**COBALT-80
HEAT SOURCE
DEMONSTRATION PROGRAM
PHASE III - FABRICATION
FINAL REPORT**

JUNE 1973

MASTER

Westinghouse
Electric
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COBALT-60 HEAT SOURCE DEMONSTRATION PROGRAM PHASE III - FABRICATION FINAL REPORT

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TECHNICAL MANAGEMENT
SAVANNAH RIVER OPERATIONS OFFICE
AIKEN, SOUTH CAROLINA
TECHNICAL AND PRODUCTION DIVISION
K. J. ANUSAVICE

Approved by:

John W. Sadler

J. W. Sadler
Project Manager, Cobalt-60
Heat Source Demonstration Program

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1.0 INTRODUCTION

The Co-60 Heat Source Demonstration Program has as its primary objective the design, development, fabrication and testing of a large terrestrial radioisotope heat source. This report summarizes the results of the third phase (Fabrication and Assembly) of a planned five phase program. The Phase III efforts completed represent a redirection of program activities resulting from funding limitations which precluded completion of the subsequent phases as planned. Summaries of the Phase I and Phase II activities, covering Preliminary Design and Detail Design, are presented in References 1 and 2, respectively.

While the Phase III activities were primarily associated with heat source and supporting equipment fabrication and assembly, a number of design and programmatic changes were implemented. In particular, efforts were in progress which were directed towards modifying the Phase IV Demonstration Test Program to include testing of a total power system using a closed-cycle Brayton conversion system.

This report identifies and documents those heat source and supporting equipment design changes which were incorporated during Phase III, using the design as documented in the Phase II Final Report as the baseline. Succeeding sections summarize those testing activities which supported the Phase II design and Phase III design changes and heat source and supporting equipment fabrication and assembly activities including discussions of significant problems encountered. The redirection of the Phase III activities resulted in completion of specific checkout operations which would be of overall benefit to the status of the program. Results of these activities and investigations are presented. The concluding sections provide a comprehensive listing of program documentation as well as appropriate references. Significant supporting documentation has been compiled in the Appendices of this report where this data has not been previously reported.

2.0 PHASE III SUMMARY

Phase III of the Co-60 Heat Source Demonstration Program was initiated in November 1970. Early in Phase III results of the supporting Savannah River Laboratory (SRL) Co-60 Materials Technology Program indicated that a change in encapsulating materials was required. Specifically Haynes 25 and Haynes 188 were found to exhibit a "breakaway oxidation" phenomena. In this same test series Hastelloy X was shown to have satisfactory and predictable corrosion characteristics. Therefore, to provide assurance of satisfactory fuel pin performance the heat source design was changed to reflect use of Hastelloy X as the encapsulating material and, further, to control the fuel pin cavity environment. Because of the lower elevated temperature strength characteristics of Hastelloy X, as compared to the Haynes alloys, the primary effort was associated with a reduction of fuel pin surface temperatures during the normal and emergency cooling operating modes. These changes represented the primary effort in the first six months of Phase III and were documented in the Phase II Final Report, Reference 2. This report summarizes effort completed subsequent to the above.

Significant accomplishments completed during Phase III include the following:

- Encapsulation of 2 MCi of Co-60
- Fabrication of the heat source, including the ASME coded pressure vessel/core assembly, and biological shielding
- Endurance testing of a prototype heat pipe for a period of 28 months
- Fabrication and qualification of the heat pipe Emergency Cooling Subsystem
- Issue of the Safety Evaluation Report, Reference 3, and the Operations Manual, Reference 4
- Heat Source Assembly.

The planned demonstration test program was modified to include testing of a total power system. Based on an evaluation of available power conversion systems, which included the AiResearch closed-cycle Brayton and Sundstrand Organic Rankine systems, the closed-cycle

Brayton system was selected for use. Selection was based on advantages offered by the direct coupling of this conversion system with the gas-cooled heat source. In implementing the test program, the AiResearch BCD power conversion system was to be coupled to the heat source following initial heat source performance testing and part way through the endurance test.

In accordance with the program redirection the following Phase IV checkout operations were completed to evaluate procedural and hardware acceptability:

- Heat source dummy fueling
- Fueling cask shielding survey
- Heat source shielding survey (single pin).

Completion of these latter activities verified the acceptability of critical characteristics of the heat source and its supporting equipment. ~~Final effort included heat source disassembly and transfer to Atomic Energy of Canada, Ltd.~~

2.1 HEAT SOURCE SUMMARY DESCRIPTION

The following generalized heat source summary description, which is applicable at the end of Phase III, is unchanged from that applicable to the end of Phase II. It is presented to provide a basis for the discussion of the detailed design changes which were implemented during Phase III.

As shown in Figure 2-1, a two-pass gas cooled system was designed with the fuel pins located within the inner core of the pressure vessel/core assembly. The pressure vessel sidewall formed the first pass of this two pass core configuration. Heat pipes, attached to the outer surface of the pressure vessel (first pass) provide for heat rejection to the environment in the event normal forced cooling is lost (termed the emergency cooling mode). Surrounding the pressure vessel is the biological shield which functions to reduce gamma radiation at accessible heat source surfaces to safe levels. Primary insulation, located between the pressure vessel and the biological shield, and secondary insulation, on the outer surfaces of the shielding, were provided to reduce heat losses.

