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LONGITUDINAL FLUX FLATTENING

by

W. L. Stiede

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LONGITUDINAL FLUX FLATTENINGINTRODUCTION

To date a great deal of emphasis has been placed on flattening the side-to-side and top-to-bottom flux distribution with only minor effort to improve the front-to-rear distribution. Minor variations in the front-to-rear distribution have been achieved by horizontal control rod and supplemental control positioning. It has been reasonably well established /1/ that the rupture potential for any one tube charge increases markedly with higher specific power and temperature; thus there is a great deal of incentive to flatten in the front-to-rear dimension. Although flattening in this dimension will cause increased neutron leakage out of the reactor, this is compensated by increased conversion efficiency resulting from a more uniform exposure distribution within the tube charge.

The purpose of this document is to describe the basic analytical methods and the techniques of flattening front-to-rear through the integrated use of enrichment and poison material in combination with natural uranium, and to point out the requirements to insure that total control criteria is satisfied in the event of a water loss with this loading. For the purpose of this survey report an old reactor, 32-piece charge length, and a symmetrical front-to-rear distribution were considered; however, the methods given can be extended quite easily to different length and non-symmetrical charges and to the K reactors. For convenience the discussion is broken down into the following parts:

- A. Analytical methods involved in arriving at material bucklings necessary for a given flat zone size.
- B. Reactor loading for a given flat zone size.
- C. Total control considerations.

SUMMARY AND CONCLUSIONS

To determine the requirements for a given flat zone the reactor was divided into three sections in the front-to-rear dimension, the central section being the flat zone. The lattice material buckling required in the end sections to support the given flat zone were then determined; the calculation was repeated for several flat zone sizes. Charge-discharge considerations and best enrichment and mint usage dictated that the front-to-rear flattening charge have the following make-up: enrichment, natural and mint, and enrichment. Knowing the required bucklings and the type charge the density of these charges was then determined.

The number of the above charges, within the radially flattened zone, as a function of flat zone size is given in curve I. Also shown in this curve is the variation of ϕ_{ave}/ϕ_{max} along the tube with longitudinal flat zone size.

Because of the placement of enriched metal in the extreme front and rear portions of the reactor, and in most cases outside the safety system, special consideration was given to total control, the method of attack being essentially that given by G. R. Parkos /2/

/1/ W. I. Neef, "Rupture Potential and Axial Power Distribution," HW-61496.

/2/ G. R. Parkos, "Hanford Safety System Capacities by Square Pile Approximations," HW-62884.

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SUMMARY AND CONCLUSIONS (Continued)

with some modification. This analysis shows that C and H Reactors, because of bigger safety systems, can easily insure subcriticality in the event of a water loss with this loading even for a 500 cm flattened zone. For the remaining older reactors the size of the flattened zone is limited and supplemental poison is required at certain times. However, variations from the simple loading scheme analyzed in this report and judicious use of partial splines for startup control could greatly alleviate these restrictions and permit a fairly large flat zone with only nominal economic costs required to meet the total control requirements.

The following steps are suggested in designing and initiating a program to reshape the axial flux distribution:

1. Determine the most practical loading and the optimum axial flux shape considering fuel element and tube performance, enrichment costs, total control restrictions, conversion ratio, front face radiation levels, and metal handling and charging costs.
2. Secure sufficiently reliable and complete front-to-rear flux monitoring so that the achieved flux distribution changes can be followed with a high degree of accuracy.
3. Improve the analytical methods used to describe the flux distribution and the reactivity of the reactor.
4. Develop the operational techniques necessary to assure stable control. An axially flattened loading will actually increase equilibrium control difficulties; however, it is believed that with poison splines stable control can be maintained with a highly flattened axial flux distribution at any of the six older reactors.

