AUG 25 1961

MASTER

Copy No

18

APAE MEMO NO. 289

AEC Research and
Development Report
UC-81, Reactors - Power
(Special Distribution)

BOBCAT

(PROGRAM NO. 56)

**CODE PREPARATION ANALYSIS
ON THE IBM-650**

ALCO PRODUCTS, INC.

NUCLEAR POWER ENGINEERING DEPARTMENT
P. O. BOX 414, SCHENECTADY 1, N. Y.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

APAE Memo No. 289

Copy No.

AEC Research and
Development Report

UC-81, Reactors-Power
(Special Distribution)

BOBCAT
(Program No. 56)
CODE PREPARATION ANALYSIS
ON THE IBM-650

By:

P. E. Bobe

R. L. Caton

Approved By:

W. S. Brown, Project Engineer

Issued: August 9, 1961

Contract No. AT(30-1)-2639
with U.S. Atomic Energy Commission
New York Operations Office

ALCO PRODUCTS, INC.
Nuclear Power Engineering Department
Post Office Box 414
Schenectady 1, N. Y.

AEC LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights: or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

ALCO LEGAL NOTICE

This report was prepared by Alco Products, Incorporated in the course of work under, or in connection with, Contract No. AT(30-1)-2639, issued by U.S. Atomic Energy Commission, NYOO; and subject only to the rights of the United States, under the provisions of this contract, Alco Products, Incorporated makes no warranty or representation, express or implied, and shall have no liability with respect to this report or any of its contents or with respect to the use thereof or with respect to whether any such use will infringe the rights of others.

DISTRIBUTION

External Copies

1 - 2

New York Operations Office
U. S. Atomic Energy Commission
376 Hudson Street
New York 14, New York

Attention: Chief, Army Reactors Staff
Reactor Division

3 - 5

U. S. Atomic Energy Commission
Washington 25, D. C.

Attention: Chief, Water Systems Project
Branch (Army Reactors)
Division of Reactor Development
Mail Station F-311

6

U. S. Atomic Energy Commission
Washington 25, D. C.

Attention: Chief, Evaluation and Planning Branch
Civilian Reactors, Division of
Reactor Development
Mail Station F-311

7

U. S. Atomic Energy Commission
Chief, New York Patent Group
Brookhaven National Laboratory
Upton, New York

Attention: Harman Potter

8

U. S. Atomic Energy Commission
Idaho Operations Office
P. O. Box 2108
Idaho Falls, Idaho

Attention: Director, Division of Military Reactors

DISTRIBUTION (CONT'D)

External Copies

- 9 U. S. Atomic Energy Commission
Reports and Statistics Branch
Division of Reactor Development
Washington 25, D. C.
- 10 - 11 Office of the Chief of Engineers
Department of the Army
Building T-7
Washington 25, D. C.
- Attention: Chief, Projects Branch
Nuclear Power Division
- 12 - 14 Nuclear Power Field Office
U. S. Army Engineer Reactors Group
Fort Belvoir, Virginia
- Attention: Chief, Nuclear Power Field Office
- 15 Nuclear Power Field Office
U. S. Army Engineer Reactors Group
Fort Belvoir, Virginia
- Attention: O. I. C. SM-1
- 16 Chief, U. S. Army Reactors Group
Fort Greeley, Alaska
APO 733
Seattle, Washington
- Attention: O. I. C. SM-1A
- 17 Chief, USAPR&DL
Thule, Greenland
APO 23
New York, New York
- Attention: O. I. C. PM-2A
- 18 - 20 Office of Technical Information Extension
P. O. Box 62
Oak Ridge, Tennessee

DISTRIBUTION (CONT'D)

External Copies

21	Union Carbide Nuclear Corporation
Oak Ridge National Laboratory
Y-12 Building 9704-1
P. O. Box "Y"
Oak Ridge, Tennessee

Attention: A. L. Boch |
| 22 | The Martin Company
P. O. Box 5042
Middle River, Maryland

Attention: AEC Contract Document Custodian |
| 23 | Combustion Engineering, Incorporated
Nuclear Division
Windsor, Connecticut

Attention: Director, Nuclear Division |
| 24 - 25 | Alco Products, Inc.
Post Office Box 145
Fort Belvoir, Virginia

Attention: W. K. Stromquist |

Internal Copies

26	K. Kasschau	37	E. F. Clancy
27	J. Gronan	38	B. E. Fried
28	E. B. Gunyou	39	D. H. Lee
29	W. S. Brown	40	J. P. Oggerino
30	J. G. Gallagher	41	S. Paluszkiewicz
31 - 32	P. E. Bober	42	S. H. Weiss
33	P. V. Oby	43 - 45	Computer File
34	R. L. Caton	46 - 47	Core Analysis File
35	M. R. Alford	48 - 52	NPED File
36	R. H. Beam		

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

ABSTRACT

This report contains a description of the BOBCAT code, (Program No. 56), programmed for the IBM-650. The code greatly facilitates the nuclear analysis of APPR-type cores by performing many of the routine calculations necessary to obtain input to various IBM-650 and IBM-704 codes. Using fuel element geometry, U-235 and B-10 loadings as input, the code prepares input to the MUFT-III and various P_3 codes as output; in addition a large amount of detailed descriptive core data which is useful in nuclear analysis calculations is generated.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TABLE OF CONTENTS

	Page
ABSTRACT -----	vii
1.0 INTRODUCTION -----	1
2.0 CALCULATIONAL APPROACH -----	3
2.1 One-Dimensional Calculations -----	3
2.1.1 Stationary Fuel Elements -----	3
2.1.2 Control Rod Fuel Elements -----	4
2.2 Two-Dimensional Calculations -----	4
2.2.1 Stationary Fuel Elements -----	4
2.2.2 Control Rod Fuel Elements -----	5
3.0 NOMENCLATURE -----	11
3.1 Input Nomenclature -----	13
3.1.1 Geometry and Loading Data -----	13
3.1.2 Density Input Cards -----	15
3.1.3 Cross Section Input -----	16
3.1.4 Stainless Steel Atom Fraction Input -----	17
3.2 Output Nomenclature -----	18
4.0 DERIVATION OF EQUATIONS -----	31
4.1 Fuel and Poison Loadings -----	31
4.2 Volumes and Volume Fractions -----	32
4.2.1 Total Element -----	32
4.2.2 Active Region -----	32
4.2.3 Dead Region -----	32
4.3 Preparation of Input to P ₃ , IBM-650 Codes -----	33
4.3.1 Dead Region -----	33
4.3.2 Active Region -----	33
4.3.2.1 Fuel Plates -----	33
4.3.2.2 Water Channels -----	34
4.3.3 Additional Input -----	35

TABLE OF CONTENTS (CONT'D)

	Page
4. 4 Preparation of Input to MUFT-III, IBM-650 Code - - - - -	36
4. 5 Miscellaneous Calculations - - - - -	37
4. 5. 1 Weight Percent of Components in the Fuel Matrix - - -	37
4. 5. 2 Atom Percent of Components in the Fuel Matrix - - -	37
4. 5. 3 Volumes of Components in the Fuel Matrix - - - - -	38
4. 5. 4 Mass of Components in the Fuel Matrix - - - - -	39
4. 5. 5 Total Core Parameters - - - - -	39
4. 5. 5. 1 Volumes - - - - -	39
4. 5. 5. 2 Masses - - - - -	40
4. 5. 5. 3 Metal-to-Water Ratio - - - - -	40
4. 6 Preparation of Nuclear Parameter Input to the PDQ(x, y) or Turbo, IBM-704 Codes - - - - -	40
4. 6. 1 Region #1 (Dead Region of Stationary Fuel Element) - -	40
4. 6. 1. 1 Thermal Parameters - - - - -	40
4. 6. 1. 2 MUFT-III Input - - - - -	41
4. 6. 2 Region #2 (Active Region of Stationary Fuel Element) -	41
4. 6. 2. 1 Thermal Parameters - - - - -	41
4. 6. 2. 2 MUFT-III Input - - - - -	41
4. 6. 3 Region #3 (Dead Regions of Control Fuel Element Containing the Side Plates) - - - - -	42
4. 6. 3. 1 Thermal Parameters - - - - -	42
4. 6. 3. 2 MUFT-III Input - - - - -	43
4. 6. 4 Region #4 (Dead Regions of Control Fuel Element Perpendicular to the Side Plates) - - - - -	44
4. 6. 4. 1 Thermal Parameters - - - - -	44
4. 6. 4. 2 MUFT-III Input - - - - -	44
4. 6. 5 Region #5 (Active Region of Control Fuel Element) - -	45
4. 6. 5. 1 Thermal Parameters - - - - -	45
4. 6. 5. 2 MUFT-III Input - - - - -	45
5. 0 PROGRAM INSTRUCTIONS - - - - -	47
5. 1 Input - - - - -	47
5. 1. 1 Burnup Table - - - - -	48
5. 1. 2 Psi (Ψ) Table - - - - -	48
5. 1. 3 Stainless Steel File - - - - -	48
5. 1. 4 Density File - - - - -	48
5. 1. 5 Cross Section File - - - - -	49
5. 1. 6 Input Cards (Variable Cards) - - - - -	49

TABLE OF CONTENTS (CONT'D)

	Page
5.1.7 Special Input Cards - - - - -	49
5.1.7.1 Comments Cards - - - - -	49
5.1.7.2 Flux Cards - - - - -	50
5.1.7.3 MUFT-III Input Cards - - - - -	51
6.0 OPERATING INSTRUCTIONS - - - - -	53
6.1 Option 1: Stationary Element Only - - - - -	53
6.2 Option 2: Control Rod Fuel Element Only - - - - -	53
6.3 Option 3: Stationary Element, Control Rod Fuel Element, and Total Core - - - - -	53
6.4 Stops - - - - -	54
6.5 Timing - - - - -	54
7.0 OUTPUT - - - - -	55
7.1 Unedited Output - Stationary Fuel Element - - - - -	55
7.1.1 Output Used for One-Dimensional Calculations - - - - -	55
7.1.2 Output Used for Two-Dimensional Calculations - - - - -	57
7.2 Unedited Output - Control Rod Fuel Element - - - - -	58
7.2.1 Output Used for One-Dimensional Calculations - - - - -	58
7.2.2 Output Used for Two-Dimensional Calculations - - - - -	60
7.3 Unedited Output - Total Core Parameters - - - - -	60
8.0 REFERENCES - - - - -	61
APPENDIX A: BOBCAT Flow Charts - - - - -	A-1
APPENDIX B: Floating Point Notation - - - - -	B-1
APPENDIX C: Fission Product Poisoning - - - - -	C-1
APPENDIX D: Composition of Stainless Steel - - - - -	D-1
APPENDIX E: Utility of the BOBCAT Code - - - - -	E-1
APPENDIX F: Sample BOBCAT Problem - - - - -	F-1

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

LIST OF FIGURES

Figure	Title	Page
2. 1	APPR-Type Stationary Fuel Element (Quarter Section)	7
2. 2	APPR-Type Control Rod Fuel Element (Quarter Section)	8
2. 3	Subdivision of a Stationary Fuel Element	9
2. 4	Subdivision of a Control Rod Fuel Element	10
A. 1	BOBCAT Stationary Fuel Element Flow Chart	A-3
A. 2	BOBCAT Control Rod Fuel Element Flow Chart	A-5
E. 1	Utilization of the BOBCAT Code	E-3
E. 2	Schematic Diagram of BOBCAT Calculations	E-5

LIST OF TABLES

Table	Title	Page
C. 1	Fission Product Poisoning (Ψ)	C-1
D. 1	Type 304L Stainless Steel	D-2
D. 2	Type 302B Stainless Steel	D-2
D. 3	Braze Stainless Steel	D-3
D. 4	Type 347 Stainless Steel	D-3
E. 1	Summary of Various IBM-Codes	E-1

1.0 INTRODUCTION

The BOBCAT code (Program No. 56), programmed for the IBM-650, was written to facilitate the nuclear analysis of APPR-type cores. Fast group parameters for both stationary and control rod fuel elements are generally calculated by use of the MUFT-III, ⁽¹⁾, ⁽²⁾ IBM-650 code. Thermal parameters are generally calculated by use of the Plate-Type P₃ ⁽³⁾ and Program No. 54, ⁽⁴⁾ IBM-650 codes, for the stationary and control rod fuel elements, respectively. The BOBCAT code, using fuel element geometry, U-235 and B-10 loadings, as input, provides input cards for the various codes mentioned above; this output may be obtained as a function of fuel burnup. In addition, BOBCAT calculates detailed descriptive core data including volumes, masses, atomic number densities, and other miscellaneous items which are of value in nuclear analysis calculations.

The calculations performed and the utility of the code in facilitating the input preparation of various commonly used codes, are shown in Appendix E. For codes such as VALPROD, ⁽⁵⁾ WINDOWSHADE, ⁽⁶⁾ CANDLE, ⁽⁷⁾ etc, properties for the overall fuel elements are generally employed; for two-dimensional codes, such as PDQ ⁽⁸⁾, ⁽⁹⁾ and TURBO, ⁽¹⁰⁾ the fuel elements may be subdivided into two or more "regions" to obtain a more precise analytical prediction of the core nuclear behavior.

Provision has been made in the code to calculate stainless steel, both as an element in itself, and as a mixture containing iron, nickel, chromium, and various other components. Either output may be used for the fast nuclear parameter calculations, depending upon which cross-sectional files one wishes to employ in the MUFT-III code; this is left to the discretion of the program user.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

2.0 CALCULATIONAL APPROACH

For one-dimensional calculations such as VALPROD, WINDOWSHADE, and CANDLE, the nuclear properties for the entire fuel element are generally desired. For two-dimensional calculations such as PDQ (x, y) and TURBO, the fuel elements are generally subdivided into "active" and "dead" regions; the latter refers to regions containing no fuel.

2.1 ONE-DIMENSIONAL CALCULATIONS

The nuclear properties for the control fuel elements are calculated somewhat differently than for the stationary fuel elements. These methods are described in the following sections.

2.1.1 Stationary Fuel Elements

A schematic cross section of an APPR-type stationary fuel element is shown in Fig. 2.1. The following nomenclature is used for the various regions:

Plate: This region includes the meat and cladding, but does not include the fuel plate dead edges. Properties for this region are calculated as if the clad and meat are homogeneously mixed. The plate thickness is C ; its width is G .

Channel: This region includes the material between the fuel plates; for this code, only water is assumed to be between the plates. The width of this region is G , the same as for the fuel plates. Its thickness is d .

Active: This is a mixed region consisting of the fuel plates and the channel. Its width is G .

Dead: This region includes the fuel plate dead edges, side plates, and all of the water in the element that is not in the channels. Its half-width is $(1/2)(D-G)$. Its properties are calculated as if all materials in the region are homogeneously distributed.

Fuel Element Cell: This includes all regions. It is made up of the active plus the dead regions.

The fast parameters are calculated by the MUFT-III code ⁽¹⁾, ⁽²⁾ for all materials in the fuel element cell homogeneously distributed. The thermal parameters are calculated by the Plate-Type P_3 code. ⁽³⁾ This code calculates the properties by a superposition of two P_3 calculations, one perpendicular to the fuel plates and the other parallel to the fuel plates.

2.1.2 Control Rod Fuel Elements

A schematic cross section of an APPR-type control rod fuel element is shown in Fig. 2.2. The nomenclature for the plate, channel, and active regions is the same as for the stationary elements. The dead region includes the fuel plate dead edges, side plates, control rod basket, and all the water not contained in the channels. The element is cylindricalized into an active region surrounded by a dead region.

The fast parameters are calculated by the MUFT-III code, for all materials in the fuel element cell homogeneously distributed. The thermal parameters of the active region are calculated by a one-dimensional P_3 calculation perpendicular to the fuel plates. The thermal properties of the dead region are calculated on a homogeneous basis. The fuel element is cylindricalized and the thermal properties of the entire fuel element are obtained by a cylindrical P_3 calculation. (4)

For the stationary fuel elements, the BOBCAT code prepares input cards to the MUFT-III code and the Plate-Type P_3 code. For the control rod fuel elements, the code prepares input to the MUFT-III code and for Program 54. (4) The latter code calculates the thermal parameters of APPR-type control rod fuel elements.

2.2 TWO-DIMENSIONAL CALCULATIONS

For two-dimensional calculations, either nuclear parameters for the overall fuel elements may be used, as described in Section 2.1, or a more detailed subdivision of the fuel elements may be desired, i. e., for two-dimensional flux and power distribution calculations. This is described in the following sections.

2.2.1 Stationary Fuel Elements

A schematic cross section of an APPR-type stationary fuel element, for two-dimensional calculations, is shown in Fig. 2.3. Two-regions are described:

Region #1: This region is identical to the dead region of the stationary fuel elements as described in Section 2.1.1.

Region #2: This region is identical to the active region of the stationary fuel elements as described in Section 2.1.1.

The thermal parameters for these two regions may be obtained from the output of the Plate-Type P_3 calculation. The fast parameters for these two regions are calculated by use of MUFT-III for the materials in these separate regions homogeneously distributed.

2. 2. 2 Control Rod Fuel Elements

A schematic cross section of an APPR-type control rod fuel element, for two-dimensional calculations, is shown in Fig. 2.4. Three regions are described:

Region #3: This region is a dead region containing the side plates, fuel plate dead edges, part of the control rod basket, and all water not contained in the active region (Region #5) and Region #4. The thermal parameters and fast parameters are calculated for the materials homogeneously distributed. The fast parameters are calculated by MUFT-III.

Region #4: This region is a dead region containing part of the control rod basket and the water not contained in Regions 3 and 5. The fast and thermal parameters are calculated as given for Region #3.

