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DESIGN OF SUPPLEMENT B TO PT-IP-262-A-11-FP, EVALUATION OF PROJECTION FUEL ELEMENTS FOR USE IN RIBBED PROCESS TUBES

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DESIGN OF SUPPLEMENT B TO PT-IP-262-A-11-FP, EVALUATION OF PROJECTION FUEL ELEMENTS FOR USE IN RIBBED PROCESS TUBES

W. H. Hodgson & M. A. Clinton

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DESIGN OF SUPPLEMENT B TO PT-IP-262-A-11-FP, EVALUATION OF PROJECTION FUEL ELEMENTS FOR USE IN RIBBED PROCESS TUBES

INTRODUCTION

One of the three major categories of HAPO fuel element failures is the side corrosion type rupture. The majority of side-corrosion failures has been characterized by oval or tear-drop shaped flow patterns containing evidence of accelerated corrosion. Thorough examination of many of these so-called "hot-spot" failures has indicated the failure was caused by poor heat transfer associated with misalignment, dimensional distortion or poor jacket-to-core bonding. It has been postulated[1] that misalignment of the fuel element is a necessary condition for formation of hot spots under the present reactor operating conditions. Neither tru-line contours nor X-8001 alloy are successful in the prevention of misalignment and associated ruptures; therefore, it has been proposed to test the effectiveness of projections on the side of the fuel element toward preventing fuel misalignment in ribbed process tubes. A previous test[2] of this element termed the "bumper fuel element" was encouraging; however, it failed to provide the conclusive proof required to justify a large-scale demonstration loading. Supplement A[3] to the basic test[4] was written to obtain necessary preliminary data. This report presents an outline of further testing required to accelerate evaluation of the bumper concept.

OBJECTIVE

The objective of this test is to authorize projection fuel testing beyond that currently scheduled for ribbed process tubes. The objective of the program of which this test is a part, is to demonstrate the feasibility and advisability of using a fuel element having projections in currently installed old reactor ribbed process tubes to reduce hot-spot rupture incidence. The purpose of this supplement is to incorporate latest laboratory findings[5] into the test and present acceleration of the evaluation by authorizing concurrent testing of all variables.

1. HW-59168, "A Postulated Hot Spot Failure Mechanism". E. C. Wood. February 9, 1959. (Secret)
2. HW-56525 C, "PT-IP-183-A-98 FP, Evaluation of Projection Fuel Elements for Use in K Process Tubes". R. E. Hall. November 5, 1958. (Secret)
3. HW-60444 D, "Supp. A, PT-IP-262-A-11-FP, Evaluation of Projection Fuel Elements for Use in Ribbed Process Tubes-Demonstration Loading". R. E. Hall. November 7, 1959. (Secret)
4. HW-60444 C, "PT-IP-262-A-11-FP, Evaluation of Projection Fuel Elements for Use in Ribbed Process Tubes". R. E. Hall. February 23, 1960. (Secret)
5. HW-65352, "Supplement to Projection Fuel Element Autoclave Failure Test". W. I. Steinkamp. May 1960.

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TEST SUMMARY

This test is composed of three parts, the first two to be executed concurrently and the last part based on encouraging results from the first two:

(a) Irradiate to high goal exposure or to failure, four columns each of 1.47 percent enriched projection and control elements to demonstrate relative rupture resistance.
(b) Irradiate a 100-tube demonstration loading of bumper fuel elements, and
(c) Provide for charging of a lead reactor's central flow zone with bumper fuel elements.

BASIS

One of the three major categories of HAPO fuel element failures is the side-corrosion type of failure. Past experience has indicated that uniform corrosion as calculated with existing techniques, could not account for the majority of these failures; but rather, some rapid corrosive mechanism must be assumed. It has been demonstrated previously[6] that misalignment of fuel elements in a process tube will produce a hot-spot type flow pattern and area of heavy corrosion. Calculations by Wood[7] indicate that temperatures sufficiently high to produce a steam jacket on fuel element surfaces can be obtained with local annulus clearance reductions to a value of less than 15 mils. Steam jacketing of an area of fuel element surface could cause further surface temperature increases, sufficient to initiate intergranular attack with relatively short incubation periods, and presumably failure, especially if imperfect Al-Si bonds are exposed. Even without reaching the steam jacketing condition, sufficiently high surface temperatures can be reached to give more rapid than predicted corrosion rates.