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DISCUSSION

A. Analytical Methods

Consider the pile, in the front-to-rear dimension, to be divided into three regions as follows:

Suppose we wish to load the pile in this dimension so that between x_1 and x_2 the flux distribution is flat or constant; this then requires that $B_2^2 = 0$, and that $\frac{d\phi_2}{dx} = 0$. To determine values for B_1^2 and B_3^2 which make the entire slab critical, one-group, one-dimensional diffusion theory can be used. This involves finding the solutions to the following equations subject to the given boundary conditions:

$$\frac{d^2\phi_1}{dx^2} + B_1^2\phi_1 = 0 \quad (1)$$

$$\frac{d^2\phi_3}{dx^2} + B_3^2\phi_3 = 0 \quad (2)$$

Boundary conditions:

$$\phi_1(0) = 0 \quad (a)$$

$$\phi_1(x_1) = 1 \quad (b)$$

$$\left. \frac{d\phi_1}{dx} \right|_{x_1} = 0 \quad (c)$$

$$\phi_3(x_2) = 1 \quad (d)$$

$$\left. \frac{d\phi_3}{dx} \right|_{x_2} = 0 \quad (e)$$

$$\phi_3(x_3) = 0 \quad (f)$$

DISCUSSION (Continued)

The boundary conditions b, c, d, and e are obtained from the fact that for $x_1 = x = x_2$

$$\phi_2'(x) = \text{A constant which can be set equal to 1}$$

$$\frac{d\phi_2(x)}{dx} = 0$$

For B_1^2 and B_3^2 positive, which they must be for the reactor to be critical, the solutions to differential equations 1 and 2 are:

$$\phi_1 = A_1 \sin b_1 x + A_2 \cos b_1 x \quad (3)$$

$$\phi_3 = A_3 \sin b_3 x + A_4 \cos b_3 x \quad (4)$$

where b_1 and b_3 are the square roots, respectively, of B_1^2 and B_3^2 . Using the first boundary condition we find that:

$$\phi_1(0) = 0 = A_1 \sin(0) + A_2 \cos(0).$$

Since $\cos(0)$ is non-zero A_2 must be zero.

$$\therefore \phi = A_1 \sin b_1 x \quad (5)$$

Using boundary conditions b and c and differentiating equation (5),

$$\frac{d\phi_1}{dx} = a_1 b \cos b_1 x, \quad (6)$$

two simultaneous equations are obtained

$$A_1 \sin b_1 x_1 = 1$$

$$A_1 b \cos b_1 x_1 = 0$$

The solution to the above equations are:

$$b_1 x_1 = \frac{\pi}{2} \text{ or } b_1 = \frac{\pi}{2x_1}$$

$$\therefore B_1^2 = \frac{\pi^2}{4x_1^2} \text{ and}$$

$$A_1 = 1$$

From Symmetry it can be shown that $B = \left(\frac{\pi}{2(x_3 - x_2)} \right)^2$

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DISCUSSION (Continued)

Also from symmetry

$$(x_3 - x_2) = x_1$$

Thus

$$b_3 = \frac{\pi}{2(x_3 - x_2)} = \frac{\pi}{2x_1} = b_1$$

The analysis reveals an easy method for computing b_1 and b_3 ; that is, for a three-region problem with a flattened central zone and $x_1 = x_3 - x_2$, the end section material buckling required for critical is just that buckling required for critical for a reactor whose dimension, in the front-to-rear direction, is $2x_1$. A table of values of b_1 and B_1^2 for various flat zone sizes ($x_2 - x_1$) and a curve of B_1^2 vs ($x_2 - x_1$) is given in Appendix I, Buckling Calculation Data.

Two comments seem appropriate at this point. The optimum flux distribution and pile loading may not be symmetrical and would probably require more than a three-region calculation to describe accurately the flux distribution and enrichment requirements. However, such calculations are considerably more tedious and not necessary for the survey examination of the calculational approach and the first order evaluation of the E metal requirements to secure a fixed degree of flattening. An IBM 709 program is available to perform these multi-region calculations.

The second point is that the flattening and leakage in the radial direction can be ignored without introducing significant error; that is, there is no net leakage of neutrons in this dimension and even if the flux distribution were not radially flattened the loading changes indicated by this method of analysis would lead to negligible change in radial flux distribution.

B. Reactor Loading

Having found the required values for the material bucklings B_1^2 and B_3^2 for a given sized flattened zone the question arises as to how, in the practice, these values can be obtained (call this required value B^2_{req}). The required buckling must be obtained by charging a mixture of materials with distinct bucklings to obtain the desired average regional buckling. Three standard materials will be considered, natural uranium, .96 per cent enriched uranium, and mint, which have wet cold material bucklings of 60, 270, and -2600 micro bucks respectively.