Region #5: This region is the active region of the control rod fuel elements as described in Section 2. 1. 2. The thermal parameters are obtained as output of Program 54. The fast parameters are calculated by MUFT-III for the materials homogeneously distributed.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

FIGURE 2.1
APPR-TYPE STATIONARY FUEL ELEMENT
(QUARTER SECTION)

FIGURE 2.2
APPR-TYPE CONTROL ROD FUEL ELEMENT
(QUARTER SECTION)

FIGURE 2.3
SUBDIVISION OF A
STATIONARY FUEL ELEMENT

FIGURE 2.4
SUBDIVISION OF A CONTROL
ROD FUEL ELEMENT

3.0 NOMENCLATURE

The nomenclature as used in the BOBCAT code is given on the following pages. Except as noted, the nomenclature applies to both stationary and control rod fuel elements. In the output nomenclature, the expressions under the column "Identification" indicate designations as found in the code output listings. When the definitions refer to specific regions (i. e., fuel plates, active, dead, region 1, region 2, etc) reference should be made to Section 2 and Fig. 2.1 through 2.4, of this report.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

3.1 INPUT NOMENCLATURE

3.1.1 Geometry and Loading Data

<u>SYMBOL</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
Z_0	Loading of U-235 per fuel plate at fuel burnup, $B = 0$.	gms
Y_0	Loading of B-10 per fuel plate at fuel burnup, $B = 0$.	gms
B	Fuel burnup fraction, where $(1-B) = N^{25}(t)/N^{25}(t=0)$.	
β	Fraction of total fissions which are thermal. (Use $\beta = 1.0$ when $B = 0$).	
Δ	Defined in Section 4.1. (Use $\Delta = 0$ in input if it is desired for the code to calculate the proper value of Δ ; if $\Delta \neq 0$ is used as input, this value will be used in the code).	
A	Width of fuel element cell (parallel to the side plates).	cm
D	Width of fuel element cell (perpendicular to the side plates).	cm
F	Total width of a clad fuel plate.	cm
G	Width of the active region (meat) of the fuel plate.	cm
t_F	Thickness of the active region (meat) of the fuel plate.	cm
t_C	Thickness of the cladding on each side of the fuel plate.	cm
g	Gap between fuel plate and side plate.	cm
h	Depth of grooves (for insertion of fuel plates) in side plate.	cm
E	Thickness of the side plate.	cm

<u>SYMBOL</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
H	Width of the side plate.	cm
H'	Width of the "active region" (parallel to side plates).	cm
L	Length of active region (meat) of the fuel plate.	cm
ϵ	Void volume fraction in meat of the fuel plate.	
θ	Pressure factor: ratio of density of pure water at desired T°F and P (psi) to the density of pure water specified in the input "density cards." This factor may also be used to calculate the effect of voids in the reactor core.	
V _{BR}	Volume of braze material (steel) per fuel element.	cm ³
$\bar{q}$	Thickness of control rod basket. (Control fuel element only).	cm
N ₁	Number of fuel plates per fuel element.	
N ₂	Number of fuel elements (stationary or control) in the core.	
J ₁	Outside width of control rod basket (control fuel element only).	cm
J ₂	Inside width of control rod basket (control fuel element only).	cm

3. 1. 2 Density Input Cards

<u>SYMBOL</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
N_H	Atomic number density of hydrogen in pure water at T^0F and P (psi).	atoms/cm ³
N_O	Atomic number density of oxygen in pure water at T^0F and P (psi).	atoms/cm ³
N_{SSP}	Atomic number density of pure stainless steel in the side plates.	atoms/cm ³
N_{SSA}	Atomic number density of pure stainless steel in the fuel matrix (meat).	atoms/cm ³
N_{SSDE}	Atomic number density of pure stainless steel in the fuel plate cladding.	atoms/cm ³
N_{SSCB}	Atomic number density of pure stainless steel in control rod baskets.	atoms/cm ³
N_{SSBR}	Atomic number density of pure stainless steel in braze material.	atoms/cm ³
μ_1	Weight fraction of U in UO_2 .	
μ_2	Weight fraction of U-235 in U.	
μ_3	Weight fraction of boron in the boron compound used as the burnable poison.	
γ	Atomic fraction of B-10 in boron (as used as the burnable poison).	
ρ_{UO_2}	Density of pure UO_2 .	gms/cm ³
$\rho_{B(comp)}$	Density of the pure boron compound used as the burnable poison.	gms/cm ³
ρ_{SSA}	Density of pure stainless steel used in the fuel matrix (meat).	gms/cm ³

<u>SYMBOL</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
ρ_{BR}	Density of pure stainless steel used in the braze material.	gms/cm ³
ρ_{SCB}	Density of pure stainless steel used in the control rod baskets (control fuel element only).	gms/cm ³
ρ_{SP}	Density of pure stainless steel used in the side plates.	gms/cm ³
ρ_{SFP}	Density of pure stainless steel used in the fuel plate cladding.	gms/cm ³
ρ_{H_2O}	Density of pure water at T°F and P (psi).	gms/cm ³
λ	Ratio of atoms of the "compound" in the boron compound to atoms of natural boron. For example, $\lambda = 1/4$ for B ₄ C and $\lambda = 1/2$ for ZrB ₂ where carbon and zirconium is the "compound," respectively.	
3.1.3 Cross Section Input		
σ_a^x	Microscopic thermal absorption cross sections for x = U-235, U-238, SS, B-10, hydrogen, and oxygen, averaged over a Maxwell-Boltzmann distribution (or other distribution) at the appropriate kT energy.	barns
σ_s^x	Microscopic thermal scattering cross sections for x = U-235, U-238, SS, B-10, hydrogen, and oxygen, at the appropriate kT energy.	barns
σ_{tr}^x	Microscopic thermal transport cross sections for x = U-235, U-238, SS, B-10, hydrogen, and oxygen, at the appropriate kT energy.	barns
$\nu\sigma_f^{25}$	Average number of neutrons produced per fission times the microscopic thermal fission cross section of U-235 averaged over a Maxwell-Boltzmann distribution (or other distribution) at the appropriate kT energy.	barns

<u>SYMBOL</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
σ_{af}^{B-10}	Microscopic fast absorption cross section of B-10.	barns
σ_{af}^{25}	Microscopic fast absorption cross section of U-235	barns
α_{th}	Average thermal capture to thermal fission ratio for U-235.	
α_f	Average fast capture to fast fission ratio for U-235.	

3.1.4 Stainless Steel Atom Fraction Input

$(AF)_A^i$	Atom fraction of component i in pure stainless steel used in fuel matrix (meat), where i = Fe, Ni, Cr, Mn, C, Si, and Mo.
$(AF)_{DE}^i$	Atom fraction of component i in pure stainless steel used in fuel plate cladding, where i = Fe, Ni, Cr, Mn, C, Si, and Mo.
$(AF)_P^i$	Atom fraction of component i in pure stainless steel used in side plate, where i = Fe, Ni, Cr, Mn, C, Si, and Mo.
$(AF)_{BR}^i$	Atom fraction of component i in pure stainless steel used in the braze material, where i = Fe, Ni, Cr, Mn, C, Si, and Mo.
$(AF)_{CB}^i$	Atom fraction of component i in pure stainless steel used in the control rod baskets, where i = Fe, Ni, Cr, Mn, C, Si, and Mo.

3.2 OUTPUT NOMENCLATURE

<u>SYMBOL</u>	<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
$\bar{Z}$	Z BAR	Loading of U-235 per fuel plate at fuel burnup B.	gms
Δ	DELTA	Defined in Section 4. 1.	
Ψ	PSI	Grams of B-10 per plate equivalent to the poisoning due to fission product accumulation at fuel burnup B per initial kg of U-235 per fuel plate.	gms/kg
$Y_{eq. F. P.}$	Y EQ FISS PROD	Grams of B-10 per fuel plate equivalent to the poisoning due to fission product accumulation at fuel burnup B.	gms
$\bar{Y}$	Y BAR	Loading of B-10 per fuel plate at fuel burnup B.	gms
Z_E^{25}	Z 25 ELEMENT	Loading of U-235 per fuel element at fuel burnup B.	gms
$Z_E^{UO_2}$	Z UO ₂ ELEMENT	Loading of UO ₂ per fuel element.	gms
Y_E^{B-10}	Y B10 ELEMENT	Loading of B-10 per fuel element at fuel burnup B.	gms
μ_4	MU SUB 4	Weight fraction of B-10 in natural boron.	
$Y_E^{B(comp)}$	Y-B COMP ELEM	Loading of the boron compound, used as the burnable poison, per fuel element.	gms
V_A	VOL ACTIVE	Volume of active region of the fuel element.	cm ³
V_E	VOL ELEMENT	Volume of the fuel element.	cm ³

<u>SYMBOL</u>	<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
V_D	VOL DEAD	Volume of the dead region of the fuel element.	cm^3
$(VF)_A$	VOL FRACT ACT	Volume fraction of the active region of the fuel element.	
$(VF)_D$	VOL FRACT DEAD	Volume fraction of the dead region of the fuel element.	
$\bar{R}_A$	R BAR ACTIVE	Equivalent radius of the active region of the control rod fuel element.	cm
$\bar{R}_E$	R BAR ELEMENT	Equivalent radius of the control rod fuel element.	cm
V_{FA}	VOL FUEL ACTIVE	Volume of the fuel matrix (meat) in the active region of the fuel element.	cm^3
V_{CA}	VOL CLAD ACTIVE	Volume of the cladding in the active region of the fuel element.	cm^3
V_{MA}	VOL METAL ACT	Volume of the metal $[\text{UO}_2 + \text{B}(\text{comp}) + \text{SS}]$ in the active region of the fuel element.	cm^3
V_{WA}	VOL H ₂ O ACTIVE	Volume of the water in the active region of the fuel element.	cm^3
V_{SCB}	VOL BASKET ELEM	Volume of control rod basket in control rod fuel element.	cm^3
C	C	Total thickness of the clad fuel plate.	cm
V_{SP}	VOL SIDE PLATES	Volume of the side plates in the fuel element.	cm^3
V_{DE}	VOL DEAD EDGES	Volume of fuel plate dead edges in the fuel element.	cm^3
V_{SSD}	VOL SS DEAD	Volume of stainless steel (metal) in the dead region of the fuel element.	cm^3
V_{WD}	VOL H ₂ O DEAD	Volume of water in the dead region of the fuel element.	cm^3

<u>SYMBOL</u>	<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
α	ALPHA	Total atoms of stainless steel in the dead region.	atoms
Σ_{aD}	SIGMA A DEAD	Thermal macroscopic absorption cross section of the dead region.	cm ⁻¹
Σ_{SD}	SIGMA S DEAD	Thermal macroscopic scattering cross section of the dead region.	cm ⁻¹
Σ_{trD}	SIGMA TR DEAD	Thermal macroscopic transport cross section of the dead region.	cm ⁻¹
V_P	VOL PLATE	Volume of a clad fuel plate.	cm ³
N_P^{B-10}	N B10 PLATE	Atomic density of B-10 in the fuel plate.	atoms/cm ³
Σ_{aBP}	SIG A B10 PLATE	Thermal macroscopic absorption cross section of B-10 in the fuel plate.	cm ⁻¹
Σ_{sBP}	SIG S B10 PLATE	Thermal macroscopic scattering cross section of B-10 in the fuel plate.	cm ⁻¹
Σ_{trBP}	SIG TR B10 PLATE	Thermal macroscopic transport cross section of B-10 in the fuel plate.	cm ⁻¹
N_P^{25}	N U235 PLATE	Atomic density of U-235 in the fuel plate.	atoms/cm ³
N_P^{28}	N U238 PLATE	Atomic density of U-238 in the fuel plate.	atoms/cm ³
N_P^O	N OXY PLATE	Atomic density of oxygen in the fuel plate.	atoms/cm ³
V_M	VOL MEAT PLATE	Volume of the fuel matrix per fuel plate.	cm ³
V_V	VOL VOID PLATE	Volume of the "void" per fuel plate	cm ³
$V_{(UO_2)P}$	VOL UO2 PLATE	Volume of UO ₂ per fuel plate.	cm ³
$V_{B(comp)P}$	VOL B COM PLATE	Volume of boron compound (burnable poison) per fuel plate.	cm ³

<u>SYMBOL</u>	<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
V_{SSPM}	VOL SS MEAT	Volume of stainless steel in the fuel matrix (meat) per fuel plate.	cm^3
N_P^{SS}	N SS PLATE	Atomic density of stainless steel in the fuel matrix (meat).	atoms/ cm^3
Σ_{aP}	SIGMA A PLATE	Thermal macroscopic absorption cross section of the fuel plate.	cm^{-1}
Σ_{sP}	SIGMA S PLATE	Thermal macroscopic scattering cross section of the fuel plate.	cm^{-1}
Σ_{trP}	SIGMA TR PLATE	Thermal macroscopic transport cross section of the fuel plate.	cm^{-1}
$\nu \Sigma_{fP}$	NU SIG F PLATE	Average number of neutrons produced per thermal fission times the thermal macroscopic fission cross section of the fuel plate.	cm^{-1}
d	D LOWER CASE	Thickness of the water gap (channel) between the fuel plates.	cm
V_{WCH}	VOL H2O CHANNELS	Volume of water in the channels of the active region.	cm^3
Σ_{aCH}	SIGMA A H2O	Thermal macroscopic absorption cross section of the channels (H_2O).	cm^{-1}
Σ_{sCH}	SIGMA S H2O	Thermal macroscopic scattering cross section of the channels (H_2O).	cm^{-1}
Σ_{trCH}	SIGMA TR H2O	Thermal macroscopic transport cross section of the channels (H_2O).	cm^{-1}
S_{ACTIVE}	S ACTIVE	Source constant for active region of stationary fuel element for input to Plate-Type P_3 code.	
S_{DEAD}	S DEAD	Source constant for dead region of stationary fuel element for input to Plate-Type P_3 code.	
q	Q LOWER CASE	Half width of stationary fuel element (parallel to fuel plates). cm	

<u>SYMBOL</u>	<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
p	P LOWER CASE	Half width of active region of stationary fuel element (parallel to fuel plates).	cm
l	L LOWER CASE	Half thickness of clad fuel plate (stationary fuel element)	cm
m	M LOWER CASE	Half thickness of clad fuel plate plus half thickness of the water channel (stationary fuel element).	cm
q _A	Q LO CASE SUB A	Source constant for active region of control fuel element for input to Program 54.	
q _D	Q LO CASE SUB D	Source constant for dead region of control fuel element for input to Program 54.	
w	W LOWER CASE	Half thickness of clad fuel plate (control fuel element).	cm
W	W UPPER CASE	Half thickness of clad fuel plate plus half thickness of the water channel (control fuel element).	cm
(VF) _P ^A	VF PLATES ACT	Volume fraction of the fuel plates in the active region (control fuel element).	
$\sum_D$	TOTAL SIG DEAD	Total macroscopic thermal cross section of dead region for control fuel element. ($\sum_D = \sum_{aD} + \sum_{SD}$).	cm ⁻¹
$\sum_D'$	SIG PRIME DEAD	Total macroscopic thermal cross section minus macroscopic thermal transport cross section of dead region for control fuel element.	cm ⁻¹
$\sum_D^2$	SIG STAR DEAD	Second order macroscopic thermal elastic scattering cross section of dead region for control fuel element. (Assumed to be zero).	cm ⁻¹
N _C ²⁵	N U235 ELEM	Atomic density of U-235 in the fuel element.	atoms/cm ³
N _C ²⁸	N U238 ELEM	Atomic density of U-238 in the fuel element.	atoms/cm ³
N _{CP} ^O	N OXY PLATE EL	Atomic density of oxygen (UO ₂ contribution only) in the fuel element	atoms/cm ³
V _{WE}	VOL H2O ELEMENT	Volume of water in the fuel element.	cm ³
N _C ^H	N HYD ELEMENT	Atomic density of hydrogen in the fuel element	atoms/cm ³

<u>SYMBOL</u>	<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
N_{CW}^O	N OXY H2O EL	Atomic density of oxygen (H ₂ O contribution only) in the fuel element.	atoms/cm ³
N_C^O	N OXYGEN ELEM	Atomic density of oxygen (from UO ₂ and H ₂ O) in the fuel element.	atoms/cm ³
N_C^{B-10}	N B10 ELEMENT	Atomic density of B-10 in the fuel element.	atoms/cm ³
N_C^{SS}	N SS ELEMENT	Atomic density of stainless steel in the fuel element.	atoms/cm ³
N_C^i	N X ELEMENT	Atomic density of component X in the fuel element, where X = Fe, Ni, Cr, Mn, C, Si, and Mo.	atoms/cm ³
$M_P^{UO_2}$	MASS UO2 MEAT	Mass of UO ₂ in the fuel matrix (meat) per fuel plate.	gms
$M_P^{B(comp)}$	MASS B COM MEAT	Mass of boron compound (burnable poison) in the fuel matrix (meat) per fuel plate.	gms
M_P^{SS}	MASS SS MEAT	Mass of stainless steel in the fuel matrix (meat) per fuel plate.	gms
M_P^T	TOTAL MEAT MASS	Total mass of fuel matrix (meat) per fuel plate.	gms
$(W)_M^{UO_2}$	WF UO2 MEAT	Weight fraction of UO ₂ in the fuel matrix (meat).	
$(W)_M^{B(comp)}$	WF B COMP MEAT	Weight fraction of boron compound (burnable poison) in the fuel matrix (meat).	
$(W)_M^{SS}$	WF SS MEAT	Weight fraction of stainless steel in the fuel matrix (meat).	
$(W)_M^B$	WF B MEAT	Weight fraction of boron in the fuel matrix (meat).	
n_M^T	TOT MEAT ATOMS	Total atoms in the fuel matrix (meat) per fuel plate.	atoms
$(A)_M^{25}$	AF U235 MEAT	Atom fraction of U-235 in the fuel matrix (meat).	
$(A)_M^{28}$	AF U238 MEAT	Atom fraction of U-238 in the fuel matrix (meat).	