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Figure 2-1. Co-60 Heat Source Final Design

The primary influences on heat source design were the selection of the emergency cooling subsystem and heat source mechanical/thermal constraints. Notable among these constraints were maximum fuel pin surface temperature, coolant outlet temperature and the desire to provide for field refueling. The loss-of-coolant operating mode is most demanding in that it understandably results in the highest material temperature levels through the heat source system. Primary heat source characteristics are presented in Table 2-1.

Before proceeding further with the description of the heat source and its primary components, it is useful to review the operating characteristics of inert-gas controlled heat pipes. Heat pipe schematic diagrams illustrating the primary heat pipe operation modes are shown in Figure 2-2. For normal heat source operation, the non-condensable inert gas/liquid metal vapor interface is located in the adiabatic leg near the evaporator section of the heat pipe. In this condition the working fluid, sodium, does not contact the condenser section and from a practical point of view the heat transport is essentially zero. During emergency cooling conditions, corresponding to a loss of coolant flow, the general increase in heat source temperatures causes an increase in heat pipe working fluid temperature.

As a result the sodium vapor pressure increases significantly which causes the interface to move along the heat pipe. The inert gas is thereby driven into the gas reservoir, exposing the condenser to sodium vapor and allowing a significant increase in heat transfer rates. This thermal switching effect is a basic characteristic of inert-gas controlled heat pipes and is controllable for a given heat pipe by establishing the inert-gas fill pressure and gas reservoir volume. Once these characteristics are established, heat transfer rates are essentially a function of heat pipe evaporator temperature level. Results of the component test program which characterized heat pipe performance and provided endurance test data are presented in Section 2.3.3.

Fuel Pin - Design of the fuel pin assembly for the heat source provides double encapsulation of the Co-60 radioisotope fuel. The fuel is in the form of standard SRL nickel plated wafers.

TABLE 2-1

1.	Heat Source Thermal Power Heat Source Thermal Efficiency	31.2 Kw BOL >90%
2.	Fuel Form Total Inventory Specific Activity Wafer Size	Co-60 wafers 2×10^6 Ci >200 Ci/g 0.745 in. dia. x 0.03 in. thick
3.	Fuel Pin Size Number Max. Surface Temp. - Normal - Emergency Capsules Encapsulating Material	1.1 in. dia. x 25 in. long 12 1755°F 1920°F 4 per pin Hastelloy X
4.	Inner Core Material Inner Core Size Coolant Channel	Ni-201 14 in. dia. x 23.7 in. long 169 at .312 in. dia.
5.	Coolant Heat Source Inlet Temperature Heat Source Outlet Temperature Flow Rate Pumping Power	Argon 850°F 1350°F max. 0.45 lb/sec 280 watts
6.	Pressure Vessel Material Operating Pressure Design Pressure Coolant Channel	304SS and Hastelloy X 65 psig 100 psig 72 at .312 in. dia.
7.	Emergency Cooling System Heat Pipe Size Number	Inert-gas controlled sodium heat pipes 0.8 in. O.D. x 68 in. long 36
8.	Biological Shield Material Radiation Dose Rate - Surface - at 1 meter	Carbon Steel ≤ 200 mr/hr ≤ 10 mr/hr
9.	Design Life - Normal Operation - Emergency Cooling	5 years 1500 hours

Figure 2-2. Schematic Diagrams of Inert Gas Controlled Heat Pipes

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The fuel wafers are contained in a helium filled capsule of Hastelloy X; the nominal capsule fuel loading is 42,000 curies. Double encapsulation is achieved by loading four capsules into the Hastelloy X fuel pin shell, with a helium atmosphere maintained. Tungsten shield plugs are located at each end of the fuel pin assembly to reduce axial gamma streaming. Provision for remote handling is achieved by a grapple on the fuel pin end cap. Both assembly and closure was accomplished remotely in a hot cell.

Hastelloy X was selected as the primary and secondary encapsulating material because it is an effective diffusion barrier for Co-60, has acceptable high temperature oxidation resistance and strength characteristics, and is fabricable and weldable. Based on SRL diffusion data of Co-60 into Hastelloy X, a total containment thickness of 0.1 inch is adequate to satisfy the limit of 1 ppm Co-60 on the fuel pin outer surface. At the high temperatures expected for normal operation and emergency cooling the encapsulating material is creep strength limited. The design is based on 1% creep for 44,000 hours at normal operating conditions and 1,500 hours at emergency operating conditions (the latter condition uses approximately 70% of the creep life). The capsules are of a design successfully fabricated and tested by SRL under the AEC Co-60 technology program.

When installed in the heat source the fuel pins are contained within a sealed cavity which will be backfilled with helium. The fuel pins are therefore isolated from direct contact with the coolant and, upon removal of the cavity cover plate, can be removed during heat source operations by use of a shielded fueling cask.

Pressure Vessel/Core Assembly - The primary functional requirements of the pressure vessel/core assembly are to effectively transfer heat to the argon coolant during normal operation, and during loss-of-coolant conditions to dissipate heat from the fuel without exceeding fuel pin surface temperature limitations. Approximately 99% of the gamma energy deposition is within the inner core while the self absorption within the fuel pin assembly is approximately 40%. The pressure vessel was designed and coded in accordance with Section VIII, Unfired Pressure Vessel, to the ASME Boiler and Pressure Vessel Code.

