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WIRE-WRAP BUNDLE COMPRESSION-CHARACTERISTICS STUDY

PHASE I

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WIRE-WRAP COMPRESSION CHARACTERISTICS STUDY

PHASE I

1.0 SUMMARY

An analytical computer comparison was made of the compression characteristics of proposed wire-wrap bundles. The study included analysis of 7- and 37-rod straight-start bundles (base configuration), and softened 37-rod configurations. The softened configuration analyzed were: straight-start with distributed wireless fuel rods, and the staggered wire-wrap start angles of 0° - 30° - 60° and 0° - 45° - 90° . The compression of the bundle simulates the bundle-to-channel interference at end-of-life conditions at which high differential swelling between the channel and bundle has been predicted. The computer results do not include the so-called "dispersion" effects. (See discussion of dispersion in Section 4.4.) The effects of other variables such as pitch length, creep, axial variations in swelling, and degree of swelling were not studied. These analytic studies give an indication of trends only. No credence should be given to specific quantitative load or deflection results quoted in this report.

The computer solutions provide analytical data on bundle loads and deflections and also provide displacement vector plots of important bundle planes. These provide a good visual aid to evaluate bundle behavior and rod deflection trends of interest. The key results of this preliminary evaluation are:

- The softening technique of distributed wireless rods produces localized deflections.
- A special edge rod wire-wrap support configuration may be needed to accommodate deflections indicated for the staggered-start design.
- The need for mechanical testing is affirmed, particularly the need for deflection measurements. These measurements should be made over a range of interference levels.
- The need for continued effort to develop low-swelling fuel rod cladding materials has been emphasized.
- The need for development of an improved wire-wrap assembly design configuration that can adjust the distribution of rod deflections within the bundle, so that clearances between rods and between edge rods and the channel remain within acceptable limits, has been highlighted.

2.0 OBJECTIVES

The wire-wrap assemblies of a target LMFBR will be required to operate to a peak burnup of approximately 150,000 MWD/T and a peak fast fluence of 2.5 to 3.0×10^{23} NVT. With the present reference core structural material (316 SS 20% CW), these operating conditions can, as presently predicted, result in significant irradiation growth of the assembly and significant growth of the fuel rod bundle relative to the channel. Excessive growth of the fuel rod bundle relative to the channel will result in distortion of the fuel rod bundle with nonuniform displacement of fuel rod spacing and reduction of the rod-to-channel edge spacing.

This computer study of wire-wrap compression characteristics was made in to help evaluate the relative worth of the proposed bundle softening techniques of distributed wireless rods and staggered wire-wrap start angles, to gain a better understanding of bundle behavior due to relative bundle-to-channel growth, and to assist in formulating a successful wire-wrap mechanical test program.

Prior experience, testing and analysis have indicated that a possible method of reducing the effects of interference is through the use of distributed wireless rods and staggered wire-wrap start angles. A mechanical test program has been proposed which will test bundle softening techniques. As originally planned, distributed wireless rods and staggered-start arrays of 0° - 30° - 60° and 0° - 45° - 90° were to be tested. The rationale behind these various bundle softening techniques, as solutions to the end-of-life bundle-to-channel interference problem and their selection as test configurations, is explained in Reference 2. These test configurations are analyzed in this study.

3.0 METHOD AND RESTRICTIONS

The study was made by use of computer models using the NASTRAN structures computer program (References 5 and 6). The models are of current design configuration of .230"-diameter rods, .015"-thick cladding, with .056" wire spacing and a wire-wrap pitch of 12 inches. Bundle size was limited to 7 and 37 rods due to high running times and cost for large bundles. The models consist of beam elements for the rods and axial compression members for the wire contacts between rods and between edge rods and the channel. The axial member extends from rod center line to rod center line or channel wall and is sized to include rod radial stiffness (see Appendix B).

The models are of the smallest repetitive section with the ends connected by tying equations so as to simulate a full bundle. The repetitive sections are of 1/6 pitch length for straight-start bundles, and 1/3 pitch length for staggered-start bundles. By stacking 6 straight-start repetitive sections on top of each other and rotating each 60° relative to the one preceding it, a full bundle pitch is achieved. For this study, uniform axial compression was assumed, as it provides adequate information for a relative comparison and is a simpler and smaller problem to analyze. For uniform axial compression, each repetitive section acts identically, thus only one need be analyzed to determine full bundle behavior. This repetitive section technique permits a minimum model size to be used. The tying equations tie together the ends of the rods with the opposite rod ends which would connect to them if a rotated section were stacked on top of the section being analyzed.

With the wireless and staggered configurations, some wire contact locations separate; this causes tension in the axial elements representing these contacts. Deflection checks of rod spacing were made and tension elements were removed by trial and error.

The analysis was made for a unit compression of 10% with results later factored to the currently predicted differential swelling interference. The worst case interference as currently predicted is 4.36% of the original bundle dimension. This is due to bundle swelling of 8.19%, less 0.70% clearance, less 3.13% channel growth. The actual behavior is the superposition of the free 8.19% swelling and the 4.36% mechanical compression. This means that the spacing and original clearance between rods to which deflection data are to be compared is .056" x 1.0819 or .0606".

The configurations analyzed are:

- 7-rod straight start
- 37-rod straight start
- 37-rod straight start with 7 wireless rods
- 37-rod 0° - 30° - 60° staggered-start angle
- 37-rod 0° - 45° - 90° staggered-start angle.

Sketches of the models showing the element node points of the model for the different axial planes are shown on pages 6 through 9. For the straight-start models, nodes are at planes $Z = 0$, $Z = 1$, and $Z = 2$. For the staggered-start models, planes are from $Z = 0$ to $Z = 4$ with planes needed an inch apart for the 0° - 30° - 60° stagger and a half-inch apart for the 0° - 45° - 80° stagger.

There are major limits to which an analytical solution can predict bundle behavior at this time. The hexagonal bundle behavior is very complex, particularly the effects of bundle size and "dispersion." The expected behavior from these effects has been indicated, based on judgment. The effects of creep, while accounted for in the interference used, are not used in the analysis as far as they affect load data.

We do not claim that the results of this work characterize the expected quantitative behavior in a 217-rod LMFBF assembly under prototypical conditions, nor that any of the quantitative values given in this report represent what will really happen in a core. This report is a first step in a rather long, iterative analysis/test data process to reach an understanding of how to design and predict the end-of-life performance characteristics of a wire-wrap assembly based on present material properties expectations for 316 SS 20% CW. As tempting as the prospect may be to try to deduce conclusions from the quantitative results given in this report, the reader is cautioned not to draw any such conclusions. This report does, however, flag many areas that should be subjects for further study and test, based on the sensitivity of these areas to design parameters and material properties characteristics.

7 ROD BUNDLE STRAIGHT START

23 NODES

20 BEAMS { 14 RODS
6 WIRE CONNECTIONS

$7 \times 4 = 28$ TYING EQUATIONS

$z = 2''$

$z = 1''$

$z = 0''$

Figure 1

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WIRE WRAP BUNDLE COMPRESSION CHARACTERISTICS STUDY

37 ROD BUNDLE REPETITIVE SECTION MODEL

STRAIGHT START

Figure 2

WIRE WRAP BUNDLE COMPRESSION CHARACTERISTICS STUDY

37 ROD BUNDLE REPETITIVE SECTION MODEL

STRAIGHT START

WITH 7 WIRELESS RODS

Figure 3

WIRE WRAP BUNDLE
COMPRESSION CHARACTERISTICS STUDY

27 ROD BUNDLE REPETITIVE SECTION MODEL

STAGGERED START $0^\circ, 30^\circ, 60^\circ$

Figure 4

WIRE WRAP BUNDLE
COMPRESSION CHARACTERISTICS STUDY

37 ROD BUNDLE REPETITIVE SECTION MODEL
 STAGGERED START $0^\circ - 45^\circ - 90^\circ$

Figure 5

4.0 RESULTS

4.1 Data Summary

Loads and deflection data adjusted to 4.36% bundle-channel interference are summarized in Table 1 below. The displacement vector plots of important bundle planes, with important dimensions displayed, are presented in Appendix A.