<u>SYMBOL</u>	<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
$(A)_M^O$	AF OXY MEAT	Atom fraction of oxygen in the fuel matrix (meat).	
$(A)_M^{SS}$	AF SS MEAT	Atom fraction of stainless steel in the fuel matrix (meat).	
$(A)_M^B$	AF B MEAT	Atom fraction of boron in the fuel matrix (meat).	
$(A)_M^{(comp)}$	AF COMP MEAT	Atom fraction of the compound portion (of the boron compound used as the burnable poison) in the fuel matrix (meat).	
V_{VE}	VOL VOID ELEM	Volume of "void" in the fuel element.	cm^3
V_{ME}	VOL METAL ELEM	Volume of metal in the fuel element.	cm^3
V_{SSE}	VOL SS ELEM	Volume of stainless steel in the fuel element.	cm^3
$V_E^{UO_2}$	VOL UO2 ELEM	Volume of UO_2 in the fuel element.	cm^3
$V_E^{B(comp)}$	VOL B COMP ELEM	Volume of the boron compound (burnable poison) in the fuel element.	cm^3
$(VF)_E^{H_2O}$	VF H2O ELEM	Volume fraction of water in the fuel element.	
$(VF)_E^{SS}$	VF SS ELEM	Volume fraction of stainless steel in the fuel element.	
$(VF)_E^{UO_2}$	VF UO2 ELEM	Volume fraction of UO_2 in the fuel element.	
$(VF)_E^{B(comp)}$	VF B COMP ELEM	Volume fraction of boron compound (burnable poison) in the fuel element.	
$(VF)_E^V$	VF VOID ELEM	Volume fraction of "void" in the fuel element.	
R_E^X	R SUP X ELEM	Metal to water volume ratio in the fuel element.	

<u>SYMBOL</u>	<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
M_E^{SS}	MASS SS ELEM	Mass of stainless steel in the fuel element.	gms
$M_E^{H_2O}$	MASS H2O ELEM	Mass of water in the fuel element.	gms
$V_C^{B(comp)}$	VOL B COMP CORE	Volume of the boron compound (burnable poison) in the reactor core.	cm ³
V_C^V	VOL VOID CORE	Volume of the "void" in the reactor core.	cm ³
V_T	TOT VOL OF CORE	Total volume of the reactor core.	cm ³
$V_C^{H_2O}$	VOL H2O CORE	Volume of water in the reactor core.	cm ³
V_C^{SS}	VOL SS CORE	Volume of stainless steel in the reactor core.	cm ³
$V_C^{UO_2}$	VOL UO2 CORE	Volume of UO ₂ in the reactor core.	cm ³
V_C^m	VOL METAL CORE	Volume of metal in the reactor core.	cm ³
$(VF)_C^{H_2O}$	VF H2O CORE	Volume fraction of water in the reactor core.	
$(VF)_C^{SS}$	VF SS CORE	Volume fraction of stainless steel in the reactor core.	
$(VF)_C^{UO_2}$	VF UO2 CORE	Volume fraction of UO ₂ in the reactor core.	
$(VF)_C^M$	VF METAL CORE	Volume fraction of metal in the reactor core.	
$(VF)_C^V$	VF VOID CORE	Volume fraction of "void" in the reactor core.	
$(VF)_C^{B(comp)}$	VF B COMP CORE	Volume fraction of the boron compound (burnable poison) in the reactor core.	

<u>SYMBOL</u>	<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
$M_C^{H_2O}$	MASS H2O CORE	Total mass of water in the reactor core.	gms
M_C^{SS}	MASS SS CORE	Total mass of stainless steel in the reactor core.	gms
M_C^{U235}	MASS U235 CORE	Total mass of U-235 in the reactor core.	gms
$M_C^{UO_2}$	MASS UO2 CORE	Total mass of UO_2 in the reactor core.	gms
M_C^{B-10}	MASS B10 CORE	Total mass of B-10 in the reactor core.	gms
$M_C^{B(comp)}$	MASS B COM CORE	Total mass of the boron compound (burnable poison).	gms
M_C^T	MASS OF CORE	Total mass of the reactor core (including water).	gms
R_C	R SUB C CORE	Metal to water volume ratio in the reactor core.	
$\Sigma_{aD(1)}$	SIG A REG 1	Thermal macroscopic absorption cross section of region 1 (stationary fuel element).	cm^{-1}
$\Sigma_{sD(1)}$	SIG S REG 1	Thermal macroscopic scattering cross section of region 1 (stationary fuel element).	cm^{-1}
$\Sigma_{trD(1)}$	SIG TR REG 1	Thermal macroscopic transport cross section of region 1 (stationary fuel element).	cm^{-1}
$\nu \Sigma_{fD(1)}$	NU SIG F REG 1	Average number of neutrons produced per thermal fission times the thermal macroscopic fission cross section of region 1 (stationary fuel element).	cm^{-1}
$K_{TD(1)}$	K THER REG 1	Thermal multiplication factor of region 1 (stationary fuel element).	cm^{-1}
$D_{D(1)}$	D THER REG 1	Thermal diffusion coefficient of region 1 (stationary fuel element).	cm
$L_{D(1)}^2$	L SQUARE REG 1	Square of thermal diffusion length of region 1 (stationary fuel element).	cm^2

<u>SYMBOL</u>	<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
$N_{HD(1)}$	N HYD REG 1	Atomic density of hydrogen in region 1 (stationary fuel element).	atoms/cm ³
$N_{OD(1)}$	N OXY REG 1	Atomic density of oxygen in region 1 (stationary fuel element).	atoms/cm ³
$N_{SSD(1)}$	N SS REG 1	Atomic density of stainless steel in region 1 (stationary fuel element).	atoms/cm ³
$N_{D(1)}^i$	N χ REG 1	Atomic density of component χ in region 1 (stationary fuel element), where χ = Fe, Ni, Cr, Mn, C, Si, and Mo.	atoms/cm ³
V_{WCH}	VOL H2O REG 2	Volume of water in region 2 (stationary fuel element).	cm ³
V_{PA}	VOL PLAT REG 2	Volume of fuel plates in region 2 (stationary fuel element).	cm ³
V_A	VOL OF REG 2	Volume of region 2 (stationary fuel element).	cm ³
$(VF)_{PA}$	VF PLAT REG 2	Volume fraction of fuel plates in region 2 (stationary fuel element).	
$(VF)_{WA}$	VF H2O REG 2	Volume fraction of water in region 2 (stationary fuel element).	
$N_{HA(2)}$	N HYD REG 2	Atomic density of hydrogen in region 2 (stationary fuel element).	atoms/cm ³
$N_{OA(2)}$	N OXY REG 2	Atomic density of oxygen in region 2 (stationary fuel element).	atoms/cm ³
$N_{(25)A(2)}$	N U235 REG 2	Atomic density of U-235 in region 2 (stationary fuel element).	atoms/cm ³
$N_{(28)A(2)}$	N U238 REG 2	Atomic density of U-238 in region 2 (stationary fuel element).	atoms/cm ³
$N_{(B-10)A(2)}$	N B10 REG 2	Atomic density of B-10 in region 2 (stationary fuel element).	atoms/cm ³
$N_{SSA(2)}$	N SS REG 2	Atomic density of stainless steel in region 2 (stationary fuel element).	atoms/cm ³

<u>SYMBOL</u>	<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
$N_A^i(2)$	N X REG 2	Atomic density of component X in region 2 (stationary fuel elements), where X = Fe, Ni, Cr, Mn, C, Si, and Mo.	atoms/cm ³
$V_{D(3)}$	VOL OF REG 3	Volume of region 3 (control fuel element).	cm ³
$V_{BD(3)}$	VOL BASK REG 3	Volume of control rod basket in region 3 (control fuel element).	cm ³
$V_{SPD(3)}$	VOL SID PLA R3	Volume of side plates in region 3 (control fuel elements).	cm ³
$V_{DED(3)}$	VOL DED EDGE R3	Volume of fuel plate dead edges in region 3 (control fuel element).	cm ³
$V_{SSD(3)}$	VOL SS REG 3	Volume of stainless steel in region 3 (control fuel element).	cm ³
$V_{WD(3)}$	VOL H2O REG 3	Volume of water in region 3 (control fuel element).	cm ³
$\alpha_{D(3)}$	ALPHA REG 3	Total atoms of stainless steel in region 3 (control fuel element).	atoms
$\Sigma_{aD(3)}$	SIG A REG 3	Thermal macroscopic absorption cross section of region 3 (control fuel elements).	cm ⁻¹
$\Sigma_{sD(3)}$	SIG S REG 3	Thermal macroscopic scattering cross section of region 3 (control fuel elements).	cm ⁻¹
$\Sigma_{trD(3)}$	SIG TR REG 3	Thermal macroscopic transport cross section of region 3 (control fuel element).	cm ⁻¹
$\nu \Sigma_{fD(3)}$	NU SIG F REG 3	Average number of neutrons produced per thermal fission times the thermal macroscopic fission cross section of region 3 (control fuel elements).	cm ⁻¹
$K_{TD(3)}$	K THER REG 3	Thermal multiplication factor of region 3 (control fuel element).	cm ⁻¹
$D_{TD(3)}$	D THER REG 3	Thermal diffusion coefficient of region 3 (control fuel element).	cm
$L_{D(3)}^2$	L SQUARE REG 3	Square of thermal diffusion length of region 3 (control fuel element).	cm ²

<u>SYMBOL</u>	<u>IDENTIFICATION</u>	<u>DESCRIPTION</u>	<u>UNITS</u>
$N_{HD(3)}$	N HYD REG 3	Atomic density of hydrogen in region 3 (control fuel elements).	atoms/cm ³
$N_{OD(3)}$	N OXY REG 3	Atomic density of oxygen in region 3 (control fuel element).	atoms/cm ³
$N_{SSD(3)}$	N SS REG 3	Atomic density of stainless steel in region 3 (control fuel element).	atoms/cm ³
$N_{D(3)}^i$	N X REG 3	Atomic density of component X in region 3 (control fuel element), where X = Fe, Ni, Cr, Mn, C, Si, and Mo.	atoms/cm ³
$V_{D(4)}$	VOL OF REG 4	Volume of region 4. (control fuel element).	cm ³
$V_{BD(4)}$	VOL BASK REG 4	Volume of control rod basket in region 4 (control fuel element).	cm ³
$V_{WD(4)}$	VOL H2O REG 4	Volume of water in region 4 (control fuel element).	cm ³
$\Sigma_{aD(4)}$	SIG A REG 4	Thermal macroscopic absorption cross section of region 4 (control fuel elements).	cm ⁻¹
$\Sigma_{sD(4)}$	SIG S REG 4	Thermal macroscopic scattering cross section of region 4 (control fuel element).	cm ⁻¹
$\Sigma_{trD(4)}$	SIG TR REG 4	Thermal macroscopic transport cross section of region 4 (control fuel element).	cm ⁻¹
$\nu \Sigma_{fD(4)}$	NU SIG F REG 4	Average number of neutrons produced per thermal fission times the thermal macroscopic fission cross section of region 4 (control fuel element).	cm ⁻¹
$K_{TD(4)}$	K THER REG 4	Thermal multiplication factor of region 4 (control fuel element).	cm ⁻¹
$D_{TD(4)}$	D THER REG 4	Thermal diffusion coefficient of region 4 (control fuel element).	cm
$L_{D(4)}^2$	L SQUARE REG 4	Square of the thermal diffusion length of region 4 (control fuel element).	cm ²
$N_{HD(4)}$	N HYD REG 4	Atomic density of hydrogen in region 4 (control fuel element).	atoms/cm ³
$N_{OD(4)}$	N OXY REG 4	Atomic density of oxygen in region 4 (control fuel element).	atoms/cm ³

SYMBOL	IDENTIFICATION	DESCRIPTION	UNITS
$N_{SSD(4)}$	N SS REG 4	Atomic density of stainless steel in region 4 (control fuel element).	atoms/cm ³
$N_{D(4)}^i$	N X REG 4	Atomic density of component X in region 4 (control fuel element), where X = Fe, Ni, Cr, Mn, C, Si, and Mo.	atoms/cm ³
$V_{WAC(5)}$	VOL H2O REG 5	Volume of water in region 5 (control fuel element).	cm ³
$V_{PAC(5)}$	VOL PLAT REG 5	Volume of fuel plates in region 5 (control fuel element).	cm ³
$V_{AC(5)}$	VOL OF REG 5	Volume of region 5 (control fuel element).	cm ³
$(VF)_{PAC(5)}$	VF PLAT REG 5	Volume fraction of fuel plates in region 5 (control fuel element).	
$(VF)_{WAC(5)}$	VF H2O REG 5	Volume fraction of water in region 5 (control fuel element).	
$N_{HAC(5)}$	N HYD REG 5	Atomic density of hydrogen in region 5 (control fuel element).	atoms/cm ³
$N_{OAC(5)}$	N OXY REG 5	Atomic density of oxygen in region 5 (control fuel element).	atoms/cm ³
$N_{(25)AC(5)}$	N U235 REG 5	Atomic density of U-235 in region 5 (control fuel element).	atoms/cm ³
$N_{(28)AC(5)}$	N U238 REG 5	Atomic density of U-238 in region 5 (control fuel element).	atoms/cm ³
$N_{(B-10)AC(5)}$	N B10 REG 5	Atomic density of B-10 in region 5 (control fuel element).	atoms/cm ³
$N_{SSAC(5)}$	N SS REG 5	Atomic density of stainless steel in region 5 (control fuel element).	atoms/cm ³
$N_{AC(5)}^i$	N X REG 5	Atomic density of component X in region 5 (control fuel element), where X = Fe, Ni, Cr, Mn, C, Si, and Mo.	atoms/cm ³

4.0 DERIVATION OF EQUATIONS

A complete formulation of all equations used in the BOBCAT code is given below. Refer to Section 3.0 for nomenclature. Except as noted, the equations apply to both stationary (FE) and control rod (CR) fuel elements.

4.1 FUEL AND POISON LOADINGS

$$Z = Z_0 (1-B)$$

$$\Delta = \frac{\left[\frac{\sigma_a^{B-10}}{\sigma_a^{25}} \right] (1 + \alpha_{th}) \beta + \left[\frac{\sigma_{af}^{B-10}}{\sigma_{af}^{25}} \right] (1 + \alpha_f) (1 - \beta)}{(1 + \alpha_{th}) \beta + (1 + \alpha_f) (1 - \beta)}$$

$$Y_{eq. F. P.} = Z_0 \Psi \times 10^{-3}$$

NOTE: Ψ (psi) is a function of fuel burnup (B) and relates the fission product poisoning to an equivalent amount of B-10. Table of B with the corresponding values of Ψ are included as input to the code. This is discussed further in Section 5 and Appendix C of this report. Appendix C shows the presently used tables at Alcoa and were obtained from reference (11).

$$Y = Y_0 (1-B) \Delta + Y_{eq. F. P.}$$

$$Z_E^{25} = Z_0 N_1$$

$$Z_E^{UO_2} = Z_E^{25} / (\mu_1 \mu_2)$$

$$Y_E^{B-10} = Y_0 N_1$$

$$\mu_4 = \frac{(10.016110)(\gamma)}{(10.016110)(\gamma) + (11.012811)(1-\gamma)}$$

$$Y_E^{B(comp)} = Y_E^{B-10} / (\mu_3 \mu_4)$$

4.2 VOLUMES AND VOLUME FRACTIONS

4.2.1 Total Element

$$A_A = GH$$

$$V_A = A_A L$$

$$A_E = AD$$

$$V_E = A_E L$$

$$V_D = V_E - V_A$$

$$(VF)_A = V_A / V_E$$

$$(VF)_D = 1 - (VF)_A$$

$$\bar{R}_A = (A_A / \pi)^{1/2} \quad (\text{CR only})$$

$$\bar{R}_E = (A_E / \pi)^{1/2} \quad (\text{CR only})$$

4.2.2 Active Region

$$V_{FA} = N_1 GL t_F$$

$$V_{CA} = 2 L N_1 t_C G$$

$$V_{MA} = V_{FA} + V_{CA}$$

$$V_{WA} = V_A - V_{MA}$$

4.2.3 Dead Region

$$V_{SCB} = 2 \bar{q} L [J_1 + J_2 - 2 \bar{q}] \quad (\text{CR only})$$

$$C = t_F + 2 t_C$$

$$V_{SP} = 2L [EH - N_1 h (C + 2g)]$$

$$V_{DE} = V_{FPDE} = L (F - G) N_1 C$$

$$V_{SSD} = V_{SP} + V_{DE} + V_{BR} \quad (\text{FE only})$$

$$V_{SSD} = V_{SP} + V_{DE} + V_{SCB} + V_{BR} \quad (\text{CR only})$$

$$V_{WD} = V_D - V_{SSD}$$

4.3 PREPARATION OF INPUT TO P₃, IBM-650 CODES

4.3.1 Dead Region

$$\alpha = V_{SP} N_{SSP} + V_{DE} N_{SSDE} + V_{BR} N_{SSBR} \quad (\text{FE only})$$

$$\alpha = V_{SP} N_{SSP} + V_{DE} N_{SSDE} + V_{SCB} + V_{BR} N_{SSBR} \quad (\text{CR only})$$

$$\sum_{x,D}(T^0_F) = \frac{1}{V_D} \left[\alpha \sigma_x^{ss} + V_{WD} \theta (N_H \sigma_x^H + N_O \sigma_x^O) \right]$$

where:

x = a (absorption), s (scattering), tr (transport)

