guess on 5.

A special deck is read into the machine. The rerun described above under Rerun is the alternative to the 3CT rerun.

F. Machine Stops

Normal Stops

There are only two normal stops in CUREBO. These are

1. 265₈ — The problem is concluded.
2. 6162₈ — The stop after each power iteration controlled by sense switch 5.

Abnormal Stops

It is impossible to list all of the programmed abnormal stops in CUREBO. A sampling of the major ones follows. If an unlisted stop occurs, a dump of core memory is recommended. The cause of an abnormal stop is an input error or a machine error. In the following table the notation "Rerun" means to use the appropriate procedure from Section E.

TABLE 6. Abnormal CUREBO Stops

<u>Octal Location</u>	<u>CURE Tapes</u>	<u>Part of Code</u>	<u>Cause</u>	<u>Action to be Taken</u>
452	All	Throughout code	Machine error (tape)	Hit "start" to get errors on-line.
454	All	Throughout code	Machine error (drum)	Hit "start" to get errors on-line.
1157	All	Throughout code	Machine error	Rerun.
1441	All	Internal rerun	Rerun not possible	Restart.
36522	1C, 1CT	PRF	Input error (geometry or increment)	Get contents of register C, and get off machine.
36510	2C, 2CT	PRF	Input error (geometry or increment)	Get contents of register C and accumulator, and get off machine.
36517	3CT	PRF	Input error (geometry or increment)	Get contents of register C, and get off machine.
31520	All	WOX	Input error (depletion)	Get off machine. Check input.

<u>Octal Location</u>	<u>CURE Tapes</u>	<u>Part of Code</u>	<u>Cause</u>	<u>Action to be Taken</u>
33460 } 27725 }	All	WOX	Input error (WOX)	Get off machine. Check input.
3165	All	CURE coefficients	Increment input error	Get off machine. Check input.
3626	1C, 2C	CURE coefficients	Too many points for drum version	Rerun using 1CT or 2CT, respectively.
5174	2C, 2CT	CURE coefficients	Deleted points or concave boundaries	Rerun using 1C or 1CT, respectively.
3413	All	CURE $\int$ guess generation	Error on $\int$ guess tape	Rerun without source guess
5656	All	BO2	Depletion step too big	Rerun using source guess and smaller ΔF .
5566	All	BO2	Depletion step too big	Rerun using source guess and smaller ΔF .

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APPENDIX A

ITERATION TECHNIQUES IN THE CURE (TWO-SPACE-DIMENSIONAL MULTIGROUP) CODE*

E. L. Wachspress, M. A. Ketchum, B. D. Baldwin, J. A. Archibald

Recent theoretical analysis and numerical studies have lead to improvements in mathematical techniques used in the CURE (two-space-dimensional) multigroup program. Considerable time saving has resulted from reduction in mesh sweep arithmetic and logic, refinement of the flux iteration scheme, and a more sophisticated source extrapolation procedure. The CURE program has been revised, extended, and modified continually to meet specific needs so that numerous ramifications are being used now. Two variations of CURE are:

- CURE1 This is a faster version of the original CURE which retains the generality of that program.
- CURE2 In this fastest of all CURE tapes, generality has been sacrificed for speed and simplicity.

Source Extrapolation

The current fission-source extrapolation procedure is more complex than the original scheme. Three major difficulties were observed with the earlier extrapolation. First, a means of improving upon the initial parameter estimate was desirable. Second, a fully automatic procedure coupling flux to source iteration criteria was lacking. Third, convergence was extremely slow for some problems. Preliminary results with the new method are encouraging although far from conclusive.

Source convergence is usually analyzed in terms of the reduction in magnitude of error modes present in the initial source. There is a reduction, $R_t(\lambda)$, after t source iterations in the magnitude of a mode with eigenvalue λ . If the unextrapolated multigroup calculation is represented by $FS^{(t-1)} = \bar{S}(t)$, then the most general extrapolation procedure now in use is of the form

$$S(t) = S(t-1) + \alpha_t [FS^{(t-1)} - S(t-1)] + \beta_t [S(t-1) - S(t-2)] ,$$

Where α and β are extrapolation parameters.

Assume an eigenvalue spectrum:

$$0 < \lambda_n \leq \lambda_1 < \lambda_0 = 1 \quad n = 2, 3, \dots$$

*A Paper presented at the American Nuclear Society Meeting in Detroit, Michigan on December 10, 1958.

FIGURE 1. EXTRAPOLATION BASED ON ESTIMATED SECOND EIGENVALUE OF λ_1 KS-21248

FIGURE 2 INTERMEDIATE POLYNOMIALS

KS-21249

The mode corresponding to λ_0 is the desired fission source distribution. This leading eigenvalue is not exactly unity as a result of normalization variation during the calculation. Source convergence analysis is simplified, however, by the assumption that $\lambda_0 = 1$. Observed convergence rates support the assumption of real positive eigenvalues for the determination of extrapolation parameters. Curves of R_t vs λ for $t = 8$ are given in Figure 1 for two iteration schemes.

CURE is the only multigroup program with a nonzero β . Appropriate α_k ($k = 1, 2, 3, \dots, t$) may be chosen to give a Chebyshev polynomial of order t after t steps with $\beta_k = 0$. The advantage of variable α_k and β_k is that recursion formulas¹ enable generation of the Chebyshev polynomial of degree k for all k instead of only for a predetermined t (Figure 2).

A major drawback of these schemes is the dependence of α_t and β_t on an estimated λ_1 . Improvement of the original estimate during the calculation is possible² but still wasteful.

This difficulty has been resolved by the addition of a steepest descent extrapolation to the Chebyshev. When $\lambda_j \geq \lambda_1$ (Figure 1), the observed convergence rate agrees with a theoretical (predictable) value, and Chebyshev extrapolation is continued until some error criterion is satisfied. When $\lambda_j < \lambda_1$, the observed rate is slower than predicted, and a three-step steepest descent process is used. This decision is made after the fifth degree Chebyshev, based on λ_j , has been generated. This approach is especially good when the eigenvalues between λ_1 and λ_j are less dense than between 0 and λ_j , a condition always satisfied in multigroup calculations. Convergence is in many cases more rapid than may be obtained by an initial estimate of $\lambda_j = \lambda_1$ with Chebyshev extrapolation throughout. This is best illustrated by considering a specific case.

Let $\lambda_1 = 0.98$ and $\lambda_2 = 0.80$. Suppose that an error reduction of 100 is required. A single steepest descent sweep applied at the end of a Chebyshev with $\lambda_j = 0.80$ will concentrate on λ_1 to the extent that an extrapolation parameter of $\alpha \approx 50$ will be used. This will multiply high mode errors by ~ 50 , so that an initial Chebyshev reduction of 5000 is required for a composite error reduction of 100. For $\lambda_j = 0.80$ this implies 10 Chebyshev or a total of 11 iterations. With $\lambda_j = \lambda_1 = 0.98$ a reduction of 100 requires 19 Chebyshev iterations. This is illustrated in Figure 3.