Table 1
Summary of Computer Results
Adjusted to 4.36% Bundle-Channel Interference

Bundle Size (No. of Rods)	7	37	37	37	37
Bundle Configuration	Straight Start	Straight Start	Straight Start With 7 Wireless Rods	0°-30°-60° Stagger	0°-45°-90° Stagger
Max. Load on Channel Flat Per Pitch (lbs) % of Straight Start	24.3	223.1 100.0	112.7 50.6	97.3 43.6	64.1 28.8
Max. Rod-to-Channel Load (lbs) % of Straight Start	12.2	60.7 100.0	41.0 67.6	38.2 62.8	23.4 38.5
Max. Rod-to-Rod Load (lbs) % of Straight Start	9.1	59.6 100.0	31.7 53.0	18.5 31.1	11.9 19.9
Max. Increase Rod-to-Rod Spacing (in.) % of Straight Start	.0089	.0151 100.0	.0270 178.8	.0496 328.2	.0442 292.7
Max. Decrease Rod-to-Rod Spacing (in.) % of Straight Start	.0098	.0198 100.0	.0472 238.7	.0417 210.7	.0478 241.7
Max. Increase Rod-to-Channel Spacing (in.)	.0	.0	.0019	.0081	.0045
Max. Decrease Rod-to-Channel Spacing (in.) % of Straight Start	.0353	.0721* 100.0	.0634* 88.0	.0464 64.4	.0470 65.2

*These would cause rod-channel contact (Note: wire spacing after 8.19% expansion for EOL conditions would be $.056 \times 1.0819 = .0606$ ").

4.2 Correlation of Loads to Previous Test Data

From previous analysis of straight-start bundles, the bundle across-flats compression spring constant was derived as:

$$K = \frac{F}{\Delta} = \frac{1}{C} \frac{129 E I N}{p^3} \quad (\text{See Reference 2}) \quad (\text{Eq. 1})$$

where:

- C = An experimentally determined constant.
- K = Bundle across-flats spring constant of the total line load per flat divided by the across flats length change, lb/inch.
- F = Total line load per flat, lb.
- Δ = Bundle-channel interference expressed as across-flats length change, in.
- E = Young's modulus of elasticity, psi.
- I = Moment of inertia of a fuel rod, in.⁴.
- N = Number of fuel rods.
- P = Wire-wrap pitch, inches.

Previous test data indicates good correlation using a value of 6.0 for C (Reference 2) for large bundles of 127 and 217 rods. Using this relationship for 7- and 37-rod bundles with 4.36% compression, the load on a flat would be 4.8 lbs for a 7-rod bundle and 55.7 lbs for a 37-rod bundle. The computer analysis gave 24.3 lbs and 223.1 lbs which is higher by factors of 5 and 4, respectively

It was previously thought that the value of 6 for C was mainly due to rod "dispersion" (see Section 4.4). The computer data indicates, while dispersion is the main effect of this softening, the combined effects of the hexagonal shape of the bundle (causing a discontinuity of the load path at the boundary and causing nonuniform and out-of-phase rod deformation) and rod radial compression (ovaling) are contributors to bundle softening. If two constants were used for C in the above equation, one for dispersion and one for hex and ovaling effects, the values would be 4.0 and 1.5, respectively, for the 37-rod bundle.

Figures 6 through 9 are a reproduction of test data for 37-rod bundles from Reference 2. The NASTRAN results (Table 1), of load on channel flat, show the distributed wireless configuration loads to be 50.6% of the straight-start loads and the 0° - 30° - 60° stagger configuration loads to be 43.6% of the straight-start loads. Applying these ratios to the straight-start relationship of Equation (1) shows reasonable correlation to the 37-rod test data.

Compression Test Results —
37-Rod Bundle, 12-Inch Pitch

Figure 6

TEST SERIES 1
 37 PIN
 PITCH - 6-inch
 P/D - 1.2
 START 0.0.0

Compression Test Results -
 37-Rod Bundle, 6-Inch Pitch

Figure 7

Compression Test Results —
37-Rod Bundle, 6-Inch Pitch, Staggered Starts

Figure 8

TEST SERIES 5
 37 Wires
 PITCH 6 inch
 P/D - 1.28
 START 0.30.60

APPLIED RADIAL LOAD, POUNDS PER UNIT PITCH

Compression Test Results —
 37-Rod Bundle, 6-Inch Pitch, Staggered Starts

Figure 9

4.3 Extrapolation of Data to Larger Bundles

Wire-wrap bundle behavior is dependent on the wire-wrap design configuration. In order to make a relative judgement, an understanding of how bundle size affects different configurations is necessary. This extrapolation discussion is made to aid a relative worth determination; but as this analysis does not include all bundle variables or design solutions, it should not be used to make a design adequacy judgment of wire-wrap bundles any more than the quantitative 7- and 37-rod results given in this report should be used to make such judgments.

The wire-wrap bundle behavior can be considered a superposition of five different behaviors. These are:

- (1) Bundle helical bending.
- (2) Rod lateral dispersion.
- (3) Rod nesting due to staggered wire supports.
- (4) Geometric effects of hexagonal loading.
- (5) Rod radial compression (ovaling).

Of these five effects, (4) and (5) are relatively small (see Section 4.2), (2) is not included in the analytical computer solution, and (3) would be present only in the staggered or wireless configurations. The analytical straight-start bundle behavior is primarily bundle helical bending. (In this context, analytical behavior means behavior without dispersion effects.) The analytical staggered bundle behavior is primarily a combination of bundle helical bending and rod nesting due to the staggered wires. For a full stagger (0-120-240) analytical bundle behavior would be mainly due to rod nesting. This indicates that analytical bundle behavior of other staggered configurations can be bound by pure bundle helical bending and pure rod nesting.

Bundle growth relative to the channel is physically restrained due to the wire-wrap on the edge rods. This physical restraint occurs only at axial locations at each flat where the wire wraps of the edge rods contact the channel. For a straight-start wire-wrap bundle, this occurs along a single line at each flat. These lines of displacement restraint are axially displaced from one hex flat to an adjacent hex flat by a distance equal to $1/6$ of the

wire-wrap pitch distance. Thus the bundle deflects into a helical configuration. Figure 10 schematically shows the helical manner in which the contact loads are applied to the straight-start bundle due to the restraint of the channel. For the staggered configurations, the edge rod-to-channel contact is over a band of axial length. As the stagger is increased, this band widens and the axial positions of the bands on the different flats start to overlap. This reduces the bundle helical bending. At a full stagger of 0-120-240 there is complete overlapping and there is no bundle helical bending (see Figure 11).

The analytical straight-start and 0-120-240 staggered-start bundle behavior listed in Table 2 can be used for the upper and lower bounds, respectively, for analytical bundle behavior. Table 3 shows upper and lower bounds of loads without creep and deflection data extrapolated from a 37-rod bundle to a 217-rod bundle based on bundle variables in Table 2.

Figure 10. Helical Load Distribution
Applied to Fuel Rod Bundle

STRAIGHT START

0-15-30 STAGGER

0-30-60 STAGGER

0-45-90 STAGGER

0-120-240 STAGGER

Figure 11. Fuel Rod Bundle External Loading
in Y-Direction Over One Pitch Length

Table 2
Analytical Rod Behavior

	Straight Start Analytical Bundle Bending	0-120-240 Staggered Start Analytical Rod Nestling
Total load on channel flat	$\left(\frac{130}{p^3} \frac{EIX}{p^3} \right) ND$	$\left(\frac{324}{p^3} \frac{EIX}{p^3} \right) D$
Average edge load rod to channel	$\left(\frac{130}{p^3} \frac{EIX}{p^3} \right) \frac{N}{N_e} D$	$\left(\frac{324}{p^3} \frac{EIX}{p^3} \right) \frac{D}{N_e}$
Rod deflection	$(X) D$	$(X) \frac{D}{N_R}$

where

E = Young's modulus of elasticity, psi.

I = Moment of inertia of a fuel rod, in.⁴.

D = Flat-to-flat bundle size, in.

X = Channel-to-bundle interference, as ratio of bundle across flats size.

P = Wire-wrap pitch, in.

N = Number of fuel rods.

N_e = Number of edge rods.

N_R = Number of rows of rods.

Table 3

Extrapolated 217-Rod Bundle Data
(Dispersion Effects Not Included)

Bundle Configuration		Straight Start	0°-30°-60° Stagger	0°-45°-90° Stagger
Max. Rod-to-Channel Load (lbs)	Upper Bound	373	235	144
	Lower Bound	NA*	40	24
Max. Rod-to-Rod Load (lbs)	Upper Bound	366	114	73
	Lower Bound	NA*	19	12
Max. Decrease Rod-to-Rod Spacing (in.)	Upper Bound	.0466	.0982	.1126
	Lower Bound	NA*	.0404	.0464
Max. Decrease Rod-to-Channel Spacing (in.)	Upper Bound	.1698	.1093	.1107
	Lower Bound	NA*	.0450	.0456

*Not applicable.

NOTE: Creep effects are not included in loads data.

