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PATHFINDER ATOMIC POWER PLANT

DESIGN, DEVELOPMENT AND FABRICATION OF PROTOTYPE LOW-ENRICHED SUPERHEATER FUEL ELEMENTS (LESH)

Submitted to
U. S. ATOMIC ENERGY COMMISSION
NORTHERN STATES POWER COMPANY
and
CENTRAL UTILITIES ATOMIC POWER ASSOCIATES

by

ALLIS-CHALMERS MANUFACTURING COMPANY
ATOMIC ENERGY DIVISION
Bethesda, Maryland

Ref: AEC Contract No. AT(11-1)-589

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Compiled by D. A. Lampe and T. M. Raby

Submitted to

U. S. ATOMIC ENERGY COMMISSION
NORTHERN STATES POWER COMPANY

and

CENTRAL UTILITIES ATOMIC POWER ASSOCIATES

by

ALLIS-CHALMERS MANUFACTURING COMPANY

under

Agreement dated 2nd Day of May 1957, as Amended
between

Allis-Chalmers Manufacturing Company and Northern States Power Company
under

AEC Contract No. AT(11-1)-589

April 1967

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Approved:

R. W. Klecker
Project Manager
Pathfinder Project

Allis-Chalmers Manufacturing Company
Atomic Energy Division
Bethesda, Md. 20014

Approved:

D. F. McElroy
Vice President
Engineering

Northern States Power Company
414 Nicollet Avenue
Minneapolis, Minnesota 55401

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 SUPERHEATER FUEL ELEMENTS (LESH)

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FOREWORD

One of a series of reports on research and development carried out in connection with the design of the Pathfinder Atomic Power Plant, this particular report deals with the design, development and fabrication of two prototype, low-enriched fuel elements for the superheater section of the plant. The Pathfinder Plant is located at a site near Sioux Falls, South Dakota and reached criticality early in 1964. Owner and operator of the plant will be Northern States Power Company of Minneapolis, Minnesota. Allis-Chalmers is performing the research, development and design, and is also responsible for plant construction.

The U. S. Atomic Energy Commission, through Contract No. AT(11-1)-589 with Northern States Power Company and Central Utilities Atomic Power Associates (CUAPA) are sponsors of the research and development program. The plant's reactor will be of the controlled-recirculation boiling water type, with integral nuclear superheater.

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Mechanical: R. L. Davie
 H. Gignilliat
 J. F. Haines

Thermal: L. L. Kintner

Physics: P. S. Lacy

Safeguards: W. R. Pearce

Development: T. Peterson
 E. Wick

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1. INTRODUCTION

Two prototype fuel elements were fabricated for the Pathfinder superheater core. These assemblies were to be similar to the proposed Low-Enriched Superheater I (LESH-I) core assemblies except for minor variations made necessary because of the small number of elements being fabricated and because of the fact that the prototypes will be inserted into the present highly enriched core.

The prototype elements were fabricated in order to confirm initial design concepts, to qualify and establish manufacturing techniques, and finally to demonstrate and evaluate actual performance in advance of the installation of the full core. The low-enriched UO_2 fuel elements were selected in preference to the present highly enriched core because fuel and fabrication costs are considerably reduced by use of the low-enriched material.

This report describes the design and analyses leading to the development and fabrication of the LESH prototypes. The report consists of a section on mechanical design and analysis, a section on thermal and hydraulic analyses, a section on physics analyses, and a section outlining required safeguards analyses. Also included, as appendices, is information on development and fabrication, and a number of relevant manufacturing specifications.

The work on this program was continued until the prototype assemblies were fabricated. At that time, all work was terminated. As a result, the safeguards analysis required in order to obtain AEC approval for inserting these assemblies was not completed. The safeguards section summarizes the pertinent safeguards aspects which should be considered if this program is resumed at a later date.

2. MECHANICAL DESIGN AND ANALYSIS

2.1 INTRODUCTION

One of the major objectives of the Low-Enriched Superheater (LESH) prototype program was to develop the design of prototype superheater fuel elements which would closely represent the proposed full LESH core. For this reason, the design conditions, operating limits, and performance specifications expected or required for the full LESH core, were used as the basis for establishing the mechanical design parameters of the prototype elements.

The seven-rod cluster LESH prototype fuel assembly consists of six outer rods, containing low enriched fuel in the form of uranium dioxide, and an inner central rod, containing burnable poison in the form of boron-stainless steel wire. The cladding, which is free standing, is Incoloy Alloy 800 material, mill annealed, and is designed to resist creep collapse. The active fuel region is nonsegmented and is 6 ft in length. Mechanical spacing of the fuel rods is accomplished by means of spiral wires welded to the cladding of the fuel rods.

The prototype assembly was designed to fit into existing superheater fuel channels and to utilize existing fuel handling equipment. The fuel rods are vertically supported within the channel. Saturated steam from the boiler at 489 F and 615 psia passes downward through the superheater core. Maximum design steady-state clad temperature is 1300 F; the anticipated maximum burnup is 15,200 Mwd/MTU.

The approach to the mechanical design of the LESH prototype elements is considered conservative. It was based largely upon operating experience with similar type fuel and upon work in the USAEC superheat development program. Conservatism in the mechanical design is reflected in the specification that cladding be free standing; that it resist instantaneous collapse, and that creep-induced deformation be minimized for the design life-time of the fuel.

2.2 MECHANICAL DESIGN DESCRIPTION

The LESH prototype fuel element design is shown in Fig. 2.1. The element consists of a seven-rod cluster of equal-diameter rods. The six outer rods contain fuel, and the center rod contains a poison wire. The assembly is approximately 82.5 in. long, and it has an envelope diameter of 0.932 in. The fuel rods contain UO_2 pellets compacted and sintered to approximately 95 percent of theoretical density. The average uranium enrichment is 7.54 w/o U-235. The active fuel length is 72.0 in. and the nominal fuel pellet diameter is 0.207 in. The fuel pellet stack rests on the bottom end plug, and it is held in position by a stainless-steel coil spring at the upper end. The cladding is Incoloy 800, mill annealed, it has an 0.247 in. dia., with a wall thickness of 0.018 in. The minimum radial gap between the fuel and the cladding is 0.0025 in. in the cold clean condition. The fission gas plenum is located above the active fuel region and is 3.0 in. long.

The poison rod consists of a boron stainless steel wire within an Incoloy 800 tube. The tube has an outer diameter of 0.247 in. and a wall thickness of 0.018 in. The poison wire is held in position within the tube by annular aluminum oxide ceramic pellets. The poison wire is approximately 72.5 in. long with an 0.146 in. dia., and it contains approximately 1.66 w/o (2.76 gm) natural boron. The wire is free to expand axially within its tube, and it is held in place by means of a stainless-steel coil spring located at the upper end. The spring places a 3-pound load on the ceramic spacer stack; this load is transmitted to a stainless-steel washer welded to the bottom of the poison wire. Wire-to-spacer radial clearance is sufficient to allow for both differential thermal expansion and irradiation-induced swelling of the boron-stainless steel wire.

Spacing between the rods is accomplished by spiral spacer wires of Incoloy 800, mill annealed, which are attached to each of the six fuel rods. Each fuel rod has three wires, 120 degrees apart at any axial position, wrapped and continuously welded on a 6-in. pitch. Spiral direction is alternated from rod to rod to permit meshing of adjacent fuel tubes with wire to their adjacent tube contacts in all cases. No wire-to-wire contact exists.

The bottom fitting is machined from 316 stainless steel and is designed to seat in the existing inner insulating tube of the superheater. Its length was established to position the bottom of the pellet stack at the required elevation in the core. This fitting consists of six radial blades located at 60 degree angles. Each blade receives the slotted end of a lower fuel rod end plug. Each slotted end plug is longitudinally welded to its respective blade at the blade circumferential surface. The center poison rod is fixed to the bottom fitting by inserting the extended end plug into a centrally drilled hole in the fitting, inserting two pins, and then welding the pins in place. All seven rods are, therefore, fixed at the bottom fitting.

At the upper end, all rods are able to expand independently. Each of the six fuel rod upper end plugs is machined with a constant diameter bounded by two retaining shoulders. When assembled, a retainer ring fits between these retaining shoulders and holds the assembly together radially. The center poison rod upper end plug also serves as the handling tool fitting. This fitting is similar to the Core 1 superheater fitting in order to permit use of the existing handling tools.

The center rod end plug is designed with a diameter which positions the center rod and guides against the upper shoulder on all fuel rods, thus holding them against the retainer ring. Suitable clearance has been provided to assure freedom for the individual rods to expand during operation. This upper end design permits easy assembly with no welding. The only function of the retainer ring is to hold the rod assembly together for handling, shipping, and storage. Once inserted in the core, the process tube of the superheater structure becomes the restraining envelope, and the retainer ring then has no function.

TABLE 2-1

LESH PROTOTYPE DESIGN DATA SUMMARY

Assembly configuration	7-rod cluster
overall element length	82.53 in.
envelope diameter	0.932 in.
nominal weight	9 lbs.
Fuel type	sintered UO_2 pellet
UO_2 enrichment	7.54 w/o U-235
loading per element	2.206 kg - U
UO_2 pellet diameter	$0.207 \pm .0005$ in.
UO_2 pellet length	$0.207 - 0.414$ in.
active fuel length	$72.0 \pm .125$ in.
Cladding type	free standing tubing
material	Incoloy 800, mill annealed
outside diameter	$0.247 \pm .001$ in.
inside diameter	$0.211 \pm .001$ in.
wall thickness	0.018 in.
Poison Type	boron s.s. wire
poison composition	1.66 w/o natural boron
poison loading per element.	2.76 gm natural boron
poison wire diameter	0.1459 in.
poison spacer	sintered Al_2O_3 pellets
Spacing arrangement	spiral wire, 3 per fuel rod
wire diameter	0.042 in.
spiral pitch	6 in.
wire material	Incoloy 800, mill annealed
Fission gas plenum length	3.0 in.

Both fuel and poison pins are assembled with springs located in the fission gas space. The spring is designed to hold the UO_2 pellet stack and Al_2O_3 spacer pellets in position during shipment and handling. A summary of the LESH prototype final design data is presented in Table 2-1.

2.3 CLADDING MATERIAL EVALUATION

Design life of the LESH prototype fuel elements is based upon expected exposure of 7000 to 8750 (or equivalent) full-power hours. At a plant load factor of 0.8, this period corresponds to an elapsed time of 12 to 15 months in the reactor. Expected exposure of the LESH-I full core is 7000 (or equivalent) full-power hours. The service conditions to which the fuel will be subjected in the reactor include (a) exposure to steam containing up to 20 ppm O_2 and a trace chloride-ion content, (b) maximum steady-state cladding surface temperature of 1300 F, and (c) fast neutron irradiation (> 1 Mev) of $\sim 1.0 \times 10^{21}$ nvt in addition to thermal neutron irradiation of about the same level. Thermal and pressure stresses have been held to levels which do not result either in plastic deformation under the worst anticipated transient conditions, nor in damaging distortions as a result of long term creep of the cladding material.

Initial consideration and literature surveys narrowed the number of possible cladding materials to three, which were then examined in detail. The three materials were Incoloy 800, Inconel 600 and Type 316 stainless steel. The characteristics of each material were reviewed and evaluated in terms of the operating environment, making use of manufacturer's data and other data and information available in the literature as well as some unpublished information made available to the investigating engineers. The most applicable, pertinent and comprehensive sources of data and information were found to be those generated under the USAEC nuclear superheat development program. As a result of the investigations carried out, Incoloy 800 in the mill annealed condition (ASTM Specification B407-T-63, Grade 1) was selected for the LESH-I full core and prototype elements. Maximum limits for boron and cobalt were also specified, the levels being those usually used for austenitic fuel cladding material. Table 2-2 gives the specified chemical analyses for cladding and for wire and rod stock; the table also gives the actual analyses of the materials used in fabrication of the prototype elements.

Tests on Incoloy 800 in high temperature steam for periods up to 13,000 hr. have demonstrated good stability of its mechanical properties. Both tensile and yield strength increase slightly with long exposure to elevated temperature; ductility decreases somewhat initially and then becomes fairly stable.^(1,2) The finer grain structure which results from mill annealing at 1800 F (rather than solution annealing at 2100 F) has been shown to provide greater resistance to strain cycling fatigue. This is not a significant factor in the LESH prototype elements, because plastic strain cycling will not occur; nonetheless, it was thought desirable to accumulate experience on this type of material because of the probability that later cores may utilize thinner cladding. The creep strength of the mill-annealed stock is somewhat lower than that of the solution-annealed stock. However,

TABLE 2-2

CERTIFIED CHEMICAL COMPOSITION AND TENSILE PROPERTIES OF SPECIFIED INCOLOY 800 STEELS

Nominal Composition %Cr/%Ni	Remarks	Chemical Content, Expressed as a Percentage												Yield Strength 0.2% Offset, psi	Ultimate Tensile Strength, psi	Elongation in 2 in., %
		Ni	Cr	Fe	C	Mn	S	Si	Cu	B	Co	Al	Ti			
20/35	Specified tubing A-C Spec #41-703	30- 35	19- 23	Bal.	0.10 max	1.50 max	0.015 max	1.00 max	0.75 max	0.01 max	0.10 max	0.15- 0.60	0.30 0.60	30,000	75,000	30
20/35	Specified rod stock A-C Spec #41-712	30- 35	19- 23	Bal.	0.10 max	1.50 max	0.015 max	1.00 max	0.75 max			0.60 max	0.60 max	30,000	75,000	30
21/30	Certified tubing material	30.2	21.2	45.7	0.07	1.07	0.007	0.37	0.27	0.003	0.09	0.48	0.51	49,100	86,900	36.5
22/32	Certified spacing wire material	31.61	22.4	44.0	0.04	1.07	0.007	0.45	0.37	0.01	0.06	nil	nil	37,500	78,200	55

creep strength is adequate to prevent creep due to internal gas pressure buildup. Some creep collapse may occur in the form of increasing cladding ovality at the point of maximum temperature. This increased ovality can occur only where the temperature reaches 1300 F, and even then it will not result in a buckling collapse onto the fuel pellets. Collapse into the fission gas space will not occur because operating temperatures in this region are lower.

It has been demonstrated that Incoloy 800 resists general oxidation under isothermal and heat transfer conditions for periods of time equivalent to those anticipated for the LESH prototype fuel.^(1,3) It is observed that a thin adherent oxide layer forms during long term exposure, and this layer resists spalling, and thereby minimizes metal loss and further oxidation. Under stress conditions, and in the presence of chloride ions, Incoloy 800 has exhibited resistance to localized stress corrosion which is excellent relative to austenitic corrosion-resisting steels. The lower neutron activation and possible activity transport of Incoloy 800 (which is low when compared to higher nickel alloys) combined with its resistance to general oxidation and stress corrosion, favored its selection for the LESH prototype elements.

Irradiation tests performed on Incoloy 800⁽⁴⁾ at elevated temperatures with neutron exposures up to 2.0×10^{21} nvt fast neutron flux (> 1.0 Mev) indicate that yield strength and tensile strength of the alloy remain relatively stable at test temperatures up to 1100 F. Some loss of strength is observed at temperatures above 1100 F, and reduced ductility of the alloy appears to occur in all cases. Mill-annealed material displays somewhat higher strength than does solution annealed.⁽¹⁾ No severe plastic deformation is expected in the LESH prototype fuel cladding material since Incoloy 800 has demonstrated its ability to maintain sufficient strength to preserve the integrity of the prototype cladding under the expected service conditions.

Cobalt and boron limitations were added to the ASTM specification for the purpose of controlling and minimizing radioactivity carryover from products of corrosion released in the superheater. In addition, more stringent aluminum and titanium limits are specified for cladding material. The presence of aluminum and titanium in the ranges specified has been found to improve the properties of the material after irradiation at operating temperatures,⁽¹⁾ and to improve welding characteristics. These improvements are significant for the cladding material, but not for the rod stack from which end fittings are made.

On the basis of the investigations carried out, it was concluded that Incoloy 800 material, mill annealed, is the best available material to meet the requirements of the LESH-I prototype fuel elements. Therefore, this material has been specified, with appropriate modifications to the existing commercial specification, for use in these prototype elements; this material also has been specified for the full core loading.

2.4 ENGINEERING ANALYSIS AND DESIGN

The reference design criteria used for the mechanical design of the LESH prototype element include the following:

- a) Fuel element configuration and fuel rod design will be similar to the expected Core II LESH-I design; i.e., the assembly will be a seven-rod cluster with fuel rods containing sintered UO_2 and a central rod containing a burnable poison. Envelope dimensions and handling characteristics will be such that the assemblies will fit into the existing superheater and that existing handling tools can be used.
- b) The fuel rod cladding will be free standing under reactor design pressure and temperature conditions and also under expected transient conditions, i.e., the cladding will be designed to resist instantaneous buckling collapse.
- c) Diametral contact between fuel pellets and cladding will occur only under the worst expected tolerance, temperature, and burnup conditions. Creep collapse over large portions of the fuel, such as would result in wrinkling and plastic strain cycling, will not occur.
- d) The fission gas plenum will be sufficiently sized to eliminate internal pressure considerations from the clad design determination.
- e) The fuel rod assembly design will be such as to permit differential axial expansion due to temperature differences between fuel assembly components.

2.4.1 Fuel Rod Design

The LESH prototype fuel rod (Fig. 2.1, Item G3) is approximately 77.5 in. overall length. It consists of 0.247 in. OD by 0.211 ID (0.018 in. nominal wall) Incoloy 800 tubing loaded with sintered UO_2 pellets. The ends of the rod are closed by welded end plugs. Spiral spacer wires, 0.042 in. dia., are wrapped and continuously welded to each rod with approximately a 0.001 in. penetration of the weld in the cladding. Each fuel rod has three spacer wires, spaced 120 degrees apart and wrapped on a 6 in. pitch. These wires provide continuous fuel rod spacing to prevent bowing and hot spot formation, but they do not impose longitudinal restraint due to thermal expansion of the fuel rods. The fuel pellet stack rests on the bottom end plug; it is held in place by a stainless steel coil spring at the upper end which minimizes the possibility of hot spots in the fuel column due to axial gaps between the pellets. The spring is designed to prevent gross movement of the fuel within the cladding during handling and fabrication, but it allows differential expansion between the fuel and cladding during reactor operation.

Incoloy 800 was selected as the prototype design reference cladding material early in the design. The maximum steady-state cladding surface temperature was established initially as 1300 F prior to detailed stress analysis. The selection of this reference temperature and cladding material was based on a review of available corrosion, irradiation, and thermal performance data which are summarized in Sec. 2.3 of this report. Additional data developed later, presented in Sec. 3, confirmed the selection of the preliminary design temperature and of the reference cladding material.

Parametric analyses of the instantaneous buckling collapse and long term creep collapse of the cladding were made for Incoloy 800 in both the Grade I and Grade II anneal conditions in the diameter and wall thickness comprising the range of interest. Based on the instantaneous collapse analysis, with additional allowances for dimensional tolerances and corrosion, the prototype cladding thickness was selected to assure against elastic buckling collapse under worst expected transient conditions. The results of the long term creep analyses indicate that limited cladding deformation may occur and could cause local areas of the hottest fuel rods to have diametral contact with the fuel. This condition of creep collapse could occur only under the worst combination of local temperature and tolerance stack-up conditions. In the instantaneous collapse analysis and creep collapse analysis, it was conservatively assumed that the fuel rod internal pressure is zero.