4.3.2 Active Region

4.3.2.1 Fuel Plates

$$V_P = \text{CGL}$$

$$N_P^{B-10} = 6.013312 \times 10^{22} \times \left(\frac{Y}{V_P} \right)$$

$$\sum_{x,BP}(T^0_F) = N_P^{B-10} \sigma_x^{B-10}$$

where:

x = a (absorption), s (scattering), tr (transport)

$$N_P^{25} = 2.561614 \times 10^{21} \times \left(\frac{Z}{V_P} \right)$$

$$N_P^{28} = 2.529266 \times 10^{21} \times \left(\frac{Z_O}{V_P} \right) \left(\frac{1 - \mu_2}{\mu_2} \right)$$

$$N_P^O = 2 \left[\frac{N_P^{25}}{(1-B)} + N_P^{28} \right]$$

$$V_M = t_F \text{ GL}$$

$$V_V = \epsilon V_M$$

$$V_{(UO_2)_P} = \frac{Z_o}{\mu_1 \mu_2 \rho_{UO_2}}$$

$$V_{B(comp)_P} = \frac{Y_o}{\mu_3 \mu_3 \rho_{B(comp)_P}}$$

$$V_{SSPM} = V_M - V_V - V_{(UO_2)_P} - V_{B(comp)_P}$$

$$N_P^{SS} = \frac{1}{V_P} \left[\frac{V_{CA}}{N_1} N_{SSDE} + V_{SSPM} N_{SSA} \right]$$

$$\sum_{xP} (T^0 F) = N_P^{25} \sigma_x^{25} + N_P^{28} \sigma_x^{28} + N_P^0 \sigma_x^0 + N_P^{SS} \sigma_x^{SS} + \sum_{xBP} (T^0 F)$$

where:

x = a (absorption), s (scattering), tr (transport)

$$\nu \sum_{fP} (T^0 F) = N_P^{25} (\nu \sigma_f^{25})$$

4.3.2.2 Water Channels

$$d = \frac{1}{N_1} [H - N_1 C]$$

$$V_{WA} = V_{WCH} = N_1 d GL$$

$$\sum_{xCH} (T^0 F) = \theta [N_H \sigma_x^H + N_O \sigma_x^O]$$

where:

x = a (absorption), s (scattering), tr (transport)

4.3.3 Additional Input

$$S_{\text{ACTIVE}} = V_{\text{WA}}/V_{\text{A}} \quad (\text{FE only})$$

$$S_{\text{DEAD}} = V_{\text{WD}}/V_{\text{D}} \quad (\text{FE only})$$

$$q = D/2 \quad (\text{FE only})$$

$$p = G/2 \quad (\text{FE only})$$

$$l = C/2 \quad (\text{FE only})$$

$$m = 1 + \frac{d}{2} \quad (\text{FE only})$$

$$q_{\text{A}} = V_{\text{WA}}/V_{\text{A}} \quad (\text{CR only})$$

$$q_{\text{D}} = V_{\text{WD}}/V_{\text{D}} \quad (\text{CR only})$$

$$w = C/2 \quad (\text{CR only})$$

$$W = w + \frac{d}{2} \quad (\text{CR only})$$

$$(VF)_{\text{P}}^{\text{A}} = w/W \quad (\text{CR only})$$

$$\sum_{\text{D}} = \sum_{\text{aD}} + \sum_{\text{sD}} \quad (\text{CR only})$$

$$\sum_{\text{D}}^{\text{I}} = \sum_{\text{D}} = \sum_{\text{trD}} = \sum_{1\text{p}}^* \quad (\text{CR only})$$

$$\sum_{\text{D}}^2 = 0 = \sum_{2\text{p}}^* \quad (\text{CR only})$$

4.4 PREPARATION OF INPUT TO MUFT-III, IBM-650 CODE

$$N_C^{25} = 2.561614 \times 10^{21} \times \frac{Z_E^{25}}{V_E}$$

$$N_C^{28} = 2.529266 \times 10^{21} \times \left(\frac{Z_O N_1}{V_E} \right) \left(\frac{1 - \mu_2}{\mu_2} \right)$$

$$N_{CP}^O = 2 \left[\frac{N_C^{25}}{(1-B)} + N_C^{28} \right]$$

$$V_{WE} = V_{WD} + V_{WA}$$

$$N_C^H = \frac{1}{V_E} \left[V_{WE} \theta N_H \right]$$

$$N_{CW} = \frac{1}{V_E} \left[V_{WE} \theta N_O \right]$$

$$N_C^O = N_{CP}^O + N_{CW}^O$$

$$N_C^{B-10} = \frac{1}{V_E} \left[N_1 N_P^{B-10} V_P \right]$$

$$N_C^{SS} = \frac{1}{V_E} \left[N_1 V_{SSPM} N_{SSA} + V_{SP} N_{SSP} + V_{BR} N_{SSBR} + (V_{FPDE} + V_{CA}) N_{SSDE} \right] \quad (\text{FE only})$$

$$N_C^{SS} = \frac{1}{V_E} \left[N_1 V_{SSPM} N_{SSA} + V_{SP} N_{SSP} + V_{BR} N_{SSBR} + V_{SCB} N_{SSCB} + (V_{FPDE} + V_{CA}) N_{SSDE} \right] \quad (\text{CR only})$$

The number densities for the elements composing stainless steel, are calculated in the following equations. (See Appendix D):

$$N_C^i = \frac{1}{V_E} \left[N_1 V_{SSPM} N_{SSA} (AF)_A^i + V_{SP} N_{SSP} (AF)_P^i + V_{BR} N_{SSBR} (AF)_{BR}^i + (V_{FPDE} + V_{CA}) N_{SSDE} (AF)_{DE}^i \right] \quad (\text{FE only})$$

where: $i = \text{Fe, Ni, Cr, Mn, C, Si, and Mo.}$

$$N_C^i = \frac{1}{V_E} \left[N_1 V_{SSPM} N_{SSA} (AF)_A^i + V_{SP} N_{SSP} (AF)_P^i + V_{BR} N_{SSBR} (AF)_{BR}^i + V_{SCB} N_{SSCB} (AF)_{CB}^i + (V_{FPDE} + V_{CA}) N_{SSDE} (AF)_{DE}^i \right] \quad (\text{CR only})$$

where: $i = \text{Fe, Ni, Cr, Mn, C, Si, and Mo.}$

4.5 MISCELLANEOUS CALCULATIONS

4.5.1 Weight Percent of Components in the Fuel Matrix

$$M_P^{UO_2} = \frac{Z_O}{(\mu_1 \cdot \mu_2)}$$

$$M_P^{B(comp)} = \frac{Y_O}{(\mu_3 \cdot \mu_4)}$$

$$M_P^{SS} = V_{SSPM} \rho_{SSA}$$

$$M_P^T = M_P^{UO_2} + M_P^{B(comp)} + M_P^{SS}$$

$$(W)_M^{UO_2} = M_P^{UO_2} / M_P^T$$

$$(W)_M^{B(comp)} = M_P^{B(comp)} / M_P^T$$

$$(W)_M^{SS} = M_P^{SS} / M_P^T$$

$$(W)_M^B = \mu_3 (W)_M^{B(comp)}$$

4.5.2 Atom Percent of Components in the Fuel Matrix

$$n_M^{25} = 2.561614 \times 10^{21} \times Z_O$$

$$n_M^{28} = 2.529266 \times 10^{21} \times Z_O \times \left(\frac{1 - \mu_2}{\mu_2} \right)$$

$$n_M^O = 2 (n_M^{25} + n_M^{28})$$

$$n_M^{SS} = V_{SSPM} N_{SSA}$$

$$n_M^{B-10} = 6.013312 \times 10^{22} \times Y_O$$

$$n_M^B = \frac{1}{\gamma} n_M^{B-10}$$

$$n_M^{(comp)} = \lambda n_M^B$$

$$n_M^T = n_M^{25} + n_M^{28} + n_M^O + n_M^{SS} + n_M^B + n_M^{(comp)}$$

$$(A)_M^{25} = n_M^{25}/n_M^T$$

$$(A)_M^{28} = n_M^{28}/n_M^T$$

$$(A)_M^O = n_M^O/n_M^T$$

$$(A)_M^{SS} = n_M^{SS}/n_M^T$$

$$(A)_M^B = n_M^B/n_M^T$$

$$(A)_M^{(comp)} = n_M^{(comp)}/n_M^T$$

4.5.3 Volumes of Components in the Fuel Elements

$$V_{VE} = V_{VN1}$$

$$V_{ME} = V_{MA} + V_{SSD}$$

$$\xi = N_1 V_{SSPM} + V_{SP} + V_{FPDE} + V_{CA} + V_{BR}$$

$$V_{SSE} = \xi \quad (\text{FE only})$$

$$V_{SSE} = \xi + V_{SCB} \quad (\text{CR only})$$

$$V_E^{UO_2} = Z_E^{UO_2}/\rho_{UO_2}$$

$$V_E^{B(comp)} = Y_E^{B(comp)}/\rho_{B(comp)}$$

$$(VF)_E^{H_2O} = V_{WE}/V_E$$

$$(VF)_E^{SS} = V_{SSE}/V_E$$

$$(VF)_E^{UO_2} = V_E^{UO_2}/V_E$$

$$(VF)_E^{B(comp)} = V_E^{B(comp)}/V_E$$

$$(VF)_E^V = V_{VE}/V_E$$

$$R_E^X = (M/W)_E = V_{ME}/V_{WE}$$

4.5.4 Mass of Components in the Fuel Elements

$$\delta = \rho_{SSA} N_1 V_{SSPM} + \rho_{SP} V_{SP} + \rho_{SFP} (V_{FPDE} + V_{CA}) + \rho_{BR} V_{BR}$$

$$M_E^{SS} = \delta \quad (\text{FE only})$$

$$M_E^{SS} = \delta + \rho_{SCB} V_{SCB} \quad (\text{CR only})$$

$$M_E^{H_2O} = \rho_{H_2O} V_{WE}$$

4.5.5 Total Core Parameters

The terms with a bar (-) above them denote control rod fuel elements. The terms without a bar denote stationary fuel elements.

4.5.5.1 Volume

$$V_C^{B(\text{comp})} = N_2 V_E^{B(\text{comp})} + \bar{N}_2 \bar{V}_E^{B(\text{comp})}$$

$$V_C^V = N_2 V_{VE} + \bar{N}_2 \bar{V}_{VE}$$

$$V_T = N_2 V_E + \bar{N}_2 \bar{V}_E$$

$$V_C^{H_2O} = N_2 V_{WE} + \bar{N}_2 \bar{V}_{WE}$$

$$V_C^{SS} = N_2 V_{SSE} + \bar{N}_2 \bar{V}_{SSE}$$

$$V_C^{UO_2} = N_2 V_E^{UO_2} + \bar{N}_2 \bar{V}_E^{UO_2}$$

$$V_C^M = N_2 V_{ME} + \bar{N}_2 \bar{V}_{ME}$$

$$(VF)_C^{H_2O} = V_C^{H_2O} / V_T$$

$$(VF)_C^{SS} = V_C^{SS} / V_T$$

$$(VF)_C^{UO_2} = V_C^{UO_2} / V_T$$

$$(VF)_C^M = V_C^M / V_T$$

$$(VF)_C^V = V_C^V / V_T$$

$$(VF)_C^{B(\text{comp})} = V_C^{B(\text{comp})} / V_T$$

4.5.5.2 Masses

$$M_C^{H_2O} = N_2 M_E^{H_2O} + \bar{N}_2 \bar{M}_E^{H_2O}$$

$$M_C^{SS} = N_2 M_E^{SS} + \bar{N}_2 \bar{M}_E^{SS}$$

$$M_C^{U25} = N_2 Z_E^{25} + \bar{N}_2 \bar{Z}_E^{25}$$

$$M_C^{UO_2} = N_2 Z_E^{UO_2} + \bar{N}_2 \bar{Z}_E^{UO_2}$$

$$M_C^{B-10} = N_2 Y_E^{B-10} + \bar{N}_2 \bar{Y}_E^{B-10}$$

$$M_C^{B(comp)} = N_2 Y_E^{B(comp)} + \bar{N}_2 \bar{Y}_E^{B(comp)}$$

$$M_C^T = M_C^{H_2O} + M_C^{SS} + M_C^{UO_2} + M_C^{B(comp)}$$

4.5.5.3 Metal-to-Water Ratio

$$R_C = (M/W)_C = V_C^M / V_C^{H_2O}$$

4.6 PREPARATION OF NUCLEAR PARAMETER INPUT TO THE PDQ(X, Y) OR TURBO, IBM-704 CODES

4.6.1 Region #1 (Dead Regions of Stationary Fuel Element)

4.6.1.1 Thermal Parameters

The macroscopic cross sections have previously been calculated in Section 4.3.1.

$$\sum_{x,D(1)} = \frac{1}{V_D} \left[\alpha \sigma_x^{SS} + v_{WD} \theta (N_H \sigma_x^H + N_O \sigma_x^O) \right]$$

where:

x = a(absorption), s (scattering), tr(transport)

$$\nu \sum_{f,D(1)} = 0$$

$$K_{TD(1)} = 0$$

$$D_D(1) = 1/3 \sum_{trD(1)}$$

$$L_D^2(1) = D_D(1) / \sum_{aD(1)}$$

4. 6. 1. 2 MUFT-III Input

$$N_{HD(1)} = \frac{V_{WD}}{V_D} \theta N_H$$

$$N_{OD(1)} = \frac{V_{WD}}{V_D} \theta N_O$$

$$N_{SSD(1)} = \frac{\alpha}{V_D} \times 10^{24}$$

$$N_{D(1)}^i = \frac{1}{V_D} \left[V_{SP} N_{SSP} (AF)_P^i + V_{FPDE} N_{SSDE} (AF)_{DE}^i + V_{BR} N_{SSBR} (AF)_{BR}^i \right]$$

where: $i = \text{Fe, Ni, Cr, Mn, C, Si, and Mo}$

4. 6. 2 Region #2 (Active Region of Stationary Fuel Element)

4. 6. 2. 1 Thermal Parameters

These are obtained as output of the Plate-Type P_3 code⁽³⁾ for stationary fuel elements.

4. 6. 2. 2 MUFT-III Input

$$V_{WCH} = V_{WA} = N_1 d GL$$

$$V_{PA} = C GL N_1$$

$$V_A = V_{WCH} + V_{PA} = N_1 LG (d + C)$$

$$(VF)_{PA} = \frac{C}{d + C}$$

$$(VF)_{WA} = \frac{d}{d + C}$$

$$N_{HA(2)} = \left(\frac{d}{d + C} \right) \theta N_H$$

$$N_{OA}(2) = \left(\frac{d}{d+C}\right) \theta \cdot N_O + \left(\frac{C}{d+C}\right) N_P^0$$

$$N_{(25)A}(2) = \left(\frac{C}{d+C}\right) N_P^{25}$$

$$N_{(28)A}(2) = \left(\frac{C}{d+C}\right) N_P^{28}$$

$$N_{(B-10)A}(2) = \left(\frac{C}{d+C}\right) N_P^{B-10}$$

$$N_{SSA}(2) = \left(\frac{C}{d+C}\right) N_P^{SS}$$

$$N_{A(2)}^i = \frac{1}{V_A} \left[N_1 V_{SSPM} N_{SSA} (AF)_A^i + V_{CA} N_{SSDE} (AF)_{DE}^i \right]$$

where: $i = \text{Fe, Ni, Cr, Mn, C, Si, and Mo.}$

4. 6. 3 Region #3 (Dead Regions of Control Fuel Element Containing the Side Plates)

4. 6. 3. 1 Thermal Parameters

$$V_{D(3)} = AL (D-G)$$

$$V_{BD(3)} = 2L \bar{q} \left[J_1 + J_2 - G \right]$$

$$V_{SPD(3)} = 2 L \left[EH - N_1 h (c + 2g) \right]$$

$$V_{DED(3)} = V_{(FPDE)D(3)} = L N_1 C (F-G)$$

$$V_{SSD(3)} = V_{BD(3)} + V_{SPD(3)} + V_{DED(3)}$$

$$V_{WD(3)} = V_{D(3)} - V_{SSD(3)}$$

$$\alpha_{D(3)} = V_{SPD(3)} N_{SSP} + V_{DED(3)} N_{SSDE} + V_{BD(3)} N_{SSCB} + V_{BR} N_{SSBR}$$

$$\sum_{x\text{D}(3)} = \frac{1}{V_{\text{D}(3)}} \left[\alpha_{\text{D}(3)} \sigma_x^{\text{SS}} + V_{\text{WD}(3)} \theta (N_{\text{H}} \sigma_x^{\text{H}} + N_{\text{O}} \sigma_x^{\text{O}}) \right]$$

where: $x = a$ (absorption), s (scattering), tr (transport)

$$\nu \sum_{\text{fD}(3)} = 0$$

$$K_{\text{TD}(3)} = 0$$

$$D_{\text{TD}(3)} = 1/3 \sum_{\text{trD}(3)}$$

$$L_{\text{D}(3)}^2 = D_{\text{TD}(3)} / \sum_{\text{aD}(3)}$$

4. 6. 3. 2 MUFT-III Input

$$N_{\text{HD}(3)} = \left[\frac{V_{\text{WD}(3)}}{V_{\text{D}(3)}} \right] \theta N_{\text{H}}$$

$$N_{\text{OD}(3)} = \left[\frac{V_{\text{WD}(3)}}{V_{\text{D}(3)}} \right] \theta N_{\text{O}}$$

$$N_{\text{SSD}(3)} = \frac{\alpha_{\text{D}(3)}}{V_{\text{D}(3)}} \times 10^{24}$$

$$N_{\text{D}(3)}^i = \frac{1}{V_{\text{D}(3)}} \left[V_{\text{SPD}(3)} N_{\text{SSP}}^i(\text{AF})_{\text{P}} + V_{\text{DED}(3)} N_{\text{SSDE}}^i(\text{AF})_{\text{DE}} + V_{\text{BD}(3)} N_{\text{SSCB}}^i(\text{AF})_{\text{CB}} + V_{\text{BR}} N_{\text{SSBR}}^i(\text{AF})_{\text{BR}} \right]$$

where: $i = \text{Fe, Ni, Cr, Mn, C, Si, and Mo.}$

4. 6. 4 Region #4 (Dead Regions of Control Fuel Element Perpendicular to the Side Plates)