A. 10 CHEBYSHEV - 1 STEEPEST DESCENT

B. 19 CHEBYSHEV

FIGURE 3 STRATEGY COMPARISON

KS-21250

KAPL-1885

The steepest descent scheme is referred to as SSRM (sum-squares-residual-minimization), and the extrapolation parameters are determined from the error residuals according to the following:

$$\text{Step I} \quad \overline{FS}^{(0)} = \overline{S}^{(1)} ; \overline{S}^{(0)} - \overline{S}^{(1)} = \overline{r}_0$$

$$\text{Step II} \quad \overline{FS}^{(1)} = \overline{S}^{(2)} ; \overline{S}^{(1)} - \overline{S}^{(2)} = \overline{r}_1$$

$$\overline{S}^{(2)} = \overline{S}^{(1)} + \alpha_1 (\overline{S}^{(2)} - \overline{S}^{(1)}) ,$$

$$\text{where} \quad \alpha_1 = \frac{\overline{r}_0 \cdot (\overline{r}_0 - \overline{r}_1)}{(\overline{r}_0 - \overline{r}_1) \cdot (\overline{r}_0 - \overline{r}_1)} .$$

$$\text{Step III} \quad \overline{FS}^{(2)} = \overline{S}^{(3)} ; \overline{S}^{(2)} - \overline{S}^{(3)} = \overline{r}_2$$

$$\overline{S}^{(3)} = \overline{S}^{(2)} + \alpha_2 (\overline{S}^{(3)} - \overline{S}^{(2)}) + \beta_2 (\overline{S}^{(2)} - \overline{S}^{(1)}) .$$

To obtain α_2 and β_2 , define

$$\overline{R}_0 = \overline{r}_0 - \overline{r}_1, \overline{R}_1 = \overline{r}_1 - \overline{r}_2$$

$$y_1 = \overline{r}_0 \cdot \overline{R}_0, y_2 = \overline{R}_0 \cdot \overline{R}_0, y_3 = \overline{r}_2 \cdot \overline{R}_0$$

$$y_4 = \overline{r}_2 \cdot \overline{R}_1, y_5 = \overline{R}_0 \cdot \overline{R}_1, y_6 = \overline{R}_1 \cdot \overline{R}_1 ;$$

then,

$$\alpha_2 = 1 + \frac{y_2 y_4 - y_3 y_5}{y_2 y_6 - y_5^2}$$

and

$$\beta_2 = \alpha_2 (\alpha_1 - 1) + \frac{y_3 - \alpha_2 y_5}{y_2} .$$

$$\text{Step IV} \quad \overline{FS}^{(3)} = \overline{S}^{(4)} .$$

In this last step the source iterate resulting from SSRM is used. The values of α and β given by the above formulas are such that

$\sum_{\text{all pts}} (S^{(3)} - S^{(4)})^2$ is minimized with respect to the α and β . If

FIGURE 4 SOURCE EXTRAPOLATION FLOW CHART

KS-21394
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F were symmetric and positive definite, this would reduce to Lanczos' (conjugate gradient) method.³

Another feature of the new CURE source iteration scheme is that no extrapolation is performed until the observed residual reduction without extrapolation is poor. Many unit cell calculations converge rapidly without extrapolation.

A more stringent flux error criterion is automatically set when source convergence is rapid. A flow chart illustrating the salient features of the iteration logic is given in Figure 4. A measure of the error is given

$$\text{by } E^{(k)} = \sum_{\text{all pts}} \left(S^{(k-1)} - S^{(k)} \right)^2.$$

Flux Iteration

The flux iteration scheme is the backbone of the two-space-dimensional multigroup program. A fully automatic technique which is currently restricted to full rectangular x-y or r-z grids is the most efficient method now available. Extensive numerical analysis, both experimental and theoretical, led to this variation of the Peaceman-Rachford method. Significant features of the scheme are:

1. Iteration parameters are automatically calculated from the difference equations, although alternative parameters may be specified.
2. Equations are normalized to approximate closely the matrix commutation property upon which Peaceman-Rachford theoretical convergence rates are based.
3. Arithmetic and logic have been reduced to require only 2600 $\mu\text{sec}/\text{point}/\text{mesh sweep}$. (The original CURE program required $\sim 6500 \mu\text{sec}/\text{point}$.)
4. A standard value of one double-sweep per group per source iteration is used.

The efficiency of one double-sweep per group was established by experimental calculations for a wide assortment of reactor configurations.* A theoretical justification is somewhat obscure. The double-sweep with a small iteration parameter concentrates on low flux eigenmodes. These, in turn, are major contributors to the converged source, which is the fundamental (lowest) mode of the composite multigroup matrix operator. To expand local flux variation (caused by absorbing slabs, for example) in terms of flux-group eigenvectors requires many of the higher modes. Numerical results lead one to believe that errors in this local flux variation are reduced by the absorption term in the Peaceman-Rachford equations.

Eigenvalue bounds ($W_{\min}$ and $W_{\max}$) for the group iteration matrix are calculated in the CURE2 program. These may be replaced by group independent input values. One may replace the single double-sweep by a process which terminates on whichever of three criteria is met first:

1. The number of double-sweeps greater than a specified value, $t_{\max}$
2. The error ratio of the first to last double-sweep greater than a specified value, $1/\epsilon$, and
3. The iteration parameter greater than $W_{\max}$ where the k^{th} double-sweep parameter is $\frac{W_{\min}}{X^{k-1}}$ and X is specified, $0 < X \leq 1$.

*The studies were initiated by R. K. Nevins. Verification of the validity of one double-sweep was made by S. W. Kitchen, J. A. Archibald, J. P. Jewett, and other users of CURE at KAPL.

Recommended values for $1/\xi$ and X are 100 and 0.1, respectively. These standard values are used when only $t_{\max}$ is specified.

A significant consequence of the one-double-sweep method, aside from reduced time requirements, is that an efficient program can now be developed without memory-contained difference equation coefficients. Recursion parameters for vertical line inversion may be calculated during the horizontal sweep, so that difference equation coefficients are needed only for the horizontal line inversion. They may be read into fast memory as needed without tape backspacing during the group flux iteration. For example, if the CURE program were rewritten to include this feature, the number of points permitted would be increased from 3300 to more than 10,000 with no loss in calculation time per mesh point.

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APPENDIX B

SAMPLE PROBLEM

A. The Problem

The sample test problem SICK is included as an illustration. Any similarities between it and a real reactor are coincidental.

SICK - PICTURE OF THE "REACTOR"

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B. Input

```

8000 BCD LSICK
8001 DEC 500.
      DEC 1,20453.0536,1.,0,2,0,3,0,2,144.,0,0,.65,.75
      DEC 1,2000.,12,10.,21.,45,25,.01,26,.54,75,.8
      DEC 10,7100.29470,1.,0,2,0,3,0,2,30.,0,0,.65,.75
      DEC 1,800.,12,10.,21.,44,25,.02,26,.54,75,.8
      DEC 18,354.4600,1,0,2,0,3,0,1,0,0,0,.6,.7
      DEC 21,1.,75,.8
      DEC 19,3022.4579,1,0,2,0,3,0,1,0,0,0,.6,.7
      DEC 21.,5,26,.5,77,.8
      DEC 79,1,1.,029484,2,3,.039312,4,4,.04457,5,6,.05943
      DEC 7,7.,19867,8,9,.2649,79
      DEC 79,10,10.,04248,11,11,.03894,12,12;.02832,13,13,.3446
      DEC 14,14,.3159,15,15,.2298,79
14400 DEC 0,0,3,0
      DEC 11,16,14,17,0
      DEC 12,2,15,2,16,2,17,2,0
      DEC 1,6,1.,1.,7,10,.95,.95,11,17,.90,.90,0
18000 DEC 1,15,2.,2.,1.,1.,2.,2.,1.,1.,0,0,0
19000 DEC 6.3,.2,70.
      DEC 1,15,.18,0
1007 DEC 3
1010 BCD LRZ
1020 DEC .5
1032 DEC 1 DO BURNOUT
22000 DEC 990,1,1,19,1,17,58,9,17,19,9,1,19,1,1,19,99C
      DEC 993,1,1,9,19,0,2,3,4,18
      DEC 0,3,1,3,1,4,6,4,6,8,7
      DEC 0,5,1,3,2,4,6,5,6,8,8
      DEC 0,7,1,3,3,4,6,6,6,8,9
      DEC 0,9,1,3,10,4,5,18,5,8,13
      DEC 0,11,1,3,11,5,8,14
      DEC 0,12,1,3,16,5,8,17
      DEC 0,13,1,3,12,5,8,15
      DEC 0,15,1,3,19,5,8,19,0,16,3,5,19,993,999
25000 DEC 996,1,3,2.,3,5,.25,5,6,2.,6,8,3.,3,9,.5,996
      DEC 997,1,2.,5,2,3,.25,3,4,4.,4,9,8.,9,11,3.,11,12,4.5
      DEC 12,13,1.,13,15,2.,15,16,.25,16,17,.5,997
      TRA 2,4