2.4.1.1 Cladding Thickness Determination

In order to maintain free standing cladding, it is necessary to ensure that short term temperature and pressure transients will not cause sudden elastic collapse of the cladding onto the fuel. A parametric analysis of the cladding was performed over a range of temperatures to determine the wall thickness required to withstand collapse, assuming a maximum design pressure (675 psig; reactor vessel) as the limiting overpressure condition. Results of the analysis for Grade I mill annealed material are shown in Fig. 2.2. The calculating method used in the collapse study utilizes the tangent modulus of elasticity, and it is valid for both thick and thin walled cylinders. An existing Allis-Chalmers computer program, written for the IBM-1620 computer, was used to determine the wall thickness required to resist elastic collapse under a given external pressure, with materials properties and cladding geometry factors as input conditions. The equation used in the code is the following:

$$\sigma_{\text{total}} = \frac{PU_o}{tV} \left(1 - \frac{t^2}{G}\right) - 2P \frac{(R^2 + 2Rt + t^2)}{(2R + t)t}$$

where:

$$V = 1 - \left[\frac{P(1 - \nu^2)(2R + t)^3}{2Et^3} \right] = 1 - \frac{P}{P_c}$$

$$G = R \left[-2t + (2R + t) \ln \left(\frac{R + t}{R} \right) \right]$$

P = external pressure, psi

U_o = initial ovality = $(D_{\text{max}} - D_{\text{min}})/4$

t = wall thickness, in.

R = inside radius, in.

ν = Poissons' ratio

E = modulus of elasticity (Young's modulus), psi

σ = stress, psi

P_c = critical buckling pressure, psi

A tubing ovality of 0.001 in. was used in the analysis to reflect the limiting condition resulting from possible creep, rather than the procured condition of the tubing. Reactor transient pressure was assumed to be 675 psig, and tubing ID was taken as 0.211 in. In the analysis, Young's modulus is replaced by the tangent modulus which takes into account the nonlinearity of the material stress-strain curve, and which is defined as follows:

$$Et = \frac{d\sigma}{dE}$$

where:

$d\sigma$ = differential stress, psi

dE = differential strain, in./in.

The tangent modulus data is derived from the materials curves for Incoloy 800, mill annealed, and is expressed as a function of stress in the temperature range of concern. Test data were supplied by Huntington Alloy Products Division of The International Nickel Company, Inc.

The computer program calculates the wall thickness to limit the maximum stress to the input value or to the critical buckling stress, whichever is lower. The allowable stress values used in the analysis were taken as 70 percent of the minimum yield (0.2 percent offset). The maximum expected transient hot spot temperature of the cladding is taken as 1450 F based on Core 1 analog simulator studies. From Fig. 2.2 it is determined that the minimum design cladding thickness under limiting transient conditions is 0.0137 in.

A corrosion allowance was added to the minimum wall thickness in determining the final wall thickness. The corrosion allowance accounts for both general penetration and a compositionally disturbed layer known to develop under the oxide. Data presented in Ref. (3) was used to estimate the effects of general corrosion on the fuel cladding. The metal loss data for Incoloy 800 are reproduced in Fig. 2.3 for the 1300 F metal temperature. An allowance of 0.8 mils was selected to reflect 1 yr. operation at the 95 percent confidence limit. An allowance for the compositionally disturbed layer was estimated on the basis of further observations made by Pearl, et al. (3). The depth of this layer appears to be proportional to the square root of time. If no equilibrium alloy-phase compositional changes are reached, the layer will grow to approximately 0.0017 in. depth in 3 yrs. In a 1-yr. period, the estimated penetration rate would result in roughly 0.001 in. total penetration.

The allowance for the depth of the compositionally disturbed layer was therefore taken as 0.001 in. This is a conservative allowance, since credit is not taken for it as a structural part of the tubing. The combined total corrosion allowance on the cladding wall was taken as 1.8 mils.

The cladding is procured to required OD and ID dimensions with ± 0.001 in. tolerance allowed on both. An eccentricity limit, defined as "maximum wall - minimum wall" at any section is also specified as 0.002 in. maximum. With these tolerances the possible range of wall thickness around the nominal value is ± 0.002 in. To assure that minimum wall thickness is available, + 0.002 in. was added to account for manufacturing uncertainties.

For the 0.247 in. OD cladding, the nominal design wall thickness was determined by adding the corrosion and procurement allowances to the minimum wall thickness to resist collapse. The following figures were the basis for this determination:

minimum wall to resist collapse	0.0137 in.
total corrosion allowance	0.0018 in.
cladding procurement tolerance	<u>0.0020 in.</u>

Total 0.0175 in.

The nominal design wall thickness was selected as 0.018 in.

2.4.1.2 Creep Analysis-Parametric Study

During operation at design temperature the cladding can be expected to undergo some deformation due to creep resulting from external pressure. The design intention for the first full core loading of LESH superheater elements is to limit local creep collapse of the cladding onto the fuel pellets to a small percentage of the hottest fuel rods. The purpose of this approach is to minimize the potential for fuel and cladding interaction during operating power transients and startup-shutdown operations.

An existing Allis-Chalmers computer program, written for the IBM 1620 computer and based on theory by N. J. Hoff, et al., (5) was utilized to perform the creep analysis. The validity of the computer program was examined for the prototype application by reviewing the theory and by comparing computer program results with published test results. (6) From this work it was concluded that a reasonable basis existed for using the code to verify the creep resistance of the cladding wall under the expected operating conditions and to investigate the effects of varying tubing geometry and materials parameters.

The analysis assumes a creep rate law of the following form:

$$\frac{d\epsilon}{dt} = K \left(\frac{\sigma}{\lambda} \right)^n$$

where:

$$\frac{d\epsilon}{dt} = \text{creep strain rate, in./in. hr}$$

K = creep law constant

n = creep law exponent

λ = creep law constant

σ = cladding stress, psi

The constants in the above relation are determined by the computer code from two data points of experimental curves of creep rate (in./in. hr) vs. stress (psi). Creep rate data was obtained from Huntington Alloy Products Division, International Nickel Company literature and other published data. (1, 7) In the analysis it was conservatively assumed that the fuel rod internal pressure is zero. The code calculates cladding stress due to external pressure. Thermal stresses are localized and self relieving; therefore they are not included in the cladding stress as a cause of creep collapse.

Input conditions required for the creep analysis include (a) cladding temperature, (b) external pressure, (c) outside diameter, (d) wall-thickness, (e) initial ovality, (f) final ovality, and (g) material creep data. The computer code calculates the time to reach final ovality under the given input conditions. The tubing ovality in inches is determined as $U_o = 1/4 (d_{\max} - d_{\min})$. An initial ovality of 0.0005 in. is used and represents the procured tube condition based on specification requirements. A final ovality of 0.001 in. is assumed and represents the condition in which the minimum cladding inside diameter equals the maximum UO_2 pellet diameter at full power conditions.

The net external pressure is 600 psig. Figure 2.4 shows cases calculated over a range of temperatures and with cladding thicknesses varying between 0.012 in. and 0.020 in. on 0.002 in. increments. At the steady-state design condition of 1300 F, and with a cladding thickness of 0.018 in., the time to reach final ovality (diametral contact with fuel) is 1000 hr. At the most probable hot operating temperature of 1251 F, based on thermal and hydraulic calculations (see Sec. 3), the time is approximately 5700 hr. Upon diametral contact, further creep of the cladding will be reduced due to the supporting effect of the fuel. It should be noted that, in the analysis, the buildup of internal pressure due to the release of fission product and other gases from the UO_2 is neglected. Also, the maximum temperature of the cladding is a local effect, and some axial migration of the hot spot is expected to occur during operation. The time at maximum temperature for any one location is estimated at 4000 hr or less. In addition, the probability of minimum-clad inner diameter, maximum initial ovality, and maximum pellet outer diameter all occurring at the point of maximum local temperature is slight. The mode of collapse is also significant in determining the effect of creep on the fuel rod integrity. Elliptical collapse of the cladding occurs, which may result in line contact over small regions of the fuel rod. No buckling collapse or wrinkling will occur, thus minimizing fuel and cladding interaction. Consequently, the creep of the fuel cladding will be limited to a small region of the fuel rod, and further creep will be very slight after contact of the cladding on the fuel. The occurrence of localized creep onto the fuel is not expected to compromise the integrity of the cladding nor to limit the specified performance of the fuel.

2.4.1.3 Fuel Rod Spacing

Spacer wires are wrapped and welded to each fuel rod to provide positive equal spacing between adjacent fuel rods and the poison rod and between the fuel rods and the superheater process tube. Fuel pin diameter was established at the maximum diameter possible to satisfy thermal and hydraulic design limitations. The process tube, into which the LESH prototype element is inserted, is a part of the existing core structure. The fuel assembly envelope diameter was designed to permit easy insertion of the fuel element into the process tube, while attempting to insure a reasonably tight fit to minimize the potential for vibration.

Spacer wire diameter is the dimension which controls the fuel assembly envelope once the fuel pin size has been established. The insulating tube "as fabricated" has an inner diameter of 0.937 ± 0.001 in. Spacer wire diameter was set at 0.042 in. to provide a cold nominal assembly to process tube diametral clearance of 0.028 in. During full power operation, this nominal clearance will be decreased due to differential thermal expansion of the assembly and the process tube, although a clearance will be maintained at all conditions.

In selecting the number of spacer wires and wire pitch, the design objective was to provide as much fuel pin fixity as possible, or restraint within the process tube, without causing an unacceptable pressure drop. At the same time, the arrangement had to provide relative ease of manufacture. Equal spacing between all rods and between the fuel rods and the insulating tube requires that the spacing wires on adjacent fuel rods mesh. To assure that the wires would mesh; i.e., would not cross over other wires, the spacer wires are wrapped in opposite directions on adjacent fuel rods.

Results of air pressure drop tests performed under the Core II contract with a LESH-1 mockup⁽⁸⁾ have shown that, down to a pitch/rod diameter ratio of 25 with three wires per rod, very little increase in the effective friction factor results within the range of Reynolds' number of interest.

In the same series of tests it was shown that, for a constant pitch/diameter ratio of 25, little increase in the friction factor results when going from one to three wires per rod.

As the pitch-to-diameter ratio is decreased below 25, a substantial increase in the friction factor occurs until, at value of 8, the friction factor is about 65 percent higher than at a value of 25. From these results, a pitch-to-diameter ratio of approximately 25 was selected for the LESH element. Using the 0.247 in. dimension of the fuel rod's outside diameter results in a pitch of approximately 6.0 in. nominal.

To provide the same mechanical spacing, or fixity, which results with three wires per rod and a 6.0 in. pitch, a single wire would have to be wrapped on a 2.0 in. pitch. The pitch-to-diameter ratio would be approximately 8; and, as indicated above, the friction factor would be substantially higher. On the basis of the information presented above, it was concluded that the design would consist of three wires per fuel rod wrapped on a 6.0 in. nominal pitch.

Spacer wires are continuously welded to the fuel rod cladding for the following reasons:

(a) To assure that wires do not change their relative position during fuel element handling and insertion into the process tube. Insertion tests have shown that this problem could exist for unwelded wires.

(b) To minimize the potential for vibration of the wire, and localized corrosion of the cladding under the wire.

(c) To maintain the wire and the tubing as an integral unit after initial straining of the wire at startup due to differential expansion between the clad and the wire. Unwelded wires would be subject to permanent deformation at full power, which results in a loosened condition at low temperatures. With the close clearances required between the LESH element and the process tube, the loosened wire condition could make reinsertion of the fuel element difficult if the element was removed prior to depletion.

(d) In the unlikely event of wire breakage, to assure that the wire will be held in position.

2.4.1.4 Effect of Welded Spacer Wire on Fuel Rod Cladding

Temperature cycling of the fuel rod from shutdown to full power conditions will result in differential thermal expansion between spacer wires and the fuel rod cladding. Spacer wire temperature at any axial location can be expected to be nearly equal to the bulk steam temperature (T_B) at that location. Cladding temperature will be equal to $T_B + \Delta T_{film}$, and at the hot spot location the ΔT_{film} may exceed 300 F.

A series of analyses were made to evaluate the probable effects of continuously-welded wires on the wire-to-cladding weld stresses. From the analyses it is concluded that, locally at the hot spot temperature region during full power cycles, the wire will be subject to plastic strain cycling. Total plastic strain from initial shutdown condition to full power operation is estimated at 0.00294 in./in. The total strain is based on local temperature difference between the cladding and the wire and not on the integrated differential strain that would apply to wires welded only at the ends of the fuel rod. The strain fatigue failure correlation recommended by Coffin⁽⁹⁾ is used in the analysis.

$$N_f = 0.33 \left[\frac{c}{\Delta E_p} \right]^n$$

where:

N_f = cycles to failure

ΔE_p = plastic strain

$c = 2.01$

$n = 0.75$

The parameters c and n are experimentally determined constants for Incoloy 800 at 1300 F. It should be noted that the 0.33 factor was given in Ref. (9) as a conservative safety allowance to account for the detrimental effects of irradiation, thermal

aging, and strain hardening in the material. Using this correlation, a cyclic lifetime of approximately 45 full power cycles is estimated. Within the inherent limitations of this calculation, 45 full power cycles minimum is considered acceptable, since the total number of full power cycles is estimated to be 20.

2.4.2 UO₂ Fuel

The fuel rods of the LESH prototype element contain sintered UO₂ pellets compacted to approximately 95 percent theoretical density. These pellets are sized to prevent cladding stresses due to differential thermal expansion, and they are dished at the ends to minimize the effect of differential axial expansion. The minimum UO₂ fuel pellet density is specified as 5.56 g per in. of pellet length, or 2.406 kg per element. Final enrichment is specified as 7.5 ± 0.08 w/o U-235. The actual UO₂ loading per element is 2.505 kg with uranium of 88 percent and enrichment of 7.54 w/o U-235.

Item 9 in Fig. 2.1 shows the LESH prototype UO₂ fuel pellet design. The length was established at a minimum of one pellet diameter (to prevent cocking) and a maximum of two pellet diameters. The pellets are stacked in each fuel rod to a total active length of 72.0 ± 0.125 in. so as to meet the total rod loading requirements.

2.4.2.1 Thermal Expansion and Pellet-Design

The fuel pellets are dished at both ends to minimize the differential axial expansion between the pellet stack and the fuel tube which may cause cladding stress as, for example, by thermal ratcheting. The objective in sizing the dish was to assure that the pellet stack axial expansion is dictated by the lower temperature shoulder region rather than by the higher temperature pellet centerline region. The pellet dish depth was conservatively sized according to the differential axial expansion between the shoulder and centerline at the calculated core peak power location at full power as follows:

$$\Delta L = 1/2 \bar{\alpha}_{\text{UO}_2} L (T_c - T_o)$$

where: —

ΔL = nominal dish depth, in.

$\bar{\alpha}_{\text{UO}_2}$ = average UO₂ linear expansion, in./in. °F

L = maximum pellet length, in.

T_c = UO₂ centerline temperature, °F

T_o = UO₂ shoulder temperature, °F

The minimum required dish depth at each end of the pellet, derived from this analysis, is 0.0012 in. To allow for transient conditions, and to make pellet manufacture and inspection practical, a minimum dish depth of 0.003 in. was specified. Previous experience indicated that ± 0.003 in. is a reasonable tolerance for pellet manufacture. Therefore, the final pellet dish depth was specified as 0.006 ± 0.003 in.

The fuel pellets are sized to prevent cladding stresses due to radial thermal expansion. Pellet diameter was fixed at 0.207 ± 0.0005 in. to assure a minimum diametral cold assembly clearance of 0.0025 in. With this pellet diameter, and with a cladding inside diameter of 0.211 ± 0.001 in., the maximum diametral clearance is 0.0055 in. in the cold condition.

Analyses were made to evaluate diametral fuel to clad differential expansion for normal operating, maximum expected transient, and fuel centerline melting cases for the hot axial location in the peak power fuel rod. Results are shown in Table 2-3. For the normal operating case, a fuel element power of 96 kw was assumed with a cell peaking factor of 1.073 and an axial peaking factor of 1.30. The local UO_2 centerline temperature under these assumptions was determined as 2325 F, and the cladding temperature was assumed to be 1300 F. Cladding expansion was calculated according to the relation:

$$\Delta d_{\text{clad}} = \bar{\alpha}_{\text{clad}} (d_i) (T_{\text{clad}} - 70)$$

where:

Δd_{clad} = diametral clad expansion, in.

$\bar{\alpha}_{\text{clad}}$ = average coefficient of expansion of clad, in./in. $^{\circ}\text{F}$

d_i = inside diameter of cladding, in.

T_{clad} = cladding surface temperature, $^{\circ}\text{F}$

The diametral expansion of the UO_2 was determined as follows:

$$\Delta d_{\text{UO}_2} = \bar{\alpha}_{\text{UO}_2} (d_o) (T_{\text{UO}_2} - 70)$$

where:

Δd_{UO_2} = diametral UO_2 pellet expansion, in.

$\bar{\alpha}_{\text{UO}_2}$ = UO_2 average coefficient of expansion, in./in. $^{\circ}\text{F}$

T_{UO_2} = volumetric average UO_2 temperature, $^{\circ}\text{F}$

TABLE 2-3

CLADDING AND FUEL PELLET RELATIVE DIAMETRAL EXPANSION

Condition	Cladding Temp. (°F)	UO ₂ Centerline Temp. (°F)	Cladding to Pellet Diametral Clearance (in.)			Remarks
			minimum	nominal	maximum	
room temperature	70	70	0.0025	0.0040	0.0055	cold assembly clearance
normal operating	1300	2325	0.0029	0.0044	0.0059	peak power rod, axial hot spot location
max. expected transient	1450	2750	0.0028	0.0043	0.0058	maximum transient cladding temperature, 20 percent over power
centerline melting	1450	4365	0.0001	0.0016	0.0032	centerline assumed at UO ₂ melting point (highly improbable case)

For the maximum expected transient condition, a cladding temperature of 1450 F was assumed and 120 percent fuel element power was used. Assumed UO₂ centerline melting was also calculated for comparison purposes, although this condition is not expected to occur. Under the assumed conditions, at the peak power location, cladding expands a relatively greater amount than the fuel pellets. Consequently, interaction or clad straining is not anticipated due to differential thermal expansion.

The axial differential expansion of the fuel column and the cladding was calculated for the peak power fuel rod at steady-state conditions. The pellet stack expansion was determined by performing an axial integration of the fuel pellet length increase based on the UO₂ temperature at the pellet shoulder. Cladding linear expansion was determined by numerically integrating $\alpha_{clad} \Delta T_{clad} dL$ along the 72.0 in. active fuel region. The following results were obtained:

$$\Delta L_{clad} = 0.674 \text{ in.}$$

$$\Delta L_{UO_2} = 0.458 \text{ in.}$$

The total differential axial expansion at the upper end of the active fuel region is, therefore, 0.216 in. The differential expansion at points below this region is progressively less and becomes zero at the bottom of the pellet stack.

2.4.3 Fission Gas Release and Internal Pressure Buildup

The fission gas plenum for the LESH prototype element is located above the active core region where it can be sized to accommodate the fission gas release without causing a reduction in fuel volume in the core. The fuel pellets are stacked continuously in the active fuel region, thus avoiding flux peaking from intermittent voids such as would occur in a segmented fuel rod design, and simplifying design and fabrication of the fuel element. The fission gas space length was fixed at 3 in. on the basis of conservative calculations made early in the design of the element, to fulfill the criterion of providing sufficient volume to eliminate internal gas pressure from fuel cladding design considerations. Subsequent calculations based on detailed power and temperature distributions of the peak power fuel rod confirmed that this objective was met.

The analysis of the fission gas release and internal pressure buildup within the cladding was based on the maximum power fuel rod in the LESH prototype element located in the core at the maximum power radial position, and producing 96 kw. A relationship for the absolute pressure within the cladding was developed as a function of the average fission gas temperature in degrees K and the equivalent full power operating time in hours. This relationship is dependent on (a) the amount of fission gases generated using the conservative assumption of 0.34 noble gas atoms per fission, (b) the fission gas release fraction which is a function of volumetric average temperature, (c) the additional gas contribution resulting from moisture and nitrogen content of the fuel and fill gas, (d) the void space within the cladding, and (e) the temperature of the gases at the time of interest.