A two pass heat source design (Figure 2-3) was selected so that the coolant initially flows through the first pass, to which the heat pipes are attached. The first pass and second pass are separated by an interpass gap which minimizes interpass heat transfer during normal operation and maintains first pass temperatures relatively low. In this condition the heat pipes are essentially "turned-off" and parasitic heat losses are minimized.

During emergency cooling, heat transfer is primarily by radial conduction through the inner core with ultimate heat removal from the outer surface of the pressure vessel through the heat pipes. Heat transfer across the interpass gap is essentially by radiation. To effectively transfer heat under these conditions, Ni-201 was selected as the inner core material because of its high thermal conductivity. High emissivity oxide coatings or surface preparations are provided on the primary heat transfer surfaces which include:

- Fuel pin and capsule O.D. (Hastelloy X)
- Fuel pin cavity bore (Ni-201)
- Inner core O.D. (Ni-201)
- Pressure vessel I.D. (304 SS)

Emergency Cooling System - A total of thirty-six sodium inert-gas controlled heat pipes, attached to the pressure vessel outer surface, are used to dissipate heat to the environment in the event of loss-of-coolant. An unusual flagpole design, with an out-of-plane bend in the adiabatic leg, was required to maintain adequate shielding where the heat pipes penetrate the heat source shield.

Radiation Shielding - The primary shielding design objective was to insure the maintenance of radiation safety during all phases of heat source operation. The shield is composed of three major sections, including top, bottom and side shields which completely enclose the pressure vessel/core assembly. Carbon steel was selected as the heat source biological shield material. This choice represented a compromise between cost and weight.

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Figure 2-3. Core Subassembly

In addition to the bulk biological shielding the fuel pins were designed with integral tungsten end plugs. These serve to reduce the direct end-on radiation from the fuel pins. This additional attenuation is required at the top due to the existence of fuel pin bores which extend through the top shield above each fuel capsule for fueling/refueling of the heat source. At the bottom of the fuel pin the lower tungsten end plug compensates for the decreased shielding effectiveness directly below the core due to the presence of inlet and outlet coolant ducts. Similarly a lower plenum shield has been provided to further reduce streaming in the coolant ducting.

Instrumentation - The heat source assembly is heavily instrumented to provide the maximum amount of system and component thermal performance data and to provide necessary inputs to the test loop safety circuitry. Specifically, instrumentation has been provided to monitor: 1) the surface temperature of a central fuel pin; 2) inner core axial and radial temperatures; 3) outer core temperatures; 4) temperature in the evaporator and adiabatic sections of selected heat pipes; 5) all heat pipes in the condenser section; and 6) selected pressure vessel and shield temperatures.

2.1.1 Phase III Heat Source Design Changes

The primary impetus for heat source design changes during Phase III was to reflect into the design the results of the materials and component test programs. Specifically, these changes can be summarily identified as follows:

- Identification of alternative high emissivity coatings for primary heat transfer surfaces -- supporting materials testing programs did not confirm the long term acceptability of the natural NiO on the inner core.
- Addition of heat pipe sump - required to remove excess sodium from the evaporator section of the heat pipe.
- Redesign of the fuel pin handling tool to reflect design changes desired by operating personnel.

It should be noted that the most significant of these design changes was that associated with alternative emissivity coatings and their effect on the thermal characteristics of the heat source. The changes in thermal predictions also required revision of the structural analyses associated with the fuel pin and pressure vessel.

In addition a number of design refinements were made to reflect the more detailed implementation of the early Phase III design changes and specific requests tendered by subcontractors and vendors. None of these are considered significant and therefore further detail is not presented.

Alternative Emissivity Coatings - For normal and emergency cooling conditions, the fuel pin surface temperature and inner core temperatures are dependent on the thermal emittance characteristics of the fuel pin, fuel pin cavity bore, inner core outside diameter and pressure vessel (outer core) inside diameter. The Phase II design was based on use of natural oxides to provide high emittance for these surfaces. The emittance values used in the heat source thermal design were based on published values and were as follows:

	<u>Fuel Pin Cavity</u>		<u>Interpass Gap</u>	
Material	Hastelloy X	Nickel	Nickel 304SS	
Emissivity	.85	.68	.68	.85
Effective Emissivity	.606		.606	

A materials testing program was initiated and completed during Phase III to verify the emissivity values which formed the basis for the thermal design of the heat source. Initial results from this test program indicated that the specified natural oxide surface treatments for the 304SS and primarily the Nickel 201 were not adequate in insuring high emissivity values for long term heat source operation. Specifically the 304SS emissivity values were generally lower than anticipated, while the values for Nickel were adequate initially but degraded substantially over the 1500 hour test period. Results of the Hastelloy X tests confirmed the design value used.

The effect of the experimental emissivity values was a potential significant increase in fuel pin surface and inner core temperature levels. Alternate coatings (see Section 2.3.2), were therefore investigated in order to maintain the fuel pin surface temperature close to the Phase II predicted values of 1710°F and 1880°F for normal operation and ECS conditions, respectively.