```

C. On-Line Output

SICK	THE CALCULATED EFFECTIVE TEMPERATURE FOR REGION 10	IS	2061.72	IN DEGREES F.	1623 DEGREES F WILL BE USED.
SICK	THE CALCULATED EFFECTIVE TEMPERATURE FOR REGION 11	IS	2061.72	IN DEGREES F.	1623 DEGREES F WILL BE USED.
SICK	THE CALCULATED EFFECTIVE TEMPERATURE FOR REGION 12	IS	2061.72	IN DEGREES F.	1623 DEGREES F WILL BE USED.
SICK	THE CALCULATED EFFECTIVE TEMPERATURE FOR REGION 13	IS	2061.72	IN DEGREES F.	1623 DEGREES F WILL BE USED.
SICK	THE CALCULATED EFFECTIVE TEMPERATURE FOR REGION 14	IS	2061.72	IN DEGREES F.	1623 DEGREES F WILL BE USED.
SICK	THE CALCULATED EFFECTIVE TEMPERATURE FOR REGION 15	IS	2061.72	IN DEGREES F.	1623 DEGREES F WILL BE USED.
SICK	THE CALCULATED EFFECTIVE TEMPERATURE FOR REGION 16	IS	2061.72	IN DEGREES F.	1623 DEGREES F WILL BE USED.
SICK	THE CALCULATED EFFECTIVE TEMPERATURE FOR REGION 17	IS	2061.72	IN DEGREES F.	1623 DEGREES F WILL BE USED.

CURE 2C 15FEB59

SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
+8.16240	+0	+0	+1	-3	+5 +.33638515	+2 +.53455667	+6	+7

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
+ .30138	+ .00000	+ .00000	+28.18578	+8	+15	+4.83619	+3	+7	+0 +.69908982

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION +1

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
+1	+4 +.18119648	-1 +.31399999	+1	+3 +.88587951	-1 +.32042310
+1	+3 +.76592995	-1 -.32136209	+0	+0	+0

SOURCE CN TAPE 3

KAPL-1885

CURE 2C	15FEB59								SICK
NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J	
+7.02047	+5 +.13817140	+2 +.42670157	+7	+7	+4 +.49741704	+2 +.25602094	+7	+7	

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
+.35040	+1.66666	+.00000	+12.33638	+8	+15	+5.46285	+4	+9	-0 +.35802169

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION +2

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
+1	+3 +.52431693	-1 +.31999999	+1	+3 +.17881454	-1 +.32042310
+1	+2 +.36084425	-1 +.32136209	+0	+0	+0

SOURCE ON TAPE 5

CURE 2C 15FEB59

SICK

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NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
+6.52215	+4 +.57597711	+2 +.37079396	+7	+7	+ 3 +.55068782	+2 +.11614364	+7	+7

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
+ .37717	+2.14286	+ .28571	+8.94514	+4	+9	+4.93358	+8	+15	-0 +.29643162

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION +3

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
+1	+3 +.34676583	-1 +.31999999	+1	+3 +.12682172	-1 +.32042310
+1	+2 +.23138291	-1 +.32136209	+0	+0	+0

SOURCE ON TAPE 3

KAPL-1885

CURE 2C 15FEB59

SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
+6.37932	+3 +.74248705	+2 -.16573003	+7	+8	+3 +.34013135	+1 -.92948760	+7	+8

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
+.38562	+1.94444	+.16666	+6.59534	+7	+8	+4.76125	+1	+14	.0 +.18629704

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION +4

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
+1	+3 +.17480702	-1 +.31999999	+1	+2 +.70830431	-1 +.32042310
+1	+2 +.10745272	-1 +.32136209	+0	+0	+0

SOURCE ON TAPE 5

KAPL-1885

CURE 2C 15FEB59

SICK

82

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
+6.36426	+3 +.13432151	+1 +.57473419	+7	+5	+2 +.30355599	+1 +.31309928	+7	+5

K EFF	ALPEA	BETA	MAX MU	I	J	MIN NU	I	J	ERROR RATIO
+.38653	+1.91489	+.14893	+6.97478	+1	+14	+6.27757	+3	+3	-1 +.50670608

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION +5

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
+1	+2 +.51413670	-1 +.31999999	+1	+2 +.17103554	-1 +.32042310
+1	+1 +.34067522	-1 +.32136209	+0	+0	+0

SOURCE ON TAPE 3

KAPL-1885

CURE 2C	15FEB59									SICK
NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J		
+6.36186	+2 +.23362857	+1 +.21522292	+7	+5	+1 +.55232874	+0 -.88722705	+7	+9		
K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO	
+ .38668	+1.91057	+ .14634	+6.47232	+3	+15	+6.14575	+4	+9	-1 +.26115484	

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION +6

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
+1	+2 +.25059856	-1 +.31999999	+1	+1 +.97869987	-1 +.32042310
+1	+1 +.19423229	-1 +.32136209	+0	+0	+0

SOURCE ON TAPE 5

CURE 2C 15FEB59

SICK

78

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
+6.36543	+1 +.87656630	+1 -.15808417	+7	+8	+1 +.23322894	+0 -.83606719	+7	+8

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
+.38646	+1.90993	+.14596	+6.49471	+4	+9	+6.26655	+1	+15	-1 +.17842248

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION +7

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
+1	+2 +.10763154	-1 +.31999999	+1	+1 +.50471918	-1 +.32042310
+1	+0 +.92705042	-1 +.32136209	+0	+0	+0

SOURCE ON TAPE 3

KAPL-1885

CURE 2C	15FEB59								SICK
NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J	
+6.36370	+1 +.16759250	+0 +.59632306	+7	+5	-0 +.35198004	-0 +.29947280	+7	+5	
K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
+ .38657	+1.90984	+ .14590	+6.45414	+3	+15	+6.31223	+4	+9	-1 +.11083059

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION +8

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
+1	+1 +.63565567	-1 +.31999999	+1	+1 +.29402963	-1 +.32042310
+1	+0 +.59263790	-1 +.32136209	+0	+0	+0

SOURCE ON TAPE 5

CURE 2C 15FEB59

SICK

98

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
+6.36306	+0 +.74640439	-0 +.42129523	+7	+5	-0 +.14571038	-0 +.17503738	+7	+5

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
+38660	+1.90983	+1.14590	+6.39628	+4	+9	+6.32919	+1	+15	-2 +.52721053

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION +9

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
+1	+1 +.40858800	-1 +.31939999	+1	+1 +.17601307	-1 +.32042310
+1	-0 +.33492297	-1 +.32136209	+0	+0	+0

SOURCE ON TAPE 3

KAPL-1885

CURE 2C 15 FEB59

SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
+6.36355	-0 +.30726359	-0 -.22567316	+7	+8	-1 +.79513384	-0 -.11760711	+8	+8

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
+38657	+1.90983	+1.14590	+6.37765	+3	+15	+6.35163	+4	+9	-2 +.20438358