The fission gas analysis was carried out by segmenting the active fuel length and determining average fission gas generation and release for each segment. The fission gas released in all segments was summed, and to this total were added the additional gases present to give the total free gas mixture as a function of equivalent full power operating time. This gas mixture was assumed to obey the ideal gas law; under this assumption, an expression for internal gas pressure as a function of temperature was developed. To relate the pressure to cladding stresses, a relationship for the generalized stress component based on Von Mises's failure criteria was determined as a function of internal pressure. Stresses for the expected operating conditions were then compared with the material yield stress data and were found to be well below the 0.2 percent offset minimum specified yield strength at the required temperatures.

The detailed calculational procedure for the fission gas analysis is as follows:

(a) The maximum power fuel rod is divided into 12 equal axial segments each 6 in. long. Average values of volumetric heat generation and average UO_2 temperature are calculated and are used to determine average amount of fission gases released from each segment in the subsequent steps of this calculation.

(b) The rate of noble fission gas atom generation (r_n) is calculated for each axial segment in gas atoms per hour as:

$$r_n = \bar{f}_n N_g [P/A]_n$$

where:

$\bar{f}_n = 1.67 \times 10^{17}$ = the calculated average fissions per segment per hour for the hottest fuel rod.

$N_g = 0.340$ = estimated number of noble gas atoms produced per fission. This value is conservative compared to reported data in Ref. (10).

$[P/A]_n$ = axial peak-to-average power factor for the n^{th} segment.

(c) The volume average UO_2 temperature was calculated for each segment using a constant volumetric heat generation for each axial segment and the average UO_2 fuel surface temperature as follows:

$$\text{VAT}_n = [\bar{T}_s]_n + \frac{\bar{q} r^2 [P/A]_n}{8\bar{k}}$$

where:

VAT_n = volumetric average UO_2 temperature.

$[\bar{T}_s]_n$ = average surface temperature for the n^{th} segment.

$\bar{q}$ = volumetric heat generation rate, average for the high power rod.

$[P/A]_n$ = axial peak-to-average for the n^{th} segment.

$\bar{k}$ = UO_2 thermal conductivity.

r = UO_2 pellet radius.

The value of thermal conductivity used in the analysis was chosen to provide a conservative result considering effects of irradiation, clearance between cladding and fuel, and temperature dependence. The effective value of thermal conductivity was selected as 1.0 Btu/hr ft $^{\circ}\text{F}$. The hot fuel rod average volumetric heat generation was calculated on the basis of a hot fuel element power of 96 kw and a cell radial peak-to-average ratio of 1.073. A plot of the UO_2 volumetric average temperature used in the fission gas analysis is shown in Fig. 2.5.

(d) Fission gas release fractions were determined for each segment as a function of the segment volume average temperature. Release data presented in Ref. (11) were used in this determination. To the release fraction curve in this reference, a second curve was drawn to represent the upper limit of data scatter. Release values were obtained from this latter curve.

(e) Gas atom release rates were calculated for each segment using the product of the generation and fraction release factors previously determined. The total fission gas release rate to the rod free volume was then obtained by adding the individual rates from each segment.

In addition to the released fission product gases, additional contributions to the total free gas mixture were included as follows:

H ₂ O	35 ppm based on UO ₂ volume, 100 percent release
Nitrogen	20 ppm based on UO ₂ volume, 100 percent release
Fill gas	volume of gas initially in plenum

The H₂O and N₂ quantities are the maximum permitted by the fuel pellet specification.

The above assumptions result in an additional gas volume of 1.5964 in.³ measured at standard conditions. Internal gas pressure was calculated using only the free volume available in the fission gas plenum, neglecting the fuel pellet dish volumes and the volume contributions of the pellet to the cladding diametral clearance.

The ideal gas law was assumed to be applicable in the range of partial pressures and temperatures anticipated. Using the ideal gas equation, with initial gas volume and fission gas atom release rate, a time-temperature equation was developed for rod internal pressure:

$$P(\tau, T_2) = 0.288 \left[1.5964 + 1.67 \times 10^{-4} \tau \right] T_2$$

where:

τ = equivalent full power operating time, hr

T_2 = average absolute temperature of the gas in the fission gas plenum, °K

This equation was written to facilitate the determination of pressure as a function of equivalent full power operating time, and to plot curves at various gas temperatures to represent significant operating conditions.

Pressure vs. time curves were generated for full power, shutdown, and abnormal shutdown radiant decay heat dissipation cases. These curves are plotted in Fig. 2.6. The average fission gas temperature during full power operation was estimated at 500 F,

based on 489 F saturated steam temperature at the superheater inlet. Gas temperature when the reactor is shut down is estimated to be 100 F maximum. For the abnormal shutdown case, 900 F was selected as the average gas temperature based on previously determined temperature distribution curves. These curves describe fuel element temperature at various locations due to decay heat, zero steam flow condition. The 900 F temperature is calculated for the upper end fitting region, assuming decay-heat steady-state conditions 0.01 hr after shutdown. Gas temperature is assumed to be that of the upper end fitting under these conditions.

Figure 2.6 gives a maximum end of life (8750 hr) internal gas pressure of approximately 1210 psig for the radiant decay heat shutdown condition. This is not a normal expected condition. For the full power normal operating condition, the maximum expected internal pressure is 860 psig. Differential pressure across the cladding is the meaningful parameter in these analyses, as it controls cladding stresses. As shown in Fig. 2.7, the internal pressure is less than reactor pressure up to approximately 3500 hr. At the end of life condition of 8750 hr, the maximum internal ΔP across the cladding wall is approximately 245 psi operating, 500 psi at normal shutdown, and 675 psi for the radiant decay heat shutdown condition.

In the region of the tubing away from the end restraints, the equations used to calculate cladding stresses are based on thick walled cylinder theory. The equations are the following:

$$S_{hi}, \text{ Hoop Stress, inside} = \left(\frac{y^2 + 1}{y^2 - 1} \right) P$$

$$S_{ho}, \text{ Hoop Stress, outside} = \left(\frac{2}{y^2 - 1} \right) P$$

$$S_a, \text{ Axial Stress} = \left(\frac{1}{y^2 - 1} \right) P$$

where: $y = \frac{(R_i + t)}{R_i}$

R_i = cladding ID

t = cladding wall thickness

P = net internal pressure

The radial stress is zero on the outside surface and $-P$ on the inside surface. The maximum stress condition occurs at the inside surface. Using Von Mises's maximum shear energy theory of failure, the generalized stress to be compared with the temperature-dependent stress limit is given by the equation:

$$S = \left\{ \frac{1}{2} \left[(S_h - S_a)^2 + (S_a - S_r)^2 + (S_r - S_h)^2 \right] \right\}^{1/2}$$

Basic cladding stresses not including end plug effects for the three limiting conditions are approximately 1750, 3575, and 4820 psi, respectively. Local end plug effects may increase these values by a factor of about two; thus the maximum stress is of the order of one-half the minimum specified yield strength at the temperature at which this stress occurs. A plot of the cladding stress due to net internal pressure vs. equivalent full power operating time is presented in Fig. 2.8.

It should be noted that the fission gas predictions are conservative in that the data and methods used are conservative and that the maximum calculated fuel centerline temperatures for the steady-state condition are at a relatively low level. As an indication of this conservatism, published test results from Chalk River indicate that in dense sintered UO_2 , "all of the fission gas produced up to 100,000 Mwd/ton will be retained below 800 C (1472 F). Retention is completely effective to 15,000 Mwd/ton up to 1200 C (2192 F)."(12) These results would indicate that only a small amount of the fission gases generated in the prototype fuel would be released and would contribute to internal gas pressure. Also, actual moisture content of the fuel pellets is well below the maximum allowed by the specification.

WIRES ARE 120° APART ON
6 INCH PITCH AS SHOWN
ON FUEL PINS ONLY (SEE NOTE 6)

WIRES ON PINS ARE WOUND
ALTERNATELY CLOCKWISE AND
COUNTERCLOCKWISE AS SHOWN
BY INDICATION ARROWS

934 MAX ENVELOPE
AT ANY SECTION
(SEE NOTE 4)

WIRE POSITION
TYPICAL
FUEL PIN
ANY SECTION

SPRING DATA		
PC. NO.	12	17
LOAD RATE	3LB/IN	965LB/IN
COIL O.D.	.195 ±.005	.204 ±.005
WIRE GAGE		.022 ±.002
FREE LENGTH	4.0	5.0
SPRING TO BE PASSIVATED TO REMOVE ALL COATINGS		
ENDS-SQUARED AND GROUND		
DIRECTION OF COILS-OPTIONAL		

.020 MAX
PROJECTION
TYP 4 PLACES

NOTES:

1. FINAL DIMENSIONS IN THIS AREA ARE TO BE DETERMINED DURING WELD DEVELOPMENT.
2. WIRES, ITEM 16, ARE TO BE ATTACHED TO FUEL TUBES BY CONTINUOUS HIGH FREQUENCY RESISTANCE WELDING.
3. BREAK ALL SHARP EDGES. .005 TO .010 X 45° CHAMFER (APPROX.).
4. FINISHED ASSEMBLY SHALL FIT INTO A .3285 ± .0005 INSIDE DIA. X 4.0 LONG GAGE AND SHALL ALSO FIT INTO A .932 ± .001 INSIDE DIA. X 84.0 LONG GAGE. ELEMENT MUST FIT INTO 84.0 LONG GAGE UNDER ITS OWN WEIGHT WITH NO ADDITIONAL INSERTION LOAD APPLIED. DESIGN OF BOTH GAGES MUST BE APPROVED PRIOR TO FABRICATION.
5. FINAL DIAMETER FOR ITEM 13 IS SPECIFIED AS A FUNCTION OF FINAL AS-FABRICATED BORON CONCENTRATION IN PROCEDURE SPECIFICATION 41-716.
6. NOMINAL PITCH BETWEEN 5 AND 7 INCHES IS ACCEPTABLE. SIX (6) INCH PITCH IS PREFERRED. TOLERANCES ON WIRE POSITION ARE AS SHOWN IN APPLICABLE DETAILS.
7. WIRE ENDS CAN BE POSITIONED ANYWHERE WITHIN LIMITS SHOWN. WIRES AT ANY END OF AN INDIVIDUAL TUBE SHOULD START WITHIN ± .125 OF EACH OTHER.
8. ALL TOLERANCES MARKED (K-L) SHALL APPLY BETWEEN POSITIONS K AND L, AS SHOWN ON ITEM 15 (LONGITUDINAL VIEW). ALL TOLERANCES MARKED (L-M) SHALL APPLY BETWEEN POSITIONS L AND M AS SHOWN ON ITEM 15 (LONGITUDINAL VIEW).

EACH SLOTTED FITTING —
IS TO BE MARKED IN .12 HIGH NUMBERS
WITH VIBRATOOL IN NUMERICAL SEQUENCE
USING NUMBERS 1 THRU 12.

18	PIN	2			41-500-680-018 .0940 DIA X .328 LG
17	SPRING		1		55T-304 ASTM A-276
16	SPACER WIRE		AR		41-500-680-016 INCOLOY-800 AC-SPEC. 41-713
15	LOWER END FITTING	1			41-500-680-015 INCOLOY-800 ASTM B 408
14	RETAINER RING	1			41-500-680-014 INCOLOY-800 ASTM B 408
13	POISON WIRE		1		41-500-680-013 BORON-55T AC-SPEC. 41-716
12	SPRING		1		41-500-680-012 ASTM A-313 SEE SPRING DATA
11	SPACER				41-500-680-011 55T-304 L ASTM A-276
10	POISON PIN SPACER		AR		41-500-680-010 ALUMINA AC-SPEC. 41-717
9	FUEL PELLET		AR		41-500-680-009 URANIUM DIOXIDE AC-SPEC. 41-718
8	TUBE		1		41-500-680-008 INCOLOY-800 AC-SPEC. 41-717
7	UPPER FITTING		1		41-500-680-007 INCOLOY-800 AC-SPEC. 41-717
6	SLATED FITTING		1		41-500-680-006 INCOLOY-800 AC-SPEC. 41-717
5	LOWER FITTING		1		41-500-680-005 INCOLOY-800 AC-SPEC. 41-717
4	LIFTING FITTING		1		41-500-680-004 INCOLOY-800 AC-SPEC. 41-717
3	POISON PIN	1			41-500-680-003
2	FUEL PIN	6			41-500-680-002
1	FUEL ELEMENT				41-500-680-001
		61	62	63	
PC	INDEX			GROUP NO. & QUANTITY	DWG. NO. & SERVICE PART NO. OR DESCRIPTION & MATERIAL

	G1-FUEL ELEMENT ASSY	
	G2-POISON PIN ASSY	
	G3-FUEL PIN ASSY	
A	BM SAME	
	WT. R. F.	
6.00	SPEC. NO. 41-716	
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UNLESS OTHERWISE NOTED
MACHINING TOLERANCES ARE

1 PLACE DECIMAL = .030	MACHINE SURFACE TEXTURE
2 PLACE DECIMAL = .0030	125
3 PLACE DECIMAL = .010	VRM

ANG. MACHINING DIMENSIONS $\pm .005$
CHAMFER & WELD PITCH = 20°

TOLERANCES DO NOT APPLY TO
COMMERCIAL STOCK OR PARTS
MATERIALS. DIMENSIONS FOR SUCH
ITEMS ARE NOMINAL.

NUMBERS SHOWN THUS: $\frac{1}{2}$
ARE PART NUMBERS AND ARE NOT
DIMENSIONS. DIMENSIONS ARE SHOWN THUS: $\frac{1}{2}$

DWG. SIZE: 11.500 - 11.500 - 50

APPROVED FOR CONSTRUCTION

APPROVAL	DATE
DR. BRYANT	3-25-65
CHD. GRS	4-15-65
APP. <i>[Signature]</i>	5-20-65
APP. <i>[Signature]</i>	5-21-65
APP. <i>[Signature]</i> R.F.B.	5-21-65
APP. <i>[Signature]</i>	5-21-65
APP. <i>[Signature]</i>	5-24-65
APP. <i>[Signature]</i>	
PROJECT	
PATHFINDER	

ALLIS-CHALMERS
MANUFACTURING COMPANY
ATOMIC ENERGY DIVISION
BETHESDA, MARYLAND

**PATHFINDER
L.E.S.H.**

PROTOTYPE FUEL ELEMENT

DWG. NO. **41-500-680**

SCALE 2:1 & NOTED DIMS & C/A

REV. **04**

FIG. 2.1

FIG. 2.2

CORROSION RATE OF INCOLOY 800 IN SUPERHEATER STEAM
(Reproduced from report GEAP-4760) Fig. 2)

FIG. 2.3

MODEL

DATE

CREEP COLLAPSE OF FUEL CLADDING FOR INCREMENTAL WALL THICKNESS

FIG. 2.4

AVERAGE UO_2 TEMPERATURE USED IN FISSION GAS ANALYSIS

FIG. 2.5

Note: Initial gas pressure is due to assumed complete release of N_2 and H_2O at the beginning of life and initial He and air fill gas.

INTERNAL ROD PRESSURE INCREASE DUE TO FISSION GAS RELEASES

FIG. 2.6

NET CLADDING PRESSURE FOR FUEL ROD OPERATING CONDITIONS

FIG. 2.7

CLADDING STRESS DUE TO NET INTERNAL PRESSURE VS. EQUIVALENT
FULL POWER OPERATING TIME

FIG. 2.8

3. THERMAL AND HYDRAULIC ANALYSIS

3.1 INTRODUCTION

This section presents the thermal and hydraulic analysis of the LESH prototype elements for the Pathfinder superheater core. The analysis is based on the assumption that the fuel poison loading and planned in-core locations for these elements will simulate maximum cladding temperature expected for the full LESH core.

3.2 SUMMARY OF THERMAL-HYDRAULIC CHARACTERISTICS

Table 3-1 is a compilation of the major thermal-hydraulic characteristics of the LESH I prototype assemblies. The LESH I prototypes will be located near the superheater shroud in the high flux region. The nominal channel and hot channel values presented in Table 3-1 represent the normal and severe conditions, respectively, expected at this location. Actual performance is expected to be closer to that anticipated for the nominal channel than to that of the hot channel.

The steam flow rate expected in the LESH assemblies is 1322 lb/hr, which is essentially the same flow through a HESH assembly at that location. Therefore, no perturbation in normal flow through the adjacent HESH assemblies is expected as a result of loading the LESH prototype assemblies in the core.

The seven-rod cluster configuration for the LESH I prototype is composed of six fuel rods and a central poison rod arranged on an equilateral triangular pitch. The fuel rods in the LESH assemblies are spaced relative to one another with spiral wire welded to each fuel rod. The fuel and poison rods are welded to the lower end fitting which supports and spaces each individual rod. The upper end fitting allows for longitudinal expansion of the fuel rods and provides a handle for lifting the assembly.

The LESH pin size (0.247 in. OD) was determined from a parametric study based on Pathfinder Core II superheater requirements. For this analysis, a Core II pressure drop of 75 psi was assumed in conjunction with a thermal design limit of a steady-state hot channel, hot spot surface temperature of 1300 F.

The power output assigned to the LESH I prototype elements was calculated from a hot channel, hot spot analysis which is assumed to produce a steady-state surface temperature of 1300 F. The pressure drop across the LESH I prototype and flux level was consistent with Core I. The relations used to assess the pressure drop characteristics of the LESH I prototype element were based on conventional loss coefficients and friction factors which were adjusted to be consistent with the experimental results obtained in the air pressure drop tests for mock-up elements similar to the prototype.

The maximum fuel and poison pin centerline temperatures were evaluated to insure that no melting occurs in the UO₂ fuel ($h = 1.1$ Btu/hr ft °F) or boron s.s. poison during full power operation. These centerline temperatures were found to be 2300 F and 1107 F, respectively.

TABLE 3-1

SUMMARY LESH I PROTOTYPE FUEL ELEMENTS
THERMAL AND HYDRAULIC CHARACTERISTICS

For Superheater Core

Total Power (Thermal)	28.5 Mw
Total Steam Flow	6.16×10^5 lb/hr
Core Pressure Drop	60.4 psi
No. of HESH Elements	409
No. of LESH I Elements	2

Geometry

Ref. Drawing	41-500-680, Rev. 04
Process Tube ID	0.937 in. (cold); 0.944 in. (hot)
Pin Diameter	0.247 ± 0.001 in.
Spacer Wire Diameter	0.0420 ± 0.0005 in.
Cladding Thickness	0.018 ± 0.002 in.
Active Fuel Length	6.0 ft

<u>For LESH Prototype</u>	<u>Maximum Power Channel</u>	<u>Maximum Power Channel With Hot Channel Factors Applied</u>
Peak Surface Temperature, °F	1015	1253
Coolant Rise Uncertainty Factor	1.0	1.157
Film Drop Uncertainty Factor	1.0	1.662
Assembly Flow Rate, lb/hr	1322	1242
Mean Steam Inlet Temperature, °F	489	489
Steam Outlet Temperature, °F	885	996

Power Shape

Axial Peaking Factor	1.52
Fuel Assembly Radial Peaking Factor	1.31
Fuel Rod Radial Peaking Factor	1.085
Overall Peaking Factor	2.16

Comparison with HESH Geometry

$$\frac{\text{Heat Transfer Area LESH}}{\text{Heat Transfer Area HESH}} = 0.528$$

$$\frac{D_e \text{ LESH}}{D_e \text{ HESH}} = 1.285$$

$$\frac{A_f \text{ LESH}}{A_f \text{ HESH}} = 0.957$$

The radiative cooling capacity of the reference design element was calculated for conditions simulating shutdown; i.e., no steam flow. Fuel and poison pin surface temperatures were calculated as a function of the decay power level within the assembly. At about 1/2 min after shutdown with no steam flow, the maximum cladding temperature within the core, conservatively assuming heat flow only in the radial direction and neglecting the heat capacity of the fuel assembly, is about 1450-1500 F in the poison pin at the peak flux location. This temperature can be expected to decrease rapidly with time. At 1 min after shutdown, the decay heat release rate is expected to be reduced to about 1/3 of what its value was at 1/2 min; thus the maximum poison cladding temperature is reduced to 970 F.