In defining surface treatments for the principal heat transfer surfaces, the Rokide C coating was selected for the outer core ID and inner core OD (interpass gap). Due to the small size of the fuel pin cavity bore, 1.28 in. diameter, flame sprayed coatings could not be applied to this surface. Therefore, the current thermal analyses are based on use of emissivity values for grit blasted nickel. A comparison of the Phase II design values and the Phase III experimental values for the revised surface treatments is as follows:

	<u>Phase II Surface Emissivity</u>	<u>Phase III Surface Emissivity</u>
Interpass Gap		
Outer Core	.85	.85
Inner Core	.68	.85
Fuel Pin Gap		
Fuel Pin	.85	.85
Fuel Pin Bore	.68	.4

The inner core emissivity along the interpass gap increased from 0.68 to 0.85. This increase would result in an increase in the outer core temperature during normal operation and a decrease in fuel pin surface temperatures during emergency cooling. The decrease in the fuel pin bore emissivity will, however, increase the fuel pin temperature during both operating modes. Since normal and emergency heat source operation are thermally coupled via the heat pipes (fabrication and testing of which had already been completed), both operating modes were investigated to determine the effect of varying the interpass gap width. Such a design change was necessary to preclude a large increase in first pass temperature which could result in excessive heat loss during normal operation through partial operation of the heat pipes.

In order to minimize the increases in first pass temperatures it was necessary to increase the interpass gap width from 0.060 to 0.170 in. A modest increase in fuel pin surface temperatures still resulted. A comparison of the fuel pin surface temperatures is as follows:

<u>Operating Mode</u>	<u>Phase II</u>	<u>Phase III</u>
Normal	1710°F	1757°F
ECS	1880°F	1920°F

As a result of the above increase in predicted fuel pin surface temperatures, the fuel pin stress analyses were revised. As was the case with the prior Phase II analyses, these analyses were completed using the extrapolated - 2σ creep properties, defined previously. Table 2-2 which indicates positive fuel pin margins, summarizes the results of these analyses. The detailed analyses are contained in Reference 3.

Heat Pipe Sump - While the downward revision of the normal and ECS heat pipe operating temperatures was considered and incorporated in the Phase II Final Report, the initial prototype heat pipe tests identified the need for a sump at the lower end of the evaporator section of the heat pipe. During these tests an axial temperature difference along the evaporator was noted which was indicative of a pool of sodium standing in the evaporator. This sodium was that required to fully saturate the wick during the ECS operating mode. Presence of this sodium in the evaporator during normal operations resulted in the sodium pool becoming superheated with intermittent boiling producing temperature excursions. To correct this a wicked 4.7 in³ sump was added to the bottom of the heat pipe evaporator section.

Addition of the sump required design changes to the side shields and also required modification of the heat source assembly procedures. The shielding changes resulted in a localized reduction in shield thickness, but since this reduction was at the lower end of the core the maximum radiation dose on the heat source surface was still below the maximum allowable design level of 200 mr/hr.

Fuel Pin Handling Tool - The mechanical design of the fuel pin handling tool as completed during Phase II was dependent upon spring action of gripper fingers for fuel pin release. Based upon recommendations of the operating personnel, who desired a positive mechanical means of

TABLE 2-2
FUEL PIN STRESS ANALYSIS SUMMARY

<u>ITEM</u>	<u>MARGIN OF SAFETY (%)</u>
Pin Cladding 1% Creep Life Expended in Design Life ⁽¹⁾	+41
Pin Cladding Rupture Life Expended in Design Life	Very High ⁽³⁾
Capsule Cladding 1% Creep Life Expended in Design Life ⁽²⁾	-.08 ⁽⁴⁾
Capsule Cladding Rupture Life Expended in Design Life	Very High ⁽³⁾
Pin Cladding 1% Creep Life Expended in Design Life - Cladding Breached	+25
Pin Cladding Rupture Life Expended in Design Life - Cladding Breached	Very High ⁽³⁾
Pin Cladding Yield Strength Available for 10 g Handling Load	+29.1
Pin End Plug Thread Shear Strength Available for 10 g Handling Load	+33.9
Pin Cladding Impact Strength Available for Free Drop from Fueling Cask to Core	+49.4

⁽¹⁾ Five years at predicted normal operating conditions (1757°F) and 60 days at emergency conditions (1920°F)

⁽²⁾ Five years at predicted normal operating conditions (1780°F) and 60 days at emergency conditions (1950°F)

⁽³⁾ Greater than 100%

⁽⁴⁾ Exceeding the design life implies that creep will occur until support is provided by the pin cladding. Further use of actual property data as compared to -2σ values will give positive margin.

release, alternate designs were investigated. As shown in Figure 2-4, the revised handling tool incorporates a central actuator rod for positive disengagement of the fuel pin. The profile of the fuel pin grapple head was also modified to eliminate the flat engagement shoulder. Use of the chamfered pickup surface minimizes the possibility of incomplete fuel pin release.

