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TITLE

TECHNICAL DESCRIPTION OF THE NEW SS ACCOUNTABILITY PROGRAM ON THE IBM-709

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TECHNICAL DESCRIPTION OF THE NEW SS ACCOUNTABILITY
PROGRAM ON THE IBM-709

C. R. RICHEY

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NOMENCLATURE AND DEFINITIONS

- $\rightarrow \sigma_a^j$ = microscopic absorption cross section for isotope j
- $\rightarrow \sigma_f^j$ = microscopic fission cross section for isotope j
- $\rightarrow \sigma_c^j$ = microscopic capture cross section for isotope j
- α_j = ratio of the thermal neutron capture to fission of isotope j
- α_j^{fast} = ratio of the fast neutron capture to fission of isotope j
- ϵ = fast fission factor for U-238
- δ = ratio of fast fission in U-238 to thermal fission in the fuel
- p = resonance escape probability for U-238
- τ = Fermi age
- B^2 = Geometric buckling
- $\rightarrow \nu^j$ = fast neutrons born per fission in isotope j

Isotopic nomenclature is as follows:

25 = U-235

28 = U-238

49 = Pu-239

40 = Pu-240

41 = Pu-241

42 = Pu-242

$$A = \frac{\sigma_f^{49}}{\sigma_a^{25}} \left[\epsilon(1-p) \nu^{49} e^{-B^2 \tau} + \alpha_{28}^{fast} \delta \right] - \frac{\sigma_a^{49}}{\sigma_a^{25}}$$

$$B = \frac{\sum a^{28}}{\sum a^{25}} = \frac{100-E}{E} \times \frac{235}{238} \times \frac{\sigma_a^{28}}{\sigma_a^{25}}$$

$$C = B + D + A y_0 + G z_0 + H s_0 \equiv \text{initial conversion ratio}$$

$$D = \frac{\sigma_f^{25}}{\sigma_a^{25}} \left[\epsilon(1-p) \nu^{25} e^{-B^2 \tau} + \alpha_{28}^{fast} \delta \right]$$

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E = Enrichment of fuel (% U-235 by weight)

$$G = \frac{\sigma_f^{40}}{\sigma_a^{25}} \left[E(1-p) V^{40} e^{-B^2 \tau} + \alpha_{28}^{fast} \delta \right] \times \frac{\text{capture}}{\text{fission}} \times \frac{\text{fast fission}}{\text{thermal fission}} = \frac{\text{fast fission}}{\text{thermal fission}}$$

$$H = \frac{\sigma_f^{41}}{\sigma_a^{25}} \left[E(1-p) V^{41} e^{-B^2 \tau} + \alpha_{28}^{fast} \delta \right]$$

$$A' = A + \frac{\sigma_a^{49}}{\sigma_a^{25}}$$

$$D' = \frac{\sigma_f^{25}}{\sigma_a^{25}} \left[E(1-p) V^{25} e^{-B^2 \tau} + (1 + \alpha_{28}^{fast}) \delta \right]$$

$$G' = \frac{\sigma_f^{40}}{\sigma_a^{25}} \left[E(1-p) V^{40} e^{-B^2 \tau} + (1 + \alpha_{28}^{fast}) \delta \right]$$

$$H' = \frac{\sigma_f^{41}}{\sigma_a^{25}} \left[E(1-p) V^{41} e^{-B^2 \tau} + (1 + \alpha_{28}^{fast}) \delta \right]$$

fast fission
thermal fission
capture
fission

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INTRODUCTION

The SSA100 program will compute the buildup and decay of SS materials, (gms Pu, U-235 burnout and uranium burnout) in fuel that has been irradiated in any of the Hanford reactors. The routine input data for the program are the IBM production records supplied by the Production Forecasting and Scheduling Operation. The purpose of this program is to compute and prepare an accurate accountability report with a minimum of manual effort. This can either be a report for fuel discharges from the reactors or a report of the entire month end reactor inventory. It is not the purpose of this report to describe in detail the data processing techniques used to provide the accountability reports, this will be left to the discretion of the SS Accountability Operation and the programmer. The purpose of this report is to present (1) the technical methods that are fundamental to the program, (2) the necessary instructions that are necessary to make changes or include additional fuel data on the data tape and (3) the necessary instructions such that buildup and decay data can be obtained for fuel elements on a non-routine basis.