3.3 DISCUSSION OF RESULTS AND CONCLUSIONS

3.3.1 Introduction

The LESH I prototype thermal and hydraulic design analysis was performed concurrently during the evolution of the mechanical design. Subsequently, preliminary analyses were performed on the conceptual design. The preliminary calculations served to define tentative hardware. The prototype hardware was tested to establish hydraulic correlations on which to base final calculations. These tests also served to refine the LESH I prototype design. The calculations performed on the LESH I prototype are divided into those pertaining to the preliminary design phase and those involving the final design.

3.3.2 Preliminary Calculations

The pressure drop across the prototypes is determined by the 409 HESH elements in Core I. The total pressure drop across the prototype assembly was fixed at the HESH Core I value of 60.4 psi for all analyses. The pressure drop within the assembly is considered in two components:

(a) The friction loss in the fuel bundle which represents a major portion of the pressure drop. This pressure drop was determined using the actual flow area and the actual wetted perimeter (i.e., including the spacer wires). The friction factor (Moody) is computed using the correlation $f = 0.226/Re^{0.2}$ which is based on experimental data from EGCR elements⁽¹³⁾. The influence of the axial pitch of the spacer wires was accounted for by multiplying the friction factor f with a wire pitch factor $F_p = 1.15$. The wire pitch factor was derived from experimental data for a seven-pin cluster.

(b) The form loss in the end fittings, which was computed by standard methods resolving the end fittings into a series of abrupt contraction and expansion losses.

The power output and flow rate which met the two design criteria of 1300 F peak surface temperature and 60.4 psi pressure drop from the preliminary design analysis were 82.56 kw and 1210 lb/hr on a per element basis.

The radiative cooling ability at the elements was calculated using two different models. One model resolved the six fuel rods into a "fuel ring" of equal volume centered symmetrically between poison tube and process tube. The temperature drop through the fuel ring is calculated using a conductivity value of 1.8 Btu/hr ft °F. The other model is a "fuel plane," with no temperature drop through the radiating plane. In both models, an 0.8 emissivity value of the radiating surface was used; this value corresponds to the value used to correlate HESH data. The "fuel ring" gives a poison tube surface temperature of about 75 F lower than the "fuel plane" in the heat dissipation region anticipated during shutdown (about 2000 Btu/hr-ft of fuel bundle). It was found that, even for the more conservative "fuel plane" model, the heat dissipation rate of the prototype elements is almost identical to that for the HESH element. The power output of a prototype element will be less than the output of a maximum power HESH element (102 kw). Therefore, the poison tube surface temperature of the prototype elements will always be lower than that of a hot HESH element during a no-steam flow condition.

3.3.3 Final Design Analysis

Air pressure drop tests were run on the reference design element. Of primary concern was the pressure loss in the fuel bundle, since this is the major component of the pressure loss in the element, and some uncertainty is involved in predicting the pressure loss through the spiral wire spacers by existing methods. The pressure drop characteristics for the reference design assembly were experimentally determined. A constant friction factor, $f = 0.19$ was found to apply for the prototype reference element in the region of rated flow. This value runs about 15 percent higher than that given by the Moody smooth pipe correlation, the effect of wire spacers being approximately that estimated during the preliminary calculations. The experimentally determined loss coefficients based on the flow area in the fuel bundle were 6.1 and 1.3 for the upper (entrance) end fitting and lower (exit) end fitting, respectively.

These test results were used to critically review the calculated pressure drop values for the prototype elements. The pressure drop associated with the upper end fitting was found to be high. The design of this component was improved. The modifications of the end fitting design permitted an increase of flow through the LESH prototype for the fixed 60.4 psi core pressure drop. The increased flow resulted in lower fuel clad temperatures. Since it was intended that these prototypes operate near the 1300 F hot spot limit, the power was increased to 91 kw by increasing the fuel enrichment. The power level of 91 kw was set prior to the Pathfinder Power Escalation Program; as a result, the hot channel factors used had not had the benefit of a review based upon experimental data. However, at this time Pathfinder has completed the power escalation program through 85 percent power.

The performance of the LESH prototypes has been reevaluated based upon this information which includes reevaluation of coolant temperature rise uncertainty factors and film drop uncertainty factors. In addition, the heat transfer coefficient correlation has been changed from

$$(Nu)_f = 0.0214 (Re)_f^{0.8} (Pr)_f^{0.333}$$

to

$$(Nu)_f = 0.0133 (Re)_f^{0.84} (Pr)_f^{0.33}$$

based upon recent pressurized steam heat transfer test data obtained by Allis-Chalmers for the Pathfinder LESH-I Core.

With this most recent information, the prototype fuel assembly performance in a maximum power channel is shown in Table 3-1. Note that the maximum temperature including hot channel factors is below the 1300 F limit. However, it is close enough so that the advanced information gained by in-pile testing of these prototype assemblies will be useful in preparing the design for subsequent low enriched superheater cores.

Table 3-2 shows the composition of the film temperature rise and bulk temperature rise uncertainties factors used in calculating the data in Table 3-1.

TABLE 3-2

HOT CHANNEL FACTORS IN TEMPERATURE CALCULATION

<u>Uncertainty</u>	<u>Factor for Coolant Rise F_B</u>	<u>Factor for Film Temperature Drop, F_F</u>
Fuel concentration	1.035	1.075
Heat flux distribution	1.10	1.20
Heat generation in poison rod	1.016	--
Film heat transfer correlation	--	1.15
Cladding circumferential temperature peaking	--	1.12
Fuel-element dimensions	(Included in hot channel com- puter calculation.)	
Product (excluding fuel-element dimensions)	1.157	1.662

4. PHYSICS ANALYSIS

4.1 INTRODUCTION

This section deals with the physics analysis performed on the Pathfinder LESH prototype elements. The two prototypes have a fuel enrichment similar to that proposed for the LESH I core. The poison content, however, was adjusted so that the neutron absorption characteristics of the prototypes will be similar to the existing HESH elements in order to avoid undue flux or power perturbation in surrounding elements during reactor operations.

A quarter cell layout of the prototype elements is shown in Fig. 4.1. As stated in Sec. 2, the prototypes are composed of six Incoloy clad fuel pins containing UO_2 and a central Incoloy clad poison pin containing a boron stainless wire. The fuel pin and poison pin are separated from each other and from the inner superheater process tube by spirally wound Incoloy spacer wires. The enrichment and poison loading are 7.5 w/o of U-235 in uranium and 2.76 g of natural boron respectively. The prototype elements are to be placed in core locations within the superheater so that they will generate an element power near the maximum limit of 96 kw, which corresponds to a maximum peak surface temperature of approximately 1300 F as indicated from the thermal analysis presented in Sec. 3.

4.2 CALCULATIONAL METHODS

The calculational methods used for the prototype analysis are identical to those developed during the Phase I testing and currently in use for Pathfinder.

Three group cross sections for the prototype elements were obtained for various enrichments and poison loadings. The cell geometry for the prototypes is that shown in Fig. 4.1. However, the volume of UO_2 was reduced by 1.1 percent to account for the dished ends on the individual fuel pellets.

The fast group cross sections were obtained with MUFT⁽¹⁴⁾. For the MUFT calculation, the cell was homogenized by volume-weighting of all materials. The U-238 absorption cross section was obtained by Hellstrand's method.⁽¹⁵⁾

For survey calculations, thermal cross sections were obtained by the SOFOCATE-I₂^{(16) (17)} routine. For these cross sections, the cell was homogenized by volume weighting and flux weighting all the materials. The flux weighting factors were obtained from I₂ and the thermal cross sections from SOFOCATE.

For the final calculations, once a tentative enrichment and poison had been selected, thermal cross sections were obtained by a MARC⁽¹⁸⁾ calculation with explicit representation of the fuel pins and central poison wire.

In Table 4-1, the reference three group cross sections are given for an enrichment of 7.5 w/o and a poison loading of 2.76 g of natural boron per element. Also included in Table 4-1 are the HESH cross sections to be used for comparison.

TABLE 4-1

THREE GROUP CROSS SECTIONS

<u>Cross Section</u>	<u>Prototype</u>	<u>HESH*</u>
$D_{1,2}$	2.0972	2.1396
$D_{2,2}$	0.8909	0.8551
$\Sigma_{a1,2}$	0.002818	0.002182
$\Sigma_{a2,2}$	0.01779	0.01073
$\Sigma_{r1,2}$	0.02768	0.02749
$\Sigma_{r2,2}$	0.04146	0.04600
$\nu\Sigma_{f1,2}$	0.00205	0.000623
$\nu\Sigma_{f2,2}$	0.01351	0.010278
D_{th}	0.3713	0.3799
Σ_{ath}	0.10077	0.10011
$\nu\Sigma_{fth}$	0.1171	0.10603
k_{∞}	1.0121	0.9845

*Contains central boron poison pin.

Again, using Phase I methods, two XY-PDQ's⁽¹⁹⁾ with explicit control rod and geometric representation were run to determine the elementwise peaking and the local pointwise peaking in the two prototype elements. The first analysis was an all rods out case, and the second analysis had rod Groups IV and V inserted. The prototype core locations used in the XY analysis are presented in Fig. 4.2.

4.3. RESULTS

The radial peaking factor, superheater power, and the power per element for the prototype in the hot channel location are presented in Table 4-2 for the all-rods-out case and for the rod Groups IV and V inserted case. The all-rods-out case (end of Pathfinder reactivity life) has the highest radial peaking factor, while the rod Groups IV and V inserted case (xenon and samarium free beginning of reactivity life) has the highest superheater power. These two cases then represent high power operating conditions for the prototype elements.

Power distribution analysis has shown that the superheater maximum power peak occurs with Groups IV and V partially inserted. Calculations were performed to obtain HESH power

TABLE 4-2

RADIAL PEAKING FACTORS AND POWER LEVELS^(a)

<u>Case</u>	<u>P(XY)^(b)</u>	<u>P_{SH} (%)</u>	<u>LESH Power (kw)</u>
All rods out	1.332	14	82.9
Rod Groups IV, V, in	1.253	18.3	107.2

(a) For the element in the SH hot channel (location #1 in Fig. 3.2).

(b) Flux tilt factors are included in P(XY).

peaks as a function of Group IV and V withdrawal for the Pathfinder I escalation to full power. Axial distributions from these calculations were used to synthesize the LESH radial results shown in Table 4-2. Two such axial slopes are shown in Fig. 4.3. Results of this analysis applied to the prototypes are given in Table 4-3. The power for the LESH prototype element located in the central portion of the Superheater core (location #2 in Fig. 4.2) and that for the average HESH element are presented in Table 4-4.

The core reactivity is increased by 0.01 to 0.02 percent Δk by the addition of the two prototype elements.

The variation in element power and/or hot spot factors due to manufacturing tolerances in the UO₂ and boron stainless steel wire is shown in Table 4-5. The estimated burnup for the two prototype elements vs. months of core operation with an 0.8 load factor (LF) is presented in Table 4-6. The estimated boron-10 depletion in the central boron stainless poison wire for the prototype element in location 1 is presented in Table 4-7.

The results of out-of-pile radiation heat transfer tests performed by Allis-Chalmers for the LESH-I core confirm the preliminary analysis work discussed in Sec. 2.3.2. The LESH design radiates heat more efficiently than the HESH design, and it therefore results in lower temperatures during shutdown periods when there is no steam flow.

TABLE 4-3

LESH POWER PEAK FACTORS

Rod Groups IV and V Partially Inserted

Radial Peak-to-Average	1.31
Axial Peak-to-Average	1.52
Superheater Power Fraction	0.150
LESH Power (low)	91

TABLE 4-4

POWER PER ELEMENT (LOCATION #2)

<u>Case</u>	<u>Average HESH Element (kw)</u>	<u>LESH Location 2 (kw)</u>
All rods out	62.2	53.3
Rod Groups IV, V, in	85.6	80.0

TABLE 4-5

POWER AND HOT SPOT VARIATION

<u>Variation</u>	<u>Power and Hot Spot Variation</u>
Poison content (1.65 w/o $\pm$ 0.03)	$\pm$ 0.5%
UO ₂ density (5.56 to 5.86 g/in.) ^(a)	$\pm$ 0.05%
U-235 enrichment (7.5 w/o $\pm$ 0.08)	$\pm$ 0.15%
Total	$\pm$ 0.7%

(a) The UO₂ density variation includes both the density variation and the pellet dimension tolerances.

TABLE 4-6

PROTOTYPE ELEMENT BURNUP (Mwd/MTU)

<u>Location</u>	<u>9 Months Operation (0.8 LF)</u>	<u>15 Months Operation (0.8 LF)</u>
#1	9100	15,200
#2	6740	11,250

TABLE 4-7

BORON-10 DEPLETION

<u>Operating Time (Mo.)</u>	<u>Average Point</u>	<u>Maximum Point</u>
9	50%	70%
15	80%	95%

4.4 CONCLUSIONS

The two LESH prototype elements meet the stated design criteria. Assuming that the reactor is operated with rod Groups IV and V partially inserted, the prototype element in the corner location will produce approximately 91 kw, which is under the maximum allowable power of 96 kw. As can be seen from the cross sections in Table 4-1 and the negligible increase in core reactivity, the two prototype elements are similar in design to the HESH elements and will not cause significant power or flux perturbations.

To more fully evaluate future LESH cores, it would be desirable to obtain operating data for the prototypes under the most severe operating conditions, i.e., a maximum peak surface temperature of 1300 F and a burnup greater than the worst LESH I element. Therefore, it is recommended that the following loading procedure be used. During the first 9 months of reactor operation, both the prototype elements will be loaded in SH hot channel locations. When the HESH is replaced by LESH I at 9 months, the two prototypes are switched to a central location (location #2 in Fig. 4.2) for additional burnup before removal at 15 months. Utilizing this loading procedure, both prototypes will operate near the maximum peak surface temperature of 1300 F for 9 months; additionally, they will achieve a burnup of approximately 13,610 Mwd/MTU, which is slightly more than the highest burnup that LESH I elements will achieve. This loading procedure will provide added assurance that LESH elements can operate satisfactorily in high power superheater locations.

PROTOTYPE QUARTER CELL LAYOUT

FIG. 4.1

LESH PROTOTYPE ELEMENT LOCATIONS

FIG. 4.2

LESH PROTOTYPE AXIAL POWER DISTRIBUTION WITH GROUP IV & V CONTROL

FIG. 4.3

5. SAFEGUARDS ANALYSIS

Only the initial safeguards study and review was performed; the analysis and license and technical specification change request has not proceeded beyond the outline stage. Such analysis will have to be prepared in support of a change request if, at a later time, it is decided to install the elements.

It is believed that only Sec. 8, Research and Development Program of the Pathfinder Atomic Power Plant Technical Specifications, would need to be revised as a result of the change request. The change would consist of a brief statement of the number of prototype assemblies which may be added to the core, and identification of permissible core locations.

To support the change request, a safeguard analysis would be included which would be based upon the following outline:

- (a) Introduction: General description of elements and purposes of installation.
- (b) Mechanical Design: Detailed description, design considerations, test results, fabrication.
- (c) Thermal Analysis: Behavior of prototypes in fully enriched superheater.
- (d) Physics: Assurance that physics considerations, including shutdown margin, are negligibly affected.
- (e) Dynamics: Discussion with regard to capability of prototypes to withstand the transient conditions for which the rest of Core I is designed.
- (f) Fuel Failures: Develop information with regard to iodine release and possible need for additional monitoring.
- (g) Safeguards Summary: Based upon the information developed above, assess affect on Core I accident analysis and determine whether or not there is additional hazard to the operating personnel or to the public.

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APPENDIX A

DEVELOPMENT AND FABRICATION

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A.1 INTRODUCTION

The original development work and fabrication techniques leading to the fabrication of the two prototype Low Enriched Superheat (LESH) elements are described in this appendix. Also included are the various steps used in qualifying manufacturing methods and a discussion of some of the problems encountered during manufacture. The prototype assemblies were made essentially to the same specification as the LESH I fuel assemblies, thereby providing advance information on the feasibility of the fabrication process used.

A.2 DEVELOPMENT

A.2.1 Wire Welding

One of the major problems encountered in the initial fabrication development phase was the production of a consistent, high-quality, continuous weld between the spacer wire and the cladding tube. The weld had to be strong enough to keep the wire attached under reactor conditions and yet not disrupt the integrity of the cladding tube. The weld could not cause a sizeable increase in the ovality of the tube, as this increase would violate the creep collapse design criteria. The weld also could not introduce in the structure of the tube wall large flaws which could significantly affect fuel clad integrity. The following steps were taken in order to qualify the welding technique.

A.2.1.1 High Frequency Welding

The basic theory of high frequency resistance welding has been established and used by many for other applications. A brief review will help clarify the method. The desirable quality of this type of weld is the very localized heat produced during welding. The use of very high frequencies for resistance welding results in most of the current being carried by the adjacent surfaces of the pieces being joined rather than by the entire surface. If high frequency current is applied to two metal pieces, and these pieces are brought together, an approach angle is formed and the current becomes "focused" at a point. The location and size of this focus is dependent upon the angle of approach, the frequency of the current, and the dimensions of the objects. This focus is the point of highest current concentration. For low frequency current, this point would generally be a point of high contact resistance or low cross section. With high frequency current, however, capacitance and inductance play a large role. In such a case, the current will not necessarily follow the path of least resistance but, rather, the path of least reactance.

The objective of the program was to develop a weld setup and welding configuration which could focus the current in order to concentrate the heat at the weld contact point.

A.2.1.2 Design and Construction of Wire Welding Tooling

A 10 kw high frequency power unit was designed and custom-built for this application at the West Allis Plant of Allis-Chalmers. This unit has a 5 to 30 megacycle frequency

range, and it features both a load and a tank circuit to stabilize the output. The output is filtered to reduce a-c ripple.

The external fixtures were designed to meet several requirements. First, it was necessary to impart a consistent pitch to the wire being welded. Second, the welding speed had to be widely variable. Third, the tube had to be accurately indexed after each weld and a 120° indexing maintained over the length of the tube. Finally, numerous adjustment mechanisms had to be provided to allow accurate control of factors and conditions affecting the weld.

Figure A.1 shows the mechanism that met the above conditions. The drawing mechanism is geared directly to the rotation mechanism. This assures a constant, predictable relationship between axial position and rotational position. A lead screw and nut is used to provide linear motion, while a sliding spline type drive transmits rotary motion to the draw head; the lead screw and spline shaft are driven by the same motor. A solid state speed control allows wide speed variation. Recirculating ball sleeves running on hardened shafts assure alignment of the draw head and also carry its weight.

Accurate indexing is simply achieved by using a lathe-collet set up to grip the tube end. A collar with a set screw, shown in Fig. A.2, is slipped over the end of the tube. A projection on the face of the collar is slipped into one of the collet slots. The three slots in the collet, accurately spaced at 120° , provide excellent indexing.

The two electrical contact shoes are spring loaded to provide constant shoe force. The force is varied with a take-up bolt which lengthens or shortens the spring. (Each shoe stand is adjustable axially along the length of the set-up.) The wire guide is also adjustable to allow varying the angle of approach between the wire and tube. Sliding type contacts are used for simplicity. All fixtures are mounted on a heavy 12-ft long, hardwood-topped, U-channel table. A separate 7-ft table has a melamine trough mounted on it at the proper height to feed the tube and wire to the weld shoes as shown in Fig. A.3.

A.2.1.3 Development of the Wire Welding Capability

The operation of a hi-frequency heater unit is dependent upon the configuration of the added external fixtures. The outside fixtures, i.e., the contact shoes and their conducting bus bars, become part of the load circuit. Therefore, operating characteristics must be determined with the fixtures in place. Both heater control settings and bus terminal configuration were varied in order to determine their effect on power output and frequency. A frequency of about 14 megacycles was found to be appropriate for the tubing wall thickness, wire diameter, and depth of penetration desired. Lower frequencies result in the heat being less localized. The final bus bar configuration gave the best power output for the production of good wire welds.