4. 6. 4. 1 Thermal Parameters

$$V_{D(4)} = LG (A-H')$$

$$V_{BD(4)} = 2 GL \bar{q}$$

$$V_{WD(4)} = V_{D(4)} - V_{BD(4)}$$

$$\sum_{xD(4)} = \frac{1}{V_{D(4)}} \left[V_{BD(4)} N_{SSCB} \sigma_x^{ss} + V_{WD(4)} \theta (N_H \sigma_x^H + N_O \sigma_x^O) \right]$$

where:

x = a (absorption), s (scattering), tr (transport)

$$\nu \sum_{fD(4)} = 0$$

$$K_{TD(4)} = 0$$

$$D_{TD(4)} = 1/3 \sum_{trD(4)}$$

$$L_{D(4)}^2 = D_{TD(4)} / \sum_{aD(4)}$$

4. 6. 4. 2 MUFT-III Input

$$N_{HD(4)} = \left[\frac{V_{WD(4)}}{V_{D(4)}} \right] \theta N_H$$

$$N_{OD(4)} = \left[\frac{V_{WD(4)}}{V_{D(4)}} \right] \theta N_O$$

$$N_{SSD(4)} = \frac{V_{BD(4)}}{V_{D(4)}} N_{SSCB}$$

$$N_{D(4)}^i = \frac{V_{BD(4)}}{V_{D(4)}} N_{SSCB} (AF)_{CB}^i$$

where: $i = \text{Fe, Ni, Cr, Mn, C, Si, and Mo.}$

4. 6. 5 Region #5 (Active Region of Control Fuel Element)

4. 6. 5. 1 Thermal Parameters

These are printed out as output of Program 54. (4)

4. 6. 5. 2 MUFT-III Input

$$V_{WAC(5)} = N_1 d GL$$

$$V_{PAC(5)} = CGLN_1$$

$$V_{AC(5)} = N_1 LG (d + C)$$

$$(VF)_{PAC(5)} = \frac{C}{d + C}$$

$$(VF)_{WAC(5)} = \frac{C}{d + C}$$

$$N_{HAC(5)} = \left(\frac{d}{d + C}\right) \theta N_H$$

$$N_{OAC(5)} = \left(\frac{d}{d + C}\right) \theta N_O + \left(\frac{C}{d + C}\right) N_P^O$$

$$N_{(25)AC(5)} = \left(\frac{C}{d + C}\right) N_P^{25}$$

$$N_{(28)AC(5)} = \left(\frac{C}{d + C}\right) N_P^{28}$$

$$N_{(B-10)AC(5)} = \left(\frac{C}{d + C}\right) N_P^{B-10}$$

$$N_{SSAC(5)} = \left(\frac{C}{d + C}\right) N_P^{SS}$$

$$N_{AC(5)}^i = \frac{1}{V_{AC(5)}} \left[N_1 V_{SSPM} N_{SSA} (AF)_A^i + V_{CA} N_{SSDE} (AF)_{DE}^i \right]$$

where: $i = \text{Fe, Ni, Cr, Mn, C, Si, and Mo.}$

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

5.0 PROGRAM INSTRUCTIONS

Program No. 56 (BOBCAT) is written for the IBM-650 through the use of the Symbolic Optimal Assembly Program (SOAP II). The program is divided into three parts:

Part I for the calculation of fixed element parameters,
Part II for control rod fuel element parameters, and
Part III for calculation of total core.

The user may run Parts I and II together or separately. Part III is automatically calculated if Parts I and II are run together, e. g. as one problem.

Included as part of the fixed element deck (Part I) is a BURNUP table and a corresponding PSI (Ψ) table. These two tables must also be used when running the control rod fuel element program (Part II). Files for density, cross section and breakdown of stainless steel for MUFT III must be used with either Part I or Part II. User must specify in the input which of these files are to be used.

5.1 INPUT

The input to Program No. 56 (BOBCAT) is in floating point form (see Appendix B) with the exception of the identification word which appears as the first word of each input card.

The identification word is XXXXoabooc where:

XXXX= problem identification (case no.)

a = 8 fixed element calculation

a = 9 no fixed element calculation

b = 8 control rod calculation

b = 9 no control rod calculation

c = card numbers, i. e. 1, 2, 3, 4

Except for the variable input cards, all data is loaded by the L-1 load routine. The format for the various input cards is given in the following sections, where LLLL and n are L-1 card identification. Special forms are available for the various input cards. These forms, together with a sample problem are shown in Appendix F.

In general, the Burnup Table (Section 5.1.1), PSI Table (Section 5.1.2), Stainless Steel File (Section 5.1.3), Density File (Section 5.1.4) and the Cross Section File (Section 5.1.5), do not need to be constructed for every problem. These may be made up into "files" which then may be used for future problems. A set of these files for various temperatures and for various types of stainless steels are available for the convenience of the user of the code.

5.1.1 Burnup Table (See Appendix C)

<u>LLLL</u>	<u>n</u>	<u>Word 2</u>	<u>Word 3</u>	<u>Word 4</u>	<u>Word 5</u>	<u>Word 6</u>	<u>Word 7</u>	<u>Word 8</u>
1800	7	B ₁	B ₂	B ₃	B ₄	B ₅	B ₆	B ₇
1807	7	B ₈	B ₉	B ₁₀	B ₁₁	B ₁₂	B ₁₃	B ₁₄
1814	7	B ₁₅	B ₁₆	B ₁₇	B ₁₈	B ₁₉	B ₂₀	B ₂₁
1821	2	B ₂₂	B ₂₃					

5.1.2 Psi (Ψ) Table (See Appendix C)

<u>LLLL</u>	<u>n</u>	<u>Word 2</u>	<u>Word 3</u>	<u>Word 4</u>	<u>Word 5</u>	<u>Word 6</u>	<u>Word 7</u>	<u>Word 8</u>
1750	7	Ψ_1	Ψ_2	Ψ_3	Ψ_4	Ψ_5	Ψ_6	Ψ_7
1757	7	Ψ_8	Ψ_9	Ψ_{10}	Ψ_{11}	Ψ_{12}	Ψ_{13}	Ψ_{14}
1764	7	Ψ_{15}	Ψ_{16}	Ψ_{17}	Ψ_{18}	Ψ_{19}	Ψ_{20}	Ψ_{21}
1771	2	Ψ_{22}	Ψ_{23}					

For each value of fuel burnup, B, there must be a corresponding value of Ψ . The relationship between B and Ψ is defined in Section 4 and in Appendix C.

5.1.3 Stainless Steel File (See Appendix D)

<u>LLLL</u>	<u>n</u>	<u>Word 2</u>	<u>Word 3</u>	<u>Word 4</u>	<u>Word 5</u>	<u>Word 6</u>	<u>Word 7</u>	<u>Word 8</u>
1500	7	(AF) _A ^{Fe}	(AF) _A ^{Ni}	(AF) _A ^{Cr}	(AF) _A ^{Mn}	(AF) _A ^C	(AF) _A ^{Si}	(AF) _A ^{Mo}
1507	7	(AF) _{DE} ^{Fe}	(AF) _{DE} ^{Ni}	(AF) _{DE} ^{Cr}	(AF) _{DE} ^{Mn}	(AF) _{DE} ^C	(AF) _{DE} ^{Si}	(AF) _{DE} ^{Mo}
1514	7	(AF) _P ^{Fe}	(AF) _P ^{Ni}	(AF) _P ^{Cr}	(AF) _P ^{Mn}	(AF) _P ^C	(AF) _P ^{Si}	(AF) _P ^{Mo}
1521	7	(AF) _{BR} ^{Fe}	(AF) _{BR} ^{Ni}	(AF) _{BR} ^{Cr}	(AF) _{BR} ^{Mn}	(AF) _{BR} ^C	(AF) _{BR} ^{Si}	(AF) _{BR} ^{Mo}
1528	7	(AF) _{CB} ^{Fe}	(AF) _{CB} ^{Ni}	(AF) _{CB} ^{Cr}	(AF) _{CB} ^{Mn}	(AF) _{CB} ^C	(AF) _{CB} ^{Si}	(AF) _{CB} ^{Mo}

5.1.4 Density File

<u>LLLL</u>	<u>n</u>	<u>Word 2</u>	<u>Word 3</u>	<u>Word 4</u>	<u>Word 5</u>	<u>Word 6</u>	<u>Word 7</u>	<u>Word 8</u>
1900	7	N _H	N ₀	N _{SSP}	N _{SSA}	N _{SSDE}	N _{SSCB}	N _{SSBR}
1907	7	μ_1	μ_2	μ_3	γ	ρ_{UO_2}	$\rho_{B(comp)}$	ρ_{SSA}
1914	6	ρ_{BR}	ρ_{SCB}	ρ_{SP}	ρ_{SFP}	ρ_{H_2O}	λ	

All atom density values, (i.e. N_H , N_O , N_{SS} , etc) are given in terms of 10^{-24} , e.g., 2×10^{-24} is entered as 2.0 which in floating point form would be 5020000000. (See Appendix B).

5.1.5 Cross Section File

<u>LLLL</u>	<u>n</u>	<u>Word 2</u>	<u>Word 3</u>	<u>Word 4</u>	<u>Word 5</u>	<u>Word 6</u>	<u>Word 7</u>	<u>Word 8</u>
1920	7	σ_a^{25}	σ_s^{25}	σ_{tr}^{25}	σ_a^{28}	σ_s^{28}	σ_{tr}^{28}	σ_a^{SS}
1927	7	σ_s^{SS}	σ_{tr}^{SS}	σ_a^{B-10}	σ_s^{B-10}	σ_{tr}^{B-10}	σ_a^H	σ_s^H
1934	7	σ_{tr}^H	σ_a^0	σ_s^0	σ_{tr}^0	$\nu\sigma_f^{25}$	σ_{aF}^{B-10}	σ_{aF}^{25}
1941	2	α_{th}	α_f					

All cross sections have the units of barns (i. e. $\times 10^{-24}$).

5.1.6 Input Cards (Variable Cards)

<u>Word 1</u>	<u>Word 2</u>	<u>Word 3</u>	<u>Word 4</u>	<u>Word 5</u>	<u>Word 6</u>	<u>Word 7</u>	<u>Word 8</u>
IDENT	Z_0	Y_0	B	β	Δ	A	D
IDENT	F	G	t_f	t_C	g	h	$\bar{E}$
IDENT	H	H'	L	ϵ	θ	V_{BR}	$\bar{q}$
IDENT	N_1	N_2	J_1	J_2			

5.1.7 Special Input Cards

The input cards described in the previous sections are sufficient to run the BOBCAT code. However, if it is desired to obtain the MUFT-III and/or various P3 code card input following the completion of BOBCAT, it is necessary to include additional input information for the edit program. In addition, to the unedited output (Section 7 and Appendix F), special "comments" cards must be added. These special input cards are described in the following sections.

5.1.7.1 Comments Cards

The comments cards precede all edit program input cards (BOBCAT output cards) for a particular run for one individual. These comments cards will contain the individual's name, some indication of the project, and the date. Only alphanumeric information is acceptable. A total of 30 characters including blanks may be specified on each card and are punched into columns 11 through 40. A sample format for the comments cards are shown with the sample problem in Appendix F. The information contained on the two comments cards is as follows:

CARD #1

Col. 11-30	Requestors' Name
Col. 31-32	Number of Month (XX)
Col. 34-35	Number of Day (XX)
Col. 37-38	Last Two Digits of Year (XX)
Col. 74	High X
Col. 75	Low X

CARD #2

Col. 11-40	Project Information (alphanumeric)
Col. 74	High X
Col. 75	Low X

5.1.7.2 Flux Cards

For the P_3 calculations as performed by the plate-type P_3 code (stationary element) and Program No. 54 (control fuel element), the number of flux points desired in the various regions may be specified by use of the special flux cards. It is a requirement of both P_3 codes that a minimum of two flux points be specified for each region (active, dead, etc). When two flux points are specified, only the P_3 fluxes at the boundaries of each region are calculated and printed out. Two types of flux cards may be used: one for the stationary fuel element and the other for the control rod fuel element.

If no flux cards are used, the edit program assigns a value of two for all flux point numbers. It should be noted that once flux point values are specified, these values are used continuously in a given run unless new flux cards are specified.

The format of the flux card for the stationary fuel element P_3 calculation (by the plate-type P_3 code) is shown below. A sample format is shown in Appendix F. The nomenclature is as follows:

XXXX	= problem identification (case number)
n_{plate}	= number of flux points to be calculated and printed out for the fuel plate (P_3 flux distribution perpendicular to the fuel plates). ($n_{plate} \geq 2$).
$n_{channel}$	= number of flux points to be calculated and printed out for the water channel (P_3 flux distribution perpendicular to the fuel plates). ($n_{channel} \geq 2$).
n_{dead}	= number of flux points to be calculated and printed out for the dead region (P_3 flux distribution parallel to the fuel plates). ($n_{dead} \geq 2$).
n_{active}	= number of flux points to be calculated and printed out for the active region (P_3 flux distribution parallel to the fuel plates). ($n_{active} \geq 2$).

The format of the flux card for the control rod fuel element P_3 calculations (by Program No. 54) is also shown below. A sample format is shown in Appendix F. The nomenclature is as follows:

XXXX = problem identification (case number).
 N_f = number of flux points to be calculated and printed out for the P_3 flux distribution calculation within and perpendicular to the fuel plates. ($N_f \geq 2$).
 N_m = number of flux points to be calculated and printed out for the P_3 flux distribution calculation in the water channel, perpendicular to the fuel plates. ($N_m \geq 2$).
 N_f' = number of flux points to be calculated and printed out in the active region for the cylindrical P_3 calculation. ($N_f' \geq 2$).
 N_m' = number of flux points to be calculated and printed out in the dead region for the cylindrical P_3 calculation. ($N_m' \geq 2$).

Stationary Element Flux Card

632XXXX010

n_{plate}

n_{channel}

n_{dead}

n_{active}

0-----0

0-----0

0-----0

Control Fuel Element Flux Card

XXXX540200

N_f

N_m

N_f'

N_m'

0-----0

0-----0

0-----0

5.1.7.3 MUFT-III Input Cards

If it is desired to run the MUFT-III code following the completion of the BOBCAT code, additional input cards are needed. These cards include the Title Card, Number Density Cards, and the Heading Card. These cards are punched from special input forms (NPED-1029-1159 Revised and NPED-1032-1159) which are available to the program user. These forms, together with a sample input format, are shown in Appendix F.

The Title Card contains the number of constituents to be included in the MUFT-III calculation. The Number Density Cards specifies the MUFT-III cross section file number corresponding to each constituent. The Heading Card specifies the neutron energy group break points, the slowing down approximation desired, and the source set to be employed.

6.0 OPERATING INSTRUCTIONS

There are three options for the running of Program No. 56 (BOBCAT), and the user must specify to the operator which of the options are desired.

6.1 OPTION 1: STATIONARY ELEMENT ONLY

A. Console setting 701951XXXX.

1. Deck Makeup

- a) Program Deck Part I (F. E.)
- b) Burnup table
- c) Psi table
- d) Stainless steel file
- e) Density file
- f) Cross section file
- g) Input cards (4) (in order-col. 10)

6.2 OPTION 2: CONTROL ROD FUEL ELEMENT ONLY

A. Console setting 701951XXXX.

1. Deck Makeup

- a) Program Deck Part II (C. R.)
- b) Burnup table
- c) Psi table
- d) Stainless steel file
- e) Density file
- f) Cross section file
- g) Input cards (4) (in order - col. 10)

6.3 OPTION 3: STATIONARY ELEMENT, CONTROL ROD FUEL ELEMENT, AND TOTAL CORE

A. Console setting 701951XXXX.

1. Deck Makeup

- a) Program Deck Part I (F. E.)
- b) Burnup table
- c) Psi table
- d) Stainless steel file
- e) Density file
- f) Cross section file

- g) Fixed element input cards (4) (in order - col. 10)
- h) Program Deck Part II (C.R.)
- i) Burnup table*
- j) Psi table*
- k) Stainless steel file*
- l) Density file*
- m) Cross section file*
- n) Control rod element input cards (4) (in order - col. 10)
- o) Program Deck Part III (T.C.)

* If the same tables and/or files are to be used for control rod fuel element calculation, it is not necessary to place tables and/or files behind Part II (C.R.) program deck. The only files that need be included with Part II are those which are different from files previously used with Part I.

6.4 STOPS

0199999999 Input cards out of order.

6.5 TIMING

The time required for BOBCAT calculations depends upon the calculation option. Including program deck read-in, the timing requirements are as follows:

(a) Stationary fuel element alone	2 min. 37 sec.
(b) Control fuel element alone	2 min. 37 sec.
(c) Stationary and control fuel elements	5 min. 37 sec.
1. Stationary element	2 min. 37 sec.
2. Control element	2 min. 25 sec.
3. Total core parameters	35 sec.