There are several ways of mixing charges to obtain the required lattice material buckling; the first which may come to mind is to mix charges in every tube. The charge would then be made up as follows: natural and enrichment in region I, natural and mint in region II, and natural and enrichment in region III, the natural and enrichment giving the desired $B_1^2_{req}$ and $B_3^2_{req}$ and natural and mint giving $B_2^2_{req} = 0$. This then implies that every tube within the central zone would be charged in this fashion. However, because of the complex charging procedure and the special pickup problem for enrichment the analysis was done for a charge consisting of E metal in the end section and a combination of natural and mint in the center. This loading would be charged in a minimum number of tubes with all other tubes maintaining their standard loading. The number and specific loadings of tubes to be charged in this manner can be determined in the following manner:

DISCUSSION (Continued)

1. Choose the flattened zone size desired and calculate as shown in section A the buckling for the three zones.
2. By the homogenization technique calculate the density of tubes to be charged with E metal in the end section (call this Fe) to give the required B_1^2 and B_3^2 .
3. By the same technique as in 2 determine the density of tubes to be charged with mint in the central section (call this Fm to obtain the required B_2^2).
4. From the results of steps 2 and 3 determine the loading.

The following development illustrates the technique of carrying out the last three steps.

The analysis of section A gives the required longitudinal component of buckling; therefore

$$B_{reg}^2(1+3) = B_x^2 + B_y^2 + B_1^2$$

where

$$B_x^2 + B_y^2 = \text{material buckling required to compensate for leakage in the x y dimension}$$

$$B_1^2 = \text{longitudinal component of material buckling}$$

$$B_{reg}^2(1+3) = \text{hot, operating material buckling}$$

For the case considered here all of the charges will be loaded homogeneously within the radially flattened zone; therefore, $B_x^2 + B_y^2$ can be taken as equal to zero. The value of Fe can be obtained from the following equation:

$$B_{reg}^2(1+3) = B_1^2 = Fe(B_e'^2) + (1-Fe) B_N'^2$$

where $B_e'^2 = \text{hot material buckling of enrichment.}$

$B_N'^2 = \text{hot material buckling of natural}$

Several flux traverses reveal, as one would expect, the flux distribution front-to-rear is sinusoidal which, of course, implies $B_N'^2$ equals the geometric buckling in the longitudinal dimension, which is equal to 15.2 μb . The wet cold buckling of natural is 60 μb ; therefore, the change in buckling from cold to hot is

$$\Delta B_{C-H} = 15.2 - 60 = -44.8$$

or about 45 μb . This 45 μb also includes horizontal rods and other poisons in the reactor. However, this study assumes no changes in the poison distribution so the use of 45 μb for the loss from the cold to the actual

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DISCUSSION (Continued)

operating case for natural uranium is a reasonable first order approximation. The cold enriched buckling should change by about the same amount in extrapolating to the operating case; therefore,

$$B_E'^2 = B_E^2 - \Delta B_{C-H} = 270 - 45 = 225 \text{ } \mu\text{b}$$

Although this is not strictly true, the error will have negligible effects on the results of the analysis. The same line of reasoning applies for F_M which is given by

$$B_2^2 = F_M(B_M'^2) + (1-F_M) B_N'^2$$

A table of values of F_E and F_M for various flat zone sizes can be found in Appendix II, Reactor Loading Data.

As an example of how the values of Appendix II were obtained consider the following example. From Appendix I we find that for a 400 cm flat zone $B_1^2 = 61.6 \text{ } \mu\text{b}$. Therefore:

$$61.6 = F_E(225.2 - 15.2) + 15.2$$

$$46.4 = F_E(210)$$

$$F_E = .221$$

Therefore, approximately one out of five tubes must be charged with E metal in the front and rear 160 cm of charge. To find F_M we have

$$0 = F_M(B_M'^2) + (1-F_M) B_N'^2$$

$$0 = F_M(-2600 - 15.2) + 15.2$$

$$-15.2 = F_M(-2615.2)$$

$$F_M = .0058$$

With this F_M this says we require $.0058(400) = 2.32 \text{ cm}$ of mint in each tube. Then if one out of five tubes are charged we then require 11.6 cm of mint. Since mint is six inches (15.2 cm) long all that is required is approximately one piece of mint in one out of five tubes.