THEORY⁽¹⁾

The differential equations that govern the rates of formation and burnout of various isotopes may be written in the following parametric form:

Let $d(\ln x) = -dt \quad \frac{dx}{x} = -dt \quad x_0 = 1$ by definition

Then $\frac{dy}{dt} = B + Ay + Hs + Dx = Ay' + Hs' + Dx'$

$$\frac{dz}{dt} = \frac{\sigma_c^{49}}{\sigma_a^{25}} y - \frac{\sigma_a^{40}}{\sigma_a^{25}} z$$

$$\frac{ds}{dt} = \frac{\sigma_c^{40}}{\sigma_a^{25}} z - \frac{\sigma_a^{41}}{\sigma_a^{25}} s$$

$$\frac{dN}{dt} = \frac{1 + \delta}{1 + \alpha_{25}} \left[x + \frac{\sigma_f^{49}}{\sigma_f^{25}} y + \frac{\sigma_f^{41}}{\sigma_f^{25}} s \right]$$

$$\frac{dM}{dt} = - \left[B + A' y' + H' s + D' x \right]$$

where

x = local atomic concentration of 25 normalized to initial value of unity

y = local atomic concentration of 49 referred to initial concentration of 25

z = local atomic concentration of 40 referred to initial concentration of 25

s = local atomic concentration of 41 referred to initial concentration of 25

M = local atomic concentration of 28 referred to initial concentration of 25

N = local concentration of fissions which have occurred during irradiation period referred to initial concentration of 25.

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The following assumptions were made in writing the above equations:

- 1) The variation in the concentration of 28 is small.
- 2) The fission cross section of 40 is negligible.
- 3) Radioactive decay of Np-239 is instantaneous -- short lived compared to irradiation time.
- 4) Epithermal captures by isotopes other than 28 are accounted for by the utilization of effective 2200 m/sec cross sections, Westcott's notation.

The solutions to the above rate equations will be taken to be a set of infinite series in the parameter t as follows:

$$x = e^{-t} = 1 + d_1 t + d_2 t^2 + d_3 t^3 + \dots \quad d_i = \frac{(-1)^i}{i!} \quad (1)$$

$$y = y_0 + a_1 t + a_2 t^2 + a_3 t^3 + \dots \quad 2a_2 = \frac{d^2 y}{dt^2} \quad (2)$$

$$z = z_0 + g_1 t + g_2 t^2 + g_3 t^3 + \dots \quad \frac{dz}{dt} = g_1 \quad (3)$$

$$s = s_0 + h_1 t + h_2 t^2 + h_3 t^3 + \dots \quad (4)$$

$$M = m_0 + k_1 t + k_2 t^2 + k_3 t^3 + \dots \quad (5)$$

$$N = n_1 t + n_2 t^2 + n_3 t^3 + \dots \quad (6)$$

The subscript o denotes initial concentration

Solving for the coefficients in the usual way results in:

$$a_1 = C_0 = B + A y_0 + H s_0 + D$$

$$g_1 = \frac{\sigma_c^{49}}{\sigma_a^{25}} y_0 - \frac{\sigma_a^{40}}{\sigma_a^{25}} z_0$$

$$h_1 = \frac{\sigma_c^{40}}{\sigma_a^{25}} z_0 - \frac{\sigma_a^{41}}{\sigma_a^{25}} s_0$$

$$k_1 = - \left[B + A' y_0 + G' z_0 + H' s_0 + D' \right]$$

$$n_1 = \frac{1 + \delta}{1 + \alpha_{25}} \left[1 + \frac{\sigma_f^{49}}{\sigma_f^{25}} y_0 + \frac{\sigma_f^{40}}{\sigma_f^{25}} z_0 + \frac{\sigma_f^{41}}{\sigma_f^{25}} s_0 \right]$$