The use of projections attached to the side of the fuel element to assure alignment has been proposed and it is possible to prepare on a production-scale, projection elements which will guarantee an annular clearance of 20 mils with solid 40-mils rails. This element, termed a "bumper fuel element" is designed to be supported on the ribs of the process tube and oriented such that the projections reduce the degree of possible misalignment. Testing to date has been directed along the lines of the self-supported types of fuel element primarily, wherein it has been demonstrated that the supports have sufficient strength, do not of themselves create a corrosion problem and in actuality have shown no evidence of hot-spot corrosion to date. In addition, a preliminary test loading of bumper fuel elements irradiated in KW Reactor was encouraging but did not provide the conclusive proof that the bumper concept would significantly reduce hot spots. Since rupture incidence and

6. HW-55789, "Final Report on PT-105-634-A, In Pile Cocked Slug Tests". P. B. McCarthy. June 2, 1958.
7. HW-59168, "A Postulated Hot-Spot Failure Mechansim". E. C. Wood. February 9, 1959.

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observed hot spot incidence appeared to be greatly reduced at the KW Reactor during the first bumper fuel test, further testing was authorized for the old reactors where high hot spot incidence was present. This test[8] authorized demonstration loadings (20 bumper and 20 control charges) for B, D, DR, F, and H Reactors in order to obtain irradiation data on a significant number of fuel elements before beginning a full reactor loading. Supplement A[9] to the basic test authorized a repeat loading of the inconclusive KW test preliminary to further testing. Material originally prepared for this test did not meet requirements and replacement charges were made. The bumper evaluation program was reactivated with the successful fabrication and charging of 20 columns each of bumper and control fuel elements on May 13, 1960, into D Reactor.

In order to accelerate and complete this testing program in time to permit pilot use of bumper fuel at a lead reactor by December, 1960, and general usage at all old reactors during late 1961, a compressed program[10] will be required. The schedule outlined below will not allow sufficient time to make ample data analysis to justify each successive step; however, enough preliminary discharging will have been accomplished to show up any major unforeseen problems prior to the initiation of the full reactor pilot loading. The following schedule will provide sufficient data to justify extension of the bumper fuel concept to the remaining older reactors by July, 1961.

(a) Charge a test utilizing a 1.47% enriched bumper and control elements for a relative rupture resistance determination as soon as possible. This test will be similar to the one performed at B Reactor[11] to evaluate potential gains for self-supported fuel elements. The tube flow rates and column lengths will be adjusted slightly to restrict uniform corrosion rates and to compensate for higher inlet water temperature. Test was charged on July 14, and will require from two to six months for results and up to four ruptures.

(b) Charge a hundred-tube demonstration load to determine the operational problems associated with bumper fuel. Programs to support charging of the 100-tube load in August, 1960, are scheduled. In order to meet this schedule, it will be necessary to use mostly resistance welded bumpers instead of the more favorable ultrasonically welded elements.* Bumper fuel for the 100-tube load may be fabricated with either three or four ribs, depending on the

8. op. cit., HW-60444 C, p. 2.
9. op. cit., HW-60444 D, p. 2.
10. HW-65717, "Status Report - Projection Fuel Testing Program, June 1960". M. A. Clinton. June , 1960.
11. HW-59756 C, "Production Test IP-247-A-8-FP, Irradiation of 1.47% Enriched Self-Supported I & E Fuel Elements in Ribless Process Tubes". R. E. Hall. July 29, 1959.

* Resistance welding requires a larger support tab size (approximately 3/8 inch wide by 2-1/8 inch long as compared to 1/8 inch wide by 1-1/2 inch long for ultrasonic welding). Ultrasonic welding is easier to control and is expected to yield a more uniform product.

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development of the charge machine. The three-rib model is designed specifically for use in spline tubes. The bulk of the 100-tube load (at least 90 tubes) will be fabricated with four solid bumpers. Tubes chosen for the part of this test using the four-rib fuel elements should be selected from non-spline cap tubes so as not to sacrifice the proven advantages of the spline system.

(c) Repeat the test loading of bumper fuel at KW Reactor, authorized by Supplement A[12] to furnish additional handling and irradiation data before the pilot pile loading. The test and fuel elements will be ready for charging in July, 1960.