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION +10

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
+1	+1 +.19161835	-1 +.31999999	+1	+0 +.92080861	-1 +.32042310
+1	-0 +.20709597	-1 +.32136209	+0	+0	+0

SOURCE ON TAPE 5

KAPL-1885

Q+D BURNOUT IS FINISHED B02 2-15-59

08
08

KAPL-1885

D. Off-Line Output

SICK				T EFF	F. BAR	B
1	1.29361	.84483	1.44539	1255.89340	.73352	.00000
2	1.29361	.84483	1.44539	1255.89340	.73352	.00000
3	1.29361	.84483	1.44539	1255.89340	.73352	.00000
4	1.29361	.84483	1.44539	1255.89340	.73352	.00000
5	1.29361	.84483	1.44539	1255.89340	.73352	.00000
6	1.29361	.84483	1.44539	1255.89340	.73352	.00000
7	1.29361	.84483	1.44539	1255.89340	.73352	.00000
8	1.29361	.84483	1.44539	1255.89340	.73352	.00000
9	1.29361	.84483	1.44539	1255.89340	.73352	.00000
10	1.29361	.78436	1.18007	1623.00000	.61634	.00000
11	1.29361	.78436	1.18007	1623.00000	.61634	.00000
12	1.29361	.78436	1.18007	1623.00000	.61634	.00000
13	1.29361	.78436	1.18007	1623.00000	.61634	.00000
14	1.29361	.78436	1.18007	1623.00000	.61634	.00000
15	1.29361	.78436	1.18007	1623.00000	.61634	.00000
18	.00000	.00000	.00000	517.50923	.00000	.00000
19	.00000	.00000	.00000	526.26779	.00000	.00000
16	1.29361	.78436	1.18007	1623.00000	.61634	.00000
17	1.29361	.78436	1.18007	1623.00000	.61634	.00000

WOX7 15 FEB. 1959 1

SICK	L	D	E	A	F	Z
	1	1.52834 .90814 .41493	.02921 .02921 .02909	.02921 .04114 .15435	.00000 .00497 .06976	.21128 .19329 .25307
	2	1.52834 .90814 .41493	.02921 .02921 .02909	.02921 .04114 .15435	.00000 .00497 .06976	.21128 .19329 .25307
	3	1.52834 .90814 .41493	.02921 .02921 .02909	.02921 .04114 .15435	.00000 .00497 .06976	.21128 .19329 .25307
	4	1.52834 .90814 .41493	.02921 .02921 .02909	.02921 .04114 .15435	.00000 .00497 .06976	.21128 .19329 .25307
	5	1.52834 .90814 .41493	.02921 .02921 .02909	.02921 .04114 .15435	.00000 .00497 .06976	.21128 .19329 .25307
	6	1.52834 .90814 .41493	.02921 .02921 .02909	.02921 .04114 .15435	.00000 .00497 .06976	.21128 .19329 .25307
	7	1.52834 .90814 .41493	.02921 .02921 .02909	.02921 .04114 .15435	.00000 .00497 .06976	.21128 .19329 .25307
	8	1.52834 .90814 .41493	.02921 .02921 .02909	.02921 .04114 .15435	.00000 .00497 .06976	.21128 .19329 .25307
	9	1.52834 .90814 .41493	.02921 .02921 .02909	.02921 .04114 .15435	.00000 .00497 .06976	.21128 .19329 .25307
	10	1.52267 .90035 .38756	.02878 .02878 .02880	.02878 .04923 .25546	.00000 .00540 .07464	.20934 .21054 .31465
	11	1.52267 .90035 .38756	.02878 .02878 .02880	.02878 .04923 .25546	.00000 .00540 .07464	.20934 .21054 .31465
	12	1.52267 .90035 .38756	.01871 .02160	.02878 .04923 .25546	.00000 .00540 .07464	.20934 .21054 .31465
	13	1.52267 .90035 .38756	.02878 .02880	.02878 .04923 .25546	.00000 .00540 .07464	.20934 .21054 .31465
	14	1.52267 .90035 .38756	.02878 .02880	.02878 .04923 .25546	.00000 .00540 .07464	.20934 .21054 .31465

WOX7 15 FEB. 1959 1

SICK	L	D	E	A	F	Z
	15	1.52267		.02878	.00000	.20934
		.90035	.01871	.04923	.00540	.21054
		.38756	.02160	.25546	.07464	.31465
	16	1.52267		.02878	.00000	.20934
		.90035	.01871	.04923	.00540	.21054
		.38756	.02160	.25546	.07464	.31465
	17	1.52267		.02878	.00000	.20934
		.90035	.01871	.04923	.00540	.21054
		.38756	.02160	.25546	.07464	.31465
	18	2.06680		.05511	.00000	.33751
		.75813	.05511	.06291	.00000	.21839
		.22803	.06197	.01208	.00000	.05249
	19	1.56392		.03154	.00000	.22210
		.90214	.03154	.03196	.00000	.16979
		.38673	.03125	.00907	.00000	.05921

GENERAL MATERIAL INDEPENDENT INPUT

ID	SICK
GENERAL TEMP.	3 50000
GENERAL XENON OPTION	
REACTOR OPERATING POWER	00000
GENERAL DENSITY	00000
SPECIAL TABLE CONTROL	3

ACTUAL MASSES AND CONCENTRATION

INITIAL			CURRENT			STRUCTURAL			CONCENTRATION		
U235	BLO	PDT/PT	U235	BLC	PDT/PT	BLO	U235	BLO			
1 2 58968	29484	1 10000	2 58968	29484	1 10000	00000	1 10000	1 10000			
2 2 78624	39312	1 10000	2 78624	39312	1 10000	00000	1 10000	1 10000			
3 2 78624	39312	1 10000	2 78624	39312	1 10000	00000	1 10000	1 10000			
4 2 89140	44570	1 10000	2 89140	44570	1 10000	00000	1 10000	1 10000			
5 3 11836	59430	1 10000	3 11836	59430	1 10000	00000	1 10000	1 10000			
6 3 11836	59430	1 10000	3 11836	59430	1 10000	00000	1 10000	1 10000			
7 3 39734	1 19867	1 10000	3 39734	1 19867	1 10000	00000	1 10000	1 10000			
8 3 52980	1 26490	1 10000	3 52980	1 26490	1 10000	00000	1 10000	1 10000			
9 3 52980	1 26490	1 10000	3 52980	1 26490	1 10000	00000	1 10000	1 10000			
10 2 33984	42480	1 10000	2 33984	42480	1 10000	00000	1 10000	1 10000			
11 2 31152	38940	1 10000	2 31152	38940	1 10000	00000	1 10000	1 10000			
12 2 22656	28320	1 10000	2 22656	28320	1 10000	00000	1 10000	1 10000			
13 3 27568	1 34460	1 10000	3 27568	1 34460	1 10000	00000	1 10000	1 10000			
14 3 25272	1 31590	1 10000	3 25272	1 31590	1 10000	00000	1 10000	1 10000			
15 3 18384	1 22980	1 10000	3 18384	1 22980	1 10000	00000	1 10000	1 10000			
16 2 31152	38940	1 10000	2 31152	38940	1 10000	00000	1 10000	1 10000			
17 3 25272	1 31590	1 10000	3 25272	1 31590	1 10000	00000	1 10000	1 10000			
18 00000	00000	-39 00000	00000	00000	00000	00000	00000	00000			
19 00000	00000	-39 00000	00000	00000	00000	00000	00000	00000			