Three problems arise in connection with charging mint. The first problem is that one must be careful in charging the mint so that all the mint does not end up in the same front-to-rear plane. This can be taken care of by alternating the location of the mint pieces in the charge in each tube so that a fairly optimum flux distribution is attained. The second problem is that the mint piece would have to be canned in I & E jacket so that flow through center of I & E enriched is not stopped. This problem is essentially solved also since the E-N load is going to use I & E canned mint. A third problem is that the mint which will be used will be about the same size as the I & E². To avoid confusion, when picking up the I & E², it is suggested that the mint cans be anodized some color so that the type of metal will be easily distinguished.

DISCUSSION (Continued)

C. Total Control Considerations

Because of the position of the enriched metal, for front-to-rear flattening, in the extreme front and rear of the reactor and in most cases outside the VSR and Ball 3X system, special consideration must be given to total control; that is, maintaining the reactor subcritical in the event of complete water loss. The total control problem for the front-to-rear flattening loading is handled in a manner similar to that by G. R. Parkos /3/ with some modification. As defined in this document, the pile is divided into three parts, in the near and far direction, such that by putting the two end sections together the pile made up of these sections is square when viewed from the top. (See Figure 1.)

Figure 1

Let us consider first the central section and see what is needed to insure sub-criticality. The requirement for this section is that it be subcritical, assuming no net leakage of neutrons in the near and far direction. For a given flat zone size and loading pattern the values of F_e and F_m (the density of enriched metal and mint, respectively) have been specified from previous calculations. Using these values of F and the dry bucklings of the materials charged in a particular region, the dry lattice material buckling of the region can be determined. To clarify consider, as an example, a pile (B, D, F) load designed to maintain a 300 cm flat zone. The front-to-rear dimensions of interest are shown in Figure 2.

Figure 2

/3/ G. R. Parkos, "Hanford Safety System Capacities by Square Pile Approximations," HW-62884.

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DISCUSSION (Continued)

The material charged in regions I, II, IV, and V is a mixture of natural and enriched metal and thus the dry lattice material buckling is the same for these regions. The reason for dividing the regions outside the flat zone is that part of the material, that in regions II and IV, lies within the VSR and ball 3X pattern and thus the dry buckling in these regions will be affected by the local strength of the safety system in use. The dry lattice buckling of each of the regions exclusive of control may now be calculated. From Appendix II the density of enriched metal, for a 300 cm flat zone, is given by $Fe = .111$, and for mint $Fm = .0058$.

$$B_I^2 = Fe(B_{ED}^2) + (1-Fe) B_{ND}^2$$

where

$$B_{ED}^2 = \text{dry buckling of enrichment}$$

$$B_{ND}^2 = \text{dry buckling of natural}$$

$$B_I^2 = B_{II}^2 = B_{IV}^2 = B_V^2 = .111(320) - .898(98) = 122.6 \text{ } \mu\text{b.}$$

Likewise,

$$B_{III}^2 = Fm(B_{MD}^2) + (1-Fm) B_{ND}^2$$

where

$$B_{MD}^2 = \text{dry buckling of mint}$$

$$B_{III}^2 = .0058(-3000) + (.9942) 98 = 84.8 \text{ } \mu\text{b}$$

Consider now that the VSR's are inserted. Since the local strength of the VSR system is $98 \text{ } \mu\text{b}$ the values of B_{II}^2 , B_{III}^2 , and B_{IV}^2 can be reduced by $98 \text{ } \mu\text{b}$ giving a buckling balance of $B_I^2 = B_V^2 = 122.6$, $B_{II}^2 = B_{IV}^2 = 122.5 - 98 = 24.6$ and $B_{III}^2 = 84.8 - 98 = -13.2$. It must now be determined if the central section with this particular arrangement of bucklings is subcritical, critical, or supercritical. If the section is supercritical it must be determined how much poison must be charged to restore the critical condition. This problem was programmed for all reactors (except KE and KW) and flat zone sizes considered, on the IBM 709 computer, and values of delta B necessary to make the central section just critical were obtained. A curve of delta B versus flat zone size is found in Appendix III, Total Control Data. From this appendix it can be seen for the example given the delta B required to restore critical is $-27.2 \text{ } \mu\text{b}$. This value can be obtained by utilizing xenon, lead cadmium, or splines. For an infinite outage; that is, the xenon-free case, the above would require approximately six tubes of lead cadmium (B_m^2 for lead-cadmium is about $-2000 \text{ } \mu\text{b}$). In a practical case the enriched metal would probably be charged preferentially toward the front, in which case partially inserted splines would work quite nicely.