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For $i > 1$

$$a_i = \frac{1}{i} \left[D d_{i-1} + A a_{i-1} + H h_{i-1} \right]$$

$$g_i = \frac{1}{i} \left[\frac{\sigma_c^{49}}{\sigma_a^{25}} a_{i-1} - \frac{\sigma_a^{40}}{\sigma_a^{25}} g_{i-1} \right]$$

$$h_i = \frac{1}{i} \left[\frac{\sigma_c^{40}}{\sigma_a^{25}} g_{i-1} - \frac{\sigma_a^{41}}{\sigma_a^{25}} h_{i-1} \right]$$

$$k_i = -\frac{1}{i} \left[D' d_{i-1} + A' a_{i-1} + G' g_{i-1} + H' h_{i-1} \right]$$

$$n_i = \frac{1}{i} \frac{1+\delta}{1+\alpha} \left[d_{i-1} + \frac{\sigma_f^{49}}{\sigma_f^{25}} a_{i-1} + \frac{\sigma_f^{40}}{\sigma_f^{25}} g_{i-1} + \frac{\sigma_f^{41}}{\sigma_f^{25}} h_{i-1} \right]$$

The average fission concentration applicable to a whole column requires values of $\bar{t}$, $\bar{t}^2$, $\bar{t}^3$, etc. for equations 1-6. These quantities are obtainable by utilizing a set of weighting factors defined as follows:

Let w_i , the weighting factor for the i th power term, be defined

$$w_i = \bar{t}^i / t_m^i$$

where t_m is the maximum value of t in the column. A derivation of the weighting factors are given in Appendix A.

The equations 1-6 are now written

$$\bar{x} = 1 + w_{11} d_{1m} t + w_{22} d_{2m} t^2 + w_{33} d_{3m} t^3 + \dots \quad (7)$$

$$\bar{y} = y_0 + w_{11} a_{1m} t + w_{22} a_{2m} t^2 + w_{33} a_{3m} t^3 + \dots \quad (8)$$

$$\bar{z} = z_0 + w_{11} g_{1m} t + w_{22} g_{2m} t^2 + w_{33} g_{3m} t^3 + \dots \quad (9)$$

$$\bar{s} = s_0 + w_{11} h_{1m} t + w_{22} h_{2m} t^2 + w_{33} h_{3m} t^3 + \dots \quad (10)$$

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$$\bar{M} = m_0 + w_1 k_1 t_m + w_2 k_2 t_m^2 + w_3 k_3 t_m^3 + \dots \quad (11)$$

$$\bar{N} = w_1 n_1 t_m + w_2 n_2 t_m^2 + w_3 n_3 t_m^3 + \dots \quad (12)$$

The final conversion into usable form is rather simple:

$$\text{gms 25 burnout/ton uranium} = 9072 E(1-\bar{x})$$

$$\text{gms 28 burnout/ton} = 9072 E \cdot \frac{238}{235} (m_0 - \bar{M})$$

$$\text{gms U burnout/ton} = 9072 E \left\{ (1-\bar{x}) + \frac{238}{235} (m_0 - \bar{M}) \right\}$$

$$\text{gms 49/ton} = 9072 E \cdot \frac{239}{235} \bar{y}$$

$$\text{gms 40/ton} = 9072 E \cdot \frac{240}{235} \bar{z}$$

$$\text{gms 41/ton} = 9072 E \cdot \frac{241}{235} \bar{s}$$

$$\text{MWD/Ton} = 43.11 EQ\bar{N}$$

where Q = heat of fission in Mev

A value of t_m required to give a desired MWD/T exposure can be obtained by the following:

Take Eq. 12

$$\bar{N} = w_1 n_1 t_m + w_2 n_2 t_m^2 + w_3 n_3 t_m^3 + \dots = t_m (w_1 n_1 + w_2 n_2 t_m + \dots)$$

$$t_m = \bar{N} \left[(w_1 n_1 + w_2 n_2 t_m + w_3 n_3 t_m^2 + \dots) \right]^{-1} \quad (13)$$

The value of t_m is determined by an iteration of trial t_m values in Equation 13 until the process converges to a single value. The first trial value is obtained from the expression

$$t_m = \bar{N} / w_1 n_1$$

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DATA TAPE MODIFICATION

The procedure for the inclusion of additional fuel to the routine for data processing accountability reports for irradiated fuels requires that certain information pertinent to the fuel elements be stored on the SSA 100 data tape. This involves the utilization of two programs; (1) Input Data Program (IDP) which is a modification of the IDIOT program⁽²⁾ and (2) SSA 100. IDP computes certain basic reactor parameters (ϵ , p , τ , etc.) and cross section data that are pertinent to the solutions of Equations 7-12. The output record for IDP is in the form of IBM cards that may be used directly as input to SSA 100 for modifying the SSA 100 data tape. SSA 100 then computes the first ten coefficients for each of the series, Equation 7-12, and stores them with other pertinent information on the data tape. The information is identified on the data tape by the lot numbers of the various fuel types. Whenever more than one lot number identifies a particular fuel type, the fuel type is reprocessed through the above system as if it were a new fuel type with the second identifying lot number. To modify any of the data already on the data tape simply requires the same procedure as described above for adding new data with the exception that the delete code necessary for the IDP input data be 01 instead of 00. This deletes the data previously stored on the data tape under the identifying lot number and stores the revised data under that lot number.

BUILDUP AND DECAY TABLES

SSA 100 will provide a buildup and decay table for any modification or addition that is made to the data tape. This will be in the form of a record report on tape #5. The description of this table is controlled by the input data to SSA 100. It is often desirable to obtain buildup and decay tables for fuel charges without modifying the data tape. A special modification of SSA 100, denoted by SSA 100M, has been prepared for this purpose. SSA 100M should be used entirely for all calculations other than modifying the data tape and data processing of production data.

OPERATING INSTRUCTIONSData Preparation for IDP SSA-50

Each case requires one card of the following format:

<u>Columns</u>	<u>Format</u>	<u>Definition</u>
1-4	I4	Lot Number
6-7	I3	Number of regions in lattice cell
8-9	I2	Reactor code 04 denotes B, D, F, DR and H reactors 06 denotes C reactor 08 denotes KW and KE reactors
10-11	I2	00 by definition
12-13	I2	00 by definition
14-15	I2	Delete code
16-18	F3.0	Number of fuel pieces in normal charge
19-23	F5.2	Weight of fuel elements in pounds
24-29	F6.3	Bare fuel element length in inches
30-35	F6.3	Canned fuel element length in inches
74		A by definition

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Each case also requires one card of the following format for each region of the lattice cell:

Columns	Format	Definition
1-2	I2	bb by definition
3-4	I2	Region number
5-6	I2	bb by definition
7-9	F3.1	0.0 by definition
10-11	I2	bb by definition
12-14	F3.1	Moderating region code 1.0 denotes H ₂ O, D ₂ O or graphite region 0.0 denotes all other regions
15-23	F9.3	Atomic mass number*
24-31	F8.3	Density of region (g/cc)
32-41	F10.5	Outside radius of region (cm.)
42-51	F10.3	Physical temperature of region** (°K)
52-58	F7.4	U-235 enrichment of region (wt %) (0 for non-uranium regions)
74		C by definition
75-76	I2	Region number

Also each case will require two cards that have a G and H punched in a column 74, respectively. Columns 2-72 of these two cards may be used for descriptive information if one wishes. Column 1 must be left blank on these two cards.

The order of the cards is determined by the alphabetical order of column 74; the order of the C cards is denoted by the numeric order of columns 75 and 76. The last case of a run must be followed by two blank cards.