7.0 OUTPUT

The output of Program No. 56 (BOBCAT) may be obtained in two different forms. The unedited format is shown in the following sections. The edited format of the output is shown in the sample problem given in Appendix F. The edited format is the most convenient and commonly used form of the output. Each value is preceded by an "identification" symbol described in Section 3.2. The edited output may be obtained for a stationary fuel element alone or a control rod fuel element alone. Total core parameters are obtained only if both stationary and control rod fuel elements are calculated. Total core parameters for a core consisting entirely of stationary (or control) fuel elements may be obtained by specifying the input value of N_2 (or $\bar{N}_2$) to be equal to $N_2 + \bar{N}_2$.

Each card of the unedited output contains an identification word (XXXXoabLoc), where:

- XXXX = problem identification (case number).
- a = 8 for stationary fuel element calculation.
- a = 9 for no stationary fuel element calculation.
- b = 8 for control rod fuel element calculation.
- b = 9 for no control rod fuel element calculation.
- L = 1 for stationary fuel element output for one-dimensional calculations.
- L = 2 for stationary fuel element output for two-dimensional calculations.
- L = 3 for control rod fuel element output for one-dimensional calculations.
- L = 4 for control rod fuel element output for two-dimensional calculations.
- L = 5 for total core parameters.

7.1 UNEDITED OUTPUT - STATIONARY FUEL ELEMENT

7.1.1 Output Used for One-Dimensional Calculations (Section 2.1.1)

<u>Card 1</u>	<u>Card 2</u>	<u>Card 3</u>	<u>Card 4</u>
XXXXoabLoc	XXXXoabLoc	XXXXoabLoc	XXXXoabLoc
$\sum_{aD}$	$\sum_{sP}$	Y_E^{B-10}	$V_E^{UO_2}$
$\sum_{sD}$	$\sum_{trP}$	$Y_E^{B(comp)}$	M_E^{ss}
$\sum_{trD}$	$\sum_{aCH}$	V_E	$M_E^{H_2O}$

Card 1
Continued

Σ_{aBP}

Σ_{sPB}

Σ_{trPB}

Σ_{aP}

Card 2
Continued

Σ_{sCH}

Σ_{trCH}

Z_E^{25}

$Z_E^{UO_2}$

Card 3
Continued

V_{WE}

V_{VE}

V_{ME}

V_{SSE}

Card 4
Continued

Z or $\bar{Z}$

Δ

$Y_{EQ.F.P.}$

Y or $\bar{Y}$

Card 5
XXXXoabLoc

Ψ

μ_4

V_A

V_D

$(VF)_A$

$(VF)_D$

V_{FA}

Card 6
XXXXoabLoc

V_{CA}

V_{MA}

V_{WA}

C

V_{SP}

V_{DE}

V_{SSD}

Card 7
XXXXoabLoc

V_{WD}

α

V_P

N_P^{B-10}

N_P^{25}

N_P^{28}

N_P^0

Card 8
XXXXoabLoc

V_M

V_V

$V_{(UO_2)P}$

$V_{B(comp)P}$

V_{SSPM}

N_P^{SS}

$\nu \Sigma_{FP}$

Card 9
XXXXoabLoc

D

S_{ACTIVE}

S_{DEAD}

q

p

l

m

Card 10
XXXXoabLoc

N_C^{25}

N_C^{28}

N_{CP}^0

N_C^H

N_{CW}^0

N_C^0

N_C^{B-10}

Card 11
XXXXoabLoc

N_C^{SS}

R_E^X

N_C^{Fe}

N_C^{Ni}

N_C^{Cr}

N_C^{Mn}

N_C^C

Card 12
XXXXoabLoc

N_C^{Si}

N_C^{Mo}

N_D^{Fe}

N_D^{Ni}

N_D^{Cr}

N_D^{Mn}

N_D^C

Card 13
XXXXoabLoc

N_D^{Si}

N_D^{Mo}

N_A^{Fe}

N_A^{Ni}

N_A^{Cr}

N_A^{Mn}

N_A^C

Card 14
XXXXoabLoc

N_A^{Si}

N_A^{Mo}

$M_P^{UO_2}$

$M_P^{B(comp)}$

M_P^{SS}

M_P^T

$W_M^{UO_2}$

Card 15
XXXXoabLoc

$W_M^{B(comp)}$

W_M^{SS}

W_M^B

A_M^{25}

A_M^{28}

A_M^0

A_M^{SS}

Card 16
XXXXoabLoc

A_M^B

$A_M^{B(comp)}$

$V_E^{B(comp)}$

$V_{FE}^{H_2O}$

V_{FE}^{SS}

$V_{FE}^{H_2O}$

$V_{FE}^{B(comp)}$

Card 17
XXXXoabLoc

V_{FE}^V

N_M^T

7.1.2 Output Used for Two-Dimensional Calculations (Section 2.2.1)

Card 1
XXXXoabLoc

D_D

L_D^2

N_{HD}

N_{OD}

N_{SSD}

V_{PA}

V_A

Card 2
XXXXoabLoc

$(VF)_{PA}$

$(VF)_{WA}$

N_{HA}

N_{OA}

N_A^{25}

N_A^{28}

N_A^{B-10}

Card 3
XXXXoabLoc

N_{SSA}

7.2 UNEDITED OUTPUT - CONTROL ROD FUEL ELEMENTS

7.2.1 Output Used for One-Dimensional Calculations (Section 2.1.2)

<u>Card 1</u>	<u>Card 2</u>	<u>Card 3</u>	<u>Card 4</u>
XXXXoabLoc	XXXXoabLoc	XXXXoabLoc	XXXXoabLoc
$\sum_{aD}$	$\sum_{sP}$	Y_E^{B-10}	$V_E^{UO_2}$
$\sum_{sD}$	$\sum_{trP}$	$Y_E^{B(comp)}$	M_E^{SS}
$\sum_{trD}$	$\sum_{aCH}$	V_E	$M_E^{H_2O}$
$\sum_{aBP}$	$\sum_{sCH}$	V_{WE}	Z or $\bar{Z}$
$\sum_{sPB}$	$\sum_{trCH}$	V_{VE}	Δ
$\sum_{trBP}$	Z_E^{25}	V_{ME}	$Y_{EQ.F.P.}$
$\sum_{aP}$	$Z_E^{UO_2}$	V_{SSE}	Y or $\bar{Y}$
<u>Card 5</u>	<u>Card 6</u>	<u>Card 7</u>	<u>Card 8</u>
XXXXoabLoc	XXXXoabLoc	XXXXoabLoc	XXXXoabLoc
Ψ	V_{CA}	V_{WD}	V_M
μ_4	V_{MA}	α	V_V
V_A	V_{WA}	V_P	$V(UO_2)_P$
V_D	C	N_P^{B-10}	$V_{B(comp)_P}$
$(VF)_A$	V_{SP}	N_P^{25}	V_{SSPM}
$(VF)_D$	V_{DE}	N_P^{28}	N_P^{SS}
V_{FA}	V_{SSD}	N_P^0	$\nu \sum_{fp}$

Card 9
XXXXoabLoc

D

$\bar{R}_A$

$\bar{R}_E$

V_{SCB}

q_A

q_D

w

Card 13
XXXXoabLoc

N_{D1}^{Ni}

N_{D1}^{Cr}

N_{D1}^{Mn}

N_{D1}^C

N_{D1}^{Si}

N_{D1}^{Mo}

N_{D2}^{Fe}

Card 17
XXXXoabLoc

A_M²⁵

A_M²⁸

A_M⁰

A_M^{SS}

A_M^B

A_M^{B(comp)}

V_E^{B(comp)}

Card 10
XXXXoabLoc

W

(VF)_{AP}

$\sum_D$

$\sum_{D1}$

N_C²⁵

N_C²⁸

N_{CP}⁰

Card 14
XXXXoabLoc

N_{D2}^{Ni}

N_{D2}^{Cr}

N_{D2}^{Mn}

N_{D2}^C

N_{D2}^{Si}

N_{D2}^{Mo}

N_{AC}^{Fe}

Card 18
XXXXoabLoc

V_{FE}^{H2O}

V_{FE}^{SS}

V_{FE}^{UO2}

V_{FE}^{B(comp)}

V_{FE}^V

N_M^T

Card 11
XXXXoabLoc

N_C^H

N_{CW}⁰

N_C⁰

N_C^{B-10}

N_C^{SS}

R_E^X

N_C^{Fe}

Card 15
XXXXoabLoc

N_{AC}^{Ni}

N_{AC}^{Cr}

N_{AC}^{Mn}

N_{AC}^C

N_{AC}^{Si}

N_{AC}^{Mo}

M_P^{UO2}

Card 12
XXXXoabLoc

N_C^{N1}

N_C^{Cr}

N_C^{Mn}

N_C^C

N_C^{Si}

N_C^{Mo}

N_{D1}^{Fe}

Card 16
XXXXoabLoc

M_P^{B(comp)}

M_P^{SS}

M_P^T

W_M^{UO2}

W_M^{B(comp)}

W_M^{SS}

W_M^B

7.2.2 Output Used for Two-Dimensional Calculations (Section 2.2.2)

<u>Card 1</u>	<u>Card 2</u>	<u>Card 3</u>	<u>Card 4</u>
XXXXoabLoc	XXXXoabLoc	XXXXoabLoc	XXXXoabLoc
V_{D1}	$\sum_{aD1}$	N_{OD1}	D_{TD2}
V_{BD1}	$\sum_{sD1}$	N_{SSD1}	L^2_{D2}
V_{SPD1}	$\sum_{trD1}$	V_{D2}	N_{HD2}
V_{DED1}	$\sum_{aD2}$	V_{BD2}	N_{OD2}
V_{SSD1}	$\sum_{sD2}$	V_{WD2}	N_{SSD2}
V_{WD1}	$\sum_{trD2}$	D_{TD1}	V_{WAC}
α_{D1}	N_{HD1}	L^2_{D1}	V_{PAC}
<u>Card 5</u>	<u>Card 6</u>		
XXXXoabLoc	XXXXoabLoc		
V_{AC}	N_{AC}^{B-10}		
$(VF)_{PAC}$	N_{AC}^{SS}		
$(VF)_{WAC}$			
N_{HAC}			
N_{AC}^0			

7.3 UNEDITED OUTPUT-TOTAL CORE PARAMETERS

<u>Card 1</u>	<u>Card 2</u>	<u>Card 3</u>
XXXXoabLoc	XXXXoabLoc	XXXXoabLoc
V_C^V	M_C^{U25}	$(VF)_C^{UO2}$
V_T	M_C^{B-10}	$(VF)_C^M$
V_C^{H2O}	R_C	$(VF)_C^V$
V_C^{SS}	$V_C^{B(comp)}$	$(VF)_C^{B(comp)}$
V_C^M	V_C^{UO2}	M_C^{UO2}
M_C^{H2O}	$(VF)_C^{H2O}$	$M_C^{B(comp)}$
M_C^{SS}	$(VF)_C^{SS}$	M_C^T

8.0 REFERENCES

1. Hellens, R. L., "Multigroup Fourier Transform Calculation, Description of the MUFT-III Code," WAPD-TM-4, July, 1956.
2. Rosen, S. S., "Supplement to MUFT-III Code, Multigroup Fourier Transform Calculation," AP Note 90, Alco Products, Inc., December 6, 1957.
3. Byrne, B. J., and Caton, R. L., "Two-Dimensional P_3 Calculation for APPR-Type Fixed Fuel Elements," AP Note 96, Alco Products, Inc., February 14, 1958.
4. Bobe, P. E., and Oby, P. V., "Calculation of Thermal Properties of APPR-Type Control Fuel Elements, Program 54," AP Note 192, Alco Products, Inc., October 23, 1959.
5. Oby, P. V., "Modified Two-Group Multiregion Calculation Using the VALPROD Code for the IBM-650," AP Note 24 (Revised), August 14, 1957.
6. Fairbanks, F. B., "Two-Group Multiregion Axial WINDOWSHADE Calculation on the IBM-650," APAE Memo 88, March 29, 1957.
7. Marlowe, O. J., and Ombrellaro, P. A., "Candle - A One-Dimensional Few Group Depletion Code for the IBM-704, Addendum 1, Candle-2," WAPD-TM-53, Add. 1, October, 1957.
8. Bilodeaux, G. G., et al, "PDQ--An IBM-704 Code to Solve the Two-Dimensional Few Group Neutron Diffusion Equation," WAPD-TM-70, August, 1957.
9. Cadwell, W. R., et al, "PDQ-3: A Program for the Solution of the Neutron Diffusion Equations in Two-Dimensions on the IBM-704," WAPD-TM-179, March, 1960.
10. Callaghan, J. B., et al, "TURBO -- A Two-Dimensional Few-Group Depletion Code for the IBM-704," WAPD-TM-95, November, 1957.
11. "S3G/S4G Progress Report, January and February, 1956," KAPL 1501.
12. Williamson, T. G., et al, "NUB-1: A Non-Uniform Burnout Code for the IBM-650," AP Note 116, Alco Products, Inc., October 23, 1958.
13. McElligott, P. E., "FINK-1: A Two-Group, Two-Region Calculation on the IBM-650," APAE Memo 121, January 28, 1958.
14. Marlowe, O. J., et al, "WANDA -- A One-Dimensional Few Group Diffusion Code for the IBM-704," WAPD-TM-28, November, 1956.

15. Judge, F., "Variational Method in the Calculation of Reactor Neutron Flux Density, (TRANVAR), KAPL-2151, to be issued.
16. Bohl Jr., H., et al, "P1-MG: A One-Dimensional Multigroup P₁ Code for the IBM-704," WAPD-TM-135, July, 1959.
17. Rosen, S.S., et al, "Primary Shielding Calculations on the IBM-650 (ROC Codes)," APAE Memo 142, October 15, 1958.
18. Oby, P.V., "SCRAM-1: Control Rod Worth Calculation on the IBM-650," Alco Products, Inc., APAE Memo 89, April 16, 1957.
19. Birken, S.H., and Pacino, S., "SCRAM-III: Control Rod Worth Calculations for Bare or Reflected Cores on the IBM-650," APAE Memo 226 to be issued.
20. Birken, S.H., and Pacino, S., "SCRAM IV: Control Rod Worth Calculations for Assymetric Arrays of Control Rods on the IBM-650," APAE Memo 241, to be issued.
21. Rosen, S.S., Editor, "Hazards Summary Report for the Army Package Power Reactor, SM-1, Task XVII," APAE No. 2, Revision 1, May 1960.
22. Bobe, P.E., Editor, "Interim Report of Nuclear Analysis Performed on SM-2 Core and Vessel, September 1, 1958 to December 31, 1959," APAE No. 65, May 27, 1960.

APPENDICES

APPENDIX A BOBCAT FLOW CHARTS

The flow charts, showing the order of calculations performed by the BOBCAT code, are shown in Fig. A.1 and A.2. Figure A.1 presents the flow chart for the stationary fuel element calculations while Fig. A.2 presents the flow chart for the control rod fuel element calculations.

FIGURE A.1
BOBCAT STATIONARY FUEL ELEMENT FLOW CHART

FIGURE A.1 (CONTINUED)

FIGURE A.2
BOBCAT CONTROL ROD FUEL ELEMENT FLOW CHART

FIGURE A.2 (CONTINUED)

A-6

APPENDIX B FLOATING POINT NOTATION

Floating point numbers, as used in BOBCAT, are comprised of two parts, a characteristic and an abscissa. The expression of numbers in floating point form is accomplished by the following steps:

1. Express number in powers of 10.

$$\begin{aligned}123.456 &= 1.23456 \times 10^2 \\0.000123 &= 1.23 \times 10^{-4} \\-36724.1 &= -3.67241 \times 10^4\end{aligned}$$

2. The characteristic is formed by adding 50 to the exponent to avoid negative characteristics. The abscissa part is the major part which must be less than 10 and greater than or equal to 1. The characteristic, CC, and the abscissa are then arranged as follows:

CC XXXX XXXX ±

Thus:

$$\begin{aligned}123.456 &\longrightarrow 52\ 1234\ 5600 \\0.000123 &\longrightarrow 46\ 1230\ 0000 \\-36724.1 &\longrightarrow 54\ 3672\ 4100- \\-0.00239 &\longrightarrow 47\ 2390\ 0000-\end{aligned}$$

The quantity zero is expressed as 00 0000 0000 +. Maximum and minimum characteristics are 99 and 01 with the exception of zero.

APPENDIX C

FISSION PRODUCT POISONING

Fission product poisoning due to fuel burnup is included in the BOBCAT code by defining an amount of B-10 which is equivalent to the poisoning due to fission products. The code uses a term Ψ , which is a function of fuel burnup B, and is defined as grams of B-10 per initial kilogram of U-235. This factor Ψ , as a function of fuel burnup, was taken from data given in reference (11) and is built into the code as a table look-up. If new data becomes available, this table may be changed. The values of Ψ presently used in the code are given in Table C.1.

It should be noted that the equivalent amount of B-10 is included both in the calculation of thermal parameters and in the calculation of the fast parameters; therefore, some account is made of the epithermal poisoning effects of the fission products.