2.2 DEMONSTRATION TEST PROGRAM

Definition of the Phase IV Test Program was completed and included in the Operations Manual, Reference 4. This document provides the detailed sequence of planned heat source operations. The Safety Evaluation Report, Reference 3, provides the safety evaluation of this test program as it applied to operations at WARD. At the request of the AEC, WANL investigated the suitability of extending the basic heat source test program to include demonstration testing of a total power system. Prime consideration was given to the use of existing conversion system hardware which could be coupled to the heat source. Two conversion systems were available — the AiResearch closed-cycle Brayton and the Sundstrand Organic Rankine. Figure 2-5 shows the proposed method of coupling these systems to the heat source. Table 2-3 presents a comparison of expected conversion system operation. It should be noted that in both cases these performance estimates represent the use of available hardware coupled to an independently designed heat source rather than the performance potential of an optimized system. When consideration had to be given to coupling only one of these systems to the heat source, WANL recommended that the AiResearch BCD be used. This selection was based primarily on the fact that direct coupling of the gas-cooled heat source with a gas conversion system offered testing flexibilities that provided a better demonstration of the high temperature capabilities of the heat source. In addition, the predicted performance of the BCD was slightly better than that for the Organic Rankine system.

The Brayton Cycle Demonstrator (BCD), shown in Figure 2-6, was built by AiResearch in 1963, and has undergone extensive testing at NASA-Houston and the AiResearch Phoenix facility. The combined Rotating Unit (CRU) includes the dynamic components of the power-conversion system. This assembly includes a compressor, turbine, and alternator, on a common shaft

Figure 2-4. Fuel Pin Handling Tool

Figure 2-5. Heat Source Loop Schematic - BCD or Organic Rankine

TABLE 2-3
CONVERSION SUBSYSTEM COMPARISON

		<u>CLOSED BRAYTON</u>	<u>ORGANIC RANKINE</u>
TECHNOLOGY STATUS			
PRIMARY HARDWARE		1963	1963
AREAS OF CHANGE		FOIL BEARINGS	L. O. SYSTEM, REGENERATOR, SURFACE CONDENSER
TEST TIME:	DELIVERED HARDWARE - HRS.	300	3000
	EQUIVALENT HARDWARE - HRS.	10, 800 BRU	--
CONTROLS		1970 - AUTOMATIC	1963 - AUTOMATIC
SUBSYSTEM PERFORMANCE:	KWe	5.82	4.59
	EFFICIENCY - %	21.1	17.4 ⁽¹⁾
MAXIMUM CAPABILITY - EFFICIENCY - %		33 (27) BRU	25 (20)

(1) With boiler heat loss of 2 KW, efficiency is 16.2%;
with argon loop pumping power included, efficiency is ~14%.

Figure 2-6. Brayton Cycle Demonstrator (BCD)

supported by gas-lubricated bearings. The CRU operates at a speed of 60,000 rpm. Heat exchangers used in this system include a cooler and recuperator. A typical cycle for the BCD coupled to the Co-60 heat source is shown in Figure 2-7. During system operation the compressor circulates the argon coolant through the loop, absorbing thermal energy from the heat source. The heated compressed gas is expanded through the turbine which drives the compressor and the alternator, producing electrical power. The recuperator recovers waste heat from the turbine discharge gas and transfers the heat to the heat source inlet. The heat sink heat exchanger removes waste heat and maintains the required compressor inlet temperature.

Controls for the BCD incorporated provisions for automatic startup and shutdown sequencing logic, maintaining desired loop temperatures, safety signals and indications of system performance as well as operating status. Speed control of the BCD is accomplished by applying electrical load to the alternator and is typically maintained within ± 1 percent. A parasitic load bank would be used to dissipate the generated power. A summary of the BCD control system is presented in Appendix C.

As part of the AiResearch subcontract activities, teardown and inspection of the BCD hardware was completed (Reference 9). This inspection was completed following receipt of the unit from NASA MSC where it had completed successful evaluative testing. Upon disassembly all critical dynamic components were cleaned and metallurgically inspected to verify mechanical integrity. The compressor, turbine and alternator showed no deterioration or serious defects and did not require modification or rework for this use. Foil bearings of an improved proprietary AiResearch design were installed. These foils are more tolerant of startup and shutdown rubs and improve bearing performance for the higher thrust loads.

Rework of the recuperator (stainless steel and nickel) was required. Specifically this assembly was cleaned to remove light contamination. New instrumentation bosses were installed and the unit was pressure and leak tested.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION

TEMPERATURES IN °R
PRESSURES IN PSIA

$$\eta_{CY} = \frac{KW_e}{Q} = 0.179$$

2-21

Figure 2-7. Typical Co-60 Heat Source/BCD Cycle

LOOP SCHEMATIC

Figure 2-8. Co-60 Demonstration Heat Source Test Loop

Figure 2-9. Heat Source and Loop Interface Piping
 $\Delta P/P$ Characteristics

Appropriate ducting is required to direct couple the BCD to the Co-60 heat source. As shown in Figure 2-8, manually operated valves direct flow through the BCD or loop, as required. The shutoff valves provided on the loop branch piping permit coupling of the BCD ducting to the loop proper during system operation without defueling. The predicted $\Delta P/P$ characteristic curve for the heat source is shown in Figure 2-9. This curve reflects the heat source characteristics from the interface points on the inlet and outlet manifolds.