4.4 Dispersion Effects

As stated previously, the bundle compression constant, expressed in Equation 1, correlates well with test data when a value of 6 is used for C . If rod deformation were uniform (and there was no dispersion), C would equal 1.0. The analytical value of 1.5 from the NASTRAN analysis can be attributed to hex and ovaling effects. (See Section 4.2.) The experimentally determined value of 6 implies the existence of more complex behavior. The behavior called "dispersion" was postulated to account for this extra bundle softening.

As an explanation of dispersion, consider the following. In a wire-wrap bundle the rods are loaded by compression (pinch loads) between rods, at axial planes where the wire wrap contacts two rods. Figure 12 shows a loading across 3 rods (1, 2, and 3) in a straight-start bundle, at a pinch plane. If P_1 is greater than P_2 , the rods will deflect in the X direction. There is space at this plane for movement in the Y direction. A load component in this direction will cause Y direction deflection restrained only by rod bending. The colinear loading across the rods is initially unstable, as any initial irregularity will cause a load component in the Y direction; this load component will cause deflection which will increase the Y direction component of the pinch load. As the pinch load decreases due to the associated bundle softening, a balance is achieved. This behavior is called dispersion. In the NASTRAN analysis there are no initial irregularities, and with small deflection theory this type of analysis is not possible, as the effect from the deflections cannot be accounted for.

To consider the effects of dispersion, consider a straight-start bundle plane with one edge of the bundle separated from the channel by the wire wrap and the opposite edge free to move toward the channel. The loads and deflections are imposed at the bundle channel contact. If the imposed deflection is accommodated at the free edge, all the rods in the load path between the two edges will be deflected the full amount. Alternately, if some imposed deflection is accommodated between rods, rods farther down in the load path need not be deflected as much and less load is required. The free edge deflection toward the channel is also reduced. Greater dispersion would occur at the higher loaded rods near the bundle channel contact. Loads and deflection

Figure 12. Colinear Loading Across Rods

decrease across the bundle from the contact to the free edge. This effect would have a magnifying effect on bundle softening and account for the large softening constant discussed above. The effects of dispersion would be to lower loads, decrease rod-to-rod clearance, and increase rod-to-channel clearance. These dispersion effects would be greater for straight-start bundles than for softened bundles due to the higher loads with the straight-start configuration.

Table 4 shows 217-rod bundle extrapolated loads data with dispersion included by dividing the values in Table 3 by a factor of 4 (see Section 4.2).

Table 5 shows deflection results followed by pluses and minuses to indicate the effects of dispersion.

In order to obtain a quantitative understanding of dispersion, an analytical solution was made of dispersion deflection vs. pinch load. Consider a straight-start bundle as shown below. Rod A is initially out of line with the B rods.

The kick load: $F_Y = 2 F_X \tan \theta$ Eq. 2

is constrained by rod bending where:

$$F_Y = K \Delta Y = K(Y_{\text{Total}} - Y_{\text{Initial}})$$
 Eq. 3

and

$$F_X = \frac{K(Y_{\text{Total}} - Y_{\text{Initial}})}{2 \tan \theta}$$
 Eq. 4

where K is the rod bending stiffness and F_X is the pinch load.

If there were no initial imperfections and the rods were in line, the critical loads could be calculated as:

$$F_{Y_{CR}} = K Y_{Total} = 2 F_{X_{CR}} \frac{Y_{Total}}{R} \quad \text{Eq. 5}$$

$$\therefore F_{X_{CR}} = \frac{K R}{2} \quad \text{Eq. 6}$$

which for any given initial geometry is strictly a function of the rod bending stiffness K . Figures 13 and 14 are plots of pinch load versus rod lateral dispersion deflection. The adjusted pinch loads in Table 4 show a maximum value of 93 pounds. Using this value in Figure 13 and 14, the lateral dispersion deflection is small in Figure 13 and critical in Figure 14. The difference between the two curves is the rod-bending stiffness used. For a 12-inch pitch, 2 inches above and below a pinch plane, there exists restraint in the lateral direction, and a beam-stiffness model as used in Figure 13 could be assumed. The random nature of dispersion would indicate the lateral movement could be positive or negative. As the rod support comes from other rods that are also bending from dispersion, the support rigidity is questionable. Figure 14 shows that the effect of changing the rod support greatly affects the dispersion deflection. The implication is that mechanical tests are necessary to determine whether critical dispersion deflections exist. For staggered-start bundles the likelihood of critical dispersion deflections is greatly reduced compared to straight-start bundles. This is from two effects:

- (1) The significantly lower pinch loads.
- (2) As the stagger is increased, the mechanism causing dispersion changes so that, with a full stagger (0-120-240), the rods are stable and there is no dispersion.

A load reduction achieved by using a larger pitch would not have a primary effect on dispersion, as the reduced rod-bending stiffness cancels out the reduced loads effect for the model assumed here.

Table 4

Extrapolated 217 Rod Bundle Loads Data with Dispersion

Bundle Configuration		Straight Start	0°-30°-60° Stagger	0°-45°-90° Stagger
Max. Rod-to-Channel Load (lbs)	Upper Bound	93	59	36
	Lower Bound	NA*	10	6
Max. Rod-to-Rod Load (lbs)	Upper Bound	92	29	18
	Lower Bound	NA*	5	3

*Not applicable.

NOTE: Creep effects are not included.

Table 5

Extrapolated 217-Rod Bundle Deflections with Dispersion

Bundle Configuration		Straight Start	0°-30°-60° Stagger	0°-45°-90° Stagger
Max. Decrease Rod-to-Rod Spacing (in.)	Upper Bound	.0466 ⁺ D	.0982 ⁺ D	.1126 ⁺ D
	Lower Bound	NA*	.0404 ⁺ D	.0464 ⁺ D
Max. Decrease Rod-to-Channel Spacing (in.)	Upper Bound	.1698 ⁻ D	.1093 ⁻ D	.1107 ⁻ D
	Lower Bound	NA*	.0450 ⁻ D	.0456 ⁻ D

*Not applicable.

⁺D Dispersion effects will increase this value

⁻D Dispersion effects will decrease this value

NOTE: The effects of dispersion are greater with the straight-start configuration than with the staggered configurations.

Total clearance before compression is .056" x 1.0819 = .0606".

Rod Bending Stiffness

$$F_y = 1138 y$$

* y_I = Initial Imperfection Deflection

Figure 13. Fuel Rod Pinch Load Versus Lateral Dispersion Deflection

Rod Bending Stiffness

$$F_y = 337 y$$

* y_I = Initial Imperfection Deflection

Figure 14. Fuel Rod Pinch Load Versus Lateral Dispersion Deflection

4.5 Load Results

The proposed softening techniques of distributed wireless rods and staggered wire-wrap start angles do soften the bundle. This is shown by the lower loads in Table 1 for the softened configurations. This is true for total load on flat, maximum rod-to-channel load, and maximum rod-to-rod load. The load reductions are as much as 80.1% for the 0° - 45° - 90° case relative to straight start for maximum rod-to-rod load. The magnitudes of the loads do not appear to be a critical problem. Maximum rod-to-rod extrapolated load with dispersion is 93 lbs and with creep effects added, this would be greatly reduced. We expect that the loads could be kept below the maximum allowable rod contact loads predicted in Reference 3 by a change in the pitch length. The curve of maximum allowable contact load versus temperature from Reference 3 is reproduced here as Figure 15. The loads could also decrease, with an improvement in bundle-to-channel interference, through the use of low-swelling alloys.

MAXIMUM ALLOWABLE CONTACT LOAD

Figure 15

4.6 Deflection Results

The deflection results show that all bundles have nonuniform deflections. This can be seen by looking at the vector plots in the Appendix and the spacing data in Table 1.

An important behavior of the staggered configurations, shown in the vector plots, is the large localized deflections at the edge relative to the interior. With the hexagonal bundle, if the edge rods have the same wire-wrap configuration as the interior rods, they will have a different loading pattern than the interior rods. This change in the loading pattern at the edge causes localized deflections. To avoid this weak link, the edge rods should have a special wire-wrap treatment, different from the rest of the bundle, so as to achieve a loading pattern similar to the interior rods. This might be achieved by a double wrap, possibly in the reverse direction. With the improved edge rod design, the staggered configurations should be more favorable. The data in Table 5 show an improvement in rod-to-channel spacing with the staggered configurations. Table 5 also shows a possible improvement in rod-to-rod spacing. As the critical rod-to-rod spacing is affected by the edge rod deflections, a reduction in the localized deflections at the edge would improve the rod-to-rod spacing. This would result in a better distribution through the bundle of the imposed deflection.

The vector plots show that where there are wireless rods, the surrounding rods deflect towards them (see page A7). These localized deflections, if true in magnitude, would indicate that the use of wireless rods is of questionable value.

Since all bundle variables or design solutions were not investigated, a design adequacy judgement of wire-wrap bundles cannot be made; but, none-the-less, the high magnitudes of the deflections indicate insufficient separation or contact could exist with high swelling.