(d) Authorize discharge and special pickup of selected paired charges of bumper and control elements charged under Supplement A[13] to give preliminary post-irradiation data prior to the full pile pilot loading. Discharge one pair at 400 MWD/T and two pairs at 800 MWD/T. The approximate discharge dates will be July 1-15 and September 1, 1960. The remaining seventeen (17) pairs will be discharged about November 15, 1960.

(e) Charge machine development has been initiated and a machine capable of charging a four-ribbed bumper element should be available by August 1. Development effort on a charge machine to handle a three-ribbed bumper with ribs spaced 90° apart should begin immediately. The machine must index the fuel so that the three bumper supports are always charged above the ribs to permit continued use of the existing spline equipment. Three ribbed bumper fuel elements may be charged when a satisfactory charge machine has been developed.

This program, in order to progress on schedule, implicitly requires that all testing be performed at one reactor to avoid duplication of equipment modification and personnel training. D Reactor is chosen to run this production test for the following reasons:

1. There are testing programs scheduled for the other old reactors which could cause conflicts with the interest of this test.

2. To balance Category I fuel production test commitments.

3. Initial bumper fuel charging was accomplished at D on May 13, 1960.

4. Solution of spline usage with bumper fuel is required before proceeding to the remaining old reactors with

12. HW-56525 D, "Supplement to PT-IP-183-A-98 FP, Evaluation of Projection Fuel Elements for Use in K Process Tubes". R. E. Hall & M. A. Clinton.

13. op. cit., HW-60444 D, p. 2

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bumper fuel, and D Reactor is the pilot reactor for spline usage for the old reactors.

Several problems other than fuel element performance determination will require solution in order that the bumper fuel program may proceed without materially affecting the production capability of the chosen reactor. Most have been mentioned previously, but are again repeated for emphasis.

1. It is desirable to provide the pilot loading with a fuel design which is compatible with spline usage. A small scale test (up to ten tubes of three-ribbed bumper elements) will be included in the 100-tube demonstration loading. Such a scheme is based on the assumption that a charging machine can be provided which is capable of indexing the fuel in the tube such that the space between the ribs (spline groove) remains unobstructed.

2. Charging machines should be designed and ready for use prior to charging the 100-tube demonstration test. A limited number of three-rib, solid rail, ultrasonically welded, bumper fuel elements (up to ten columns) will be fabricated and available for hand charging during the 100-tube loading.

3. On-pile nozzle modification techniques are being developed to support the pilot load. Off-pile nozzle modification techniques are well developed and may be used to prepare for the 100-tube demonstration load if on-pile development work has not progressed far enough to be used. One hundred front face nozzles will be required by August 1, 1960.

4. Fuel handling techniques are currently being investigated in conjunction with the self-support fuel element program, and all procedures and ideas acquired to date will be used in both programs. A very limited amount* of irradiated bumper fuel handling data will be available before the pilot pile loading scheduled for December, 1960.

5. Fuel fabrication method and fuel element design must be determined by October 15, in order to have sufficient fuel available to support the pilot reactor loading in December.

* Possibly 24 tubes from D by November 15, 1960.

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Solid rail supports are authorized on the basis of work performed by Hanford Laboratories Operation[14] which indicates that tube damage and rupture removal pushing forces appear to be more dependent upon the amount of uranium attack than the type of support. Although more testing may be needed, it appears prudent to evaluate the use of solid rail bumper fuel elements in reactor immediately; since, they are easier to fabricate and will give a higher degree of assurance that the minimum 15 mil annular clearance necessary to prevent hot-spot occurrence can be maintained (as opposed to collapsible bridge rail supports).

TEST DETAILS

I. Material

A. Fuel Elements - Test and Control

1. Cores

All cores for the relative rupture resistance determination (run-to-rupture test) shall be 1.47% enriched and shall meet all HAPO purity specifications.

Cores for the 100-tube demonstration loading will be normal production natural uranium.

Cores for the pilot pile loading shall be normal production natural uranium and 0.94% enriched uranium. Pilot pile load should use OIII size components if available.