After the power source characteristics had been determined, development of the welding process was begun. Various contact shoe configurations, positions, and pressures

were tried, along with various approach angles of the wire-to-tube. It was found that a wide contact area on the weld shoes was neither necessary nor desirable. The best results were obtained with a slightly domed blunt end of about 3/16 in. diameter on the tube shoe and a blunt 3/16 in. end with a 1/16 in. groove (about 0.020 in. deep) on the wire shoe. The blunt type shoe gave high contact pressure with the lowest force, thus giving good electrical contact with low drag. Contact shoes which conformed to the tube required higher force to maintain good electrical contact, yet were upset easily by foreign material. (The high frequency current allows use of very small contact area for relatively high current.) A groove was necessary on the wire shoe to prevent the wire from slipping out.

Tests were run with the shoes in various positions other than directly across from each other. No advantage could be observed with these configurations. Having the shoes directly opposed, resulted in balanced forces, so this positioning was selected.

Once the basic configuration of the fixtures was established, a series of experiments were performed to determine the effect of other variables. Since the power output of the hi-frequency unit was independent of the other variables and could be changed as required, the tests were conducted at constant power output. Three variables: the welding speed, the shoe pressure, and the angle of wire approach, were selected for investigation. The ranges selected were 3-28 fpm for welding speed, 0-7 lb shoe pressure, and 5-30° for wire angle.

As a result of this investigation it was observed that increasing the welding speed generally improved the overall quality of the weld though decreasing its strength. Welds made at high speed were more consistent in configuration, resulting in less linear tube distortion, and showed less discoloration. This was expected, since at high speed advantage could be taken of the local "skin effect" produced by the high frequency current, while at low speeds the heating by conduction becomes significant. At very low speeds, about 3-5 fpm, the entire cross section of the wire and a large portion of the tube cross section became heated. At high speeds, about 20-28 fpm, only a bright orange speck was seen at the point of contact between the wire and tube. No attempt was made to weld at speeds in excess of 28 fpm. Welding time was also considered in selecting optimum speeds. A 7-ft tube is welded in 15 sec at 28 fpm and requires about 1 min handling. Welding at three times that speed would cut the total time from 75 sec to 65 sec.

Shoe pressure also had a marked effect on the weld. Weld strength generally was decreased by increased shoe pressure. This is apparently due to the fact that the higher pressure tended to force the wire into a smaller local approach angle at the region of heating, moved the focus point closer to the contact shoes, and thereby reduced the temperature of the local hot spot. At very low contact pressures, on the other hand, the weld became inconsistent. This is because the presence of small distortions or kinks in the wire created a drastic shift in the focus point.

The approach angle as determined by the wire guide also had an effect on the weld. The angle near the focus (labeled local approach angle in Fig. A.4) is controlled by three factors. The wire guide position gives the apparent approach angle. The shoe pressure then alters this apparent angle to give the local pressure in the region of focus. The degree of stiffness of the wire during welding depends upon welding speed. Therefore, welding speed also affects the local approach angle. If the guide is moved away from the tube, then much higher wire shoe force is required to give the proper local approach angle. On the other hand, moving the guide close to the tube, thus producing an approach angle close to the desired local approach angle, would result in high sensitivity to contact shoe pressure. The slightest pressure from the contact shoe then closes the local approach angle and shifts the focus toward the wire shoe. Thus the wire guide has to be sufficiently far away from the tube so that, when shoe force is applied, the contact between wire and tube continues to occur beyond the wire shoe.

A.2.1.4 Development of the Specific Production Parameters

A set of fabrication parameters was established to produce a weld that would meet product specification. The dimensional limitations imposed by the specification were depth of penetration and nugget width. The depth of penetration or heat-affected zone was not to exceed 0.002 in., and the nugget width had to be greater than 0.002 in. Other dimensional considerations were limits on linear tube distortion and cross sectional tube distortion. Qualitative limitations were product discoloration, weld cracks, weld voids, and keyholes.

Since distortion and discoloration had to be held to a minimum, a maximum speed of 28 fpm was selected. Experience showed that an approach angle of about 14° was best. Although greater approach angles ($20-30^{\circ}$) were less sensitive to wire kinks, very high shoe pressures were required. Small approach angles ($5-10^{\circ}$) were extremely sensitive to wire condition. The selected angle of 14° allowed a low shoe pressure of about 2 lb, and yet was relatively insensitive to moderate kinks in the wire.

The induction heater was initially tuned to deliver power at 14 megacycles. The other controls (power stat, power output control, and grid control) were adjusted to vary the power. A r-f field strength meter was used to monitor the "actual power." Through experimentation it was found that good welds were achieved when a relative field strength reading of 4-5 was obtained on the meter. Therefore, before each series of welds the equipment was adjusted to give this relative power output.

When the final production parameters were established, a series of nine full length welds was made to qualify the process and to evaluate its capability. The beginning and end of each weld was mounted and evaluated. No difference could be determined between the beginning and end of the weld or between first, second, and third wires. This set of welds was used to develop standards for the prototype fuel assemblies. The

discoloration and distortion levels were acceptable. The largest rounded weld edge and sharpest weld contour encountered were also found to be acceptable and were photographed for future reference. Another set of three wires was welded to a tube and sectioned transversely along the length. This showed no variation due to axial position. Illustrations of acceptable welds are shown in Fig. A.5. Views of the welded wire are shown in Fig. A.6.

A.2.1.5 Special Tests of Wire Welded Tubes

Two tests were run to show that the welded spacer wire does not affect the mechanical integrity of the tube. The first was a burst test, and the second was a high temperature collapse test.

Two 2-ft long pin assemblies were made up with wires welded on and with end caps installed on each end. Two additional pin assemblies were made without spacer wires. All assemblies were pressurized internally until they burst, with the result that all tubes burst at about the same pressure. All wire welded tubes burst in regions away from the spacer wire as shown in Fig. A.7.

The high temperature collapse test was run with four more assemblies at maximum design conditions with no collapse occurring in any of the assemblies.

A.2.2 End Cap Welding

A.2.2.1 Design and Construction of Welding Setup

Past experience with Incoloy 800 indicated that the best results would be obtained using a cork-type (i.e., a truncated cone) cap. This type of configuration is best welded with the torch set at about a 30° angle from the perpendicular. A glass tee was modified to a 60° angle, and brackets were made to position the torch within this tee as shown in Fig. A.8. The tee also served another purpose, that of providing a controlled atmosphere chamber. This tee and torch assembly was then mounted on the moving stand of a modified glass lathe fuel welding setup. This setup, which is normally used for fuel pin welding, consists of the following: a modified Litton glass lathe used to provide accurate positioning and rotation; a thyatron-controlled, variable-speed motor to provide speed control; and a Miller ESR-150 power source. The torch used for the end cap welding has a micrometer type adjusting nut so that it can be accurately positioned to produce the proper arc-gap. This is necessary, since feeler gages cannot be used within the glass tee.

A.2.2.2 Termination of Spacer Wires

An unusual problem encountered with the LESH type fuel elements was the termination of the spacer wires. Two basic approaches were investigated. One was to leave the wires full length on the tube. The tube and wires would then be trimmed all at once

when the tube-wire subassembly is cut to length. The other was to cut the wires shorter than the tube. The only disadvantage to the first approach was that of the wires becoming part of the end cap weld. The second approach had several problems, i.e., the wire must be trimmed without cutting into the tube wall, the end of the remaining wire had to be chamfered without marring the tube, and both operations must not affect the weld. In view of the serious difficulties encountered in the latter approach, the first approach was selected for preliminary work.

A.2.2.3 Weld Development

It was not known at the start whether the spacer wire ends could be successfully included in the end cap weld. The first welds were made using samples with square ended spacer wires. Two problems were caused by the wire. First the wire added excessively to the size of the weld puddle; and second, the wire attracted the corona as it passed by the torch.

These two problems made it necessary to use excessive current to obtain sufficient penetration in the region of the wires. To eliminate this problem, the wires were chamfered to a 30° angle. This eliminated arc wandering and reduced the amount of material being added to the weld puddle. This modification produced welds of satisfactory appearance.

A series of welds was then made for metallographical examination. The basic parameters used were: weld current, 22 amp; speed, 10 rpm; welding time, 8 sec; and a delay start to permit welding current to be established before initiation of rotation. The examination showed no cracks, voids or inclusions and did not reveal any problems caused by the spacer wire.

One problem was discovered during welding of the end caps. In some instances, oxide film formed on the end cap and tubing, and it was entrapped in the weld nugget as shown in Fig. A.9. Even though this is acceptable, because there was sound weld metal equivalent to the wall thickness of the fuel tube, several attempts were made to eliminate the problem. The first solution attempted was to pickle the end caps and ream and polish the tube ends immediately before welding. A new series of welds were prepared with no significant improvement noted. Next, an improved gas cover was tried. It was possible that the oxide layer formed as a result of poor atmosphere. Argon gas with a flow rate of 15 cfh was found to give welds with the cleanest appearance and with sufficient penetration. However, no improvement was noted in reducing the formation of oxide film. Finally it was determined that regardless of the source of oxide, a set length of time was required for the film to develop. Therefore, it was thought that shortening the welding time might result in purer welds. The welding speed was therefore increased to 20 rpm, and the weld time was decreased to 4 sec. The current was also increased to 30 amp to give required penetration. This step did not completely eliminate the entrapment of oxide film, but it did reduce it considerably in size and frequency, thus enabling the welds to meet product specification. Figures A.10 and A.11 show longitudinal cross sections of typical production welds with and without spacer wire respectively.

A.2.3 Slotted Cap - Lower Fitting Weld

Specifications for this weld required it to be free of cracks and to have a minimum penetration of 0.040 in. Initially, these welds were made using two passes. Metallographic examination revealed that cracks developed in the first weld pass while the second weld pass was being applied. To resolve this problem, a "weaving" weld pattern was developed that would weld both legs of the slotted cap with one pass. This method proved successful in eliminating the cracks and also produced excellent penetration.

A.2.4 Boron Stainless Poison Wire

The poison wire was made by cutting boron stainless plate into square sections and cold swaging them into rods of 3/16 in. dia. Several samples were analyzed for boron content, both at Allis-Chalmers and at outside laboratories. The results were averaged, and the average was used to determine the required final diameter of the wire.

A.3 LESH PROTOTYPE FABRICATION

A.3.1 Fuel Pin Fabrication

The first stage of fuel pin fabrication was fabrication of the wire-welded tubes. Three spacer wires were welded to each 7-ft length of tubing. Each tube was then inspected for straightness by passing it through a 1-ft long tube with an inside diameter of 0.339 in. The tubes were cut to length; the ends were ground, and the spacer wires were chamfered. The piece trimmed from each end was used as a metallurgical sample. Each tube was flushed with alcohol.

Lower end caps were pressed into the tube until the uninserted portion of each cap projected out a distance of 0.030 in. The caps were then welded, as were the six metallurgical samples. The lower end cap was positioned so that the slot in the cap was visually oriented with respect to the spacer wires.

The fuel tubes were then loaded with UO₂ pellets, and the upper end caps were welded to the tubes. Each pellet stack was laid out in a "V" trough, measured, weighed, and inserted into the tube. Helium was then introduced into the gas space at the upper end of the fuel pin. This was done via a small tube that was inserted into the gas space and gradually withdrawn. The spring was immediately inserted; the upper cap was inserted immediately thereafter and was pressed into the tube until its uninserted portion projected out a distance of 0.030 in. The upper ends were then welded, as were the six metallurgical samples. Each weld was brushed with a stainless steel wire brush to remove discoloration.

All fuel pins were then inspected and accepted. Inspection consisted of a helium leak test, a dye-penetrant examination of end cap welds, dimensional inspection, and visual inspection. Dimensional inspection included inspection of the 120° wire indexing, the length, the tube diameter and the overall diameter, i.e., tube plus wires.

A.3.2 Poison Pin Fabrication

Fabrication of the two poison pins was similar to that of the fuel pins; the two main exceptions were that no spacer wires were welded to the tubes, and that the tubes contained poison material instead of fuel pellets. The bottom end fittings were pressed into the tubes until the protruding edge of each fitting projected out 0.030 in. The fittings were then welded, as was one metallurgical sample. The poison wire (boron-stainless steel) was cut to length. Alumina spacer sleeves were slipped onto the poison wire. The poison wire and alumina sleeves were then inserted in the tube. The upper space was filled with helium, and the spring was immediately inserted. Immediately thereafter the lifting fitting was inserted until its protruding edge projected 0.030 in. The fitting was then welded, as was one metallurgical sample. Weld discoloration was removed with a stainless steel wire brush.

The poison pins were then inspected and accepted. Inspection consisted of a helium leak test, a dye-penetrant examination of the welds, and dimensional and visual inspection.

A.3.3 Final Assembly

Final assembly consisted of inserting the six fuel pins into the retainer ring and joining the lower end caps to the lower finned fitting. This step was followed by insertion of the poison pin. The upper fittings of the six fuel pins were first slipped into the retainer ring (as shown in Fig. A.12). The slotted lower end caps were oriented, slipped onto the lower finned fitting, and clamped in place. The poison pin was then slipped down the center and into the lower end finned fitting, and the two small pins were driven in. The slotted lower end caps or fittings were welded to the lower finned fitting, and the two small pins were welded at each side. The completed lower assembly (shown in Fig. A.13) was wire brushed to remove any discoloration.

The completed assemblies were inspected and accepted. Inspection consisted of visual examination of the structural welds, general visual examination, inspection of overall length and check of the conformance to the envelope.

A.3.4 Packaging

The completed assemblies were packaged as follows:

- a. Each assembly was flushed with alcohol and wiped.
- b. Each assembly was inserted in a close-fitting stainless steel tube. Packing material was placed at each end to absorb shock. Each end of the stainless steel tube was sealed.
- c. The unit was wrapped in shock absorbent material and was placed in a wooden shipping box as shown in Fig. A.14.

draw
head

lead
screw

square-sliding
spline drive

HIGH FREQUENCY POWER UNIT

FIG. A.1

DETAILS OF WELDING MECHANISM

FIG . A.2

Melamine
wire feed

Melamine
tube feed

R-F field
strength meter

WELDING MACHINE FIXTURES

FIG. A.3

APPROACH ANGLE

FIG. A.4

ILLUSTRATIONS OF ACCEPTABLE WELDS

FIG. A.5

LONGITUDINAL AND CROSS SECTION VIEWS OF WELDED WIRE

FIG. A.6

pressure
fitting

TYPICAL BURST TEST ILLUSTRATION

FIG. A.7

END CAP WELDING SETUP

FIG. A.8

ENTRAPPED OXIDE FILM IN WELD NUGGET

FIG. A.9

CROSS SECTION OF TYPICAL PRODUCTION WELD

FIG. A.10

CROSS SECTION OF TYPICAL PRODUCTION WELD

FIG. A.11

UPPER ASSEMBLY OF FUEL ELEMENT

FIG. A.12

LOWER ASSEMBLY OF FUEL ELEMENT

FIG. A.13

PROTOTYPE FUEL ELEMENT IN SHIPPING BOX

FIG. A.14

APPENDIX B

MATERIAL AND FABRICATION SPECIFICATIONS

1. Specification No. 41-703: Tentative Specification for Incoloy 800
Tubing for Nuclear Fuel Elements B-2
2. Specification No. 41-712: Specification for Incoloy 800 Rod for
Fabrication End Plugs for Nuclear Fuel Applications B-9
3. Specification No. 41-713: Specification for Incoloy 800 Wire for
Nuclear Application B-14
4. Specification No. 41-1001: Specification for Uranium Dioxide
Pellets B-20
5. Specification No. 41-716: Procurement Specification for Pathfinder
LESH Prototype Fuel Elements B-31

TENTATIVE SPECIFICATION
FOR
INCOLOY 800 TUBING FOR NUCLEAR FUEL ELEMENTS

April 8, 1965

ALLIS-CHALMERS
Atomic Energy Division
Bethesda, Maryland 20014

1. SCOPE

This specification details the requirements for Incoloy 800 seamless round tubing for use in Nuclear Reactor Applications.

2. APPLICABLE DOCUMENTS

- 2.1 ASTM B407-63T: Nickel-Iron-Chromium Alloy Seamless Pipe and Tube
- 2.2 ASTM E112-61: Estimating the Average Grain Size of Metals
- 2.3 ASTM E-45-63: Determining the Inclusion Content of Steel
- 2.4 MIL-STD-271C (Ships): Non-Destructive Testing Requirements for Metals

3. GENERAL REQUIREMENTS

The material shall conform to Ref. 2.1 except as modified herein.

4. SPECIFIC REQUIREMENTS

4.1 Dimensions

The tubing shall be supplied to the nominal dimensions and tolerances specified on the Purchase Order or applicable attached document. These requirements shall be assured by 100% inspection.

4.2 Straightness

It shall be assured by 100% inspection that tubing bow tolerance in any plane does not exceed 0.010" per linear foot and .050" in any 6 foot length.

4.3 Specific Material Requirements

Ref. 2.1 (ASTM B407-63T - Nickel-Iron-Chromium Alloy Seamless Pipe and Tube).

4.3.1 Chemical Analysis

The chemical requirements shall conform to Ref. 2.1 except for the following:

Aluminum	0.15 - 0.60%
Titanium	0.30 - 0.60%
Boron	0.01% max.
Cobalt	0.10% max.

4.3.2 Condition and Mechanical Properties

4.3.2.1 Anneal

The finished tubing shall be cold-drawn and bright annealed (mill anneal) at approx. 1800 F. Cracked ammonia shall not be used as the annealing atmosphere for any anneal. The bright annealing atmosphere shall be dry, pure hydrogen gas (less than 0.004% by volume water and 0.007% air, dew point -73 F).

The intended annealing procedure shall be submitted to A-C for approval prior to use.

4.3.2.2 Mechanical Properties

The following mechanical property requirements shall be met when tested at room temperature:

Tensile Strength	75,000 psi min.
Yield (0.2% offset)	30,000 psi min.
% Elongation (in 2 in.)	30% min.
Hardness	R _B 88 max.

Number of samples and test procedures shall conform with the requirements of Ref. 2.1.

4.4 Surface Finish

4.4.1 It shall be assured to a quality level of AQL = 6.5%, LTPD or LQ = 68.4%, β or Pa = .10, that the surface roughness on ID and OD shall be 63 rms or less.

4.4.2 Inside and outside surfaces of the tubing shall be bright and free of discoloration and carbonization, and shall be free of grease, dirt, metal particles and other foreign matter.

4.4.3 Discontinuities such as pits, gouges, and score marks in excess of 0.002" in depth (ID or OD) shall be cause for rejection.

4.4.4 Tube surfaces shall be free from all cracks, laps, seams, and other discontinuities made visible by the applicable test. Any discontinuity made visible by the test may be removed by accepted methods, if done in conformance with Sec. 4.7.

4.5 Grain Size and Condition

It shall be assured to a quality level of AQL = 1.5%, LTPD or LQ = 11.6%, β or Pa = .10, that the requirements of Sec. 4.5 are met.

4.5.1 The average grain size of the finished tubing shall be within the ASTM designation #5 or smaller. Average grain size shall be determined in accordance with Ref. 2.2 at 100X.

4.5.2 No less than 3 grains shall comprise the wall thickness at any section.

4.6 Internal Defects

It shall be assured to a quality level of AQL = 1.5%, LTPD or LQ = 11.6% at β or Pa = .10 that the severity of the defects listed below are not exceeded. These requirements shall be evaluated by metallographic methods at 100X.

4.6.1 All tubes shall be free of seams, cracks, laps, contamination with oxide or undefined foreign material, and indications of unusual or abnormal microstructure.

Acceptance for the contamination and microstructure requirements shall be based on a mutually agreed upon metallographic standard. Any indications which are greater in extent, or more severe than those of the standard, shall be cause for rejection.

4.6.2 Evidence of intergranular attack (such as that due to excessive pickling) in excess of .0005 in. in depth at either surface (ID or OD) shall be cause for rejection.

4.6.3 Acceptance for inclusions shall be as shown in Ref. 2.3 on Fig. 5, "Chart for Determining the Inclusion Content of Steel, #2-A, B, C, D thin series". Any microscopic field examined as specified in Ref. 2.3 shall be equal to or better than this standard.