To indicate the sensitivity to rod clearance, the curve of cladding temperature versus P/D from Reference 4 is reproduced here as Figure 16. Temperature values for reduced edge clearance would be lower as this is a cooler region; therefore, clearance limits at the edge could be smaller than between rods.

Figure 16. Maximum Cladding Surface
Temperatures for Interior Rods

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APPENDIX A

DISPLACEMENT VECTOR PLOTS

7 ROD WIRE WRAP BUNDLE REPETITIVE SECTION STRAIGHT START
10 PERCENT BUNDLE COMPRESSION
 STATIC DEFOR.

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7 ROD WIRE WRAP BUNDLE REPETITIVE SECTION STRAIGHT START
10 PERCENT BUNDLE COMPRESSION
STATIC DEFOR.

9

9

37 ROD WIRE MESH BUNDLE REPETITIVE SECTION STRAIGHT START

10 PERCENT BUNDLE COMPRESSION
STATIC DEFORMATION

S7 ROD WIRE WRAP BUNDLE REPETITIVE SECTION STRAIGHT START
 WITH SEVEN WIRELESS RODS
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

$$g = 1.0''$$

S7 ROD WIRE MESH BUNDLE REPETITIVE SECTION STRAIGHT START
 WITH SEVEN WIRELESS RODS
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

3

3

97 ROD WIRE WRAP BUNDLE REPETITIVE SECTION
 0-30-60 STAGGER
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

$g = 1.0$

37 ASD WIRE WRAP BUNDLE REPETITIVE SECTION
 0-30-60 STAGGER
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

37 ROD WIRE MESH BUNDLE REPETITIVE SECTION
 0-30-60 STAGGER
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

37 ROD WIRE WRAP BUNDLE REPETITIVE SECTION
 0-90-60 STAGGER
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

37 ROD WIRE WRAP BUNDLE REPETITIVE SECTION
 0-45-90 STAGGER
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

37 AWG WIRE MESH BUNDLE REPETITIVE SECTION
 0-45-90 STAGGER
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

37 ROD WIRE WRAP BUNDLE REPETITIVE SECTION
 0-45-90 STAGGER
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

S7 ROD WIRE MESH BUNDLE REPETITIVE SECTION
 0-45-90 STAGGER
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

57 ROD WIRE MESH BUNDLE REPETITIVE SECTION
 0-45-80 STAGGER
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

37 ROD WIRE WRAP BUNDLE REPETITIVE SECTION
 0-45-90 STAGGER
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

37 800 WIRE WARP BUNDLE REPETITIVE SECTION
 0-45-90 STAGGER
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

97 ADD WIRE WRAP BUNDLE REPETITIVE SECTION
 0-45-80 STAGGER
 10 PERCENT BUNDLE COMPRESSION
 STATIC DEFORMATION

APPENDIX B

CALCULATION OF ROD RADIAL STIFFNESS

WIRE-WRAP FUEL ROD BUNDLE

ROD AND WIRE RADIAL STIFFNESS

FUEL ROD CLADDING STIFFNESS

DIAMETRICALLY OPPOSITE AND EQUAL CONCENTRATED LOADS

$$y = \frac{6.5 \frac{P}{Et} \left(\frac{R}{t} \right)^{1.5}}{(18)^{.75}}$$

REF: ROARK "FORMULAS
FOR STRESS AND STRAIN"
pg. 301

MAT: 20% COLD WORKED 316 STAINLESS STEEL

$$E = (28.637 - 0.0044T - 1.682 \times 10^{-6}T^2) \times 10^6$$

REF: NEDG 13933 PG. 22-23

ASSUME 1000°F $\therefore T = 537^\circ\text{C}$ $E = 25.8 \times 10^6$

$$R = .115", t = .015"$$

$$\frac{y}{P} = \frac{6.5}{25.8 \times 10^6 (.015)} \left(\frac{.115}{.015} \right)^{1.5} \div (18)^{.75} = 40.8 \times 10^{-6} \text{ in./lb.}$$

WIRE STIFFNESS

$$\frac{y}{P} = \frac{L}{AE}$$

ASSUME $A = (.03)^2$
 $E = 25.8 \times 10^6$

$$\frac{y}{P} = \frac{.056}{(.03)^2 25.8 \times 10^6} = 2.41 \times 10^{-6} \text{ in./lb.}$$

TOTAL EFFECTIVE STIFFNESS

ROD CENTER TO ROD CENTER

$$\left(\frac{y}{p}\right)_{\text{TOTAL}} = \frac{.286}{AE} = 40.8 \times 10^{-6} + 2.41 \times 10^{-6} = 43.21 \times 10^{-6}$$

$$E = 25.8 \times 10^6$$

$$A_{\text{EFF}} = \underline{257 \times 10^{-6}}$$

TOTAL EFFECTIVE STIFFNESS

ROD CENTER TO CHANNEL

$$\left(\frac{y}{p}\right)_{\text{TOTAL}} = \frac{.171}{AE} = \frac{40.8 \times 10^{-6} + 2.41 \times 10^{-6}}{2} = 22.81 \times 10^{-6}$$

$$E = 25.8 \times 10^6$$

$$A = \underline{291 \times 10^{-6}}$$

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING —
 DIMENSIONS: 209A4270 63/ 2 118D9983
 FOR EXPLANATION OF GEOMETRIC DIMENSIONING & TOLERANCING SYMBOLS, REFER TO USAS Y14.5 SECTIONS 3.4.4.5.

TITLE: DUCT TUBE
 FIRST MADE FOR: FTR DRIVER FUEL ASSEMBLY
 FCF 828E B82

NOTES:

- DUCT TUBE TO CONFORM TO AWS-1524 & RDT STANDARD E6-20, AUSTENITIC STAINLESS STEEL HEXAGONAL DUCT TUBES FOR CORE COMPONENTS AND ASSEMBLIES TYPE 316, 208 & SS COLD WORKED STAINLESS STEEL, SEAMLESS.
- MAXIMUM TWIST TO BE WITHIN 0° 50'.
- MAXIMUM TWIST TO BE WITHIN 0° 30'.
- STRAIGHTNESS TO BE WITHIN .015 OVER ANY 12 INCH LENGTH AND .060 OVER 42.750 AND 57.750 LENGTHS ABOVE AND BELOW THE LOAD PAD RESPECTIVELY. IN ADDITION, THE LOAD PAD, OVER ITS ENTIRE 4.000 INCH LENGTH, SHALL BE CONCENTRIC WITH THE CENTER LINE, DETERMINED BY THE 4.335 HEX INSIDE DIMENSIONS AT THE ENDS OF THE 100.500 DUCT TUBE WITHIN .040 DIA.
- IDENTIFICATION NUMBER CHARACTERS SHALL BE .250 ± .050 HIGH.

transl ltr dtd -
 7-9-74 fed.
 893/11-3-10
 Vol. 2

CONTROL A	
REVISIONS	PRINTS TO
PRELIMINARY	
FG	
DATE: 29 AUG 1972	118D9983
AID-BRO	SUNNYVALE

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING -								
APPLIED PRACTICES	SURFACES	TOLERANCES ON DIMENSIONED PHASES						
Z09A4270	125✓	<table border="1"> <tr> <th>FEAT-CLASS</th> <th>MAXIMUM</th> <th>MINIMUM</th> </tr> <tr> <td>-</td> <td>-</td> <td>-</td> </tr> </table>	FEAT-CLASS	MAXIMUM	MINIMUM	-	-	-
FEAT-CLASS	MAXIMUM	MINIMUM						
-	-	-						

FOR EXPLANATION OF GEOMETRIC DIMENSIONING & TOLERANCING SYMBOLS REFER TO USASI Y14.5 SECTIONS 3, 4 & 5.

128D4357

TITLE	DATE	BY	CHKD BY	APP'D BY
HANDLING SOCKET ASSEMBLY				

FIRST MADE FOR FTR DRIVER FUEL ASM.

[illegible]

* H.E.D.L. - WESTINGHOUSE DRAWINGS

FCF-264R189

SECTION A-A

DETAIL C

SECTION B-B

CONTROL A

NOTES:

1. HANDLING SOCKET ASSEMBLY TO CONFORM TO AWS-1913 AND AEC-ROT STANDARD EB-16. "DRIVER FUEL ASSEMBLY" INDICATED PROVISIONS OF AEC-ROT STANDARD FE-2. "QUALITY ASSURANCE PROGRAM REQUIREMENTS" TO APPLY..
2. WELD USING COMPOSITION ER308 WELDING ROD CONFORMING TO AEC-ROT STANDARD MI-2. "STAINLESS STEEL WELDING RODS AND BARE ELECTRODES. WELDING TO CONFORM WITH AEC-ROT STANDARD FE-2, WELDING OF REACTOR CORE COMPONENTS AND TEST CAPSULES.
3. WELDING SYMBOLS ARE IN ACCORDANCE WITH AWS A2.0.