Nominal Core Dimensions	1.47% E	OIINB	OIIINB	OIIIEB	Water Mix
O.D.	1.356"	1.356"	1.356"	1.355"	1.351"
I.D.	0.416"	0.416"	0.423"	0.423"	0.416"
Length	7.000"	8.325"	8.325"	6.000"	6.000"

2. Cladding

Can and spire components shall be X-8001 alloy aluminum and finished fuel element dimensions shall be:

14. HW-65352, "Supplement to Projection Fuel Element Autoclave Failure Test". W. I. Steinkamp. May, 1960.

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Nominal Canned Dimensions	1.47% E	OIINB	OIIINB	OIIIEB	Water Mix
O.D.	1.450"	1.450"	1.444"	1.444"	1.444"
I.D.	0.310"	0.310"	0.310"	0.310"	0.310"
Max. Circumscribed Circle	1.530"	1.530"	1.530"	1.530"	1.530"
Rail Height	0.040"	0.040"	0.040"	0.040"	0.040"
Guaranteed Annulus	0.020"	0.020"	0.020"	0.020"	0.020"
Effective Charge Length	7.540"	8.865"	8.865"	6.540"	8.440"
Component Code	0-2*	0-2	Z-2	Y-2	M-2

* Cut to fit 7.000" length core.
All finished dimensions will be within normal fuel tolerances. Tolerances for bumper elements are in Appendix II.

3. Supports

The bumper supports are to be fabricated from X-8001 alloy aluminum and may be attached to the fuel element by either resistance spot welding or ultrasonic welding techniques. The rails will be of the solid design and will be attached on 90° centers. Two variations may be made:

a. Four Rib Element

Eight solid rails, four each end on 90° centers in line, attached by either ultrasonic or resistance welding.

b. Three Rib Element

Six solid rails, three each end on 90° centers in line, attached by ultrasonic welding.

4. Quality

All elements accepted for reactor charging must pass the normal quality control specifications in effect at the time this test is prepared.

5. Quantity

a. Four charges of 19 pieces of 1.47% enriched material plus eight spares will be required for each of the test and control groups.

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Column	Makeup	Pieces/Charge	Spares/Charge	Total
1-4	1.47% Bumpers	19	2	84
5-8	1.47% Normal	19	2	84
				168

b. All fuel elements utilized in the demonstration loading will be OIINB and will be assembled into charges of 34 pieces each including the mixer. Twenty-four (24) four ribbed spares and 15 three-ribbed spares shall be shipped with the numbered columns.*

c. All fuel elements for the pilot load should be of the OIIINB or OIIIEB geometry and shall be lot charged. OIINB and OIIEB geometries may be used if it appears that OIII component delivery schedules would delay the loading schedule.

d. Mixers will be required for both the demonstration loading (100 tubes) and the pilot pile load. Mixer pieces will be fabricated with bumpers and will be charged one per column in the position selected by the Process Engineer. The mixer location for the 100-tube load will be number seven from the rear. Mixer pieces used in numbered columns will receive pre-irradiation measurements.

II. Testing

A. Pre-irradiation Measurements

1. Relative Rupture Resistance Test (1.47% E)

Pre-irradiation numbering and measurements of UT-2, weight O.D., I.D., length, warp, and total bond count (if possible) on all pieces.

2. Demonstration Loading (100 Tube)

All pieces shall be numbered and fuel quality monitored by utilizing Quality Certification techniques if lots are of sufficient size.

3. Pilot Pile Load

All pieces shall be lot charged and monitored using Quality Certification methods for both natural and enriched material.

* Mixer pieces in selected columns will be replaced with a spare piece.

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B. Irradiation Testing

1. Charging

All numbered columns are to be charged in numerical order with piece number one downstream. Charging will be followed by a representative of Research and Engineering, IPD.

a. 1.47% Enriched Test

All columns will be hand charged identically and over-bored nozzles will be installed on the bumper tubes. Early discharge of all fuel columns in the specified configuaration for the 1.47% E load is authorized. Charging sequence shall be:

1. Normal downstream dummy charge (except - without expendables).
2. Eight perfs, expendable or tubular.
3. Nineteen 1.47% enriched elements.

All eight columns will be charged into a 3 x 7 block so that no two columns are adjacent, as indicated below:

T		C		T		C
	S		S		S	
C		T		C		T

T - Test Column
C - Control Column
S - Spline Cap Tube

b. One Hundred-Tube Test

Selected tubes will have downstream thermocouple trains installed. The prototype charging machine (to handle four bumper fuel elements) should be used for the bulk of the charging. A small amount of hand charging will be required if any three ribbed fuel elements are charged (up to ten tubes).