SELF-SHIELDING PARAMETERS

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L	KU2, KPH2	KU3, KPH3	GAMMAU2	GAMMAU3	KPD2	KPD3	GAMMAPD2	GAMMAPD3	GAMMAPH2	GAMMAPH3
1	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
2	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
3	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
4	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
5	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
6	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
7	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
8	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
9	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
10	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
11	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
12	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
13	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
14	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
15	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
16	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
17	1 20000	1 20000	1 10000	1 10000	1 20000	1 20000	1 10000	1 10000	00000	00000
18	00000	00000	00000	00000	00000	00000	00000	00000	00000	00000
19	00000	00000	00000	00000	00000	00000	00000	00000	00000	00000

SELF-SHIELDING FACTORS

EFFECTIVE MASSES

	FU2	FU3	FP2	FP3	KF	KP	U235	H10	DISCRETE RATIO
1	1 10000	1 10000	1 10000	1 10000	00000	00000	2 58968	29484	1 10000
2	1 10000	1 10000	1 10000	1 10000	00000	00000	2 78624	39312	1 10000
3	1 10000	1 10000	1 10000	1 10000	00000	00000	2 78624	39312	1 10000
4	1 10000	1 10000	1 10000	1 10000	00000	00000	2 89140	44570	1 10000
5	1 10000	1 10000	1 10000	1 10000	00000	00000	3 11886	59430	1 10000
6	1 10000	1 10000	1 10000	1 10000	00000	00000	3 11886	59430	1 10000
7	1 10000	1 10000	1 10000	1 10000	00000	00000	3 39734	1 19867	1 10000
8	1 10000	1 10000	1 10000	1 10000	00000	00000	3 52980	1 26490	1 10000
9	1 10000	1 10000	1 10000	1 10000	00000	00000	3 52980	1 26490	1 10000
10	1 10000	1 10000	1 10000	1 10000	00000	00000	2 33984	42430	1 10000
11	1 10000	1 10000	1 10000	1 10000	00000	00000	2 31152	38940	1 10000
12	1 10000	1 10000	1 10000	1 10000	00000	00000	2 22656	28320	1 10000
13	1 10000	1 10000	1 10000	1 10000	00000	00000	3 27568	1 34460	1 10000
14	1 10000	1 10000	1 10000	1 10000	00000	00000	3 25272	1 31590	1 10000
15	1 10000	1 10000	1 10000	1 10000	00000	00000	3 18384	1 22980	1 10000
16	1 10000	1 10000	1 10000	1 10000	00000	00000	2 31152	38940	1 10000
17	1 10000	1 10000	1 10000	1 10000	00000	00000	3 25272	1 31590	1 10000
18	00000	00000	00000	00000	00000	00000	00000	00000	00000
19	00000	00000	00000	00000	00000	00000	00000	00000	00000

L	VCC	TEMP. ACT.	TEMP. EFF	DENSITY	TAUL	TAU2	THINNESS	LO
1	3 60319	3 50000	4 12559	80000	2 52325	2 31217	00000	
2	3 80425	3 50000	4 12559	80000	2 52325	2 31217	00000	
3	3 80425	3 50000	4 12559	80000	2 52325	2 31217	00000	
4	3 91182	3 50000	4 12559	80000	2 52325	2 31217	00000	
5	4 12158	3 50000	4 12559	80000	2 52325	2 31217	00000	
6	4 12158	3 50000	4 12559	80000	2 52325	2 31217	00000	
7	4 40644	3 50000	4 12559	80000	2 52325	2 31217	00000	
8	4 54193	3 50000	4 12559	80000	2 52325	2 31217	00000	
9	4 54193	3 50000	4 12559	80000	2 52325	2 31217	00000	
10	3 30162	3 50000	4 16230	80000	2 52906	2 31267	00000	
11	3 27649	3 50000	4 16230	80000	2 52906	2 31267	00000	
12	3 20108	3 50000	4 16230	80000	2 52906	2 31267	00000	
13	4 24468	3 50000	4 16230	80000	2 52906	2 31267	00000	
14	4 22430	3 50000	4 16230	80000	2 52906	2 31267	00000	
15	4 16316	3 50000	4 16230	80000	2 52906	2 31267	00000	
16	3 27649	3 50000	4 16230	80000	2 52906	2 31267	00000	11
17	4 22430	3 50000	4 16230	80000	2 52906	2 31267	00000	14
18	3 35446	3 50000	3-46000	80000	2 37500	2 12234	00000	
19	4 30225	3 50000	3-46000	80000	2 49582	2 28869	00000	

F FACTORS				XENON	PMW	POWER
L	OPTION	F1	F2	OPTION		FRACTIONS
1	3	65000	75000	2	1 42457	1 10000
2	3	65000	75000	2	1 56609	1 10000
3	3	65000	75000	2	1 56609	1 10000
4	3	65000	75000	2	1 64181	1 10000
5	3	65000	75000	2	1 85579	1 10000
6	3	65000	75000	2	1 85579	1 10000
7	3	65000	75000	2	2 28608	1 10000
8	3	65000	75000	2	2 38146	1 10000
9	3	65000	75000	2	2 38146	1 10000
10	3	65000	75000	2	1 12744	1 10000
11	3	65000	75000	2	1 11682	1 10000
12	2	65000	75000	2	84960	1 10000
13	3	65000	75000	2	2 10338	1 10000
14	3	65000	75000	2	1 94770	1 10000
15	2	65000	75000	2	1 68940	1 10000
16	2	65000	75000	2	1 11682	1 10000
17	2	65000	75000	2	1 94770	1 10000
18	3	60000	70000	1	00000	00000
19	3	60000	70000	1	00000	00000

STRUCTUAL INPUT

	WATER	ZIRCONIUM	ALUMINUM	IRON	S. STEEL	ZIRCALOY	VOID	ETHYLENE	INCONEL
1	45000	00000	00000	00000	-1 10000	54000	00000	00000	00000
2	45000	00000	00000	00000	-1 10000	54000	00000	00000	00000
3	45000	00000	00000	00000	-1 10000	54000	00000	00000	00000
4	45000	00000	00000	00000	-1 10000	54000	00000	00000	00000
5	45000	00000	00000	00000	-1 10000	54000	00000	00000	00000
6	45000	00000	00000	00000	-1 10000	54000	00000	00000	00000
7	45000	00000	00000	00000	-1 10000	54000	00000	00000	00000
8	45000	00000	00000	00000	-1 10000	54000	00000	00000	00000
9	45000	00000	00000	00000	-1 10000	54000	00000	00000	00000
10	44000	00000	00000	00000	-1 20000	54000	00000	00000	00000
11	44000	00000	00000	00000	-1 20000	54000	00000	00000	00000
12	44000	00000	00000	00000	-1 20000	54000	00000	00000	00000
13	44000	00000	00000	00000	-1 20000	54000	00000	00000	00000
14	44000	00000	00000	00000	-1 20000	54000	00000	00000	00000
15	44000	00000	00000	00000	-1 20000	54000	00000	00000	00000
16	44000	00000	00000	00000	-1 20000	54000	00000	00000	00000
17	44000	00000	00000	00000	-1 20000	54000	00000	00000	00000
18	1 10000	00000	00000	00000	00000	00000	00000	00000	00000
19	50000	00000	00000	00000	00000	50000	00000	00000	00000

TOPOLOGICAL MATERIAL EDIT

	1	2	3	4	5	6	7	8	9	10
17	59	59	59	59	59	59	59	59	59	59
16	19	19	19	19	19	19	19	19	59	59
15	19	19	18	18	19	19	19	19	59	59
14	12	12	18	18	15	15	15	19	59	59
13	12	12	18	18	15	15	15	19	59	59
12	16	16	18	18	17	17	17	19	59	59
11	11	11	18	18	14	14	14	19	59	59
10	10	10	18	18	13	13	13	19	59	59
9	10	10	18	18	13	13	13	19	59	59
8	3	3	18	6	6	9	9	19	59	59
7	3	3	18	6	6	9	9	19	59	59
6	2	2	18	5	5	8	8	19	59	59
5	2	2	18	5	5	8	8	19	59	59
4	1	1	18	4	4	7	7	19	59	59
3	1	1	18	4	4	7	7	19	59	59
2	19	19	18	19	19	19	19	19	59	59
1	19	19	19	19	19	19	19	19	59	59
0	59	59	59	59	59	59	59	59	59	59