4.7 Rework

Rework for external defects may be performed provided that the requirements of Sec. 4 and all quality requirements of this specification are met. Rework procedures shall be submitted to A-C for approval prior to use.

4.8 Halide Content

The maximum halide content on the tubing surfaces shall not exceed 0.0005 mg/sq. in.

4.9 Final Cleaning

All tubes shall be vapor-degreased to insure that all surfaces are free of lint, grease, oil, and other foreign matter. After degreasing, the tubes shall be washed in clean alcohol and dried in air.

5. QUALITY REQUIREMENTS

5.1 General

- 5.1.1 All materials and end products shall be subjected to all non-destructive and destructive test methods and inspections required by this specification, referenced specifications, and drawings.
- 5.1.2 All instruments and devices used to perform the required inspection must be periodically calibrated. The accuracy and precision of all instruments and devices must be consistent with dimensions and tolerances.
- 5.1.3 A-C Source Inspection is required prior to shipment unless waived in writing by A-C prior to the date of shipment. Material or end product received without proof of, or written waiver on, Source Inspection may be returned to the vendor. Final acceptance will be made by A-C Receiving Inspection; however, this does not waive the right of subsequent rejection because of undiscovered or latent defects. Forty-eight (48) hours notice is required to schedule A-C Source Inspection. The vendor shall provide, without additional charge, all reasonable facilities and assistance for any inspection made on its premises.
- 5.1.4 Allis-Chalmers Quality Department may at any time conduct an audit to determine if the quality requirements of the Purchase Order are being satisfied and if satisfactory quality records are being maintained.
- 5.1.5 Certificates required by this specification must be signed by a responsible representative or official of the company. All certificates shall be identified with Purchase Order Number and Date, Part Number if applicable, Part Name, Quantity, applicable A-C Specification Number, Material Heat Number, and lot designation.

Certificates shall be furnished to the A-C Source Inspector at the time of his inspection; or if Source Inspection has been waived, the certificates shall accompany the material shipped. Four (4) copies of all required certificates shall be furnished.
- 5.1.6 Materials or end products which do not meet the requirements of the Purchase Order and all applicable drawings and specifications shall be submitted to the Allis-Chalmers Material Review Board for disposition. The Allis-Chalmers Deviation Report, Form 7714, shall be completed by the vendor, giving as much detailed information as possible; or the vendor may use a similar type of Deviation Report if the form is approved by A-C prior to use.
- 5.1.7 If the vendor has a Quality System in operation, i.e., similar or conforming to MIL-Q-9858, this system shall be applicable in satisfying the requirements of this specification. The vendor shall submit a Quality Manual for

A-C review and approval. In the event the vendor does not have a Quality System, he shall submit for A-C review and approval a detailed inspection procedure which will be used in conjunction with this specification.

5.2 Specific

5.2.1 The vendor shall use reliable and valid statistical acceptance sampling procedures, such as MIL-STD-105, which will satisfy the requirements of Secs. 4.4.1, 4.5, and 4.6. If MIL-STD-105D is used, the lot quality, LQ, approach may be used regardless of lot size in order to assure the Quality Level required and minimize the sample size.

5.2.2 The vendor shall submit, for A-C review and approval, detailed inspection methods which will satisfy the requirements of the following:

- 4.1 Dimensions
- 4.2 Straightness
- 4.3.2.2 Mechanical Properties
- 4.4.1 Surface Roughness
- 4.8 Halide Content

5.2.3 Visual Inspection

To satisfy requirements of Secs. 4.4.2, 4.4.3, and 4.4.4, the following visual inspection shall be performed:

Outside Surface

All tubes shall be inspected. Illumination shall be at least 100 foot-candles of yellow fluorescent light at that portion of the tube surface being inspected. The tube shall be inspected according to the following method: the tube shall be rotated and translated slowly while discontinuity is noted, the tube shall be further examined under a 10X magnifier. If there is any doubt as to the acceptability of the discontinuity, it may be removed in accordance with Sec. 4.7.

The requirements of Sec. 4.4.4 shall be verified by performing a fluid penetrant inspection on the outside surface of all tubes in accordance with Ref. 2.4. Any indication shall be cause for rejection.

Halide aerosol carriers shall not be employed. The vendor shall submit the type of penetrant test and test procedure for A-C approval prior to the start of production.

Inside Surface

The inside surface of all tubes shall be inspected. Illumination shall be at least 100 foot-candles of yellow fluorescent light so arranged that light reflected from the

walls of the tube will allow the viewer to pick out surface discontinuities. Should the discontinuity exceed permissible levels, the tube shall be rejected.

5.2.4 Eddy Current or Ultrasonic Testing

All tubing shall receive 100% eddy current or ultrasonic inspection. Discontinuities within the tubing, if in excess of 0.002 in. in depth or width, shall be cause for rejection.

The vendor shall establish defect correlation (correlation study) and inspection procedures which insure detection of discontinuities as defined in this section. The vendor must demonstrate this capability and receive written approval of procedures from A-C prior to production testing.

5.2.5 Check Analysis

The chemical composition requirements of Sec. 4.3.1 shall be verified by two check analyses from each heat of material.

5.3 Certificates

With each shipment the vendor shall furnish four (4) copies of a "Certificate of Compliance" stating that the end product identified by the certificate is in compliance with the Purchase Order requirements, applicable specifications, and drawings, and that records substantiating the compliance are on file and available for examination and audit; and four (4) copies of a "Certified Test Report" stating the specific findings of tests associated with the end product as required for the following:

- 4.1 Dimensions
- 4.2 Straightness
- 4.3.1 Chemical Analysis
- 4.3.2.2 Mechanical Properties
- 4.5 & 4.6 Metallographic - Specimens or Photographs
- 4.8 Halide Content

6. PACKAGING AND MARKING

The tubing shall be packaged in boxes lined with polyethylene or a dry finish wrapper. Each tube shall be in a separate plastic tube or wrapper. The tubing shall be packaged in a manner which will prevent damage during handling and shipping.

Heat Number, Size, Specification No., Purchase Order No., and name of vendor shall be stenciled on each individual tube wrapper and on each shipping container.

SPECIFICATION FOR
INCOLOY 800 ROD
FOR
FABRICATING END PLUGS
FOR
NUCLEAR FUEL APPLICATIONS

May 25, 1965

Prepared By:

ALLIS-CHALMERS
ATOMIC ENERGY DIVISION
BETHESDA, MARYLAND 20014

1. SCOPE

This specification details the requirements for hot-finished or cold-drawn Incoloy 800 round bars for fabricating end caps for Nuclear Fuel Applications. Material shall conform to all the requirements of Ref. 2.1 except as modified herein.

2. APPLICABLE DOCUMENTS

- 2.1 ASTM B-408-63T: Nickel-Iron-Chromium Alloy Rod and Bar
- 2.2 ASTM E-112-61: Estimating the Average Grain Size of Metals
- 2.3 ASTM E-45-63: Determining the Inclusion Content of Steel

3. REQUIREMENTS

3.1 Dimensions

The material shall be supplied to the nominal dimensions and tolerances specified on the Purchase Order or applicable attached document.

3.2 Chemical Analysis

The chemical requirements shall conform to Ref. 2.1.

3.3 Condition and Anneal

The material shall be cold-drawn or hot-finished, annealed, and pickled or cold-drawn or hot-finished and bright annealed. The annealing temperature shall be approximately 1800 F (Mill anneal).

3.4 Mechanical Properties

The following mechanical property requirements shall be met when tested at room temperature:

Tensile Strength	75,000 psi min.
Yield (0.2% offset)	30,000 psi min.
% Elongation (in 2 in.)	30% min.
Hardness	R _B 88 max.

Number of samples and tensile test procedures shall be in accordance with the requirements of Ref. 2.1.

3.5 Grain Size

It shall be assured to a Quality Level of AQL = 6.5%, LTPD or LQ = 68.4%, β or P_a = .10, that the average grain size of the finished bar is within the ASTM designation #5 or smaller. Average grain size shall be determined in accordance with Ref. 2.2 at 100X.

3.6 Internal Defects

The requirements of this section (3.6) shall be assured to a quality level of AQL = 1.5%, LTPD or LQ = 11.6 at β or Pa = .10. These requirements shall be evaluated by metallographic methods at 100X.

3.6.1 The final product shall be free of defects such as seams, cracks, voids and laminations.

3.6.2 Acceptance for inclusions shall be as shown in Ref. 2.3 on Fig. #5 "Chart for Determining the Inclusion Content of Steel," #2A, B, C, D, thin and heavy series. Any microscopic field examined as specified in Ref. 2.3 shall be equal to or better than the standard.

3.7 Rework

Rework for external defects may be performed provided that the requirements of Sec. 3 and all quality requirements of this specification are met. Defect areas found by any inspection method may be removed by cutting the material and removing the defect plus one inch each side of the defect.

3.8 Cleanliness

The surface of the material shall be bright and free of discoloration, grease, dirt, metal particles and other foreign matter.

4. QUALITY REQUIREMENTS

4.1 General

4.1.1 All materials and end products shall be subjected to all non-destructive and destructive test methods and inspections required by this specification, referenced specifications, and drawings.

4.1.2 All instruments and devices used to perform the required inspection must be periodically calibrated. The accuracy and precision of all instruments and devices must be consistent with dimensions and tolerances.

4.1.3 A-C Source Inspection is required prior to shipment unless waived in writing by A-C prior to the date of shipment. Material or end product received without proof of, or written waiver on Source Inspection may be returned to the vendor. Final acceptance will be made by A-C Receiving Inspection, however, this does not waive the right of subsequent rejection because of undiscovered or latent defects. Forty-eight (48) hours notice is required to schedule A-C Source Inspection. The vendor shall provide, without additional charge, all reasonable facilities and assistance for any inspection made on its premises.

4.1.4 Allis-Chalmers Quality Department may at any time conduct an audit to determine if the quality requirements of the Purchase Order are being satisfied and if satisfactory quality records are being maintained.

4.1.5 Certificates required by this specification must be signed by a responsible representative or official of the Company. All certificates shall be identified with Purchase Order Number and Date, Part Number if applicable, Part Name, Quantity, applicable A-C Specification Number, Material Heat Number and lot designation. Certificates shall be furnished to the A-C Source Inspector at the time of his inspection, or if Source Inspection has been waived, the certificates shall accompany the material shipped. Four (4) copies of all required certificates shall be furnished.

4.1.6 Materials or end products which do not meet the requirements of the Purchase Order and all applicable drawings and specifications shall be submitted to the Allis-Chalmers Material Review Board for disposition. The Allis-Chalmers Deviation Report, Form 7714, shall be completed by the vendor giving as much detailed information as possible or the vendor may use a similar type of Deviation Report if the form is approved by A-C prior to use.

4.1.7 If the vendor has a Quality System in operation, i.e., similar or conforming to MIL-Q-9858, this system shall be applicable in satisfying the requirement of this specification. The vendor shall submit a Quality Manual for A-C review and approval. In the event the vendor does not have a Quality System, he shall submit for A-C review and approval a detailed inspection procedure which will be used in conjunction with this specification.

4.2 Specific

4.2.1 The vendor shall use reliable and valid statistical acceptance sampling procedures, such as MIL-STD-105, which will satisfy the requirements of Secs. 3.5 and 3.6. If MIL-STD-105D is used, the lot quality, LQ, approach may be used regardless of lot size in order to assure the Quality Level required and minimize the sample size.

4.2.2 Check Analysis

The chemical composition requirements of Sec. 3.2 shall be verified by two check analyses from each heat of material. Samples shall be obtained from finished rod.

4.3 Certificates

With each shipment the vendor shall furnish four (4) copies of a "Certificate of Compliance" stating that the end product identified by the certificate is in compliance with the Purchase Order requirements, applicable specifications and drawings, and that records substantiating the compliance are on file and available for

examination and audit; and four (4) copies of a "Certified Test Report" stating the specific findings of tests associated with the end product as required for the following:

- 3.2 Chemical Analysis
- 3.4 Mechanical Properties
- 3.5 & 3.6 Metallographic

In addition to the certified test reports, all metallographic specimens or photomicrographs of the specimens, used in assuring the requirements of Secs. 3.5 and 3.6 are to be submitted to the purchaser.

5. PACKAGING AND MARKING

Material shall be packaged in a manner which will prevent damage during handling and shipping.

Heat Number, Size, Specification Number, Purchase Order Number, and Name of Vendor shall be stenciled on each shipping container.

SPECIFICATION
FOR
INCOLOY 800 WIRE
FOR NUCLEAR APPLICATION

May 25, 1965

Prepared By:

ALLIS-CHALMERS
ATOMIC ENERGY DIVISION
BETHESDA, MARYLAND 20014

1. SCOPE

This specification details the requirements for cold-drawn and annealed Incoloy 800 wire for use in Nuclear Reactor Applications. Material shall conform to Ref. 2.1 except as modified herein.

2. APPLICABLE DOCUMENTS

- 2.1 ASTM B-408-63T: Nickel-Iron-Chromium Alloy Rod and Bar
- 2.2 ASTM E-112-61: Estimating the Average Grain Size of Metals
- 2.3 MIL-STD-271C (Ships): Non-Destructive Testing Requirements of Metals

3. REQUIREMENTS

3.1 Dimensions

The wire shall be supplied in straight lengths to the nominal dimensions, straightness and tolerances specified on the Purchase Order or attached document. These requirements shall be assured by 100% inspection.

3.2 Chemical Analysis

The chemical requirements shall conform to Ref. 2.1 except for the following:

Boron	0.01% max.
Cobalt	0.10% max.

3.3 Halides

There shall be no halide-containing materials used during the fabrication of this product.

3.4 Condition and Anneal

The material shall be cold-drawn and bright-annealed at approximately 1800 F (mill anneal). Cracked ammonia shall not be used as the annealing atmosphere for any anneal. The bright annealing atmosphere shall be dry, pure hydrogen gas (less than 0.004% by volume water and 0.007% air, dew point -73 F). The annealing procedure shall be submitted to the purchaser for review prior to use.

3.5 Mechanical Properties

The following mechanical property requirements shall be met when testing at room temperature:

Tensile Strength	75,000 psi min.
Yield (0.2% offset)	30,000 psi min.
% Elongation (in 2 in.)	30% min.

The number of samples and the test procedures shall conform to the requirements of Ref. 2.1.

3.6 Surface Finish

3.6.1 It shall be assured to a Quality Level of AQL = 6.5%, LTPD or LQ = 68.4%, β or Pa = .10%, that the surface roughness of the wire is 63 RMS or less.

3.6.2 The outside surface of the wire shall be bright and free of discoloration and carbonization, and shall be free of grease, dirt, metal particles and other foreign matter. Discontinuities such as pits, gouges and score marks in excess of 0.002" in depth shall be cause for rejection.

3.6.3 Wire surfaces shall be free from all cracks, laps, seams, and other discontinuities made visible by the applicable test. (See Sec. 4.2.3.) This requirement shall be assured to a Quality Level of AQL = 2.5%, LTPD or LQ = 11.3%, β or Pa = .10.

3.7 Grain Size

It shall be assured to a Quality Level of AQL = 6.5%, LTPD or LQ = 68.4%, β or Pa = .10, that the average grain size of the finished wire is within the ASTM designation 5 or smaller. Average grain size shall be determined in accordance with Ref. 2.2 at 100X.

3.8 Internal Defects

It shall be assured to a Quality Level of AQL = 2.5% LTPD or LQ = 11.3% at β or Pa = .10, that the requirements of this section (Sec. 3.8) are met. These requirements shall be evaluated by metallographic methods at 100X.

3.8.1 Wire shall be free of seams, cracks, laps, and porosity.

3.8.2 Evidence of intergranular attack (such as that due to excessive pickling) in excess of 0.0005 in. in depth shall be cause for rejection.

3.9 Final Cleaning

All wire shall be vapor-degreased to insure that all surfaces are free of lint, grease, oil, and other foreign matter. After degreasing, the wire shall be washed in clean alcohol and dried in air. Materials used in cleaning must be halide-free.

4. QUALITY REQUIREMENTS

4.1 General

4.1.1 All materials and end products shall be subjected to all non-destructive and destructive test methods and inspections required by this specification, referenced specifications, and drawings.

4.1.2 All instruments and devices used to perform the required inspection must be periodically calibrated. The accuracy and precision of all instruments and devices must be consistent with dimensions and tolerances.

4.1.3 A-C Source Inspection is required prior to shipment, unless waived in writing by A-C prior to the date of shipment. Material or end product received without proof of, or written waiver on, Source Inspection may be returned to the vendor. Final acceptance will be made by A-C Receiving Inspection, however, this does not waive the right of subsequent rejection because of undiscovered or latent defects. Forty-eight (48) hours notice is required to schedule A-C Source Inspection. The vendor shall provide, without additional charge, all reasonable facilities and assistance for any inspection made on its premises.

4.1.4 Allis-Chalmers Quality Department may at any time conduct an audit to determine if the quality requirements of the Purchase Order are being satisfied and if satisfactory quality records are being maintained.

4.1.5 Certificates required by this specification must be signed by a responsible representative or official of the Company. All certificates shall be identified with Purchase Order Number and Date, Part Number if applicable, Part Name, Quantity, applicable A-C Specification Number, Material Heat Number and lot designation. Certificates shall be furnished to the A-C Source Inspector at the time of his inspection, or if Source Inspection has been waived, the certificates shall accompany the material shipped. Four (4) copies of all required certificates shall be furnished.

4.1.6 Materials or end products which do not meet the requirements of the Purchase Order and all applicable drawings and specifications shall be submitted to the Allis-Chalmers Material Review Board for disposition. The Allis-Chalmers Deviation Report, Form 7714, shall be completed by the vendor giving as much detailed information as possible, or the vendor may use a similar type of Deviation Report if the form is approved by A-C prior to use.

4.1.7 If the vendor has a Quality System in operation, i.e., similar or conforming to MIL-Q-9858, this system shall be applicable in satisfying the requirements of this specification. The vendor shall submit a Quality Manual for A-C review and approval. In the event the vendor does not have a Quality System, he shall submit for A-C review and approval a detailed inspection procedure which will be used in conjunction with this specification.

4.2 Specific

4.2.1 The vendor shall use reliable and valid statistical acceptance sampling procedures, such as MIL-STD-105, which will satisfy the requirements of the Secs. 3.6.1, 3.6.3, 3.7 and 3.8. If MIL-STD-105D is used, the lot quality, LQ, approach may be used regardless of lot size in order to assure the Quality Level required and minimize the sample size.

4.2.2 The vendor shall submit for A-C review and approval, detailed inspection methods which will satisfy the requirements of the following:

- 3.1 Dimensions
- 3.5 Mechanical Properties
- 3.6 Surface Finish

4.2.3 Visual Inspection

The requirements of Sec. 3.6.3 shall be assured by performing a fluid penetrant inspection on the outside surface of randomly selected finished lengths of wire in accordance with Ref. 2.4. Any indication shall be considered a defect.

Halide-containing aerosol carriers or penetrants shall not be used. The vendor shall submit the type of penetrant and the intended test procedure for purchaser approval prior to use.

4.2.4 Check Analysis

The chemical composition requirements of Sec. 3.2 shall be verified by two check analyses from the finished product representing each heat of material.

4.3 Certificates

With each shipment the vendor shall furnish four (4) copies of a "Certificate of Compliance" stating that the end product identified by the Certificate is in compliance with the Purchase Order requirements, applicable specifications and drawings, and that records substantiating the compliance are on file and available for examination and audit; and four (4) copies of a "Certified Test Report" stating the specific findings of tests associated with the end product as required for the following:

- 3.1 Dimensions
- 3.2 Chemical Analysis
- 3.5 Mechanical Properties
- 3.7 & 3.8 Metallographic

In addition to the certified test reports, all metallographic specimens or photomicrographs of the specimens used in assuring the requirements of Sec. 3.7 and 3.8 are to be submitted to the purchaser.