2.2.1 Loop Changes - BCD Demonstration Test

Addition of a demonstration test with the BCD required a number of loop modifications. To permit completion of this test without requiring defueling of the heat source and extensive piping modifications at that time, the loop design was modified to incorporate inlet and outlet manifolds as well as required valving which would permit direct coupling of the BCD to the heat source (Figure 2-8). At the time the above design changes were incorporated in the loop design, bellows were added in the piping section between the preheater and the heat source to eliminate the need for an expansion loop. The revised piping design also included provisions for maximizing the commonality of loop sensors for the two operating modes, i.e., demonstration loop and BCD.

Revised loop piping stress analyses were completed to reflect the changes in loop geometry and are summarized in Table 2-4. These analyses are applicable for the following heat source operating conditions:

Design Pressure - 100 psig
Heat Source/Heat Exchange Loop - 1400°F
Heat Exchange/Preheater - 650°F
Preheater/Heat Source Loop - 900°F

The above temperatures represent a 50° margin over the intended operating point. For BCD, operation loop pressure is reduced significantly. Detailed analyses are contained in Reference 3.

TABLE 2-4
LOOP PIPING STRESS SUMMARY

Piping Section	Oper. Temp. °F	Des. Temp. °F	Mat'l ⁽¹⁾	Req'd ⁽²⁾ tm in	Flexibility Analysis			Additive Stresses		
					Stress psi	Allow. psi	MS ⁽³⁾	Stress psi	Allow psi	MS ⁽³⁾
H.S. to Heat Exch.	1350	1400	304 SS	0.153	12,650	23,787	.46	936	1400	.33
Heat Exch. to Blower	600	650	CS	0.0146	18,600	27,750	.33	1601	15,000	.89
Blower to Preheater	600	650	CS	0.0146	13,300	27,750	.52	<1601	15,000	>.89
Preheater to H.S.	850	900	304 SS	0.0238	[125 cycles] ⁽⁴⁾			653	9,400	.93

(1) Seamless -4" Sch 40

(2) Actual - 0.237

(3) $MS = 1 - \frac{\text{Actual}}{\text{Allowable}}$

(4) Life cycles for the bellows is the limiting criteria in this loop.

2.3 TESTING

The Phase III testing program encompassed two primary areas, materials testing, as well as component development tests. Materials tests were completed to support the basic heat source design as well as specific design changes implemented within Phase III. Supplementary materials tests were completed by SRL primarily in the area of oxidation tests of candidate capsule and core materials.

Within the confines of component development tests are included those tests to confirm heat pipe operating characteristics and to demonstrate the long term capability of the heat pipe to function in the emergency cooling subsystem. Also included within this activity is the qualification testing of the individual heat pipes for the heat source system.

2.3.1 SRL Materials Testing

As part of the Co-60 Materials Technology Program, SRL provided assistance in evaluating candidate capsule and core materials. Preliminary results contained in Reference 5 were the basis for selecting Hastelloy X as the capsule material and incorporating heat source design features that minimize the oxidation of Nickel 201.

Specimens of prospective capsule and core materials were heated in ambient furnace air at 1000°C and 1125°C bracketing heat source normal and emergency operating conditions, to measure their oxidation resistance. The following conclusions were drawn from this work:

- Hastelloy X (Figure 2-10) has the best oxidation resistance of all materials tested. There was a 0.003 inch layer of adherent oxide and 0.016 inch depth of changed microstructure after 3000 hours at 1125°C.
- Haynes 188 and Haynes 25 suffer "breakaway" oxidation above 1000°C (see Figure 2-11).
- Welded Haynes 188 oxidizes at the same or perhaps a slightly lower rate than wrought Haynes 188.

Figure 2-10. Oxidation of Nickel 200 and Hastelloy X

Haynes 25

Haynes 188

Figure 2-11. Oxidation of Haynes Alloys (From DP-1293)

- Oxide on Nickel 200 (Figure 2-10) is adherent and compact, and it forms at a predictable rate. Observed thicknesses of oxide were 0.034 inch after 6000 hours at 1000°C and 0.066 inch after 3650 hours at 1125°C. (Nickel 201 is more oxidation resistant than Nickel 200).

SRL has completed oxidation tests on WANL supplied samples from the actual heats of Hastelloy X and Nickel 201 used to fabricate the fuel pins and the inner core of the heat source, respectively. These tests covered air testing at 1000°C and 1125°C. Results of the nickel tests, Reference 6, are in agreement with prior tests through 3000 hours (see Figure 2-10); the test at 1000°C has continued to 10,000 hours and results will be published in Reference 7. Similarly, the Hastelloy X oxidation resistance following 13,000 hours at 1000°C (see Figure 2-10) is in good agreement with prior data.

Heating tests of capsules in air containing unirradiated cobalt metal have been in process for a significant period of time. Reference 7 reports that a Hastelloy X capsule (.095 inch wall) was intact after 45,800 hours at 1000°C.

2.3.2 WANL Materials Testing

Creep testing of Hastelloy X and Nickel 201, the latter initiated during Phase II, were completed in Phase III. In addition, emissivity investigations and evaluation of the emissive coatings used in the heat source were completed.