(G1) SEE NOTE 1 & 3

		CONTROL A	
<div style="border: 1px solid black; padding: 5px; transform: rotate(-15deg); display: inline-block;"> PRELIMINARY A </div>		PRINTS TO	
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Q 2			
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Q 4			
Q 5			
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Q 12			
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Q 99			
Q 100			

NOTES:

1. MANHOLES SOCKET TO CONFORM TO AWS-1013 AND AWS E10-10. DRIVER FUEL ASSEMBLY INDICATED PROPORTIONS TO NOT EXCEED STANDARD F-6. "QUALITY VERIFICATION PROGRAM REQUIREMENTS" TO APPLY. TYPE 316 SST-ANNEALED TO CONFORM TO STD STANDARD W-9. "STAINLESS STEEL BARS AND SHAPES," OR NOT STANDARD W-2. "STAINLESS AND LOW ALLOY STEEL FORGINGS," WHEN AS MODIFIED BY AWS-1013.
2. CRACKING-CARBIDE HARD SURFACE IDENTIFIED SURFACES ALL AROUND THICKNESS: .001 - .005. HARD SURFACES TO CONFORM TO NOT STANDARD E-38. "LOW-FRICTION HARD SURFACES FOR CORE COMPONENTS."
3. IDENTIFICATION NO. CHARACTERS SHALL BE .750 X .030 HIGH. NUMBER TO BE IDENTICAL WITH THE IDENTIFICATION NOTCH SERIAL NO.
4. HARD SURFACING OVERSPRAT IS PERMITTED OVER LENGTH INDICATED.
5. HARD SURFACING OVERSPRAT IS PERMITTED ON THIS SURFACE.
6. NOTCHES AT LOCATIONS 30" THEN 300" ARE IDENTIFICATION NOTCHES (SEE TABLE 1) AND ARE TO BE MACHINED AS REQUIRED FOR SERIALIZATION PER ORIGINATOR DATA.

NOTCH ORIENTATION		
20°		ALL
40°		FUEL ASM INTMD ORIFICE ZONE
60°		FUEL ASM OUTER ORIFICE ZONE
100°		
120°		
160°		
180°		
200°	L	
220°	D	
240°		
260°		
280°		
300°		

PRELIMINARY

ATD: BRO...	828E97
-------------	--------

GENERAL ELECTRIC

195B8040

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING:

APPLIED PRACTICES
209A4270SURFACES
125✓FRACTIONS
1/32DECIMALS
—ANGLES
5°REV
NO 0

195B8040

TITLE

PIN

FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY

FCF - 264R189

NOTES:

1. PIN TO CONFORM TO HWS 1913 & AEC - RDT STD. E13-16. "DRIVER FUEL ASM." INDICATED. PROVISIONS OF AEC - RDT STD. F2-4 "QUALITY VERIFICATION PROGRAM REQUIREMENTS TO APPLY.
2. INCONEL 718 TO CONFORM TO AEC - RDT STD. M2-18 "NICKEL - CHROMIUM ALLOY BARS. FORGINGS & FORGING STOCK" AS MODIFIED BY HWS - 1913. SOLUTION HEAT TREAT AND PRECIPITATION HARDEN PER TABLE 2 OF ASTM-A637 FOR GRADE 718.

① MATERIAL : INCONEL 718
(SEE NOTE 2)

CONTROL A

REVISIONS

PRINTS TO

— PRELIMINARY —

QA
INS ENG
MATL ENG
COG ENG
CHECKED BY
DATE 11 MAY '73
CHART

APPROVALS

B R D
SUNNYVALE

BY

DEPT

195B8040

CONF ON SHEET

BY

ASSEMBLY NO. 12000
ON ORDER

GENERAL ELECTRIC

198B7012

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING:				
APPLIED PRACTICES	SURFACES	TOLERANCES ON DIMENSIONS		
		FRACTIONS	DECIMALS	ANGLES
209A4270	125✓	1/64	±.005	5°

REV NO 0
198B7012
CONT ON SHEET SH NO

TITLE
CROSS BAR
FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY
FCF 12804357

NOTE:

- CROSS BAR TO CONFORM TO HWS-1913 AND RDT STANDARD E13-16, "DRIVER FUEL ASSEMBLY". INDICATED PROVISIONS OF RDT STANDARD F2-4 QUALITY VERIFICATION PROGRAM REQUIREMENTS TO APPLY. TYPE 316 SST ANNEALED TO CONFORM TO RDT STANDARD M7-3, "STAINLESS STEEL BARS AND SHAPES", AS MODIFIED BY HWS-1913.

① 316 SST ANNEALED
(SEE NOTE 1)

CONTROL A

DATE	
TIME	
DATE	
TIME	
DATE	
TIME	
DATE	
TIME	

PRELIMINARY
A

APPROVALS
ATQ-BRQ
SUNNYVALE
198B7012

GENERAL ELECTRIC

162C9010

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING:-

APPLIED PRACTICES	SURFACES	TOLERANCES ON DIMENSIONS
209A4270	125	$\pm \frac{1}{64} \pm .005$

FOR EXPLANATION OF GEOMETRIC
DIMENSIONING AND TOLERANCING SYMBOLS
REFER TO USAS1 Y14.5 SECTIONS 3, 4 AND 5.

LOCK RING

FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY

FCF 264R189

NOTES:

1. LOCK RING TO CONFORM TO NUS-1913 AND AEC-RDT STANDARD E13-16. "DRIVER FUEL ASSEMBLY". INDICATED PROVISIONS OF AEC-RDT STANDARD F2-4 QUALITY VERIFICATION PROGRAM REQUIREMENTS TO APPLY. TYPE 316 SST ANNEALED TO CONFORM TO AEC-RDT STANDARD M7-3. "STAINLESS STEEL BARS AND SHAPES", AS MODIFIED BY NUS-1913.

① 316 SST ANNEALED
(SEE NOTE 1)

CONTROL A

PRELIMINARY

DESIGNED BY	
CHECKED BY	
DATE	
BY	
FOR	
DATE	

MAY 10, 1974

ATD-BRO

162C9010

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING -			
APPLIED PRACTICES	SURFACES	TOLERANCES ON DIMENSIONS	FINISHES
Z09A4270	125	$\pm \frac{1}{64}$ $\pm .005$ $\pm 1^\circ$	
FOR EXPLANATION OF GEOMETRIC DIMENSIONING AND TOLERANCING SYMBOLS REFER TO ASHBY Y14.6 SECTIONS 3, 4 AND 5			

TRANSITION RING

FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY
FCF 128D4357

SECTION A-A

① 316 SST ANNEALED
(SEE NOTE 1)

NOTES:

- TRANSITION RING TO CONFORM TO NWS-1913 AND AEC-RDT STANDARD E13-16, "DRIVER FUEL ASSEMBLY". INDICATED PROVISIONS OF AEC-RDT STANDARD F2-4 QUALITY VERIFICATION PROGRAM REQUIREMENTS TO APPLY. TYPE 316 SST ANNEALED TO CONFORM TO AEC-RDT STANDARD M7-3, "STAINLESS STEEL BARS AND SHAPES", AS MODIFIED BY NWS-1913.
- CHROME-CARBIDE COAT INDICATED SURFACES ALL AROUND. THICKNESS: .003-.004 COATING TO CONFORM TO AEC-RDT STANDARD E6-38, "LOW-FRICTION HARD SURFACES FOR CORE COMPONENTS".

SECTION C-C

.060 TYP ONLY
ON DIAMETERREMOVE SHARP
CORNERS (TYP)HOLE TO BE MATCH
DRILLED WITH LOCK
RING 162C9010
(2 PLACES)

CONTROL A

PRELIMINARY

AID-BRO
SUNNYVALE

162C9008

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING --			
APPROX PRACTICES	SURFACES	TOLERANCES ON DIMENSIONS	FINISHES
209A4270	125✓	± .005 ± 1°	

GENERAL ELECTRIC

162C9199

COLLAR

FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY
FCF 12804337

1 316 SST ANNEALED (SEE NOTE 1)

NOTES:

- COLLAR TO CONFORM TO HWS-1913 AND RDT STANDARD E13-16, "DRIVER FUEL ASSEMBLY". INDICATED PROVISIONS OF RDT STANDARD F2-4 QUALITY VERIFICATION PROGRAM REQUIREMENTS TO APPLY. TYPE 316 SST ANNEALED TO CONFORM TO RDT STANDARD H7-3, "STAINLESS STEEL BARS AND SHAPES" AS MODIFIED BY HWS-1913.
- CHROME-CARBIDE COAT INDICATED SURFACES ALL AROUND. THICKNESS: .003-.005. COATING TO CONFORM TO RDT STANDARD E6-38, "LOW FRICTION HARD SURFACES FOR CORE COMPONENTS".
- HARD SURFACING OVERSPRAY IS PERMITTED OVER LENGTH INDICATED.