5. PACKAGING AND MARKING

The wire shall be packaged in boxes lined with polyethylene or a dry-finish wrapper. The wire shall be packaged in a manner which will prevent nicks, scratches or kinks from occurring during handling or shipping.

The Heat Number, Size, Specification Number, Purchase Order Number and Name of Vendor shall be stenciled on the shipping container.

**SPECIFICATION
FOR
URANIUM DIOXIDE PELLETS**

May 25, 1965

Prepared By:

ALLIS-CHALMERS
Atomic Energy Division
Bethesda, Maryland

1. SCOPE

This specification presents the requirements for uranium dioxide (UO_2) fuel pellets for use in nuclear reactors.

2. APPLICABLE STANDARDS

- 2.1 MIL-STD-105D: Sampling Procedures and Tables for Inspection by Attributes, U. S. Government Printing Office, Washington, D.C.
- 2.2 MIL-STD-414: Sampling Procedures and Tables for Inspection by Variables for Per Cent Defective, U. S. Government Printing Office, Washington, D.C.
- 2.3 QE-104 - Allis-Chalmers Quality Engineering Procedure, Industrial Statistics: Administration and Methods, Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin.
- 2.4 H-109 - Quality Control and Reliability Handbook: Statistical Procedures for Determining Validity of Suppliers' Attribute Inspection, U. S. Government Printing Office, Washington, D.C.

3. REQUIREMENTS

3.1 General Requirements

The fuel pellets shall conform to the requirements of this specification.

3.2 Specific Requirements

3.2.1 Chemical Composition

3.2.1.1 U-235 Enrichment

The U-235 isotopic enrichment of the total uranium in the pellet shall be as specified in the applicable attachment. Blending of other enrichments to achieve the specified enrichment is permitted only in the gaseous (UF_6) stage of the UO_2 powder production process. Further, each bottle of UF_6 shall be enriched to within $\pm 10\%$ (relative) of the specified enrichment for the order.

3.2.1.2 Oxygen to Uranium Ratio

The ratio of oxygen to uranium atoms in the fuel pellets shall not exceed 2.02:1. The quality level to be maintained shall be as indicated below:

	<u>AQL</u>	<u>LTPD</u>	<u>β</u>
Process Capability Study:	1.0%	16%	.10
Production Sampling:	6.5%	68%	.10

3.2.1.3 Specific Impurities

The pellets shall not exceed the following specific impurity limits:

<u>Impurity</u>	<u>Maximum Limit</u>
Carbon	75 ppm
Fluorine	50 ppm
Nitrogen	75 ppm

The quality level to be maintained shall be as indicated below:

	<u>AQL</u>	<u>LTPD</u>	<u>β</u>
Process Capability Study:	1.0%	16%	.10
Production Sampling:	6.5%	68%	.10

3.2.1.4 Equivalent Boron Content (EBC)

The total impurity content of the pellets shall not exceed an EBC of 4 parts per million on a weight basis. The computed EBC shall be based on the elements and conversion factors listed in Addendum A. The quality level to be maintained shall be as indicated below:

	<u>AQL</u>	<u>LTPD</u>	<u>β</u>
Process Capability Study:	1.5%	25%	.10
Production Sampling:	6.5%	68%	.10

3.2.1.5 Uranium Content

The total uranium content of the pellets shall be equal to or greater than 88.05 weight percent. The following quality levels shall be assured:

	<u>AQL</u>	<u>LTPD</u>	<u>β</u>
Process Capability Study:	1.0%	16%	.10
Production Sampling:	6.5%	68%	.10

3.2.1.6 Dryness

It shall be assured with 95% confidence that 95% of the pellets (quality level 95% γ x 95% P) have a water (H₂O) content less than or equal to 35 ppm on a weight basis.

3.2.2 Physical Requirements

3.2.2.1 Dimensions

It shall be assured with 95% confidence that 99% of the pellets (quality level 95% γ x 99% P) shall meet all the dimensions and associated tolerances as shown on the drawings specified in the applicable attachment.

3.2.2.2 Density

3.2.2.2.1 There shall be 95% confidence (quality level 95% on $\bar{x}$) that the average W/L of the fuel pellets is greater than that specified in the applicable attachment.

3.2.2.2.2 It shall be assured with 95% confidence that 99% of the pellets (quality level 95% γ x 99% P) have a density equal to or greater than that specified in the applicable attachment.

3.2.2.3 Chips and Cracks

The requirements listed below shall be assured to the following quality level:

<u>AQL</u>	<u>AOQL</u>
65%	1.0%

3.2.2.3.1 The total area of all chips on the cylindrical surface of each pellet shall not exceed 5% of the cylindrical surface area of the pellet. Any one chip shall not exceed 2% of the cylindrical surface area of the pellet. No cylindrical surface chip shall exceed 0.025 in. in depth.

3.2.2.3.2 The total area of the chips on the flat surface of land of the pellet shall not exceed an area equivalent to a 180° sector of the circle. Any one chip on the flat surface or land shall not exceed a 90° sector. Edge chips shall be included in the chip evaluation.

3.2.2.3.3 Cracked pellets may be accepted provided they survive a free fall of 2 feet onto a non-yielding hard surface.

3.2.2.3.4 Pellets shall be free from foreign material such as marking crayon, grinding wheel binder, etc.

4. QUALITY REQUIREMENTS

4.1 General

4.1.1 All materials and end products shall be subjected to all non-destructive and destructive test methods and inspections required by this specification, referenced specifications, and drawings.

4.1.2 All instruments and devices used to perform the required inspection must be periodically calibrated. The accuracy and precision of all instruments and devices must be consistent with dimensions and tolerances.

4.1.3 A-C Source Inspection is required prior to shipment unless waived in writing by A-C prior to the date of shipment. Material or end products received without proof of, or written waiver on, Source Inspection may be returned to the vendor. Final acceptance will be made by A-C Receiving Inspection; however, this does not waive the right of subsequent rejection because of undiscovered or latent defects. Forty-eight (48) hours notice is required to schedule A-C Source Inspection. The vendor shall provide, without additional charge, all reasonable facilities and assistance for any inspection made on its premises.

4.1.4 Allis-Chalmers Quality Department may at any time conduct an audit to determine if the quality requirements of the Purchase Order are being satisfied and if satisfactory quality records are being maintained. The Auditor may use H-109, Ref. 2.4, or any appropriate statistical test to verify the inspection results of the vendor.

4.1.5 Certificates required by this specification must be signed by a responsible engineer or official of the company. All certificates shall be identified with Purchase Order Number and Date, Part Number, Part Name, Quantity, applicable A-C Specification Number, and Lot Designation.

Certificates shall be furnished to the A-C Source Inspector at the time of his inspection; or, if Source Inspection has been waived, the certificates shall accompany the material shipped. Four (4) copies of all required certificates shall be furnished.

4.1.6 Materials or end products which do not meet the requirements of the Purchase Order and all applicable drawings and specifications shall be submitted to the Allis-Chalmers Material Review Board for disposition. The Allis-Chalmers Deviation Report, Form 7714, shall be completed by the vendor giving as much detailed information as possible, or the vendor may use a similar type of Deviation Report if the form is approved by A-C prior to use.

4.1.7 If the vendor has a Quality System in operation, i.e., similar or conforming to MIL-Q-9858, this system shall be applicable in satisfying the requirements of

this specification. The vendor shall submit a Quality Manual for A-C review and approval. In the event the vendor does not have a Quality System, he shall submit for A-C review and approval a description of the inspection system which will be used in conjunction with this specification.

4.1.8 Prior to the start of the Process Capability Study, the vendor shall submit an overall Quality Plan to Allis-Chalmers for review and approval.

4.1.8.1 The Quality Plan shall contain, but is not limited to, the following:

- a) Statistical sampling plans, methods and procedures, including references.
- b) Inspection and test equipment, methods and procedures.
- c) Control and reporting of non-conforming material.
- d) In-Process and final acceptance inspection and test points of the manufacturing process.

4.1.8.2 All changes or revisions to the approved Quality Plan shall be reviewed and approved by A-C prior to use.

4.2 Specific

4.2.1 A Process Capability Study shall be designed and used to demonstrate the process is capable of producing pellets which meet the requirements of the sections of this specification as noted below. Pellets selected randomly from the first production lot shall be used to perform this study. Raw data, analysis of the data, conclusions and recommendations of the study must be reported to the Purchaser on a timely basis. In no event may production progress beyond the third lot until the purchaser has approved the Process Capability Study. In lieu of demonstrating the capability of the process the vendor may submit for review and approval by Allis-Chalmers objective evidence that the vendor has previously demonstrated the capability of the process. Reliable and valid statistical sampling procedures such as MIL-STD-105D, Ref. 2.1, MIL-STD-414, Ref. 2.2, shall be used. All statistical applications shall be in accordance with QE-104, Ref. 2.3.

3.2.1.2	3.2.1.6
3.2.1.3	3.2.2.1
3.2.1.4	3.2.2.2
3.2.1.5	3.2.2.3

4.2.2 Prior to the use of a chemical analysis method for evaluation of characteristics, the vendor shall submit the precision and accuracy of the method for review and approval. Raw data, method of precision, and accuracy shall also be included.

4.2.3 The vendor shall design and submit to the purchaser for review and approval a suitable plan and test to show compliance with Sec. 3.2.2.3.2.

4.2.4 The vendor shall design and use in-process control, Ref. 2.3, or lot-by-lot acceptance sampling plans, such as MIL-STD-105D, Ref. 2.1 or MIL-STD-414, Ref. 2.2, which will satisfy the requirements of the paragraphs listed below. The raw data and calculated data generated by the sampling plans or in-process control plans shall be furnished to Allis-Chalmers.

3.2.1.2	3.2.1.6
3.2.1.3	3.2.2.1
3.2.1.4	3.2.2.2
3.2.1.5	3.2.2.3

4.2.5 The vendor shall verify the compliance with Sec. 3.2.1.1 by performing an isotopic analysis of one pellet randomly selected from each lot. The results of the isotopic analysis shall be within $\pm 5\%$ (relative) of that required, or the lot shall be rejected. The vendor shall also certify the enrichment of each lot of pellets.

4.2.6 To fulfill the requirement of Sec. 3.2.2.3.1, the vendor shall submit duplicate sets of visual standards for review and approval prior to production. One set shall be used by the vendor, and the other set shall be retained by the purchaser.

4.3 Certificates

With each shipment the vendor shall furnish four (4) copies of a "Certificate of Compliance" stating that the end product identified by the Certificate is in compliance with the Purchase Order requirements, applicable specifications, and drawings; and that records substantiating the compliance are on file and available for examination and audit.

4.3.1 With each shipment the vendor shall furnish four (4) copies of a Certified Test Report stating the specific findings of tests associated with the end product as required for the following:

- U-235 Enrichment (3.2.1.1)
- Oxygen to Uranium Ratio (3.2.1.2)
- Specific Impurities (3.2.1.3)
- Equivalent Boron Content (3.2.1.4)
- Uranium Content (3.2.1.5)
- Dryness (3.2.1.6)
- Density (3.2.2.2)

4.3.2 With each shipment the vendor shall furnish four (4) copies of "Certified Inspection Results" stating the specific finding of the inspection on the end product as required for the following:

Dimensions (3.2.2.1)

Chips (3.2.2.3)

5. PACKING AND SHIPPING

5.1 The vendor shall design and furnish containers and packing materials to prevent damage or contamination of the pellets during shipment and unpacking and to meet all applicable federal and local regulations for such shipments. The design of shipping containers and packing material shall be submitted to A-C for review and approval.

5.2 The containers may be of the returnable or non-returnable type but shall be made in sufficient quantity to assure delivery of required pellets on schedule.

5.3 The shipping container shall be identified to indicate the vendor, material, lot number and quantity in addition to any required for radioactive material warning designations.

ADDENDUM A

EQUIVALENT BORON CONTENT OF IMPURITIES IN
URANIUM DIOXIDE

In accordance with Specification 43-101-865, paragraph 3.2.1.4, the following table of conversion factors shall be used to convert the ppm (by weight) of impurity elements to EBC. The sum of the calculated EBC's shall be used to determine the total EBC.

Example: (Impurity, ppm) (Conversion Factor) = (EBC, ppm)
 (Iron, 100 ppm) (0.000672) = 0.0672 EBC ppm

<u>Impurity Element</u>	<u>Conversion Factor</u>
Boron	1.000
Cadmium	0.325
Chromium	0.000799
Cobalt	0.00923
Copper	0.000868
Iron	0.000672
Manganese	0.00344
Molybdenum	0.000403
Nickel	0.00112
Nitrogen	0.00192
Silver	0.00823
Tungsten	0.00150
Vanadium	0.00141
Samarium	0.524
Europium	0.433
Gadolinium	4.189
Dysprosium	0.0969

Attachment No. 2

Mark 401

SPECIFIC REQUIREMENTS

FOR

2 - LOW ENRICHED SUPERHEATER

PROTOTYPE FUEL ELEMENTS

1. (Ref. Section 3.2.1.1)

The enrichment of the Uranium in the U-235 isotope shall be $5.93 \pm .08$ weight percent.

2. (Ref. Section 3.2.2.2)

2.1 The density of each fuel pellet shall be greater than 5.56 grams per inch of pellet length.

2.2 Delete the requirements of paragraph 3.2.2.2.1. The requirements of paragraph 3.2.2.2.2 shall apply.

3. (Ref. Section 3.2.2.1)

The applicable pellet drawing is 41-500-680, Rev. 01.

4. A general description of the pellet manufacturing process shall be submitted to the Purchaser as a part of the Vendor's proposal. It is understood and agreed that no proprietary or company confidential information on manufacturing procedures is required.

Attachment No. 3

Specific Requirements

For

Pathfinder Core II - Superheater Fuel

(LESH - I)

1. (Ref. Section 3.2.1.1)

The enrichment of the uranium in the U-235 isotope shall be $6.95 \pm .05$ weight percent.

2. (Ref. Section 3.2.2.2)

2.1 Delete the requirements of section 3.2.2.2.1.
The following shall apply:

There shall be 95% confidence (quality level on $\bar{x}$) that the average density (weight per unit length) of the fuel pellets is between the maximum and minimum specified below:

maximum - 5.732 grams/inch
minimum - 5.618 grams/inch

2.2 Delete the requirements of section 3.2.2.2.2.
The following shall apply:

It shall be assured with 95% confidence that 99% of the individual pellets (quality level 95% x 99%P) have a density (weight per unit length) within the limits specified below:

maximum - 5.959 grams/inch
minimum - 5.391 grams/inch

3. (Ref. Section 3.2.2.1)

The applicable pellet drawing is 41-500-693.

4. A general description of the pellet manufacturing process shall be submitted to the Purchaser as a part of the Vendor's proposal. It is understood and agreed that no proprietary or company confidential information on manufacturing procedures is required.

PROCUREMENT SPECIFICATION
FOR
PATHFINDER LESH PROTOTYPE
FUEL ELEMENTS

October 15, 1965

Prepared By:

ALLIS-CHALMERS
ATOMIC ENERGY DIVISION
BETHESDA, MARYLAND 20014

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SPECIFIC REQUIREMENTS1. SCOPE

This specification presents the requirements for the materials, components, and completed low-enrichment superheater (LESH) fuel element prototypes for irradiation under Appendix D.5 of the Pathfinder Project. Also included are the pre-irradiation inspection requirements for the completed fuel elements.

2. APPLICABLE DOCUMENTS

- 2.1 Drawing 41-500-680 Rev. 03 LESH Prototype Fuel Element
- 2.2 41-1001 Uranium Dioxide Pellets
- 2.3 41-703 Incoloy 800 Tubing for Nuclear Fuel Elements
- 2.4 41-713 Incoloy 800 Wire for Nuclear Application
- 2.5 41-712 Incoloy 800 Rod for Fabricating End Caps
- 2.6 ASTM A-276 Austenitic Stainless Steel
- 2.7 ASTM B-408 Nickel-Iron-Chromium Alloy Rod and Bar
- 2.8 MIL-STD-271C Non-Destructive Testing
- 2.9 A-C Industries Group, Atomic Energy Division Quality Manual
- 2.10 ASTM A-313 Corrosion-Resisting Steel Spring Wire
- 2.11 ASTM B-407 Nickel-Iron-Chromium Alloy Seamless Pipe & Tube

3. REQUIREMENTS3.1 General Requirements3.1.1 Process Approvals

The F&CC Department, AED-Greendale is responsible for establishing and controlling the manufacturing process. Copies of the final revisions of all such procedures, processes, etc., reflecting the actual procedures used, are to be forwarded to AED-B Engineering Department for information.

3.2 Specific Requirements3.2.1 Material3.2.1.1 Uranium Dioxide Pellets

The uranium dioxide pellets shall meet the requirements of Ref. 2.1 and 2.2 including attachment No. 2 "Specific Requirements for 2 Low Enriched Superheater Prototype Fuel Elements," and the final enrichment which was revised from $5.93 \pm .08$ w/o to $7.5 \pm .08$ w/o.

3.2.1.2 Springs

The springs shall meet the requirements of Ref. 2.1 and 2.10.

3.2.1.3 Spacer Wire

The spacer wires shall meet the requirements of Ref. 2.1 and 2.4.

3.2.1.4 Cladding Tubing

The tubing shall meet the requirements of Ref. 2.1 and 2.3 as modified by the "Specific Requirements for Incoloy 800 Tubing for Prototype LESH Superheater Fuel Elements" document dated 4/21/65.

3.2.1.5 Fuel and Poison Pin End Plugs (Upper fitting, lifting fitting, lower fitting, and slotted fitting)

All end plugs shall be fabricated from material which meets the requirements of Ref. 2.5.

3.2.1.6 Poison Pin Alumina Spacer

3.2.1.6.1 Dimensions

It shall be assured with 85% confidence that 79% of the alumina spacer pellets (85% γ x 79% P) meet all dimensional and tolerance requirements as required by Ref. 2.1.

3.2.1.6.2 Chemistry

It shall be assured with 90% confidence that 85% of the finished alumina pellets (90% γ x 85% P) conform to the following chemical composition by weight:

Al ₂ O ₃	99.00% Min.
SiO ₂	0.08% Max.
MgO	0.08% Max.
Fe ₂ O ₃	0.10% Max.
Na ₂ O	0.06% Max.
C	0.01% Max.
CaO	0.08% Max.
ZrO ₂	0.08% Max.
Water soluble (as NaCl)	25 ppm Max.

Total Hafnium, Cadmium, Boron, and Rare Earths shall not exceed 100 ppm.

3.2.1.6.3 Density

The density of the finished alumina spacer pellets shall be a minimum of 3.70 grams/cc. This shall be assured to a quality level of 85% γ x 70% P.

3.2.1.6.4 Dryness

The finished alumina shall be sufficiently dry so that when heated for four hours at 200 C in a vacuum, the weight loss shall not exceed 30 ppm. The furnace pressure shall not exceed 1000 microns. This requirement shall be assured by 100% testing of the production spacer pellets.

Subsequent handling and storage of the alumina spacer pellets shall be such that the specified quality of dryness is maintained in the completed poison pin.

3.2.1.6.5 Impurities

Any foreign materials such as organic binders, lubricants, etc., utilized in the fabrication process must be completely removed.

3.2.1.6.6 Manufacturing Process

The alumina spacer pellets may be manufactured by any process which produces a product consistent with the requirements of this specification.

3.2.1.7 Poison Wire

3.2.1.7.1 Fabrication

Poison wires shall be fabricated from nominally 2.0 w/o B-stainless plate stock by cutting strips and cold swaging to final diameter.

If necessary to meet final diameter requirements, final diameter reduction may be accomplished by centerless grinding.

Swaged short wire lengths shall be butt-welded together to form the full length wire.

3.2.1.7.2 Each boron-stainless poison wire shall be fabricated to conform to the total length requirements of Ref. 2.1. Item (11) shall be fabricated to fit the final wire diameter, and in conformance to other requirements of Ref. 2.1.

3.2.1.7.3 Wire diameter and boron loading shall conform to the following:

The objective average boron concentration over the 72.5 in. wire length is 1.84 w/o. The required average wire diameter corresponding to this is 0.1459 inch.