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Tubes will be selected from non-spline cap tubes and will be equipped with overbored nozzles.

c. Pilot Pile Test

All charging to be accomplished with modified charging machines through overbored nozzles.

2. Irradiation

During irradiation, weekly flow and daily temperature data for each of the columns in the run-to-rupture (1.47% E) portion of this test shall be recorded. Daily temperature data will be recorded for all tubes equipped with thermocouple probes. No special data recording will be required routinely for the demonstration and pilot loadings.

The relative rupture resistance test shall be irradiated until any of the following criteria have been met:

a. Two ruptures have been sustained in the control material* and sufficient exposure has accumulated on the test material to indicate a statistically significant improvement in rupture resistance, up to a factor of 40 improvement at the 95% confidence level.
b. One failure occurring in the test material before the second control failure may terminate the test.
c. Two failures in the bumper (test) material occurring before the desired factor of improvement, but after the two control failures, will terminate the test.
d. The test may be terminated upon reaching a point where uniform corrosion calculations indicate that the failure mechanism will probably not be hot spotting.

Goal exposure for columns utilized in the demonstration loading shall be assigned by the test author with the concurrence of the Manager, D Processing. Initially, this goal shall be set 100 MWD/T** above normal variable goal in effect at time of charging. If data from the relative rupture resistance test become available before reaching the above goal, the goal exposure may be reset to not more than 50% of the improvement demonstrated at the 95% confidence level. Should two failures occur in the demonstration load, the load may be discharged at the request of the test author.

Goal exposure changes will be made by request from the test author with the concurrence of the Manager, D Processing.

* After the second control failure, the remaining two control columns may be discharged.
** Factor of 2 improvement.

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Goal exposure for the pilot pile load will be based on available data at the time of charging and will be assigned by the test author with the concurrence of the Manager, D Processing.

3. Operating Conditions

a. 1.47% Enriched

Desired operating conditions for columns utilized for the 1.47% enriched test are listed below:

1. Tube Flow - 51-55 gpm.
2. Tube Power - 1000-1150 KW.
3. Tube Inlet - 10-20 C.
4. Tube Corrosion Index - CWT of 45 or greater.
5. Control Rods - At least a lattice unit from test location.

b. Demonstration Load

Tubes charged with bumper fuel of the OIIN geometry will run approximately 5% higher in outlet temperature than OIIN non-bumpered material due to the reduced tube flows caused by higher hydraulic resistances associated with the bumper projections. Total pile flow will be reduced neglibibly.

c. Pilot Load

If OIII fuel geometries are used, there should be negligible tube and pile flow changes during the transition. Use of OII geometries will result in individual tube flow reductions of approximately 5% and pile flow reductions somewhat less, but still significant.

4. Rupture Potential (1.47% E Test)

A similar test conducted in B Reactor[15] under essentially identical conditions produced two control failures within 24 operating days (first at 17, second at 24). It is anticipated that failures in this test will occur under similar irradiation; however, it may take considerably longer. Rupture potential can be calculated for the estimated conditions and failures predicted, but the uncertainty on these calculations are large and factors of improvement based on a comparison of actual and "predicted" rupture

15. HW-59756 E, "Irradiation Summary Report - PT-IP-247-A-FP, Irradiation of 1.47 Enriched Self-Supported I & E Fuel Elements in Ribless Process Tubes". R. E. Hall. April 7, 1960. (Secret)

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performance would not be accurate enough for purposes of fuel evaluation. Therefore, this test will be evaluated by using two control material ruptures as the basis for improved rupture performance of the bumper fuel.

5. Discharge

a. 1.47% Enriched Test

All columns (eight) shall be picked up special.

b. Demonstration Test

Up to ten columns may be picked up special at the discretion of the test author, in addition to any monitor columns charged under PT-216-A-7-FP (Quality Certification).

c. Pilot Pile Load

No special pickup will be authorized by this test.

d. General

During discharge operations involving bumper fuel elements, particular care should be taken to report pertinent observations relative to post-discharge handling. Whenever practical a Research and Engineering representative will observe these discharges.

6. Thermocouple Probes

Downstream thermocouple trains to measure annular temperature distribution may be used in the demonstration and pilot pile loadings as required by the test author. While it is anticipated that up to twenty probes may be used during the early phase of this program, not more than ten probes are authorized in-pile at any one time.