The equivalent end section can now be treated. Referring again to the first diagram, the equivalent end sections are joined together to form a square pile which is then cylindrized (see Figure 3).

DISCUSSION (Continued)

Figure 3

Cylindricized Equivalent End Section

The material contained in Region 1 is natural and mint and in some cases includes limited amounts of enrichment. This region is also within the VSR and ball 3X system. Region II contains enrichment for radial flattening and, as in Region I, is within the ball 3X and VSR system. The remaining region contains a mixture of natural and enriched metal, and for large flattened zones, mint. There are no control elements (VSR or Ball 3X) in Region III.

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DISCUSSION (Continued)

First we must find B_1^2 and B_3^2 , where the subscripts denote the regions mentioned above. These were found in the following manner: Since for a given flat zone Fe, Fm, and the loading pattern are specified the dry buckling in every region of the control plane can be determined. These values can now be weighted (by area) to obtain B_1^2 and B_3^2 . An example of a calculation of this type is given in the Appendix on total control data. A set of curves of $B_1'^2$ where $B_1'^2 = B_1^2 + \delta B_c$ versus B_2^2 (where B_2^2 is the buckling of the E ring) with B_3^2 as a parameter were generated. From these curves, given a B_1^2 and B_3^2 , the value of B_2^2 required for critical can be obtained. These curves are the same as those found in HW-62884 except they cover a different range of values. These curves can be found in Appendix III. Having found B_1^2 and B_3^2 it now is a simple matter to find the allowable number of E metal columns. Again consider a longitudinal flat zone size of 300 cm (B, D, F Reactors) and $\delta B_c = 98 \mu b$.

$$B_1'^2 = 94.2 - 98 = -3.8$$

$$B_3^2 = 107.5 \approx 110$$

From the curves we obtain

$$B_2^2 = -130$$

Now B_{m2}^2 , the lattice material buckling of the E ring, is

$$B_{m2} = B_2 - \delta B_c$$

since the E ring is considered to be within the control zone.

$$\therefore B_{m2}^2 = -130 + 98 = -32.$$

The number of E columns is given by

$$\#E = A H F$$

where

A = thickness of the enriched slab corresponding to the radii used in the buckling calculation

H = height of the enriched slab on near or far side.

For B, D, IR, and F Reactors: A = 2.24 and H was chosen as 30. Therefore, A x H = 67.2. F is given by:

$$B_{m2}^2 = F(320) + (1-F)(98)$$

$$B_{m2}^2 = F(222) = \frac{B_{m2}^2 - 98}{222}$$

For the above example

$$F = \frac{-32 - 98}{222} = \frac{-130}{222} = -.586$$

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DISCUSSION (Continued)

Therefore,

$$\#E = (67.2)(-.586) = -.39.3.$$

Since B, D, and F Reactors normally carry about 17 to 20 columns in the near and far side enrichment rings the total number of columns which must be compensated for is about 59. For an infinite outage this would require about nine columns per side. Complete data can be found in Appendix III.

ACKNOWLEDGEMENTS

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IRRADIATION PROCESSING DEPARTMENT

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x_1	x_2	$x_2 - x_1$	b_1	B_1^2
350	455	105	4.49×10^{-3}	20.2 μb
300	505	205	5.24 "	27.5 μb
250	555	305	6.28 "	39.4 μb
200	605	405	7.85 "	61.6 μb
150	655	505	10.47 "	109.6 μb
100	705	605	15.71 "	247.8 μb

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TABLE II
MINIMUM BUCKLING FREQUENCY TO SUPPORT
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B^2 required for Critical (μb)

300
60
40
20
200
80
60
40
20
100
80
60
40
20

100 200 300 400 500 600

Flat Zone Size (Cm)

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APPENDIX II

REACTOR LOADING DATA

Flat Zone Size	B_1^2	$B_1^2-15.2$	Fe	Fm	No. of Tubes for Desired Flatten- ing = N	Cm of Mint per Tube = M	NM	No. of Mint Pieces	ϕ_{avg}/ϕ_{max}
500	107	91.8	.437	.0058	1 out of every 2.3	2.9	6.67	.66	.94
400	61	45.8	.221	.0058	1 out of every 4.6	2.3	10.58	1.04	.89
350	48.5	33.3	.159	.0058	1 out of every 6.3	2.03	12.79	1.26	.87
300	38.5	23.3	.111	.0058	1 out of every 9.0	1.74	15.66	1.54	.85
200	27	11.8	.056	.0058	1 out of every 17.8	1.16	20.64	2.03	.80