To allow for expected variables in the fabrication process, the poison wire full length average boron concentration and diameter must conform to and be limited within the range of values tabulated as follows:

Average Boron Concentration	Corresponding Required Average Wire Diameter - In
<u>Weight percent</u>	<u>(To be within ± 0.001 inch of value indicated)</u>
1.70	.1520
1.71	.1515
1.72	.1511
1.73	.1506
1.74	.1502
1.75	.1497
1.76	.1493
1.77	.1488
1.78	.1484
1.79	.1480
1.80	.1475
1.81	.1471
1.82	.1467
1.83	.1463
(1.84)	(.1459)
1.85	.1455
1.86	.1451
1.87	.1447
1.88	.1443
1.89	.1440
1.90	.1435
1.91	.1432
1.92	.1428
1.93	.1425
1.94	.1421
1.95	.1418

Any local sample (of one inch maximum length) shall have a boron concentration between 1.70 and 1.95 w/o. This requirement shall be assured for the completed full length poison wire, which includes butt welds. Local diameter variation shall be limited to ± 0.003 inch with respect to the actual full length average diameter.

3.2.1.8 Retainer Ring

The retainer ring shall be fabricated from material meeting the requirements of Ref. 2.7. If machined from solid stock, the ring shall be given a mill anneal prior to finish machining.

3.2.1.9 Lower End Fitting

The Lower End Fitting shall be fabricated from material meeting the requirements of Ref. 2.7 and in accordance with Ref. 2.1.

3.2.2 Fuel and Poison Pins

3.2.2.1 Fuel Loading

The following requirements shall be assured by 100% testing: Each fuel pin shall contain a minimum of 399.34 grams of UO_2 . Pellet stack length shall conform to requirements of Ref. 2.1.

3.2.2.2 Fuel Pins - Helium Atmosphere

The free volume within the finished fuel pins shall contain a minimum of 50%, by volume, Bureau of Mines, Grade A Helium.

3.2.2.3 Poison Pin Boron Loading

Requirements specified per Sec. 3.2.1.7.

3.2.2.4 Poison Pins - Helium Atmosphere

The free volume within the finished poison pins shall contain a minimum of 50% volume, Bureau of Mines, Grade A Helium.

3.2.2.5 Fuel and Poison Pin End Plug Weld Requirements

3.2.2.5.1 Weld Surface Defects

It shall be assured by 100% inspection that the end plug welds and the weld heat effected zone surfaces are free from cracks, laps or sharp discontinuities.

3.2.2.5.2 Weld Internal Defects

It shall be assured with 90% confidence that 85% of the fuel pin and poison pin end plug weld regions ($90\% \gamma \times 85\% P$) are free of internal defects as described below:

a) cracks, laps, and seams including those propagating from the surface.

b) The maximum void dimension in any transverse section of the weld shall not exceed 0.005 inch.

No combination of small voids or porosity in any quadrant shall exceed an area of 0.00002 sq. in. where the quadrant shall be arranged to obtain the largest total void projected area.

Any series of interconnecting voids, regardless of size or area, shall be limited to a total length of 0.005 inch.

c) Minimum wall thickness shall not be less than 0.015 in.

d) Inclusions greater than 0.005 inch in any dimension.

3.2.2.6 Spacer Wire Weld Requirements

3.2.2.6.1 Position

The position of the welded spacer wires shall be within the tolerance limits specified in Ref. 2.1.

3.2.2.6.2 Radial Location

The wire welding process shall limit the degree of sink of wire into the clad to 0.0005 inch maximum, when compared to the theoretical location based on unwelded wire to tube tangential surface contact.

3.2.2.6.3 Weld Criteria

Each spacer wire shall be continuously high frequency resistance welded to the fuel sheath to the finished ends of the wire.

In the event that the resistance weld cannot be continued to the wire ends, a local TIG weld may be employed at wire ends. The intended TIG weld process will be subject to approval by AED-B Engineering.

3.2.2.6.4 Transverse Dimension of Weld

The wire to tube weld shall have a minimum width of 0.002 inch. The depth of penetration of the heat affected zone in the fuel pin clad shall not exceed 0.002 inch.

These requirements shall be assured to a quality level of 90% γ x 85% P.

3.2.2.6.5 Defects

The wire to tube weld region shall be internally free of cracks and porosity, and from any sharp notch type discontinuities in any orientation at the surface.

It shall be established that a zone of complete fusion exists in the weld region without evidence of a contaminated interface or oxide layer.

These requirements shall be assured to a quality level of 90% γ x 85% P.

3.2.2.6.6 Discoloration

Wire and tube surfaces in the heat-affected area shall be free of discoloration or surface oxide to an extent defined by a mutually-agreed-to standard.

3.2.2.6.7 Weld Mechanical Properties

The tensile properties of both tube and wire shall not be impaired by the weld process.

Ductility of the heat affected material and the weld fillet shall be shown to be within 90% of the fully annealed unwelded wire or tube ductility, whichever is less.

3.2.2.7 Helium Leak Rate

It shall be assured by 100% testing that each individual fuel pin and poison pin indicates a helium leak rate of less than 5.0×10^{-9} standard cc/sec.

3.2.2.8 Surface Defects

It shall be assured by 100% inspection that the finished fuel and poison pins are free of scratches, gouges or dents in excess of 0.002 inch deep in the tube area and 0.005 inch deep in the end plugs. Gross discoloration due to end plug welding shall be removed.

3.2.3 Identification

All fuel and poison pins shall be permanently identified as follows:

- a) Fuel pins shall be identified by marking the Serial Number on the slotted fitting (Pc. #6, Drawing 41-500-680). The Serial Numbers shall be 1 to 12 consecutive.
- b) The poison pin shall be identified by marking the Serial Number on the lifting fitting (Pc. #4, Drawing 41-500-680). This number shall be P-1 and P-2 and will also be the fuel element assembly number. The identification shall be approximately 1/8" high and .005" to .015" deep, located on the lower portion of the .312 diameter.

NOTE: Before proceeding with assembly, see Pre-Irradiation Requirements, Sec. 4.3.

3.2.4 Fuel Element Assembly

3.2.4.1 Assembly Method

Establishing a satisfactory assembly method shall be at the F&CC Dept's discretion. The final established method shall be submitted to AED-B Engineering for information.

3.2.4.2 Slotted Fitting to Lower End Fitting Welds

3.2.4.2.1 The structural welds shall conform to all requirements of Ref. 2.1.

3.2.4.2.2 Penetration

The depth of the continuous fusion zone between blade and slot measured parallel to the slot surface shall be a minimum 0.040 inch on both sides of the blade.

This requirement shall be assured by destructive testing of two pre-production weld mockups.

3.2.4.2.3 Surface Defects

Each full length weld shall be free of cracks and any sharp surface discontinuities.

3.2.4.3 Cleanliness

All the components and the finished fuel element shall be free from all grease, dirt, lint, moisture or other foreign materials. Residual halides shall not exceed 0.0005 mg/in.². The assembled and cleaned fuel element assembly shall be sealed in polyethylene.

3.2.4.4 Uranium Contamination

It shall be assured by 100% inspection that surface contamination shall not exceed 5.0×10^{-6} gms/ft² of U-235, including all uncertainties associated with the inspection methods used.

4. QUALITY REQUIREMENTS

4.1 General

4.1.1 All materials and end products shall be subjected to all non-destructive and destructive test methods and inspections required by this specification, referenced specifications, and drawings.

4.1.2 The general requirements stated in Ref. 2.9 shall apply to this specification.

4.1.3 All instruments and devices used to perform the required inspection must be periodically calibrated. The accuracy and precision of all instruments and devices must be consistent with dimensions and tolerances.

4.1.4 Materials or end products which do not meet the requirements of this and other applicable specifications and drawings shall be submitted to the Materials Review Board.

4.1.5 Quality Plan

An approved quality plan, including revisions and changes, shall be prepared by Quality Engineering.

4.2 Specific

4.2.1 Internal Atmosphere

The requirement of Sec. 3.2.2.2 and 3.2.2.4 shall be assured by a description and approval of the process used for filling the tubes.

4.2.2 Cleaning

The cleaning procedures shall be proven capable of removing residual halides to the level required by Sec. 3.2.4.3.

4.2.3 End Plug Weld Metallography

The requirements of Sec. 3.2.2.5.2 shall be assured by metallographic sectioning of sample welds, and viewed at 100X minimum. Each weld sectioned shall be mounted transversely and polished incrementally every .005" through the weld region. A sufficient number of longitudinal sections shall be mounted to show typical weld characteristics. These sections will be used for information purposes only.

4.2.4 Fluid Penetrant Examination of End Plug Welds

The requirements of Sec. 3.2.2.5.1 shall be assured by examination of the weld areas with a Type IV fluid penetrant using the methods outlined in Ref. 2.8. The standard of acceptance is: no indication of defects as described in Sec. 3.2.2.5.1.

4.2.5 Spacer Wire Weld Evaluation

4.2.5.1 The requirements of Sec. 3.2.2.6.1, 3.2.2.6.2, and 3.2.2.6.3 shall be assured through process and procedures approved by AED-B Engineering.

4.2.5.2 Metallography

4.2.5.2.1 The requirements of Sec. 3.2.2.6.4 and 3.2.2.6.5 shall be assured by metallographic sections of sample weld areas.

Transverse sections shall include the entire heat affected zone, and shall be evaluated at 250X.

4.2.5.3 Discoloration

Acceptance for the requirements of Sec. 3.2.2.6.6 shall be based on visual standards.

4.2.5.4 Mechanical Property Tests

To assure the requirements of Sec. 3.2.2.6.7, tests shall be performed on welded pre-production samples. Detailed test procedures shall be established and submitted to Engineering for approval.

4.2.6 Surface Defects

The requirements of Sec. 3.2.2.8 shall be assured by visual inspection against standards. Measurements shall be made in borderline cases only.

4.2.7 Helium Leak Test

The requirements of Sec. 3.2.2.7 shall be assured by giving each fuel and poison rod a mass spectrometer helium leak test. The rods shall be pressurized in ambient temperature helium to a pressure of 95 psig for a minimum of 5 minutes. Within 10 minutes after removal of the tubes from the pressure chamber, the tubes shall be inserted in alcohol to determine visible leaks. Within 2 hours after pressurizing, each fuel rod shall be given a vacuum leak test by an approved process. The equipment shall be capable of detecting a helium leak of 10^{-9} std. cc/sec.

4.2.8 Visual Examination of Structural Welds

The requirements of Sec. 3.2.4.2.3 shall be assured by 100% visual examination of welds at 60X minimum. The standard of acceptance is no indication as described in Sec. 3.2.4.2.3.

4.2.9 Metallographic Evaluation of Structural Welds

The requirements of Sec. 3.2.4.2.2 shall be assured by transverse metallographic section, evaluated at 10X. A minimum of four transverse sections, equally spaced over the weld length, shall be evaluated from each of the two required welds.

4.2.10 Aluminum Oxide Spacer Pellets

4.2.10.1 Certificates of Compliance

To assure the requirements of Sec. 3.2.1.6, three (3) copies of a "Certificate of Compliance" shall be furnished by the supplier, stating that the end product identified by the certificate is in compliance with the Purchase Order requirements and all applicable specifications and drawings. These substantiating records shall be retained for a period of one year after removal from the reactor of the last fuel element assembly.

4.2.10.2 Moisture in Alumina in Finished Poison Pin

Intended procedures to assure the moisture requirements for finished pins, as specified in Sec. 3.2.1.6.4, shall be submitted for approval.

4.2.11 Poison Wire Assurance Tests

Quality level and inspection procedures to assure the boron loading and diameter requirements of Sec. 3.2.1.7.2 shall be submitted for approval by AED-B Engineering.

4.2.12 Fuel Element Assembly Cleanliness

The requirements of Sec. 3.2.4.3 shall be assured by passivating, cleaning, and packaging the finished fuel rods according to an approved procedure. Further assembly shall be done in a clean room. All handling after cleaning shall be done with clean lint-free gloves.

Passivating shall be accomplished using nitric acid only.

It shall be demonstrated, for approval by Engineering, that the post-passivation rinse procedure is capable of removing all acid from the fuel rod surface. Of particular concern is the crevice formed between spacer wires and tube.

4.2.13 Uranium Contamination

The requirements of Sec. 3.2.4.4 shall be assured by inspecting the assembly according to an approved procedure.

4.2.14 Identification and Traceability of Material and Product

Records and identification shall be kept for one year after removal from the reactor to maintain the identity of all pellet lots and cladding heats throughout manufacturing. This information shall be traceable to the fuel assembly and individual fuel or poison pin.

4.2.15 Test Reports

Two (2) copies of a test report stating the specific findings of tests, or (2) photomicrographs (where appropriate), shall be furnished to AED-B Engineering for the following:

- 3.2.1.7 Poison Wire
- 3.2.2.1 Fuel Loading
- 3.2.6.1 Dimensional, Chemistry, and Dryness for Alumina Spacers
- 3.2.2.5.2 Weld Internal Defects (All Metallography)
- 3.2.2.6.4 & 3.2.2.6.5 (All Metallography)
- 3.2.2.7 Helium Leak Rate
- 3.2.4.2.2 Structural Weld Penetration (Metallography)
- 3.2.4.4 Uranium Contamination
- Chemical and physical tests required for all materials.

4.3 Pre-Irradiation Inspection Data

This section delineates the inspection and records required as pre-irradiation data for the two (2) LESH prototype fuel elements.

4.3.1 General

The various data for each of the two (2) elements shall be compiled and recorded on the forms provided. Five (5) copies of all completed data forms are to be transmitted to AED-B Engineering.

4.3.2 Specific

4.3.2.1 Data Sheet 1

(a) Copies of the certified chemical analysis provided by the tubing and wire supplier shall satisfy the requirements for fuel pin clad and spacer wire chemistry analysis. In the event that either has been produced using more than one heat of material resulting in more than one chemical analysis, the analysis must be identified with the Fuel Pins.

(b) Copies of the chemical analysis and U-235 enrichment provided by the pellet supplier shall satisfy the requirement for pellet chemistry analysis and enrichment.

(c) The measured pellet stack height shall be recorded.

(d) The recorded fuel pin length shall be the measured length of the pin from the bottom of the 0.080" wide slot in Piece No. 6 to the 0.211" diameter shoulder of Piece No. 7. Reference: 76.48" dimension on Drawing 41-500-680.

4.3.2.2 Data Sheet 2

(a) Diameter measurements shall be recorded for each fuel pin at approximately 6" - 7" intervals. The first reading shall be 1" from the bottom of the slot in the slotted end fitting, Piece No. 6. Two readings shall be taken at each longitudinal location with the 0° - 180° reading on the slot centerline. The longitudinal location of the reading shall be recorded on the data sheet.

(b) Each poison pin diameter shall be inspected and recorded at the positions shown on the Data Sheet. The 1" position is measured from the bottom edge of the .240" shoulder. The 0° - 180° plane shall be oriented to the centerline of the identification marking on the lifting fitting piece number 4.

4.3.2.3 Data Sheet 3

(a) The envelope diameter defined by the fuel rod and the spacer wire shall be inspected and recorded at approximately 6" - 7" intervals longitudinal from the bottom. The 0°, 160°, and 240° readings shall all be taken at the same longitudinal location, with the 0° reading on the centerline of the slot in piece number 6. The longitudinal location of the reading shall be recorded on the Data Sheet.

4.3.2.4 Photomicrographs

The photomicrographs listed in this section shall be taken at 100X and shall be printed on 8-1/2" x 11" sheets. Sectioning performed during development work may be used where applicable provided production material has been used. Each print shall be clearly identified with the subject.

Photomicrographs shall include but not be limited to the following:

- (a) Typical transverse clad tubing for each heat used in production.
- (b) Typical longitudinal clad tubing for each heat used in production.
- (c) Typical transverse through fuel pin slotted end fitting weld.
- (d) Typical longitudinal through fuel pin slotted end fitting weld.
- (e) Typical transverse through fuel pin upper end fitting weld.
- (f) Typical longitudinal through fuel pin upper end fitting weld.
- (g) Typical transverse through fuel pin and spacer wires.

4.3.2.5 Photographs

Five copies of the following 8-1/2 x 11" colored photographs shall be provided for each fuel assembly:

1. Close up view of upper end
2. Close up view of lower end
3. Close up view showing typical 4-inch length of fuel assembly
4. Full length view of complete assembly suspended in vertical position

4.3.2.6 Sample Material

The following material samples will be retained for post-irradiation work:

- (a) Two (2) 6" long sections of clad tubing
- (b) One (1) 6" long section of Boron-Stainless Wire (taken from wire used in production)
- (c) Two (2) sections of Alumina
- (d) Two (2) UO₂ pellets
- (e) One (1) 8" section of tubing with spacer wires attached.

5. PACKING AND SHIPPING

5.1 Fuel Assembly Protection

Each completed fuel assembly shall be sealed in a plastic container of polyethylene (.004 in. min. thickness) or its equivalent, which shall be moisture and dust tight.

Each assembly, after sealing in plastic, shall be contained in a full length aluminum or stainless steel tube for all subsequent handling and shipping. Each assembly shall be loaded in the shipping container in a clean, dry condition.

All necessary precautions shall be taken during packing to protect each fuel element from damage during shipment.

5.2 Containers

The F&CC Dept. shall supply suitable expendable or returnable shipping containers for transporting the fuel assemblies. Each shipping container shall be designed to provide maximum support to the fuel assemblies to prevent damage during shipment. In addition, the shipping containers shall be designed so that the fuel assemblies can be loaded and unloaded in either the horizontal or vertical direction.

5.3 Marking

Each container shall include a list of the contents of the container showing the Purchase Order Number, Equipment Number, etc. Each container shall be identified to indicate the vendor, component, and quantity in addition to any requirements for radioactive material warning regulations.

5.4 Regulations

The shipping containers shall fulfill all requirements of the U.S. Atomic Energy Commission, the Interstate Commerce Commission and local regulations regarding transportation of radioactive materials.

5.5 Shipping Schedule

A shipping schedule shall be submitted as soon as practical and kept current. A minimum of five (5) days notice shall be given before shipment.

Low Enriched Superheater Fuel Element
Pre-Irradiation Data

Element Identification _____

Drawing Number _____

Date _____

1. Fuel Pin Data

1.1 Fuel Pin Clad Chemistry Analysis _____

1.2 Spacer Wire Chemistry Analysis _____

1.3 Fuel Pellet Chemistry Analysis _____

1.4 Fuel Pellet Enrichment _____

1.5 Fuel Pellet Stack Height
(2 significant figures)

Pin Number _____ Height _____

Pin Number _____ Height _____

Pin Number _____ Height _____

Pin Number _____ Height _____

Pin Number _____ Height _____

Pin Number _____ Height _____

1.6 Fuel Pin Length (2 significant figures)

Pin Number _____ Length _____

Pin Number _____ Length _____

Pin Number _____ Length _____

Pin Number _____ Length _____

Pin Number _____ Length _____

Pin Number _____ Length _____

1.7 Force needed to insert element into
full-length gauge (84" long) _____

Fuel Pin Diameter Dimensional Data (Record to 4 significant figures)

Pin No.	Direction	Longitudinal Location from Bottom													
	0° - 180°														
	90° - 270°														
	0° - 180°														
	90° - 270°														
	0° - 180°														
	90° - 270°														
	0° - 180°														
	90° - 270°														
	0° - 180°														
	90° - 270°														
	0° - 180°														
	90° - 270°														

Posion Pin Diameter Dimensional Data (Record to 4 significant figures)

Pin No.	Direction														
		1"	7-1/2"	14"	20-1/2"	27"	33-1/2"	40"	46-1/2"	53"	59-1/2"	66"	72-1/2"	76"	
	0° - 180°														
	90° - 270°														

Wire Diameter Plus Fuel Rod Dimension (Record to 4 significant figures)

Pin No.	Direction	Longitudinal Location from Bottom															
	0°																
	120°																
	240°																
	0°																
	120°																
	240°																
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