Output Data from IDP

Each case will result in five cards of output data from IDP. These five cards have the following formats:

* The following mass numbers must be used for the various materials:

H ₂ O = 1.0	Zirconium = 90.0
D ₂ O = 2.0	Uranium metal = 238.0
Graphite = 12.0	Uranium oxide = 270.0
Aluminum = 27.0	

** It has been found necessary to use temperatures that are approximately 100° higher than the physical temperatures of graphite and H₂O regions to obtain what is presently believed to be the proper neutron temperature in the fuel region.

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Columns	Format	Definition
Card #1		
1-4	I4	Lot Number
5	I1	Reactor code (see input A card)
6-12	F7.3	Inside radius of fuel element (cm.)
13-19	F7.3	Outside radius of fuel element (cm.)
20-26	F7.3	Canned fuel element length (inches)
27-30	F4.0	Number of fuel pieces in charge
31-36	F6.2	Weight of fuel element (pounds)
37-42	F6.4	U-235 enrichment (wt. %)
43	I1	0 by definition
Card #2		
1-12	E12.5	Effective absorption cross section 28
13-24	E12.5	" " " " 25
25-36	E12.5	" " " " 49
37-48	E12.5	" " " " 40 <i>check possibly low</i>
49-60	E12.5	" " " " 41
Card #3		
1-12	E12.5	Effective fission cross section 25
13-24	E12.5	" " " " 49
25-36	E12.5	" " " " 40
37-48	E12.5	" " " " 41
49-60	E12.5	κ_1 (See Eq. 2, Appendix A) }
61-72	E12.5	κ_2 (See Eq. 2, Appendix A) }
Card #4		
1-12	E12.5	Fermi Age (τ)
13-24	E12.5	Fast effect (ϵ)
25-36	E12.5	Resonance escape probability (p)
Card #5		
1-12	E12.5	A_1 (See Eq. 2, Appendix A) }
13-24	E12.5	A_2 (See Eq. 2, Appendix A) }
25-36	E12.5	B_1 (See Eq. 2, Appendix A) }
36-48	E12.5	B_2 (See Eq. 2, Appendix A) }
49-55	F7.3	Bare fuel element length (inches)

Input Data for SSA 100

In addition to the five output cards obtained from IDP, the following additional data is required for SSA 100 to modify the data tape:

See A and B are calculated from section

$$\sigma = \sigma_d (S + 1)$$

S = ratio of

g and Ds are calculated for all neutron groups

Requires this by running input program

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Columns	Format	Definition
Card #6		
1	I1	0 by definition
2-50	H	Descriptive material (label for table)
61-66	H	Security classification

Card #7

1	I1	Reactor code (See A card for IDP input)
2-3	I2	Number segments of differing fuel types
4-7	I4	Lot number
8-9	I2	Number of 8 inch spacers between normal dummy charge and first fuel element
10-15	F6.3	Distance in inches between dummy and segment wanted*
16-17	I2	Number of pieces in segment
18-25		Repeat of columns 10-17 for 2nd segment
26-57		Repeat of columns 10-17 out to column 57 for up to a total of six segments in all

Card #8

Continued repeating from card #7 for additional segments. (This card will usually be blank but is necessary to the operation of SSA 100)

Card #9

1-5	I5	HW number
6-8	I3	Page number for tables first page
9-12	I4	Start exposure (MWD/T)
13-16	I4	Exposure #2
17-20	I4	Exposure #3
21-24	I4	Exposure #4
25-27	I3	Exposure increments between Ex. #1 and Ex. #2
28-30	I3	Exposure increments between Ex. #2 and Ex. #3**
31-33	I3	Exposure increments between Ex. #3 and Ex. #4**
34	I1	Table type Code: 1 denotes normal fuel 2 denotes enriched fuel 3 denotes depleted fuel
35-36	I2	01 by definition
37-41	F6.3	Heat of fission; leave blank if 203.0 Mev is inferred.

* The segments for which the table is computed must have the lot number that is defined in columns 4-7. To compute tables for other lot numbers in the tube charge requires a new case. The heat generations (MWD/T) given in table will pertain only to the heat generation within the segments for which the table is computed.