CURE 2C 15FEB59 SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J	
8.16240	0	0	1	-0	5 .33638515	2 .53455667	6	7	
K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
30138	.00000	.00000	28.18578	8	15	4.83619	3	7	0 .69908982

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION 1

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
1	4 .18119648	-1 .31999999	1	3 .88587951	-1 .32042310
1	3 .76592995	-1 .32136209	0	0	0

CURE 2C 15FEB59 SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J	
7.02047	5 .13817140	2 .42670157	7	7	4 .49741704	2 .25602094	7	7	
K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
.35040	1.66666	.00000	12.33638	8	15	5.46285	4	9	-0 .35802169

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION 2

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
1	3 .52431693	-1 .31999999	1	3 .17881454	-1 .32042310
1	2 .36084425	-1 .32136209	0	0	0

CURE 2C 15FEB59

SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J	
6.52215	4 .57597711	2 .37079396	7	7	3 .55068782	2 .11614364	7	7	
K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
.37717	2.14286	.28571	8.94514	4	9	4.93358	8	15	-0 .29643162

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION 3

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
1	3 .34676583	-1 .31999999	1	3 .12682172	-1 .32042310
1	2 .23138291	-1 .32136209	0	0	0

CURE 2C 15FEB59

SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J	
6.37932	3 .74248705	2 -.16573003	7	8	3 .34013135	1 -.92948760	7	8	
K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
.38562	1.94444	.16666	6.59534	7	8	4.76125	1	14	-0 .18629704

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION 4

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
1	3 .17480702	-1 .31999999	1	2 .70830431	-1 .32042310
1	2 .10745272	-1 .32136209	0	0	0

CURE 2C 15FEB59 SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
6.36426	3 .13432151	1 .57473419	7	5	2 .30355599	1 .31309928	7	5

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
.38653	1.91439	.14893	6.97478	1	14	6.27757	3	3	-1 .50670608

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION 5

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
1	2 .51413670	-1 .31999999	1	2 .17103554	-1 .32042310
1	1 .34667522	-1 .32136209	0	0	0

CURE 2C 15FEB59 SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
6.36186	2 .23362857	1 .21522292	7	5	1 .55232874	0 -.88722705	7	9

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
.38668	1.91057	.14634	6.47232	3	15	6.14575	4	9	-1 .26115484

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION 6

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
1	2 .25059856	-1 .31999999	1	1 .97869987	-1 .32042310
1	1 .19423229	-1 .32136209	0	0	0

CURE 2C 15FEB59

SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
6.36543	1 .87656630	1 -.15808417	7	8	1 .23322894	0 -.83606719	7	8

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
.38646	1.90993	.14596	6.49471	4	9	6.26655	1	15	-1 .17842248

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION 7

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
2	.10763154	-1 .31999999	1	.50471918	-1 .32042310
0	.92705041	-1 .32136209	0	0	0

CURE 2C 15FEB59

SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
6.36370	1 .16759250	0 .59632306	7	5	-0 .35198004	-0 .29947280	7	5

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
.38657	1.90984	.14590	6.45414	3	15	6.31223	4	9	-1 .11083059

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION 8

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
1	.63565567	-1 .31999999	1	.29402963	-1 .32042310
0	.59263790	-1 .32136209	0	0	0

CURE 2C 15FEB59 SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
6.36306	0 .74640439	-0 .42129523	7	5	-0 .14571038	-0 .17503738	7	5

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
.38660	1.90983	.14590	6.39628	4	9	6.32919	1	15	-2 .52721053

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION 9

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
1	1 .40868800	-1 .31999999	1	1 .17601307	-1 .32042310
1	-0 .33492297	-1 .32136209	0	0	0

CURE 2C 15FEB59 SICK

NU	SUM DELTA S SQRD	MAX DELTA S	I	J	SUM S BAR-S SQRD	MAX S BAR-S	I	J
6.36355	-0 .30726359	-0 -.22567315	7	8	-1 .79513384	-0 -.11760711	8	8

K EFF	ALPHA	BETA	MAX NU	I	J	MIN NU	I	J	ERROR RATIO
.38657	1.90983	.14590	6.37765	3	15	6.35163	4	9	-2 .20438358

FLUX CONVERGENCE SUMMARY FOR POWER ITERATION 10

SWEEP	FLUX ERROR	W MIN	SWEEP	FLUX ERROR	W MIN
1	1 .19161835	-1 .31999999	1	0 .92080861	-1 .32042310
1	-0 .20709597	-1 .32136209	0	0	0

GENERAL MESH DATA

I	9		
J	17	B	.00000
NO. OF WDS. IN COLLAPSED MESH	180		
NO. OF WDS. IN EA. RCD. OF K MESH	360	W MINIMUM	.00000
NO. OF WDS. IN EA. RCD. OF COEF. MESH	450	CHI	.10000
PERIODIC	NO	N-FLUX CONVERGENCE DIVISOR	10.0
NO. OF RCDS. -K MESH = NO. RCDS. -COEF. MESH	2		
NO. OF LETHARGY GROUPS	3	Q AND D BURNOUT	YES
PROBLEM NO.	SICK		
TYPE OF GEOMETRY	R-Z		
IS SOURCE-FLUX GUESS AVAILABLE	YES		
ADDRESS OF FIRST WORD IN S-MESH	3120		
MAX FLUX ITERATNS FACTOR	1.00		
MAX NO. FLUX ITER. FOR ANY GP./PW. ITER.	1.0	SUFFIX FOR POWER ITERATION NO.	
PERPENDICULAR BUCKLING	.00000000	NU	6.363555
		VOLUME OF THE CORE	4570.125
SOURCE EXTRAPOLATION PARAMETER	2.50	EXTRAPOLATE	YES
NO. OF GPS. SKIPPED IN COMPUTING F	1	TSCHEBYSCHIEFF P-2	4 .11034999
POWER CONVERGENCE CRITERION	.50000	TSCHEBYSCHIEFF P-1	4 .28889999
ARE SIGMAS MACHINE CALCULATED	YES		
MAXIMUM FUEL INDEX	17	FLUX ITERATION INDEX	1.0000000
		GROUP INDEX	3
D MAX FOR PEACEMAN-RACHFORD	3294	POWER ITERATION INDEX	10