Hastelloy X Creep Tests - Following selection of Hastelloy X as the encapsulating material, creep data were obtained using material from the actual heat used to fabricate the fuel pin components. Results from these tests are shown in Figure 2-12 which compares the WANL test results with the estimated creep strength extrapolated from prior data. As shown the average strength levels are slightly higher than the estimated nominal. The table of results is as follows:

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Figure 2-12. Stress Versus LM Parameter for 1% Creep Strain of Hastelloy X

<u>Test No.</u>	<u>Stress psi</u>	<u>Time for 1% Strain-Hrs.</u>	<u>Final Strain and Time</u>
1	360	860	1.5% at 1210 hrs.
2	440	360	7.0% at 1510 hrs.
3	280	700	1.5% at 1510 hrs.

Test number 3, the low stress level specimen, did not continue the high strength level behavior observed for the first two specimens, but was still at the estimated nominal level predicted from other creep test results. The creep curve for the low stress level specimen showed a gradually decreasing creep rate with time so the creep strength behavior at higher total strain is better than indicated on the Larson-Miller relationship. Figure 2-13 shows the creep curve for the third specimen.

In summary, the relatively short time creep tests (≈ 1500 hr.), support the original predictions for Hastelloy X. The results can be applied with confidence to the emergency cooling, conditions, which span a similar time interval (1500 hours).

Nickel 201 Creep Tests - The Nickel 201 creep test program was conducted to obtain high temperature creep data to support the design of the inner core. The final three tests, at a low stress level in argon, indicate that the original design extrapolation from high stress level tests in air was accurate. Table 2-5 presents the results of the test program. These data are also presented in a Larson-Miller plot in Figure 2-14.

As shown in Figure 2-14, there is no significant difference between the early air and nitrogen tests and the most recent argon tests. Long time tests in air at high temperatures would be expected to show lower strength levels because of rapid oxidation and metal recession of the pure nickel.

Figure 2-13. Creep Curve for Hastelloy X Tested in Argon at 2000°F

TABLE 2-5
NICKEL 201 CREEP AND CREEP RUPTURE TEST RESULTS

TEST ATMOSPHERE	AIR	AIR	AIR	AIR	AIR	AIR	AIR	AIR	NITROGEN	ARGON	ARGON	ARGON
Specimen Number	5	1	4	2	8	3	6	7	9	--(4)	--(4)	--(4)
Temperature, °F	1350	1350	1350	1350	1650	1650	1650	1650	1650	1650	1875	1875
Stress, psi	5000	4000	6400	3500	2500	2500	1700	1250	1875	550	250	145
Rupture Time, Hrs.	144	506	23.3	1315	71.3	124	315	865	149.3	1603	403	1675
Rupture Strain, %	44.0	23.2	(1)	17.4	31.0	28.0	9.3	9.0	8.0	--	--	--
Min. Creep Rate, %/Hrs.	0.1290	0.0256		0.0060	0.22	0.121	0.0118	0.004	0.033	0.0006	0.002	0.0003
Time to 1.0% Strain, Hrs.	1.0	2.5		7.0	0.6	1.6	2.3	20.0	2.3	1310	145	1675/2100 ⁽³⁾
Time to 5.0% Strain, Hrs.	9.0	40.0		170	12.5	17.0	262	730	82.0	--	--	--
Time to 10.0% Strain, Hrs.	35.2	223.0		785	31.5	47.5	--	--	--	--	--	--
Total Primary Strain, %	8.3	6.0		6.4	4.5	11.1	3.1	2.6	3.65	--	--	--
Transition Strain, % (2)	12.2	10.2		9.1	7.0	13.8	4.35	4.6	6.0	--	--	--
Transition Time, Hrs.	52.5	227.5		676	22.5	75.0	2210	640	0.110	--	--	--
Intercept, %	5.5	4.5		4.1	2.6	4.6	1.72	1.78	2.3	--	--	--
Reduction of Area, %	43.6	18.0	87.0	13.0	24.6	19.0	5.8	2.5	7.0	--	--	--
Measured Elongation, %	45.5	23.5	10.5	18.0	--	29.3	10.5	9.8	8.0	1.20	1.45	0.80
Machine Number	22	22	22	22	12	3	3	15	23	--	--	--
Rupture (LM Parameter) ⁽⁵⁾	22.2	22.8	21.5	23.2	25.6	25.9	26.4	26.9	26.0	--	--	--
1% Strain (LM Parameter) ⁽⁵⁾	21.1	20.5	--	20.9	23.2	23.7	23.9	25.1	23.9	27.1	28.8	30.2/30.3

- (1) Specimen fractured near end of gage length
 (2) Start of third stage creep
 (3) Specimen was bent following the test
 (4) Incomplete test report
 (5) $LM = T^0K (20 + \log t)$

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Figure 2-14. Stress Versus LM Parameter for Rupture and 1% Creep Strain of Nickel 201

Emittance Testing - Thermal balance emittance tests were run in vacuum on Nickel 201, 304SS, and Hastelloy X specimens. These specimens were prepared with a natural oxide coating using the same technique expected to be used for the actual heat source components to establish the relatively high emissivity values which formed the basis for the thermal design. Initial results from these tests, Reference 2, were as follows:

<u>Material</u>	<u>Test Temperature</u>	<u>Measured ϵ</u>
Nickel 201	1840°F	.75
304SS	1250°F	.88
Hastelloy X	2000°F	.90

Subsequent investigations showed the loss of the oxidized coating from the Nickel 201 following a 1500 hour soak at a temperature of 1830°F in argon. It was concluded that the loss of the oxide from the pre-oxidized specimen resulted from establishing equilibrium with other alloys containing more stable oxide formers such as Cr.