CONTROL A	
REVISIONS	PRINTS TO
QA HAS MADE CON CHECKED BY DATE 1974 MAY 13, 1974	PRELIMINARY ATD-BRO SUNNYVALE 162C9199

CONT. ON PAGE 10

TITLE	102070
BOTTOM END CAP	CONT ON SHEET
FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY	
ECF-128D4353	

FOR EXPLANATION OF GEOMETRIC DIMENSIONING
AND TOLERANCING SYMBOLS REFER TO ASME Y14.5
SECTIONS 3, 4 & 5.

BOTTOM END CAP

FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY
FCF-128D4353

NOTES:

1. END CAP TO CONFORM TO RDT E13-9 AS MODIFIED BY GE-BRO SPEC. 22A3485
2. FOR USE ON OUTER CORE ZONE FUEL RODS, (P1).
3. FOR USE ON INNER CORE ZONE FUEL RODS, (P2).
4. INCREASE IN SLOT TOLERANCE ALLOWS FOR MAT'L MOVEMENT WHEN SLOT IS MACHINED.

PART NO.	"C"	MATERIAL
1	.500	TYPE 316SST 20% COLD WORKED (SEE NOTE 1)
2	.750	

CONTROL A

REVIEWS		PRINTS TO	
1	FILED NOV 30 1971		
NE 12189			
2	FILED NOV 30 1971		
NE-12246			

9A H 8 1/2 hrs 9/58/73
FAB ENG
REYNOLD for BRA 1/4
MATE: ENG
99 and 9/24/73
COG. MGR
J. H. H. 1/4
CHECKED
2 APR. 1973
WILLIAMS SEP 22 1973

ATD-BRO
SUNNYVALE

162C9006

TITLE	CONT. ON SHEET
BOTTOM END CAP	
FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY	
FCF-128D4353	

FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY
FCF-128D4353

FOR EXPLANATION OF GEOMETRIC DIMENSIONING
AND TOLERANCING SYMBOLS REFER TO ASME Y14.5
SECTIONS 3, 4 & 5.

1. END CAP TO CONFORM TO RDT E13-9 AS
MODIFIED BY GE-BRO SPEC. 22A3485

2. INCREASE IN SLOT TOLERANCE ALLOWS FOR MAT'L
MOVEMENT WHEN SLOT IS MACHINED.

① TYPE 316 SST
20% COLD WORKED
(SEE NOTE 1)

162C9085

REV N	
012	

CONTROL A

REVIEWS		PRINTS
1	<i>WILLIAMS</i> NE-12189 <i>WV</i>	
2	<i>WILLIAMS</i> NE-12247 <i>WV</i>	

CA R. S. Young 9/28/73
SAC CHS
J. E. Howell to REA 9/28/73
MAF: JCH
J. Spivey 9/28/73
C. W. Mayes 7/26/73
Omit #25

25 SEPT. 1973
C. Williams sent to A.D.

ATD-BRO
SUNNYVALE

GENERAL ELECTRIC

162C9205

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING:-			
APPLIED PRACTICES	SURFACES	TOLERANCES ON MACHINED DIMENSIONS	
	✓	FRACTIONS	DECIMALS
		±	±

TITLE
HEX CHANNEL (HARD SURFACED)
 FIRST MADE FOR FIRE DRIVER FUEL ASM
 FCF 264R1B9

① MAKE FROM 828E882 P1

NOTES

1. CHROME CARBIDE HARD SURFACE EXTERNAL SURFACE ALL AROUND OVER INDICATED LENGTH. THICKNESS .003-.005. HARD SURFACING TO CONFORM TO RST STANDARD EG-38T- LOW FRICTION HARD SURFACING FOR CORE COMPONENTS.
2. HARD SURFACING OVERLAY IS PERMITTED OVER LENGTH INDICATED.

CONTROL A

REVISIONS

PRINTS TO

PRELIMINARY
 A

27 JUNE 1974

ATD BEO
 SUNNYVALE

162C9205

FCF-128D4353

NOTES:

1. BREAK ALL CORNERS .005 R MAX. UNLESS OTHERWISE NOTED.
2. FOR USE ON OUTER CORE ZONE FUEL RODS
3. FOR USE ON INNER CORE ZONE FUEL RODS
4. END CAP TO CONFORM TO RDT E13-9 AS MODIFIED BY GE-BRO SPEC. 22X3485.

(SEE NOTE 3)

(SEE NOTE 2)

PART NO.	"B"	"C"	MAT'L.
1	.150	.050	TYPE 316 20% COLD WORKED STN. STL. (SEE NOTE 4)
2	OMIT	OMIT	

1

CONTROL A

REVISIONS

PRINTS TO :

1	DAW	NOV 13 1973	CHW
NE-12188			

RA	R. S. Young	9/28/73
FBI LAB	524444	RA 9/28/73
NATLIS ENG	2 copies	9/28/73
COE. WORK	Pittsburgh	9/28/73
CHECKED		

CS 125 25 SEPT 1973

ATD-BRO
SUNNYVALE

195B-8132

CONT ON SHEET SH NO.

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING:--			
APPLIED PRACTICES	SURFACES	TOLERANCES ON MACHINED	
		FRACTIONS	DECIMALS
209A4270	63 ✓	+ —	+ .005

FOR EXPLANATION OF GEOMETRIC
DIMENSIONING AND TOLERANCING SYMBOLS
REFER TO USASI Y14.5 SECTIONS 3, 4 AND 5.

REV NO 0123

192B4254

CONT ON SHEET SH NO

TITLE

TOP END CAP

FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY
FCF-128D4353

NOTES:

1. BREAK ALL CORNERS .005 R MAX. UNLESS OTHERWISE NOTED.
2. FOR USE ON OUTER CORE ZONE FUEL RODS.
3. FOR USE ON INNER CORE ZONE FUEL RODS.
4. END CAP TO CONFORM TO RDT E13-9 AS MODIFIED BY GE-BRO SPEC. 22A3485.

216 ± .002 DIA

⊙	A	.001 DIA
---	---	----------

① MATL: TYPE 316 $\frac{1}{32}$ DRILL
20% COLD WORKED x .120 $\begin{smallmatrix} +.030 \\ -.000 \end{smallmatrix}$
SST (SEE NOTE 4) DEEP

② OTHERWISE
SAME AS P1

CONTROL A

REVISIONS

PRINTS TO

1	Rule ^{NOV 29, 1973}	Chill
	NE-12188	660
2	Rule ^{NOV 29, 73}	Chill
	NE-12322	660
3	Wing ^{JAN 23, 74}	Chill
	NE 12323	

QA of 84 Young 9/28/73
FAB. ENG
RETAINILL for RLA 9/10/73
MAT'L'S ENG
9/28/73
COG. MGR.
9/28/73
CHECKED

MADE BY
B.E. No. 1. Nov 8, 1972
ISSUED
William S. SEPT 28, 1971

APPROVALS

ATD-BRO
SUNNYVALE

DIV OR
DEPT

192B4254

GENERAL ELECTRIC

REV 0		PARTS LIST FOR 264R189		TITLE FTR DRIVER FUEL ASSEMBLY		PARTS LIST FOR 264R189		CONT ON SHEET FL SH NO. 2	
CONT ON SHEET FL SH NO. 2		FIRST MADE FOR 893-11, TASK 3							
GROUP NO AND QUANTITY		PART NO.		NAME		DRAWING NO., DESCRIPTION, MATERIAL, WEIGHT			
G2 G1									
2 2		24		PIN		195B8040 P1			
1 1		25		PISTON RING		H-4-21529 WESTINGHOUSE H.E.D.L. DWG.			
92		26		FUEL ROD ASM		128D4353 G1			
192		27		FUEL ROD ASM		128D4353 G2			
25		28		FUEL ROD ASM		128D4353 G3			
25		29		FUEL ROD ASM		128D4353 G4			
26 26		30		GRID SPACER		128D4492 G1			
1 1		31		LOCK RING		162C9010 P1			
X X		32		DRAWING LIST		325X193			

DESCRIPTION OF GROUPS		REVISIONS		PRINTS TO	
PRELIMINARY					
APPROVALS		ATD-BRO		DIV OR DEPT	
SUNNYVALE		LOCATION		PARTS LIST FOR 264R189	
CONT ON SHEET FL SH NO. 2					

PP-501-P (10-68)
PRINTED IN U.S.A.