TABLE C.1
FISSION PRODUCT POISONING (Ψ)

<u>Burnup B</u>	<u>Ψ</u>	<u>Burnup B</u>	<u>Ψ</u>
0	0	0.2125	0.175
0.003	0.025	0.250	0.185
0.010	0.05	0.30	0.1975
0.018	0.075	0.305	0.20
0.033	0.10	0.350	0.210
0.05	0.112	0.40	0.2225
0.069	0.125	0.41	0.225
0.10	0.135	0.45	0.235
0.135	0.150	0.50	0.248
0.150	0.155	0.505	0.250
0.20	0.170	0.550	0.260
		0.60	0.2723

APPENDIX D COMPOSITION OF STAINLESS STEEL

Provision has been made in the BOBCAT code to calculate the number densities of stainless steel in addition to the number densities of the materials composing stainless steel. The input to the code includes values of $(AF)_j^i$, atom fractions, defined as follows:

$$(AF)_j^i = N_{ij}/N_{SSj}$$

$$N_{SSj} = \sum_{i=1}^n N_{ij}$$

where:

N_{ij} = atoms of component i in stainless steel of type j per cm^3 of steel.

Provision has been made for eight different components of stainless steel including, Fe, Ni, Cr, Mn, C, Si, and Mo. For most calculations, only Fe, Ni, Cr, and Mn are considered; in these cases, $(AF)_j^C = (AF)_j^{Si} = (AF)_j^{Mo} = 0$.

Tables D.1 through D.4 presents data for various stainless steels which are most commonly used for the APPR-type fuel elements; only Fe, Ni, Cr, and Mn are included in general.

TABLE D. 1
TYPE 304 L* STAINLESS STEEL

Density = 7.9 gms/cm³

Atom (i)	Weight Fraction	Atomic Weight	$N_i \times 10^{24}$ (Atoms/cc of steel)	Atomic Fraction (AF) _i
Fe	0.68902	55.85	0.058701	0.689700
Ni	0.09	58.69	0.007296	0.085723
Cr	0.19	52.01	0.017382	0.204227
Mn	0.02	54.93	0.001732	0.020350
C	0.00028	12.01	} OMIT	
Si	0.01	28.09		
Mo	-	95.95		
(Other)	0.0007			
			$\sum_{i=1}^4 N_i = 0.085111 \times 10^{24}$	$\sum_{i=1}^4 = 1.000000$

* Type of steel used in the SM-1 Core I fuel elements.

TABLE D. 2
TYPE 302B* STAINLESS STEEL

Density = 7.9 gms/cm³

Atom (i)	Weight Fraction	Atomic Weight	$N_i \times 10^{24}$ (Atoms/cc of steel)	Atomic Fraction (AF) _i
Fe	0.69778	55.85	0.059447	0.708648
Ni	0.0852	58.69	0.006907	0.082336
Cr	0.1822	52.01	0.016668	0.198693
Mn	0.010	54.93	0.000866	0.010323
C	-	12.01	} OMIT	
Si	0.0239	28.09		
Mo	-	95.95		
(Other)	0.00092			
			$\sum_{i=1}^4 N_i = 0.083888 \times 10^{24}$	$\sum_{i=1}^4 = 1.000000$

* Type of steel used in fuel matrix in the SM-1 Core I fuel elements.

TABLE D.3
BRAZE* STAINLESS STEEL

Density = 7.56 gms/cm³

Atom (i)	Weight Fraction	Atomic Weight	$N_i \times 10^{24}$ (Atoms/cc of steel)	Atomic Fraction (AF) _i
Fe	0.2658	55.85	0.021670	0.355270
Ni	0.4946	58.69	0.038372	0.629090
Cr	0.0041	52.01	0.000358	0.005869
Mn	0.0072	54.93	0.000596	0.009771
C	-	12.01	} OMIT	
Si	0.1130	28.09		
Mo	0.0755	95.95		
(Other)	0.0398			

$$\sum_{i=1}^4 N_i = 0.060996 \times 10^{24} \quad \sum_{i=1}^4 = 1.000000$$

* Type of steel used as braze material in the SM-1 Core I fuel elements.

TABLE D.4
TYPE 347* STAINLESS STEEL

Density = 7.9 gms/cm³

Atom (i)	Weight Fraction	Atomic Weight	$N_i \times 10^{24}$ (Atoms/cc of steel)	Atomic Fraction (AF) _i
Fe	0.70028	55.85	0.059660	0.700317
Ni	0.0955	58.69	0.007742	0.090880
Cr	0.1829	52.01	0.016732	0.196408
Mn	0.0122	54.93	0.001056	0.012395
C	0.00049	12.01	} OMIT	
Si	0.0068	28.09		
Mo	0.0005	95.95		
(Other)	0.00133			

$$\sum_{i=1}^4 N_i = 0.085190 \times 10^{24} \quad \sum_{i=1}^4 = 1.000000$$

* Type of steel as used in the SM-2 Core I fuel elements.

APPENDIX E UTILITY OF THE BOBCAT CODE

The BOBCAT code together with MUFT-III and the various P₃ codes described before, greatly facilitates the calculation of nuclear parameters, atomic number densities, and other miscellaneous data, as input to many IBM nuclear codes of interest. The most commonly used nuclear codes as employed by Alco's Core Analysis Group, at the present time, are shown in Fig. E.1. Each code requires either nuclear parameters or atomic number densities, or a combination of both, as part of its input. These codes are summarized in Table E.1. A summary of the calculations performed and the output obtained from BOBCAT are shown in Fig. E.2.

TABLE E.1
SUMMARY OF VARIOUS IBM-CODES

<u>Core Burnup</u>	<u>Reactivity</u>	<u>Flux and Power Distributions</u>	<u>Shielding</u>	<u>Control Rod Worth</u>
TURBO ⁽¹⁰⁾	PDQ ⁽⁸⁾⁽⁹⁾	PDQ	ROC ⁽¹⁷⁾	SCRAM ⁽¹⁸⁾⁽¹⁹⁾⁽²⁰⁾
CANDLE ⁽⁷⁾	TURBO	WANDA ⁽¹⁴⁾		PDQ
NUB-1 ⁽¹²⁾	FINK-1 ⁽¹³⁾	TRANVAR ⁽¹⁵⁾		
	VALPROD ⁽⁵⁾	VALPROD		
	WINDOWSHADE ⁽⁶⁾	WINDOWSHADE		
	CANDLE	P1-MG ⁽¹⁶⁾		

UTILIZATION OF THE BOBCAT CODE

FIGURE E.1

SCHEMATIC DIAGRAM OF BOBCAT CALCULATIONS

APPENDIX F

SAMPLE BOBCAT PROBLEM

A sample problem, as performed by the BOBCAT code, is presented on the following pages. The case considered was the SM-1 Core I as described in reference (21). The core temperature and pressure were taken at 68°F and 1200 psia, respectively. The data used in the input represents the best information available at the time of this report.

The input is presented on the special forms which have been especially designed for this code. The cross section data was taken from reference (22).

The output listing of the code is also presented. The output is presented in its edited form which is most convenient for use by the user of the code. Also presented are the input cards to the MUFT-III and various P₃, IBM-650 codes, as described in Section 2 of this report.

PROGRAM NO. 56 (BOBCAT)
STAINLESS STEEL FILES

Card 1	0	0	1	5	0	0	0	0	0	7	4	9	7	0	8	6	4	8	0	0	(AF) _A ^{Fe}
											4	8	8	2	3	3	6	0	0	0	(AF) _A ^{Ni}
											4	9	1	9	8	6	9	3	0	0	(AF) _A ^{Cr}
											4	8	1	0	3	2	3	0	0	0	(AF) _A ^{Mn}
											0	0	0	0	0	0	0	0	0	0	(AF) _A ^C
											0	0	0	0	0	0	0	0	0	0	(AF) _A ^{Si}
											0	0	0	0	0	0	0	0	0	0	(AF) _A ^{Mo}
Card 2	0	0	1	5	0	7	0	0	0	7	4	9	6	8	9	7	0	0	0	0	(AF) _{DE} ^{Fe}
											4	8	8	5	7	2	3	0	0	0	(AF) _{DE} ^{Ni}
											4	9	2	0	4	2	2	7	0	0	(AF) _{DE} ^{Cr}
											4	8	2	0	3	5	0	0	0	0	(AF) _{DE} ^{MN}
											0	0	0	0	0	0	0	0	0	0	(AF) _{DE} ^C
											0	0	0	0	0	0	0	0	0	0	(AF) _{DE} ^{Si}
											0	0	0	0	0	0	0	0	0	0	(AF) _{DE} ^{Mo}
Card 3	0	0	1	5	1	4	0	0	0	7	4	9	6	8	9	7	0	0	0	0	(AF) _P ^{Fe}
											4	8	8	5	7	2	3	0	0	0	(AF) _P ^{Ni}
											4	9	2	0	4	2	2	7	0	0	(AF) _P ^{Cr}
											4	8	2	0	3	5	0	0	0	0	(AF) _P ^{Mn}
											0	0	0	0	0	0	0	0	0	0	(AF) _P ^C
											0	0	0	0	0	0	0	0	0	0	(AF) _P ^{Si}
											0	0	0	0	0	0	0	0	0	0	(AF) _P ^{Mo}

(Continued on page 2
of NPED-1084-561)

12 punch in columns 1, 10, 20, - - - - 80.

PROGRAM NO. 56 (BOBCAT)
STAINLESS STEEL FILES (CONT'D)

0	0	1	5	2	1	0	0	0	7	4	9	3	5	5	2	7	0	0	0
										4	9	6	2	9	0	9	0	0	0
										4	7	5	8	6	9	0	0	0	0
										4	7	9	7	7	1	0	0	0	0
										0	0	0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0	0	0

Card 4

(AF)BR^{Fe}
(AF)BR^{Ni}
(AF)BR^{Cr}
(AF)BR^{Mn}
(AF)BR^C
(AF)BR^{Si}
(AF)BR^{Mo}

0	0	1	5	2	8	0	0	0	7	4	9	6	8	9	7	0	0	0	0
										4	8	8	5	7	2	3	0	0	0
										4	9	2	0	4	2	2	7	0	0
										4	8	2	0	3	5	0	0	0	0
										0	0	0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	0	0	0

Card 5

(AF)CB^{Fe}
(AF)CB^{Ni}
(AF)CB^{Cr}
(AF)CB^{Mn}
(AF)CB^C
(AF)CB^{Si}
(AF)CB^{Mo}

12 punch in columns 1, 10, 20, - - - - 80.

PROGRAM NO. 56 (BOBCAT)

BURNUP TABLE

CARD NO. 1										PERMUTATION TABLE										
0	0	1	8	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	B ₁	
Card 1										4	7	3	0	0	0	0	0	0	B ₂	
										4	8	1	0	0	0	0	0	0	B ₃	
										4	8	1	8	0	0	0	0	0	B ₄	
										4	8	3	3	0	0	0	0	0	B ₅	
										4	8	5	0	0	0	0	0	0	B ₆	
										4	8	6	9	0	0	0	0	0	B ₇	

Card 2	0	0	1	8	0	7	0	0	0	7	4	9	1	0	0	0	0	0	0	B ₈
											4	9	1	3	5	0	0	0	0	B ₉
											4	9	1	5	0	0	0	0	0	B ₁₀
											4	9	2	0	0	0	0	0	0	B ₁₁
											4	9	2	1	2	5	0	0	0	B ₁₂
											4	9	2	5	0	0	0	0	0	B ₁₃
											4	9	3	0	0	0	0	0	0	B ₁₄

0	0	1	8	1	4	0	0	0	7	4	9	3	0	5	0	0	0	0	0	B15
Card 3										4	9	3	5	0	0	0	0	0	0	B16
										4	9	4	0	0	0	0	0	0	0	B17
										4	9	4	1	0	0	0	0	0	0	B18
										4	9	4	5	0	0	0	0	0	0	B19
										4	9	5	0	0	0	0	0	0	0	B20
										4	9	5	0	5	0	0	0	0	0	B21

0	0	1	8	2	1	0	0	0	2	4	9	5	5	0	0	0	0	0	B22
Card 4										4	9	6	0	0	0	0	0	0	B23

12 punch in columns 1, 10, 20, - - - - 80.

PROGRAM NO. 56 (BOBCAT)

PSI (Ψ) TABLE

0	0	1	7	5	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	Ψ_1
Card 1										4	8	2	5	0	0	0	0	0	0	Ψ_2
										4	8	5	0	0	0	0	0	0	0	Ψ_3
										4	8	7	5	0	0	0	0	0	0	Ψ_4
										4	9	1	0	0	0	0	0	0	0	Ψ_5
										4	9	1	1	2	0	0	0	0	0	Ψ_6
										4	9	1	2	5	0	0	0	0	0	Ψ_7

0	0	1	7	5	7	0	0	0	7	4	9	1	3	5	0	0	0	0	0	Ψ_8
Card 2										4	9	1	5	0	0	0	0	0	0	Ψ_9
										4	9	1	5	5	0	0	0	0	0	Ψ_{10}
										4	9	1	7	0	0	0	0	0	0	Ψ_{11}
										4	9	1	7	5	0	0	0	0	0	Ψ_{12}
										4	9	1	8	5	0	0	0	0	0	Ψ_{13}
										4	9	1	9	7	5	0	0	0	0	Ψ_{14}

0	0	1	7	6	4	0	0	0	7	4	9	2	0	0	0	0	0	0	0	Ψ_{15}
Card 3										4	9	2	1	0	0	0	0	0	0	Ψ_{16}
										4	9	2	2	2	5	0	0	0	0	Ψ_{17}
										4	9	2	2	5	0	0	0	0	0	Ψ_{18}
										4	9	2	3	5	0	0	0	0	0	Ψ_{19}
										4	9	2	4	8	0	0	0	0	0	Ψ_{20}
										4	9	2	5	0	0	0	0	0	0	Ψ_{21}

0	0	1	7	7	1	0	0	0	2	4	9	2	6	0	0	0	0	0	0	Ψ_{22}
Card 4										4	9	2	7	2	3	0	0	0	0	Ψ_{23}

12 punch in columns 1, 10, 20, - - - - 80.

PROGRAM NO. 56 (BOBCAT)
DENSITY FILES

Card 1	0	0	1	9	0	0	0	0	0	7	4	8	6	6	9	4	6	2	0	0	NH
											4	8	3	3	4	7	3	1	0	0	NO
											4	8	8	5	1	1	1	0	0	0	NSSP
											4	8	8	3	8	8	8	0	0	0	NSSA
											4	8	8	5	1	1	1	0	0	0	NSSDE
											4	8	8	5	1	1	1	0	0	0	NSSCB
											4	8	6	0	9	9	6	0	0	0	NSSBR

Card 2	0	0	1	9	0	7	0	0	0	7	4	9	8	7	6	3	0	0	0	0	μ_1
											4	9	9	3	0	7	0	0	0	0	μ_2
											4	9	7	5	9	0	0	0	0	0	μ_3
											4	9	1	9	8	0	0	0	0	0	γ
											5	1	1	0	9	0	0	0	0	0	ρ_{UO_2}
											5	0	2	5	3	5	0	0	0	0	$\rho_{B(comp)}$
											5	0	7	9	0	0	0	0	0	0	ρ_{SSA}

Card 3	0	0	1	9	1	4	0	0	0	6	5	0	7	5	6	0	0	0	0	0	ρ_{BR}
											5	0	7	9	0	0	0	0	0	0	ρ_{SCB}
											5	0	7	9	0	0	0	0	0	0	ρ_{SP}
											5	0	7	9	0	0	0	0	0	0	ρ_{SFP}
											5	0	1	0	0	1	3	0	0	0	ρ_{H_2O}
											4	9	2	5	0	0	0	0	0	0	λ
											0	0	0	0	0	0	0	0	0	0	

12 punch in columns 1, 10, 20, - - - - 80.

PROGRAM NO. 56 (BOBCAT)
CROSS SECTION FILE

Card 1	0	0	1	9	2	0	0	0	0	7	5	2	5	1	2	6	5	6	4	4	σ_a^{25}
											5	0	9	0	0	0	0	0	0	0	σ_s^{25}
											5	2	5	2	1	6	3	0	0	0	σ_{tr}^{25}
											5	0	2	1	1	8	0	3	6	0	σ_a^{28}
											5	0	9	0	0	0	0	0	0	0	σ_s^{28}
											5	1	1	1	0	9	3	0	0	0	σ_{tr}^{28}
											5	0	2	2	7	0	2	7	5	0	σ_a^{SS}
Card 2	0	0	1	9	2	7	0	0	0	7	5	1	1	0	4	4	0	0	0	0	σ_s^{SS}
											5	1	1	2	5	8	6	0	0	0	σ_{tr}^{SS}
											5	3	2	9	3	2	4	9	8	0	σ_a^{B-10}
											5	0	4	4	0	0	0	0	0	0	σ_s^{B-10}
											5	3	2	9	3	6	6	0	5	1	σ_{tr}^{B-10}
											4	9	2	5	4	1	6	4	0	0	σ_a^H
											5	1	3	4	3	2	0	0	0	0	σ_s^H
Card 3	0	0	1	9	3	4	0	0	0	7	5	1	2	7	1	7	0	0	0	0	σ_{tr}^H
											0	0	0	0	0	0	0	0	0	0	σ_a^0
											5	0	3	9	0	0	0	0	0	0	σ_s^0
											5	0	3	6	4	2	0	0	0	0	σ_{tr}^0
											5	3	1	0	6	5	1	3	9	4	$\nu\sigma_f^{25}$
											5	1	8	3	6	2	0	0	0	0	σ_{af}^{B-10}
											5	1	1	9	2	9	0	0	0	0	σ_{af}^{25}
Card 4	0	0	1	9	4	1	0	0	0	2	4	9	1	8	0	0	0	0	0	0	α_{th}
											4	9	4	2	0	0	0	0	0	0	α_f

12 punch in columns 1, 10, 20, - - - - 80.