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APPENDIX II

(Continued)

Recall that

$$B_1^2 = Fe(225) + (1-Fe)(15.2)$$

$$Fe = \frac{B_1^2 - 15.2}{(225.2-15.2)}$$

and

$$B_2^2 = Fm(-2600) + (1-Fm)(15.2) = 0$$

$$Fm = \frac{15.2}{2615} = .0058$$

A brief explanation of columns 6, 7, and 8 of the above table is in order. Since the dry buckling of mint is so great Fm is taken to be the density that one must charge the mint per tube to obtain $B_2^2 = 0$; therefore, (flat zone size) (Fm) is equal to the number of cm of mint which is required per tube for a given flattened zone. Since column 6 of the table gives the number of tubes which must be charged enrichment in the end section to obtain B_1^2 then column 6 times column 7 gives the cm of mint which must be charged in the tubes which contain enrichment to obtain $B_2^2 = 0$. The remainder of the table is self explanatory.

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APPENDIX III

TOTAL CONTROL DATA - SECTION A

Central Section Total Control Requirement

Curve III gives the change in buckling required to restore criticality in the central section. It should be noted that for C and H reactors, for either the VSR's or ball 3X, the delta B required to restore critical is positive. This means that the central section is subcritical with the given loading and requires no supplementary poison.

ΔB required for Critical

45
40
35
30
25
20
15
10
5
-5
-10
-15
-20
-25
-30
-35
-40
-45

ΔB required to insure sub-critical condition in central section for limit initial elevating loading

CURVE III

$G \& H \quad S = 150 \text{ (Ball 24)}$

$G \& H$

$S = 120 \text{ (NVR'S)}$

100 200 300 400 500

FLAT ZONE SIZE (CM)

$D, D, T, F \quad S = 150 \text{ (Ball 24)}$

$D, D, T, F \quad S = 120 \text{ (Ball 24)}$

$D, D, T, F \quad S = 90 \text{ (NVR'S)}$

APPENDIX III

TOTAL CONTROL DATA - SECTION B

Calculation of $B_1'^2$ and B_3^2 for Equivalent End Section

Figure 4 is one-fourth of a top view of H and C Reactors, as is Figure 5 of B, D, DR, and F. The diagram shows appropriate dimensions and the areas of significant portions. As an example of the type of calculation which was done to determine the values of B_1^2 and B_3^2 for the equivalent end section, consider a 300 cm longitudinal flat zone for (B, D, DR, F). For this size flat zone this means that from zero to 150 cm the material consists of natural and mint and has a B^2 of 84.8 μb (from previous calculation). The material which lies in the region between 150 and 255 cm is natural and enrichment. To find B_1^2 then we have the following:

$$\frac{A_M B_1^2_M + A_E B_1^2_E}{A_M + A_E} = B_1^2$$

where

A_M = Area of section charged natural and mint

A_E = Area of section charged natural and enrichment

B^2_1 = Material buckling of area charged natural and mint

B^2_{1E} = Material buckling of area charged natural and enrichment

$B^2_{1E} = Fe(B^2_{ED}) + (1-Fe)(B^2_{ND})$

$B^2_{1M} = Fm(B^2_{MD}) + (1-Fm)(B^2_{ND})$

From a previous calculation we can obtain Fe and Fm. Therefore, we have

$$\begin{aligned} B^2_{1E} &= Fe(B^2_{ED}) + (1-Fe) B^2_{ND} \\ &= .111 (320) + .889 (98) \\ &= 122.6 \end{aligned}$$

$$\begin{aligned} B^2_{1M} &= Fm(B^2_{MD}) + (1-Fm) B^2_{ND} \\ &= .0058 (-3000) + .9942 (98) \\ &= 84.8 \end{aligned}$$

From Figure 1 we find that

$$A_M = 27,000 \text{ cm}^2$$

$$A_E = 9,000 \text{ cm}^2$$

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APPENDIX III

TOTAL CONTROL DATA - SECTION B

(Continued)

$$\begin{aligned} \therefore B_1^2 &= \frac{9,000 (122.6) + 27,000 (84.8)}{36,000} \\ &= 94.2 \end{aligned}$$

Again for B_3^2

$$B_3^2 = A_E B_{3E}^2 + A_N B_{3N}^2 / A_{3E} + A_{3N}$$

Where A_E and B_{3E}^2 are defined as above and

A_N = Area of section charged natural

B_{3N}^2 = Material buckling of area charged natural

B_{3E}^2 is determined in the same manner as B_{1E}^2

$$\therefore B_{3E}^2 = 122.6$$

and B_{3N}^2 is taken to be 98 μ b.