TOPOLOGICAL POWER EDIT

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POWER ITERATION		10							PROBLEM NO. SICK	
J	I	1	2	3	4	5	6	7	8	9
17	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
16	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
15	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
	.000000	.162513	.163126	.163126	.181175	.000000	.000000	.000000	.000000	.172436
14	.000000	.180684	.184211	.184211	.205168	.000000	.000000	.000000	.000000	.195480
	.000000	.180684	.184211	.184211	.205168	.000000	.000000	.000000	.000000	.195480
13	.000000	.240459	.244970	.244970	.271586	.000000	.000000	.000000	.000000	.258905
	.000000	.240459	.244970	.244970	.271586	.000000	.000000	.000000	.000000	.258905
12	.000000	.291385	.296028	.296028	.324131	.000000	.000000	.000000	.000000	.309538
	.000000	.291385	.296028	.296028	.324131	.000000	.000000	.000000	.000000	.309538
11	.000000	.510632	.517827	.517827	.563781	.000000	.000000	.000000	.000000	.538904
	.000000	.510632	.517827	.517827	.563781	.000000	.000000	.000000	.000000	.538904
10	.000000	.698243	.706816	.706816	.765143	.000000	.000000	.000000	.000000	.731781
	.000000	.698243	.706816	.706816	.765143	.000000	.000000	.000000	.000000	.731781
9	.000000	1.068940	1.072506	1.072506	1.105533	.000000	.000000	.000000	.000000	1.059495
	.000000	.994476	.997874	.997874	1.028930	.000000	.000000	1.018857	.985993	.985993
8	.000000	1.762429	1.759218	1.759218	1.772725	.000000	.000000	1.740275	1.695538	1.695538
	.000000	1.762429	1.759218	1.759218	1.772725	.000000	.000000	1.740275	1.695538	1.695538
7	.000000	2.133421	2.129379	2.129379	2.145298	.000000	.000000	2.106058	2.051971	2.051971
	.000000	2.133421	2.129379	2.129379	2.145298	.000000	.000000	2.106058	2.051971	2.051971
6	.000000	2.140478	2.136422	2.136422	2.152394	.000000	.000000	2.113032	2.058763	2.058763
	.000000	2.140478	2.136422	2.136422	2.152394	.000000	.000000	2.113032	2.058763	2.058763
5	.000000	1.785377	1.781992	1.781992	1.795312	.000000	.000000	1.762487	1.717219	1.717219
	.000000	1.785377	1.781992	1.781992	1.795312	.000000	.000000	1.762487	1.717219	1.717219
4	.000000	1.135228	1.132966	1.132966	1.141069	.000000	.000000	1.120234	1.091589	1.091589
	.000000	1.135228	1.132966	1.132966	1.141069	.000000	.000000	1.120234	1.091589	1.091589
3	.000000	.834438	.830584	.830584	.831755	.000000	.000000	.816341	.796892	.796892
	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
0	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

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TOPOLOGICAL POWER EDIT

POWER ITERATION		10							PROBLEM NO.	SICK
J	I	6	7	8	9	10	10	10	10	10
17	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
16	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
15	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
	.133574	.133574	.104838	.104838	.081942	.000000	.000000	.000000	.000000	.000000
14	.148901	.148901	.115421	.115421	.092736	.000000	.000000	.000000	.000000	.000000
	.148901	.148901	.115421	.115421	.092736	.000000	.000000	.000000	.000000	.000000
13	.198306	.198306	.153691	.153691	.122807	.000000	.000000	.000000	.000000	.000000
	.198306	.198306	.153691	.153691	.122807	.000000	.000000	.000000	.000000	.000000
12	.240485	.240485	.186701	.186701	.146713	.000000	.000000	.000000	.000000	.000000
	.240485	.240485	.186701	.186701	.146713	.000000	.000000	.000000	.000000	.000000
11	.422363	.422363	.328674	.328674	.256194	.000000	.000000	.000000	.000000	.000000
	.422363	.422363	.328674	.328674	.256194	.000000	.000000	.000000	.000000	.000000
10	.578130	.578130	.451444	.451444	.352756	.000000	.000000	.000000	.000000	.000000
	.578130	.578130	.451444	.451444	.352756	.000000	.000000	.000000	.000000	.000000
9	.883508	.883508	.696601	.696601	.539849	.000000	.000000	.000000	.000000	.000000
	.821928	.821928	.648032	.648032	.502479	.000000	.000000	.000000	.000000	.000000
8	1.457302	1.457302	1.159358	1.159358	.897054	.000000	.000000	.000000	.000000	.000000
	1.457302	1.457302	1.159358	1.159358	.897054	.000000	.000000	.000000	.000000	.000000
7	1.764350	1.764350	1.404059	1.404059	1.086645	.000000	.000000	.000000	.000000	.000000
	1.764350	1.764350	1.404059	1.404059	1.086645	.000000	.000000	.000000	.000000	.000000
6	1.770209	1.770209	1.408738	1.408738	1.090277	.000000	.000000	.000000	.000000	.000000
	1.770209	1.770209	1.408738	1.408738	1.090277	.000000	.000000	.000000	.000000	.000000
5	1.476552	1.476552	1.175062	1.175062	.909447	.000000	.000000	.000000	.000000	.000000
	1.476552	1.476552	1.175062	1.175062	.090447	.000000	.000000	.000000	.000000	.000000
4	.939067	.939067	.747560	.747560	.578751	.000000	.000000	.000000	.000000	.000000
	.939067	.939067	.747560	.747560	.578751	.000000	.000000	.000000	.000000	.000000
3	.691387	.691387	.551366	.551366	.421687	.000000	.000000	.000000	.000000	.000000
	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
2	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
1	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
0	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000
	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

TOPOLOGICAL FLUX EDIT

PROBLEM NO. SICK

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GROUP 1

	1	2	3	4	5	6	7	8	9	10
17	3.221703	3.172385	3.032795	3.007138	2.986999	2.722223	2.195091	1.561898	1.464133	.000000
16	3.464704	3.411421	3.258377	3.252341	3.211663	2.927455	2.360446	1.679679	1.567836	.000000
15	3.597836	3.542127	3.376806	3.358074	3.330615	3.039657	2.450987	1.743146	1.623627	.000000
14	4.756999	4.678759	4.434835	4.400270	4.380670	4.019257	3.242242	2.298591	2.141471	.000000
13	6.114298	6.010877	5.690942	5.652960	5.622030	5.168003	4.170427	2.950814	2.750976	.000000
12	6.884168	6.766528	6.403315	6.361665	6.325897	5.919336	4.696412	3.319446	3.094807	.000000
11	11.040145	10.849328	10.258757	10.186996	10.135529	9.333581	7.530928	5.312027	4.948868	.000000
10	14.527863	14.275711	13.494218	13.403744	13.332373	12.277534	9.902839	6.978070	6.498539	.000000
9	18.624007	18.305435	17.329365	17.218337	17.110255	15.725652	12.673613	8.914254	8.296319	.000000
8	29.877106	29.372789	27.837752	27.671710	27.477870	25.206089	20.296266	14.249658	13.255772	.000000
7	36.122955	35.513229	33.656975	33.456247	33.222001	30.475058	24.538058	17.226602	16.021494	.000000
6	36.244303	35.632576	33.770039	33.558690	33.333711	30.577606	24.620478	17.284372	16.073090	.000000
5	30.238202	29.727878	28.174057	28.006110	27.810055	25.510698	20.540837	14.420367	13.408240	.000000
4	19.147488	18.824774	17.840770	17.733579	17.610820	16.153244	13.006662	9.132309	8.490470	.000000
3	12.316100	12.115197	11.515092	11.443167	11.349198	10.387574	8.364011	5.888663	5.478877	.000000
2	11.899358	11.666866	11.107126	11.057267	10.932373	10.003312	8.054623	5.678396	5.273771	.000000
1	11.026223	10.848077	10.332274	10.253549	10.168812	9.301177	7.489632	5.282877	4.918651	.000000
0	3.200000	.032000	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