GENERAL ELECTRIC

REV 0		PARTS LIST FOR 264R189		TITLE FTR DRIVER FUEL ASSEMBLY		PARTS LIST FOR 264R189		CONT ON SHEET 2 SH NO. 1	
CONT ON SHEET 2 SH NO. 1		FIRST MADE FOR 893-11, TASK 3							
GROUP NO AND QUANTITY		PART NO.		NAME		DRAWING NO., DESCRIPTION, MATERIAL, WEIGHT			
G2 G1									
1 1		1		SHIELD & INLET ASM.		828E867 G1			
1 1		2		SHIELD & INLET ASM		828E867 G2			
2 2		3		LOCKING BAR		H-4-21494-It.3			
2 2		4		ATTACHMENT RAIL		128D4350 P10			
2 2		5				P11			
2 2		6				P12			
2 2		7				P13			
2 2		8				P14			
2 2		9				P15			
2 2		10				P16			
2 2		11				P17			
1 1		12				P18			
2 2		13				P1			
2 2		14				P2			
2 2		15				P3			
2 2		16				P4			
2 2		17				P5			
2 2		18				P6			
2 2		19				P7			
2 2		20				P8			
1 1		21		ATTACHMENT RAIL		128D4350 P9			
1 1		22		HEX CHANNEL		162C9205P1			
1 1		23		HANDLING SOCKET ASSEMBLY		128D4357 G1			

DESCRIPTION OF GROUPS		REVISIONS		PRINTS TO	
PRELIMINARY					
APPROVALS		ATD-BRO		DIV OR DEPT	
SUNNYVALE		LOCATION		PARTS LIST FOR 264R189	
CONT ON SHEET 2 SH NO. 1					

PP-501-P (10-68)
PRINTED IN U.S.A.

209A4270 63/

FOR EXPLANATION OF GEOMETRIC DIMENSIONING AND TOLERANCING SYMBOLS REFER TO USAS1 Y4.5 SECTIONS 3.4 & 5.

128D4350

ATTACHMENT RAIL

FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY

FCF - 128D4351

SECTION H-H

DETAIL "E"

NOTES:

- REF. DRAWING: WESTINGHOUSE DWG. NO. H-4-21493 REV. 2.
- ATTACHMENT RAIL TO CONFORM TO HMS-1916 AND AEC-RDT, STANDARD E13-16 "DRIVER FUEL ASS'Y", INDICATED PROVISIONS OF AEC-RDT STANDARD F2-4, "QUALITY VERIFICATION PROGRAM REQUIREMENTS" TO APPLY TYPE 316 SST COLD WORKED (20% MAX) TO CONFORM TO AEC-RDT STANDARD MS-1, "STAINLESS STEEL PLATE, SHEET AND STRIP", AS MODIFIED BY HMS-1916.

PART NO.	DIM "A"	DIM "B"	DIM "C"	DIM "D"
1	.451	2.648	1.746	.500
2	.594	2.934		
3	.737	3.220		
4	.880	3.506		
5	1.018	3.792		
6	1.166	4.078		
7	1.309	4.364		
8	1.452	4.650		
9	1.570	4.886	1.746	.500

PART NO.	DIM "A"	DIM "B"	DIM "C"	DIM "D"
10	.481	2.648	1.686	.750
11	.624	2.934		
12	.767	3.220		
13	.910	3.506		
14	1.048	3.792		
15	1.196	4.078		
16	1.339	4.364		
17	1.486	4.650		
18	1.600	4.886	1.686	.750

OPTIONAL CONSTRUCTION

FULL PENETRATION ELECTRON BEAM WELD PERMITTED AS SHOWN. NO SPATTER ALLOWED

.261 ± .004 DIA. 2 HOLES
Ø .002 ± .001

DESCRIPTION OF GROUPS		REVISIONS	CONTROL A
PRELIMINARY ABC		PRINTS TO	
ATD-BRO SUNNYVALE		128D4350	

209A4270 128D4485
 FOR EXPLANATION OF GEOMETRIC
 DIMENSIONS AND TOLERANCE SYMBOLS
 REFER TO USAS Y14.5 SECTIONS 3, 4 AND 5

128D4485		SHIELD BLOCK ASSEMBLY	
PART NAME FOR FTR DRIVER FUEL ASM		DRAWING NO. DESCRIPTION MATERIAL WEIGHT	
1	1	SHIELD BLOCK	128D4483 P4
2	2	SHIELD BLOCK B1	128D4484 P1
3	3	SHIELD BLOCK B3	128D4484 P3
4	4	SHIELD BLOCK A1	128D4483 P1
5	5	SHIELD BLOCK A3	128D4483 P3
6	6	DRIFILE RING	H-4-21473 IT. 4

WESTINGHOUSE HEDL DRAWING
 FCF 828E867

NOTES:

- SHIELD BLOCK ASSEMBLY TO CONFORM TO NBS-1973 AND RDT STANDARD E13-16, "DRIVER FUEL ASSEMBLY". INDICATED PROVISIONS OF RDT STANDARD F2-2, QUALITY ASSURANCE PROGRAM REQUIREMENTS TO APPLY.
- WELD USING COMPOSITION ER 308 WELDING RODS CONFORMING TO RDT STANDARD M1-2, "STAINLESS STEEL WELDING RODS AND GASE ELECTRODES." WELDING TO CONFORM TO RDT STANDARD F6-2, "WELDING OF REACTOR CORE COMPONENTS AND TEST CAPSULES." ROOT PENETRATION TO BE .005 TO .030.

(61) WELDING SYMBOLS ARE
 (62) IN ACCORDANCE WITH AWS A2.0

CONTROL A		PRELIMINARY	
DESCRIPTION OF GROUPS	REVISIONS	PRINTS TO	
GROUP 1	1		
GROUP 2	1		
GROUP 3	1		
GROUP 4	1		
GROUP 5	1		
GROUP 6	1		
GROUP 7	1		
GROUP 8	1		
GROUP 9	1		
GROUP 10	1		
GROUP 11	1		
GROUP 12	1		
GROUP 13	1		
GROUP 14	1		
GROUP 15	1		
GROUP 16	1		
GROUP 17	1		
GROUP 18	1		
GROUP 19	1		
GROUP 20	1		
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GROUP 26	1		
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GROUP 90	1		
GROUP 91	1		
GROUP 92	1		
GROUP 93	1		
GROUP 94	1		
GROUP 95	1		
GROUP 96	1		
GROUP 97	1		
GROUP 98	1		
GROUP 99	1		
GROUP 100	1		

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING—		128D4484		SHIELD BLOCK	
209AAZ70	125/	: .010 ± .002	FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY		
FOR EXPLANATION OF GEOMETRIC DIMENSIONING AND TOLERANCING SYMBOLS REFER TO ASME Y14.5 SECTIONS 3, 4 AND 5.			FCF 128D4485

TABLE 1			
PART No.	"F" DIA	"G" DIA	SHIELD BLOCK ORIFICE ZONE IDENTIFICATION
1	HOLD	HOLD	B1
2	HOLD	HOLD	B2
3	HOLD	HOLD	B3

- NOTES:
- SHIELD BLOCK TO CONFORM TO NBS-1013 AND RDT STANDARD 813-10, "DRIVER FUEL ASSEMBLY" INDICATED PROVISIONS OF RDT STANDARD F2-4, "QUALITY VERIFICATION PROGRAM REQUIREMENTS" TO APPLY. TYPE 316 SST ANNEALED TO CONFORM TO RDT STANDARD H7-3, "STAINLESS STEEL BARS AND SHAPES" OR RDT STANDARD H2-2, "STAINLESS AND LOW ALLOY STEEL FORGINGS", BOTH AS MODIFIED BY NBS-1013.
 - .120 ± .002 R TO EXTEND AROUND 100° MIN. OF THE CIRCUMFERENCE OF EACH HOLE.