C. Post-Irradiation Examination

After irradiation, all pieces which received pre-irradiation measurements and any special material requested by the test author shall be sent to the 105-C Metal Examination Facility for the following measurements:

1. Weight loss.
2. Warp and ellipticity.
3. Diameter changes.

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4. Visual and weasel.
5. Any other measurements[16] specifically requested and agreed upon before beginning the post examination.

Selected elements may be examined further in the Radiometallurgy Laboratory.

D. Hazards

Hazards peculiar to this test are principally associated with the presence of the "bumper" projections on the fuel surface. These arise from the fact that the bumpers do restrict fuel element displacement in the process tube so that it is conceivable that these elements could stick tighter after rupture than do non-bumpered elements.

W. H. Hodgson

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16. HW-59756, "PT-IP-247-A-8-FP, Irradiation of 1.47% Enriched Self-Supported I & E Fuel Elements on Ribless Process Tubes". R. E. Hall. July 29, 1959.

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APPENDIX I

DATA TO BE RECORDED IN PRODUCTION TEST NOTEBOOK

I. Fuel Element Core Lot Numbers

A. Casting Data

1. Site
2. Dingot or Ingot
3. Chemical Composition Each Ingot or Dingot
4. Unusual Conditions

B. Fabrication Data

1. Site
2. Type of Fabrication (Rolled, Extruded, Cast, Etc.)
3. Attendant Conditions

C. Heat Treatment

1. Site
2. Form of Material When Treated
3. Heat Treating Salt
4. Attendant Conditions

D. Finishing Data (Machined or Centerless Ground)

E. Finished Dimensions (Pre-Assembly)

F. Properties

1. Orientation Data-SORT Readings
2. Grain Size - UT-2 Data
3. Other Significant Properties

G. Pre-Assembly Treatment (Including Inspection)

1. Reject Rates

II. Can-Lot Numbers

A. Type Alloy

B. Chemical Composition

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C. Fabrication Data

1. Site
2. Type of Fabrication
3. Attendant Conditions

D. Heat Treatment

E. Finished Dimensions (Pre-Assembly)

F. Properties

1. Hardness
2. Tensile Data
3. Other

G. Pre-Assembly Treatment (Including Inspection)

III. Assembly Process

A. Process Used

B. Brief Explanation of Process

C. Attendant Conditions

IV. Post-Assembly Treatment

A. Protective Coating

B. Autoclaving

C. Support Type-Welding Procedure

D. Inspection

V. Pre-Irradiation Examination

A. Weight

B. O.D. and I.D.

C. Length

D. Warp or Elypticity

VI. Log-Running account with dates recording the progress of the PT, unusual incidents (such as a slight change in process during assembly), and other deviations whether or not they seem pertinent at the time of occurrence.

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APPENDIX II

To better define the limitations for fabrication of projection fuel elements, a set of specifications[17] for self-supported and bumper projections is being prepared. The following definitions and tolerances are to be used for this test until issuance of Reference 17 and/or a specification for ultrasonically welded supports at which time the documented specifications shall supersede the following:

Definitions

Rail Height - maximum height of attachment above can wall as measured after attachment.

Maximum Circumscribed Circle - maximum diameter of fuel element in any transverse section of fuel element.

Specifications

The following criteria referring to solid bumper fuel elements only, must be adhered to:

1. Rail height for OIIN I & E fuel elements shall be: maximum - 0.040 inch; minimum - 0.038 inch.

2. Rail height for OIII I & E, fuel elements shall be: maximum - 0.040 inch; minimum - 0.038 inch.

3. Rail length for OIIN and OIIIN I & E fuel elements shall be:

   a) spot welded - 2 1/8" ± 1/64".
   b) ultrasonically welded - 1 1/2" ± 1/64".

4. Maximum circumscribed circle for OIIN and OIIIN I & E fuel elements shall be 1.530 inch.

5. Rail location for OIIN and OIIIN I & E fuel elements shall be: 1/2 ± 1/16" from the end of the fuel element and spaced 90° ± 2 1/2° apart. Center lines of the rows of supports shall be in-line ±2 1/2°.

17. HW-65271, "Provisional Process Specifications for the Attachment of Support Rails by Electrical Resistance Spot Welding". E. V. Padgett. To Be Issued.

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