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TOPOLOGICAL FLUX EDIT

PROBLEM NO. SICK

GROUP 2

	1	2	3	4	5	6	7	8	9	10
17	1.425865	1.403585	1.356594	1.335028	1.326085	1.182082	.936183	.646571	.594952	.000000
16	1.555305	1.529695	1.471885	1.542852	1.437692	1.288561	1.020632	.704889	.653058	.000000
15	1.615572	1.592485	1.534163	1.549955	1.499051	1.339478	1.059636	.733905	.673286	.000000
14	2.154771	2.130268	2.057564	2.027380	2.010606	1.787259	1.410677	.980647	.901950	.000000
13	2.871002	2.836493	2.736926	2.711802	2.674722	2.382795	1.881813	1.303555	1.199652	.000000
12	3.326349	3.284247	3.161489	3.135256	3.090679	2.762274	2.183051	1.505924	1.382709	.000000
11	5.593947	5.519800	5.303952	5.254511	5.187641	4.654180	3.682592	2.528381	2.319908	.000000
10	7.410028	7.310268	7.021553	6.956449	6.868979	6.171496	4.886811	3.352105	3.075346	.000000
9	9.591091	9.453030	9.047879	8.956982	8.860677	7.998182	6.341858	4.339754	3.978014	.000000
8	15.307605	15.079670	14.409829	14.260372	14.116369	12.780423	10.146534	6.935096	6.354760	.000000
7	18.490866	18.215517	17.406512	17.225896	17.052251	15.439538	12.258415	8.378433	7.676259	.000000
6	18.550939	18.274717	17.463092	17.281740	17.107748	15.489835	12.298382	8.405753	7.700506	.000000
5	15.470610	15.240285	14.563484	14.412122	14.267179	12.917898	10.256410	7.010118	6.421395	.000000
4	9.746222	9.601196	9.175034	9.079542	8.988556	8.138893	6.462467	4.416901	4.045668	.000000
3	6.183013	6.088771	5.812171	5.755029	5.696668	5.166359	4.103920	2.800283	2.564310	.000000
2	5.943682	5.850541	5.585905	5.560864	5.468074	4.966442	3.945705	2.689764	2.471613	.000000
1	5.444695	5.359842	5.115808	5.064223	5.014143	4.549735	3.614681	2.464552	2.255507	.000000
0	3.204231	.032042	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

TOPOLOGICAL FLUX EDIT

PROBLEM NO. SICK

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GROUP 3

	1	2	3	4	5	6	7	8	9	10
17	.231319	.232186	.273584	.269471	.259559	.188852	.148479	.116640	.121902	.000000
16	.235358	.234284	.273357	.390917	.257056	.191235	.150834	.119387	.130767	.000000
15	.225298	.228258	.270476	.299741	.254617	.184340	.144081	.119435	.112805	.000000
14	.224555	.233755	.283134	.256749	.266134	.184223	.140973	.124315	.124988	.000000
13	.298602	.310595	.373832	.367386	.351633	.245164	.187469	.164270	.163888	.000000
12	.372884	.385705	.453749	.485141	.428149	.306520	.235179	.199965	.198224	.000000
11	.670468	.690979	.803341	.825603	.759378	.552602	.425625	.356509	.352080	.000000
10	.934106	.959369	1.103051	1.124243	1.043845	.770804	.597002	.500227	.493879	.000000
9	1.556803	1.574296	1.673131	1.656917	1.589746	1.281612	1.007904	.822590	.798220	.000000
8	2.879424	2.888435	2.966599	2.904143	2.813630	2.372149	1.888657	1.526515	1.471546	.000000
7	3.488326	3.498341	3.592357	3.516830	3.407362	2.874351	2.289405	1.853357	1.784036	.000000
6	3.499941	3.510488	3.604310	3.528562	3.418705	2.883964	2.297098	1.857093	1.790015	.000000
5	2.919504	2.928294	3.006532	2.943373	2.851724	2.405716	1.916205	1.543187	1.493206	.000000
4	1.862827	1.368067	1.916692	1.876559	1.818515	1.535470	1.223522	.989014	.953285	.000000
3	1.439153	1.437188	1.459538	1.428886	1.389230	1.189346	.949627	.753396	.715865	.000000
2	1.451912	1.445847	1.465958	1.490040	1.387156	1.199916	.958709	.744384	.736667	.000000
1	1.395335	1.390087	1.397167	1.373124	1.337773	1.153367	.921379	.712707	.684837	.000000
0	3.213621	.032136	.000000	.000000	.000000	.000000	.000000	.000000	.000000	.000000

VOLUME OF CORE

4570.13

SICK

REGION NUMBER VOL, MATERIALS SUM K*FLUX, EACH MATERIAL/CORE VOLUME, GROUPS 1,2,3, AND 4 P L / P TOTAL POWER DENSITY

1	96.00	.43856	.22463	.04564	.02737	1.30289
2	128.00	.93498	.48111	.09525	.05750	2.05298
3	128.00	.77094	.39747	.07702	.04676	1.66962
4	145.13	.60817	.30886	.06141	.03703	1.16611
5	193.50	1.29668	.66146	.12807	.07777	1.83689
6	193.50	1.06927	.54637	.10357	.06326	1.49410
7	684.00	2.10544	1.04452	.20848	.12559	.83910
8	912.00	4.48922	2.23670	.43441	.26359	1.32089
9	912.00	3.70328	1.82672	.34953	.21358	1.07026
10	48.00	.14809	.07640	.01154	.00811	.77195
11	36.00	.06781	.03412	.00454	.00333	.42276
12	32.00	.03239	.01499	.00191	.00142	.20341
13	408.00	.90057	.44775	.06317	.04538	.50837
14	306.00	.41288	.19930	.02416	.01832	.27365
15	272.00	.19693	.08727	.01007	.00778	.13074
16	8.00	.01093	.00528	.00066	.00049	.28218
17	68.00	.06656	.03074	.00346	.00270	.18160
18	79.10	.33424	.17181	.03366	.00000	.00000
19	505.27	1.06320	.51046	.11256	.00000	.00000

P TOTAL

718.17245

SUM P FOR MATERIAL L / P TOTAL

1.00000

NU CRIT. 1 .62999999 DELTA NU -0 .19999999 DELTA F 2 .70000000

BO2 2-15-59		DEPLETION OUTPUT				SICK	
L	O	ACT MASS FUEL	ACT MASS BORON	PDT/PT	PDT-1/PT-1	UT	PT
1	2	.57052202	-0 .24580447	1 .10000000	1 .10000000	0 .96751124	0 .83368768
2	2	.74598999	-0 .29254057	1 .10000000	1 .10000000	0 .94880697	0 .74415083
3	2	.75350604	-0 .31029467	1 .10000000	1 .10000000	0 .95836646	0 .78931287
4	2	.86547896	-0 .37907604	1 .10000000	1 .10000000	0 .97092099	0 .85051839
5	3	.11341579	-0 .45728781	1 .10000000	1 .10000000	0 .95419653	0 .76945619
6	3	.11443175	-0 .48162925	1 .10000000	1 .10000000	0 .96274401	0 .81041436
7	3	.38854899	1 .17588511	1 .10000000	1 .10000000	0 .97787537	0 .88531289
8	3	.51134850	1 .21780959	1 .10000000	1 .10000000	0 .96517272	0 .82223328
9	3	.51484954	1 .22643315	1 .10000000	1 .10000000	0 .97178097	0 .85478729
10	2	.33416452	-0 .38775682	1 .10000000	1 .10000000	0 .98329959	0 .91279856
11	2	.30884311	-0 .37176622	1 .10000000	1 .10000000	0 .99140702	0 .95471554
12	2	.22556300	-0 .27660179	1 .10000000	1 .10000000	0 .99559945	0 .97670126
13	3	.27250307	1 .32374123	1 .10000000	1 .10000000	0 .98847604	0 .93946962
14	3	.25124823	1 .30617495	1 .10000000	1 .10000000	0 .99417631	0 .96921479
15	3	.18329529	1 .22618940	1 .10000000	1 .10000000	0 .99703709	0 .98428812
TOTAL	4	.27300478	2 .17965091	WEIGHTED AVER.		0 .97441413	0 .86891346

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Q+D BURNOUT IS FINISHED B02 2-15-59