PROGRAM NO. 56 (BOBCAT) SPECIAL INPUT CARDS

Comments Card 1

			BLANK					
W	I	L	L	I	A	M		S
S	M	I	T	H				
0	6	0	0	1	0	0	0	6
			BLANK					
			BLANK					
			BLANK					
			Hi	Lo				
			x	x				

High x in column 74 required.
Low x in column 75 required.

Comments Card 2

				BLANK				
S	M	-	1		C	O	R	E
I			T	E	S	T		C A
S	E							
				BLANK				
				BLANK				
				BLANK				
				Hi Lo				
				X X				

High x in column 74 required.
Low x in column 75 required.

Flux Card (Stationary Element)

[illegible]

Flux Card
(Control Fuel Element)

[illegible]

PROGRAM NO. 56 (BOBCAT) VARIABLE CARDS

Card 1

9	9	9	8	0	8	8	0	0	1
5	1	2	8	6	2	0	0	0	0
4	8	2	0	0	3	0	0	0	0
0	0	0	0	0	0	0	0	0	0
5	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
5	0	7	4	6	1	2	5	0	0
5	0	7	4	6	1	2	5	0	0

IDENT.

Z₀Y₀

B

 β Δ

A

D

Card 2

9	9	9	8	0	8	8	0	0	2
5	0	7	0	4	5	9	6	0	0
5	0	6	4	5	1	6	0	0	0
4	8	4	9	5	3	0	0	0	0
4	8	1	2	7	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
4	8	6	3	5	0	0	0	0	0
4	9	1	2	7	0	0	0	0	0

IDENT.

F

G

t_Ft_C

g

h

E

Card 3

9	9	9	8	0	8	8	0	0	3
5	0	7	2	7	2	0	2	0	0
5	0	7	4	6	1	2	5	0	0
5	1	5	5	2	4	5	0	0	0
4	8	9	7	8	0	0	0	0	0
5	0	1	0	0	0	0	0	0	0
5	0	4	3	4	4	3	9	1	0
0	0	0	0	0	0	0	0	0	0

IDENT.

H

H'

L

 ϵ θ V_{BR} $\bar{q}$

Card 4

9	9	9	8	0	8	8	0	0	4
5	1	1	8	0	0	0	0	0	0
5	1	3	8	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

IDENT.

N₁N₂J₁J₂

PROGRAM NO. 56 (BOBCAT) VARIABLE CARDS

Card 1

9	9	9	9	0	8	8	0	0	1
5	1	2	6	1	1	0	0	0	0
4	8	1	8	2	8	0	0	0	0
0	0	0	0	0	0	0	0	0	0
5	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
5	0	7	4	6	1	2	5	0	0
5	0	7	4	6	1	2	5	0	0

IDENT.

Z₀Y₀

B

 β Δ

A

D

Card 2

9	9	9	9	0	8	8	0	0	2
5	0	6	4	8	2	0	8	0	0
5	0	5	8	8	7	7	2	0	0
4	8	4	9	5	3	0	0	0	0
4	8	1	2	7	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
4	8	6	3	5	0	0	0	0	0
4	9	1	2	7	0	0	0	0	0

IDENT.

F

G

t_Ft_C

g

h

E

Card 3

9	9	9	9	0	8	8	0	0	3
5	0	6	6	5	2	2	6	0	0
5	0	6	6	3	2	2	2	2	0
5	1	5	5	2	4	5	0	0	0
4	8	9	7	8	0	0	0	0	0
5	0	1	0	0	0	0	0	0	0
5	0	3	8	6	1	6	8	0	0
4	9	1	2	7	0	0	0	0	0

IDENT.

H

H'

L

 ϵ θ V_{BR} $\bar{q}$

Card 4

9	9	9	9	0	8	8	0	0	4
5	1	1	6	0	0	0	0	0	0
5	0	7	0	0	0	0	0	0	0
5	0	7	0	6	4	3	7	5	0
5	0	6	8	1	0	3	7	5	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

IDENT.

N₁N₂J₁J₂

CONTROL ROD FUEL ELEMENTS

PROGRAM 56 BOBCAT

CASE NO 9998 WILLIAM S SMITH DATE 6/10/61

PROJECT SM-1 CORE I TEST CASE

STATIONARY ELEMENT PARAMETERS

1	Z BAR	5128620000	DELTA	5057202011	*
2	PSI	0000000000	Y EQ FISS PRCD	0000000000	*
3	Y BAR	4820030000	Z 25 ELEMENT	5251516000	*
4	Z UO2 ELEMENT	5263165452	Y B10 ELEMENT	4936054000	*
5	MU SUB 4	4918336612	Y B COMP ELEM	5025905536	*
6	VOL ACTIVE	5326593285	VOL ELEMENT	5330755030	*
7	VOL DEAD	5241617454	VOL FRACT ACT	4986468083	*
8	VOL FRACT DEAD	4913531917	VOL FUEL ACTIVE	5231776147	*
9	VOL CLAD ACTIVE	5216295460	VOL METAL ACT	5248071607	*
10	VOL H2O ACTIVE	5321786124	C	4874930000	*
11	VOL SIDE PLATES	5192579742	VOL DEAD EDGES	5144286441	*
12	VOL SS DEAD	5214121057	VOL H2O DEAD	5227496397	*
13	ALPHA	5111913807	SIGMA A DEAD	4876232957	*
14	SIGMA S DEAD	5019031216	SIGMA TR DEAD	5016425980	*
15	VOL PLATE	5126706448	N B10 PLATE	4545100209	*
16	SIG A B10 PLATE	4913225627	SIG S B10 PLATE	4619844091	*
17	SIG TR B10 PLAT	4913244150	N U235 PLATE	4727451569	*
18	N U238 PLATE	4620182340	N OXY PLATE	4758939606	*

19	VOL MEAT PLATE	5117653415	VOL VOID PLATE	5017265040	*
20	VOL UO2 PLATE	5032194420	VOL B COM PLATE	4856773035	*
21	VOL SS MEAT	5112650695	N SS PLATE	4868588462	*
22	SIGMA A PLATE	5016957206	SIGMA S PLATE	4976577125	*
23	SIGMA TR PLATE	5024513565	NU SIG F PLATE	5029239747	*
24	D LOWER CASE	4933958388	VOL H2O CHANELS	5321786124	*
25	SIGMA A H2O	4817015313	SIGMA S H2O	5024281386	*
26	SIGMA TR H2O	5019408372	S ACTIVE	4981923402	*
27	S DEAD	4966069387	Q LOWER CASE	5037306250	*
28	P LOWER CASE	5032258000	L LOWER CASE	4837465000	*
29	M LOWER CASE	4920725694	N U235 ELEM	4642908137	*
30	N U238 ELEM	4531545978	N OXY PLATE EL	4692125469	*
31	VOL H2O ELEMENT	5324535763	N HYD ELEMENT	4853408372	*
32	N OXY H2O ELEM	4826704185	N OXYGEN ELEM	4827625440	*
33	N B10 ELEMENT	4470493817	N SS ELEMENT	4814594485	*
34	N FE ELEMENT	4810154689	N NI ELEMENT	4712768633	*
35	N CR ELEMENT	4729291246	N MN ELEMENT	4623380721	*
36	N C ELEMENT	0000000000	N SI ELEMENT	0000000000	*
37	N MO ELEMENT	0000000000	MASS UO2 MEAT	5135091917	*
38	MASS B COM MEAT	4914391964	MASS SS MEAT	5199940490	*
39	TOTAL MEAT MASS	5213517632	WF UO2 MEAT	4925960106	*
40	WF B COM MEAT	4710646808	WF SS MEAT	4973933430	*

41	WF B MEAT	4680809272	TOT MEAT ATOMS	5013049555	*
42	AF U235 MEAT	4856180760	AF U238 MEAT	4741303983	*
43	AF OXY MEAT	4912062231	AF SS MEAT	4981323960	*
44	AF B MEAT	4746615866	AF COMP MEAT	4711653965	*
45	VOL VOID ELEM	5131077072	VOL METAL ELEM	5262192664	*
46	VOL SS ELEM	5253187768	VOL UO2 ELEM	5157949955	*
47	VOL B COM ELEM	5010219146	VF H2O ELEM	4979778049	*
48	VF SS ELEM	4917294006	VF UO2 ELEM	4818842431	*
49	VF B COMP ELEM	4633227559	VF VOID ELEM	4810104711	*
50	R SUP X ELEM	4925347760	MASS SS ELEM	5342003565	*
51	MASS H2O ELEM	5324567659	SIG A REG 1	4876232957	*
52	SIG S REG 1	5019031216	SIG TR REG 1	5016425980	*
53	NU SIG F REG 1	0000000000	K THER REG 1	0000000000	*
54	D THER REG 1	4920293056	L SQUARE REG 1	5026619793	*
55	N HYD REG 1	4844230944	N OXY REG 1	4822115472	*
56	N SS REG 1	4828626948	N FE REG 1	4819531066	*
57	N NI REG 1	4727999656	N CR REG 1	4757200957	*
58	N MN REG 1	4657582246	N C REG 1	0000000000	*
59	N SI REG 1	0000000000	N MO REG 1	0000000000	*
60	VOL H2O REG 2	5321786124	VOL PLAT REG 2	5248071607	*
61	VOL OF REG 2	5326593284	VF PLAT REG 2	4918076596	*
62	VF H2O REG 2	4981923403	N HYD REG 2	4854844605	*

63	N OXY REG 2	4828487729	N U235 REG 2	4649623092	*
64	N U238 REG 2	4536482800	N B10 REG 2	4481525825	*
65	N SS REG 2	4812398459	N FE REG 2	4786873235	*
66	N NI REG 2	4710385037	N CR REG 2	4724923485	*
67	N MN REG 2	4618028322	N C REG 2	0000000000	*
68	N SI REG 2	0000000000	N MO REG 2	0000000000	*

CONTROL ROD ELEMENT PARAMETERS

1	Z BAR	5126110000	DELTA	5057202011	*
2	PSI	0000000000	Y EQ FISS PROD	0000000000	*
3	Y BAR	4818280000	Z 25 ELEMENT	5241776000	*
4	Z UO2 ELEMENT	5251222919	Y B10 ELEMENT	4929248000	*
5	MU SUB 4	4918336612	Y B COMP ELEM	5021015286	*
6	VOL ACTIVE	5321572435	VOL ELEMENT	5330755030	*
7	VOL DEAD	5291825954	VOL FRACT ACT	4970142786	*
8	VOL FRACT DEAD	4929857214	R BAR ACTIVE	5035255601	*
9	R BAR ELEMENT	5042095593	VOL FUEL ACTIVE	5225776766	*
10	VOL CLAD ACTIVE	5213218854	VOL METAL ACT	5238995620	*
11	VOL H2O ACTIVE	5317672873	VOL BASKET ELEM	5219112949	*
12	C	4874930000	VOL SIDE PLATES	5184934562	*
13	VOL DEAD EDGES	5139365726	VOL SS DEAD	5231929145	*
14	VOL H2O DEAD	5259896809	ALPHA	5127082090	*
15	SIGMA A DEAD	4878055730	SIGMA S DEAD	5018917467	*
16	SIGMA TR DEAD	5016371782	VOL PLATE	5124372263	*
17	N B10 PLATE	4545101820	SIG A B10 PLATE	4913226099	*
18	SIG S B10 PLATE	4619844800	SIG TR B10 PLAT	4913244623	*
19	N U235 PLATE	4727442565	N U238 PLATE	4620175719	*
20	N OXY PLATE	4758920273	VOL MEAT PLATE	5116110479	*
21	VOL VOID PLATE	5015756048	VOL UO2 PLATE	5029370940	*

22	VOL B COM PLATE	4851812835	VOL SS MEAT	5111545967	*
23	N SS PLATE	4868591771	SIGMA A PLATE	5016952711	*
24	SIGMA S PLATE	4976578956	SIGMA TR PLATE	5024509254	*
25	NU SIG F PLATE	5029230157	D LOWER CASE	4933958387	*
26	VOL H2O CHANELS	5317672873	SIGMA A H2O	4817015313	*
27	SIGMA S H2O	5024281386	SIGMA TR H2O	5019408372	*
28	Q LO CASE SUB A	4981923403	Q LO CASE SUB D	4965228626	*
29	W LOWER CASE	4837465000	W UPPER CASE	4920725693	*
30	VF PLATES ACT	4918076597	TOTAL SIG DEAD	5019698024	*
31	SIG PRIME DEAD	4933262423	SIG STAR DEAD	0000000000	*
32	N U235 ELEM	4634795604	N U238 ELEM	4525581659	*
33	N OXY PLATE EL	4674707539	VOL H2O ELEMENT	5323662553	*
34	N HYD ELEMENT	4851507606	N OXY H2O EL	4825753803	*
35	N OXYGEN ELEM	4826500878	N B10 ELEMENT	4457186529	*
36	N SS ELEMENT	4817502788	N FE ELEMENT	4812141535	*
37	N NI ELEMENT	4715249402	N CR ELEMENT	4735314648	*
38	N MN ELEMENT	4630484666	N C ELEMENT	0000000000	*
39	N SI ELEMENT	0000000000	N MO ELEMENT	0000000000	*
40	MASS UO2 MEAT	5132014324	MASS B COM MEAT	4913134554	*
41	MASS SS MEAT	5191213139	TOTAL MEAT MASS	5212335880	*
42	WF UO2 MEAT	4925952201	WF B COMP MEAT	4710647439	*
43	WF SS MEAT	4973941331	WF B MEAT	4680814062	*

44	TOT MEAT ATOMS	5011909107	AF U235 MEAT	4856161844	*
45	AF U238 MEAT	4741290077	AF OXY MEAT	4912058170	*
46	AF SS MEAT	4981330033	AF B MEAT	4746617129	*
47	AF COMP MEAT	4711654281	VOL VOID ELEM	5125209676	*
48	VOL METAL ELEM	5270924765	VOL SS ELEM	5263621547	*
49	VOL UO2 ELEM	5146993503	VOL B COMP ELEM	4982900536	*
50	VF H2O ELEM	4976938806	VF SS ELEM	4920686550	*
51	VF UO2 ELEM	4815279940	VF B COMP ELEM	4626955114	*
52	VF VOID ELEM	4781969277	R SUP X ELEM	4929973420	*
53	MASS SS ELEM	5350247891	MASS H2O ELEM	5323693314	*
54	VOL OF REG 3	5264860396	VOL BASK REG 3	5211207584	*
55	VOL SID PLA R3	5184934562	VOL DED EDGE R3	5139365726	*
56	VOL SS REG 3	5223637612	VOL H2O REG 3	5241222784	*
57	ALPHA REG 3	5120353754	SIG A REG 3	4882057475	*
58	SIG S REG 3	5018708479	SIG TR REG 3	5016284812	*
59	NU SIG F REG 3	0000000000	K THER REG 3	0000000000	*
60	D THER REG 3	4920468970	L SQUARE REG 3	5024944574	*
61	N HYD REG 3	4842548441	N OXY REG 3	4821274220	*
62	N SS REG 3	4831380866	N FE REG 3	4821521933	*
63	N NI REG 3	4728873913	N CR REG 3	4763367848	*
64	N MN REG 3	4663475878	N C REG 3	0000000000	*
65	N SI REG 3	0000000000	N MO REG 3	0000000000	*

66	VOL OF REG 4	5226965552	VOL BASK REG 4	5182617841	*
67	VOL H2O REG 4	5218703767	SIG A REG 4	4871003059	*
68	SIG S REG 4	5019564376	SIG TR REG 4	5016743973	*
69	NU SIG F REG 4	0000000000	K THE REG 4	0000000000	*
70	D THE REG 4	4919907660	L SQUARE REG 4	5028037749	*
71	N HYD REG 4	4846435026	N OXY REG 4	4823217513	*
72	N SS REG 4	4826076555	N FE REG 4	4817985000	*
73	N NI REG 4	4722353605	N CR REG 4	4753255366	*
74	N MN REG 4	4653065789	N C REG 4	0000000000	*
75	N SI REG 4	0000000000	N MO REG 4	0000000000	*
76	VOL H2O REG 5	5317672873	VOL PLAT REG 5	5238995621	*
77	VOL OF REG 5	5321572435	VF PLAT REG 5	4918076596	*
78	VF H2O REG 5	4981923403	N HYD REG 5	4854844605	*
79	N OXY REG 5	4828487379	N U235 REG 5	4649606816	*
80	N U238 REG 5	4536470832	N B10 REG 5	4481528737	*
81	N SS REG 5	4812399057	N FE REG 5	4786877481	*
82	N NI REG 5	4710385531	N CR REG 5	4724924676	*
83	N MN REG 5	4618028941	N C REG 5	0000000000	*
84	N SI REG 5	0000000000	N MO REG 5	0000000000	*

TOTAL CORE PARAMETERS

1	VOL B COMP CORE	5144635791	VOL VOID CORE	5313573964	*
2	TOT VOL OF CORE	5513839763	VOL H2O CORE	5510979968	*
3	VOL SS CORE	5424664859	VOL UO2 CORE	5325310527	*
4	VOL METAL CORE	5428597945	VF H2O CORE	4979336387	*
5	VF SS CORE	4917821735	VF UO2 CORE	4818288266	*
6	VF METAL CORE	4920663608	VF VOID CORE	4798079454	*
7	VF B COMP CORE	4632251846	MASS H2O CORE	5510994242	*
8	MASS SS CORE	5519478706	MASS U235 CORE	5422500400	*
9	MASS UO2 CORE	5427588475	MASS B10 CORE	5115747880	*
10	MASS B COM CORE	5211315173	MASS OF CORE	5533243110	*
11	R SUB C CORE	4926045563		0000000000	*