** The exposure increment must be chosen such that the last exposure computed by the increment equal Ex. #4.

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SSA 100 Operation

Three tape units are required; tape #1 is a working tape, tape #2 is the data tape and tape #5 is the output report. Sense switch #1 is in the down position, all others being in the up position. Operation of SSA 100M differs in that tape #2 becomes a working tape.

SSA100 Output Report (Buildup and Decay Tables)

The output report is printed on fifty lines per page paper from tape #5. This report should be self explanatory with only the following note: The first ten coefficients in Equation 7-12 are printed on the first page of the report labeled under the notation defined in this document. The labels CR and CL denote, respectively, the radial and longitudinal weighting factors.

LIMITATIONS

The SSA 100 program is limited to solid, cored and I and E fuel elements.

RESULTS

The isotopic content of the plutonium product at various irradiations as calculated by SSA 100M are given in Figures 1 through 3 for the OIIN, CIIN and KIIIN fuel element. To illustrate the dependency of the isotopic content on initial U-235 enrichment, the calculations were carried out with three enrichments for each fuel element: (1) 0.712 wt %, (2) 0.94 wt % and (3) 1.44 wt %. The temperature of the graphite and water were taken to be 450° C and 60° C, respectively. Therefore, the input physical temperatures used in the calculations were 550° C and 160° C for graphite and water, respectively.

ACKNOWLEDGEMENT

J. D. Orton of the Technical Programming Operation carried the ball in programming SSA 100 and satisfying the wishes of both technical and accountability personnel.

Clifford R. Richey

Reactor Physics
Research and Engineering
IRRADIATION PROCESSING DEPARTMENT

CR Richey:eck

REFERENCES

- (1) Private notes of R. O. Gumprecht
- (2) HW-63411, IDIoT--A Lattice Parameter Code for the IBM 709, C. R. Richey, February 1, 1960.

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% P_u -239 Vs. MWD/T

K_{III}N ——— C_{III}N - - - - O_{III}N - - - -

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%P_U - 241 vs. MWD/T

K_{III}N ——— C_{II}N ——— O_{II}N ———

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APPENDIX A: Derivation of the Weighting Factors

Given

$$y = y_0 + a_1 t + a_2 t^2 + a_3 t^3 + \dots$$

$$\bar{y} = \frac{1}{V} \int_0^V y \, dV$$

where V is the total volume of uranium in the column. Therefore

$$\bar{y} = y_0 + \frac{a_1}{V} \int_0^V t \, dV + \frac{a_2}{V} \int_0^V t^2 \, dV + \dots \quad (1)$$

t is a function of axial position in the column, radial position from the axis of the fuel, and irradiation time, i.e.

$$t = \phi_1(l) \phi_2(r) \phi_3(\theta)$$

where

l = distance from front-to-rear in column
r = radial distance from axis of fuel element
 θ = irradiation time

Now

$$V = \pi(R_0^2 - R_I^2) L$$

where

R_0 = outside radius of fuel element
 R_I = inside radius of fuel element
 L = length of normal charge
 $dV = 2\pi r \, dr \, dl$

The first integral in Eq. (1) becomes

$$\frac{a_1}{\pi(R_0^2 - R_I^2) L} \int_0^L \int_{R_I}^{R_0} 2\pi r [\phi_1(l) \phi_2(r) \phi_3(\theta)] \, dr \, dl$$

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Since $\phi_3(\theta)$ is independent of r and l it may be taken out of the integral as a constant (time is not being varied). Therefore the above integral becomes

$$a_1 \left[\frac{\phi_3(\theta)}{L} \int_0^L \phi_1(l) dl \right] \cdot \left[\frac{2}{(R_0^2 - R_I^2)} \int_{R_I}^{R_0} r \phi_2(r) dr \right]$$

$\phi_1(l)$ can be expressed by a normalization factor times a flux function which will be taken to a sine function from front-to-rear of the reactor.