CONTROL A	
DESCRIPTION OF GROUPS	REVISIONS
1.1	1.1
1.2	1.2
1.3	1.3
1.4	1.4
1.5	1.5
1.6	1.6
1.7	1.7
1.8	1.8
1.9	1.9
1.10	1.10
1.11	1.11
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1.13	1.13
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1.33	1.33
1.34	1.34
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1.37	1.37
1.38	1.38
1.39	1.39
1.40	1.40
1.41	1.41
1.42	1.42
1.43	1.43
1.44	1.44
1.45	1.45
1.46	1.46
1.47	1.47
1.48	1.48
1.49	1.49
1.50	1.50
1.51	1.51
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1.381	1.381
1.382	1.382
1.383	1.383
1.384	1.384
1.385	1.385
1.386	1

NOTES:

3. SWIELD BLOCKS TO CONFORM TO NWS-1913 AND RBT STANDARD E13-16. "DRIVER FUEL ASSEMBLY" INDICATED PROVISIONS OF RBT STANDARD F2-4 "QUALITY VERIFICATION PROGRAM REQUIREMENTS TO APPLY." TYPE 316 SST ANNEALED TO CONFORM TO RBT STANDARD M7-3 "STAINLESS STEEL BARS AND SHAPES" OR RBT STANDARD M2-2 "STAINLESS AND LOW ALLOY STEEL FORGINGS" BOTH AS MODIFIED BY NWS-1913.

PART No	"F" DIA	SHIELD BLOCK ORIFIER ZONE IDENTIFICATION
1	HOLD	A1
2	HOLD	A2
3	HOLD	A3

CONTROL A	
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PRELIMINARY

FILE 27-197

ATD.-BRO
SUNNYVALE

128D4483

209A4270
FOR EXPLANATION OF GEOMETRIC DIMENSIONING AND TOLERANCING SYMBOLS REFER TO ASME Y14.5 SECTIONS 3, 4 & 5.

128D4353		FUEL ROD	
FIRST MADE FOR FTR DRIVER FUEL ASSEMBLY		DRAWING NO. DESCRIPTION MATERIAL WEIGHT	
1	1	1	1
2	2	2	2
3	3	3	3
4	4	4	4
5	5	5	5
6	6	6	6
7	7	7	7
8	8	8	8
9	9	9	9
10	10	10	10
11	11	11	11
12	12	12	12
13	13	13	13
14	14	14	14
15	15	15	15
16	16	16	16

NEED (NESTINGHOUSE) DRAWINGS
PCF-128D4351

NOTES:

- 01.03; TYPE 3.1: .0075 MAX. PELLET CLAD GAP. ENRICHED FOR USE IN CORE ZONES II & III (OUTER).
- 02.04; TYPE 3.2: .0075 MAX. PELLET CLAD GAP. ENRICHED FOR USE IN CORE ZONE I (INNER).
- END CAP TO CLAD WELD DIA. SHALL NOT EXCEED .2375.
- FUEL ROD TO CONFORM TO ROT E13-5 FTR DRIVER FUEL ROD.
- FUEL ROD ASM. SHALL BE STRAIGHT WITHIN .010 PER FOOT OF DISTANCE BETWEEN CONTACT POINTS WITH A MAXIMUM DISTANCE BETWEEN CONTACT POINTS OF ONE FOOT, WHEN LYING UNRESTRAINED ON A SURFACE TABLE AND ORIENTED TO GIVE MAXIMUM GAPS BETWEEN TABLE AND FUEL ROD ASM.
- PT. P2, & P13 TO BE WELDED TO NUMBERED END OF P3.
- IDENTIFICATION NUMBER TO BE STAMPED TOP END CAP. NUMBER TO INCLUDE VENDOR CODE, SERIAL NUMBER (TYPE NUMBER CHARACTER HEIGHT IS TO BE .0002 INCH).
- NO P6 & P5 PER ORDERING DATA (WESTINGHOUSE ELECTRIC CORP.).
- FUEL ROD TO CONFORM TO ROT E13-5 AS MODIFIED BY GE-800 SPECIFICATION 22A3486.
- CENTER LINE OF INTERIM ROD IDENTIFICATION FEATURE TO BE ALIGNED WITH CENTER LINE OF SLOT IN BOTTOM END CAP. P13, WITHIN $\pm .20$.
- ORIENTATION IDENTIFICATION LETTER "A" TO BE STAMPED ON BOTTOM END CAP ON SAME SIDE AS IDENTIFICATION FEATURE OF P16 AND P16. CHARACTER HEIGHT TO BE .125 $\pm$.005.

- G1 SEE NOTE 1
G2 SEE NOTE 2
G3 SEE NOTE 2
G4 SEE NOTE 2

DETAIL "B"
(TYP FOR G1 & G2 ONLY)

CONTROL-A

REVISIONS		PRINTS TO	
1	128D4353	1	1
2	NE-12190	2	2
3	216-231	3	3
4	NE-12245	4	4
5	ATD-BRO	5	5
6	SUNNYVALE	6	6
7	128D4353	7	7

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING:
 DIMENSIONS: 209A4270 SURFACES: 125, .005, .2
 FOR EXPLANATION OF GEOMETRIC DIMENSIONING AND TOLERANCING SYMBOLS REFER TO USAS1 Y14.5 SECTIONS 3, 4 & 5

TITLE: 128D4352 ROD ATTACHMENT
 FIRST MADE FOR: FTR DRIVER FUEL ASM.

FCF-828E867

NOTES:
 1. PIN ATTACHMENT TO CONFORM TO MMS-1313 AND REC-NUT STD. E13-16, "DRIVER FUEL ASSEMBLY". INDICATED PROVISIONS OF REC-NUT STANDARD FD-2, "QUALITY ASSURANCE PROGRAM REQUIREMENTS" TO APPLY.

PART NO	DIM "C"	MATERIAL
1	.873	316 SST
2	.843

SECTION B-B

DESCRIPTION OF GROUPS		REVISIONS	CONTROL A
PRELIMINARY		PRINTS TO	
DATE: 9 MAR 1973		APPROVAL: AID-BRO SUNNYVALE	128D4352

ENGINE MADE FOR FTR DRIVER FUEL ASSEMBLY

FCF 264R189

1. SHIELD AND INLET ASSEMBLY TO CONFORM TO AWS - 1913 AND ROT STANDARD E13-16, "DRIVER PULP ASSEMBLY," INDICATED PROVISIONS OF ROT STANDARD F2-2, "QUALITY ASSURANCE PROGRAM REQUIREMENTS" TO APPLY.
2. IDENTIFICATION NUMBER TO BE SPECIFIED IN ORDERING DATA AND TO INDICATE APPLICABLE ENRICHMENT ZONE AND ORIFICE ZONE. CHARACTER HEIGHT TO BE .250 ± .050. IDENTIFICATION NUMBER MUST BE ORIENTED WITH RESPECT TO PART 5 OR PART 6 AS SHOWN.
3. WELD USING COMPOSITION ER-309 WELDING RODS CONFORMING TO ROT STANDARD M1-2, "STAINLESS STEEL WELDING RODS AND BARE ELECTRODES," WELDING TO CONFORM TO ROT STANDARD F4-2, "WELDING OF REACTOR CORE COMPONENTS AND TEST CAPSULES," ROOT PENETRATION TO BE .005 DP, .030 DP.

G1
G2

CONTROL A	
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PRELIMINARY

ATD - BRQ	828E367
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UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING
 209A4270 SURFACES 6.3 1.003 1.1
 HEX CHANNEL (RECESSED)
 PART MADE FOR FTR DRIVER FUEL ASSEMBLY
 FCF 107,092,05

SECTION A-A & A*-A* (SEE NOTE 3)
 SECTION B-B & B*-B* (SEE NOTE 3)
 (DIMENSIONS SAME AS SECT A-A, ROTATED 60° CW)
 SECTION C-C & C*-C* (SEE NOTE 3)
 (DIMENSIONS SAME AS SECT A-A, ROTATED 120° CW)
 SECTION D-D & D*-D* (SEE NOTE 3)
 (DIMENSIONS SAME AS SECT A-A, ROTATED 180° CW)
 SECTION E-E & E*-E* (SEE NOTE 3)
 (DIMENSIONS SAME AS SECT A-A, ROTATED 240° CW)
 SECTION F-F & F*-F* (SEE NOTE 3)
 (DIMENSIONS SAME AS SECT A-A, ROTATED 300° CW)

1 TYP PROJECTION FOR SECTIONS A-A, B-B, C-C, D-D, E-E, & F-F

- NOTES: 1. MAKE FROM DUCT TUBE ASSEMBLY 118D9983 (BASED ON WESTINGHOUSE DWGS. H-4-21382 & H-4-21476)
 2. ALL AXIAL DIMENSIONS FROM BASE LINE ARE 1.020 WITH SPECIFIED PARALLELISM TOLERANCE.
 3. ALL SECTIONS & DETAILS NOTED WITH * SYMBOL ARE FROM THE AREA OF REDUCED CHANNEL WALL THICKNESS.

1 SEE NOTES 1 & 2

1.0005 TYP 26 PLACES SEE NOTE 2

CONTROL A	
REVISIONS	PRINTS TO
1. 11/11/73	NE 12308
25 MAY 1973	
ATD-BRD	
SUNNYVALE	
828E882	