From Figure 1 we find

$$A_{3E} = 35,100$$

$$A_{3N} = 71,100$$

$$\begin{aligned} \therefore B_3^2 &= A_{3E} B_{3E}^2 + A_{3N} B_{3N}^2 / A_{3E} + A_{3N} \\ &= 122.6 (35,100) + 98 (71,100) / 106,200 \\ &= 107.5 \end{aligned}$$

C and H Reactors

Flat zone size	B_1^2	B_3^2
500	84.8	147.4
400	97.1	122.6
350	99.4	116.0
300	100.0	110.5
200	100.2	104.3

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APPENDIX III

TOTAL CONTROL DATA - SECTION B
(Continued)

B, D, DR, and F Reactors

<u>Flat Zone Size</u>	<u>B₁²</u>	<u>B₃²</u>
500	84.8	122.1
400	84.8	115.3
350	90.9	111.0
300	94.2	107.5
200	97.6	103.4

Figure 4

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APPENDIX III

TOTAL CONTROL DATA - SECTION B

(Continued)

Figure 5

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Curve IV

Minimum Swirling Arrangement
of Equilibrium and Position for
Class IV Safety System and Geometry

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APPENDIX IIITOTAL CONTROL DATA - SECTION CEquivalent End Section Total Control RequirementsB, D, DR, and F Reactors - $\delta B_c = 98 \mu b$

<u>Flat Zone size</u>	<u>B_1^2</u>	<u>$B_1'^2$</u>	<u>B_3^2</u>	<u>B_2^2</u>	<u>B_{m2}^2</u>	<u>#E</u>
500	84.8	-13.2	122.1	-321	-223	-97.4
400	84.8	-13.2	115.3	-257	-159	-78.0
350	90.9	-7.1	111.0	-219	-121	-66.2
300	94.2	-3.8	107.5	181.5	-83.5	-55.0
200	97.6	-.4	103.4	130.5	-32.5	-39.5

B, D, F Reactors $\delta B_c = 135 \mu b$

500	84.8	-50.2	122.1	-235	-100	-59.9
400	84.8	-50.2	115.3	-184	-49	-44.5
350	90.0	-44.1	111.0	-148	-13	-33.6
300	94.2	-40.8	107.5	-124	11	-26.3
200	97.6	-37.4	103.4	-90	45	-16.1

DR Reactor $\delta B_c = 150 \mu b$

500	84.8	-65.2	122.1	-215	-65	-49.3
400	84.8	-65.2	115.3	-164	-14	-33.9
350	90.9	-59.1	111.0	-126	24	-22.4
300	94.2	-55.8	107.5	-100	50	-14.5
200	97.6	-52.4	103.4	-64	86	-3.6

C and H Reactors $\delta B_c = 120 \mu b$

500	84.8	-35.2	147.4	92	212	68.4
400	97.1	-22.9	122.6	102	222	74.3
350	99.4	-20.6	116.0	110	230	79.0
300	100.0	-20	110.5	115	235	82.1
200	100.2	-19.8	104.3	120	240	85.1

C and H Reactors $\delta B_c = 150 \mu b$

500	84.8	-65.2	147.4	124.0	274	105.5
400	97.1	-52.9	122.6	147.0	297	119.2
350	99.4	-50.6	116.0	150.0	300	122.7
300	100.0	-50.0	110.5	154.0	304	123.4
200	100.2	-49.8	104.3	160.0	310	127.0

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Curve 1

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FORT BELVOIR, VIRGINIA

$\sqrt{S \cdot H} = 1.20$

$\sqrt{S \cdot H} = 1.50$

No. F Columns

0 10 20 30 40 50 60 70 80 90 100 110 120

100

200

300

400

500

DATE

FILMED

6/14/94

END