$$\phi_1(l) = \phi_{1\max} \sin \frac{\pi(l+\lambda)}{L+2\lambda} = \phi_{1\max} \cdot \psi(l)$$

where λ is the front and rear extrapolation length of the reactor flux. $\phi_2(r)$ can also be expressed by a normalization factor times a flux function which will be taken as

$$\phi_2(r) = \phi_{2\max} \cdot \beta(r)$$

where $\beta(r)$ obtained from a P_3 solution to the transport equation in cylindrical geometry is

$$\beta(r) = \frac{A_1 I_0(H_1 r) + A_2 I_0(H_2 r) + B_1 K_0(H_1 r) + B_2 K_0(H_2 r)}{A_1 I_0(H_1 R_0) + A_2 I_0(H_2 R_0) + B_1 K_0(H_1 R_0) + B_2 K_0(H_2 R_0)} \quad (2)$$

The integral can now be written

$$\begin{aligned} \frac{a_1}{V} \int_0^V x dv &= a_1 \phi_3(\theta) \phi_{1\max} \phi_{2\max} \left[\frac{1}{L} \int_0^L \psi(l) dl \right] \cdot \left[\frac{2}{(R_0^2 - R_I^2)} \int_{R_I}^{R_0} r \beta(r) dr \right] \\ &= a_1 x_{\max} w_1^0 w_1^1 = a_1 x_{\max} w_1 \end{aligned}$$

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Where

$$w_1^1 = \frac{1}{L} \int_0^L \psi(1) \, d1$$

$$w_1^r = \frac{2}{(R_o^2 - R_I^2)} \int_{R_I}^{R_o} r \phi(r) \, dr$$

$$w_1 = w_1^r \cdot w_1^1$$

By similar techniques it can be shown that

$$w_1^1 = \frac{1}{L} \int_0^L \psi^1(1) \, d1$$

$$w_1^r = \left(\frac{2}{R_o^2 - R_I^2} \right) \int_{R_I}^{R_o} r \phi^1(r) \, dr \quad C R$$

$$w_1 = w_1^r \cdot w_1^1$$

Therefore

$$\bar{y} = y_o + a_1 w_1 t_{\max} + a_2 w_2 t_{\max}^2 + \dots$$

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Weighting Factors for Segments of a Charge

The weighting factor for a short column or a segment of a charged column can easily be obtained from the same reasoning used in the above derivation. In calculating the longitudinal weighting factors the front-to-rear flux function will remain

$$\phi_1^{(1)} = \phi_{1 \max} \sin \left[\frac{\pi (1 + \lambda)}{L + 2\lambda} \right]$$

but the limits of integration will be the extremes of the segment. It should be emphasized that L remains the length of a normal charge. Therefore the weighting factors can be written for a particular segment in the more general form

$$w_i^r = \frac{2}{(R_o^2 - R_I^2)} \int_{R_I}^{R_o} r \beta^1(r) dr \quad C R (j)_i = 1, 2, 3, \dots$$

$$w_i^1 = \frac{1}{L_2 - L_1} \int_{L_1}^{L_2} \psi^i(l) dl$$

where L_2 and L_1 are the extremes of the segment.

If there exist more than one segment having a particular fuel lot number in the charged column, the weighting factor for this fuel material is

$$w_i = \frac{\sum_{\text{segi}} [(L_2 - L_1)_{\text{segi}} (w_i)_{\text{segi}}]}{\sum_{\text{segi}} (L_2 - L_1)_{\text{segi}}}$$

where segi denotes the i segment. In the above equation the sum is taken over only those segments that have the same fuel lot code.

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The heat generation fraction that corresponds to the i th segment is determined from

$$HF_i = \frac{[(R_o^2 - R_i^2)(L_2 - L_1)w_i E]_{\text{seg}i}}{\sum_{\text{all seg}i} [(R_o^2 - R_i^2)(L_2 - L_1)w_i E]_{\text{seg}i}}$$

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