Since the natural oxide coating could not be used to attain the required emissivity values on the fuel pin cavity bore and inner core O.D., other emissive coatings were investigated. These included platinized alumina, iron titanate, calcium titanate, and Rokide C (Norton Co.). Of these, calcium titanate and Rokide C were considered prime candidates for use.

A substantial background of long term durability data applied to flame sprayed coatings of calcium titanate. Emittance values of 0.9 have been obtained and maintained for 20,000 hours at temperatures up to 1350°F. Several experienced vendors were identified in coating stainless steel and nickel alloy surfaces. Rokide C, a coating developed to provide a wear resistant surface, has demonstrated an emissivity value of 0.95 at temperatures of from 1200°F to 1500°F. This coating has a higher temperature capability than does the calcium titanate coating. However, for this material, a less extensive background of long term durability data at temperature was available. As in the case with calcium titanate, several experienced vendors were available for applying Rokide C.

Both the calcium titanate and Rokide C coatings are applied over a nichrome substrate which improves both the adherence and emittance properties of the final coating. Neither coating implies a compatibility problem with either stainless steel or nickel. Rokide C is composed of 85% Cr_2O_3 , 8% SiO_2 , 3% Al_2O_3 and traces of other oxides.

Selection of the coatings was based on the combined results of bend tests, to evaluate adherence on the base metal, and emissivity measurements. These tests were completed using samples coated by the potential vendors. In all cases the vendor applied a Nichrome substrate to the base metal. For the bend tests, sheet stock of .064 in thickness was used. The bend test specimens are summarized as follows:

<u>Specimen I. D.</u>	<u>Coating</u>	<u>Base Metal</u>
13	0.010 in. Calcium Titanate	304 SS
14	0.006 in. Rokide C	Nickel 201
17	0.021 in. Rokide C	304 SS
18	0.016 in. Rokide C	Nickel 201

As a comparative test, the specimens were heated in argon to 1270°F and 1650°F for the stainless steel and nickel base material, respectively. The specimens were heated and cooled in one hour, with a one hour hold at temperature. This transient is faster than that projected for heat source operations. The specimens were then examined for spalling or discoloration and were subjected to a room temperature 90° bend test using a 4t punch (t being coated specimen thickness) with a supported span of 15t. Specimen 14 had an uncoated area in the as-received condition which resulted from a hold-down pad. The specimens were examined for adherence around the bend radius. Figure 2-15 shows the specimens before and after bending. Although cracks were evident in all specimens, each displayed acceptable adherence over the severely strained bend radius with no significant spalling occurring. The degree of cracking observed is proportional to the coating thickness which would be expected with a brittle coating. A coating thickness of 0.010 in. which should provide an adequate thickness to insure emissivity properties was specified for the production coating so that adherence

After Thermal Cycle

After Bending

Figure 2-15. High Emittance Coatings Bend Test Specimens

properties similar to bend test specimen number 14 can be expected. During the course of the emittance measurements, the specimens were subjected to further thermal cycling. In general the Rokide C coatings were more adherent than the calcium titanate coating.

Finally to conclude the selection of emittance coatings for the inner and outer core for the heat source, additional total hemispherical emittance measurements were made. A cooling rate technique (Reference 8) was used, which being different from the total energy balance measurements previously made, would provide a cross check on these measurements.

The plasma sprayed, oxide coatings were measured as well as bare metal and oxidized surfaces to cover the conditions expected in heat source use. The emittance measurements were made at the expected maximum operating temperature of the material in question. Because of the measurement technique, which involved measuring the cooling rate of a specimen under conditions where only radiation heat transfer was operative, the tests were made in 1×10^{-5} torr vacuum, but the vacuum exposure did not significantly alter the appearance or the emittance of the specimens tested.

Table 2-6 compiles the final emittance measurements which were made. Bare nickel and the various conditions of machining and grit blasting were measured since a grit blasted nickel fuel pin cavity will be used in service and a comparison with smoother surfaces was desired, both as a check on the usefulness of mechanical roughing and also as a measure of test validity. The polished nickel emissivities obtained compare very favorably to that observed in literature, including the marked increase of emittance with temperature.

The Hastelloy X fuel pins will be used in the grit blasted and double oxidized condition and the mean value of .85 obtained at 1900°F is in the range expected for a roughened, oxidized surface. The spread in the reported emissivity of Hastelloy X at 1900°F was due to the lack of specific heat data at high temperatures for this alloy. The lower emissivity value results from an extrapolation of the manufacturer's data for specific heat. A value of 0.85 was used for thermal design purposes.

TABLE 2-6
TOTAL HEMISPHERICAL EMITTANCE
AS DETERMINED BY COOLING RATE TECHNIQUE

- NICKEL 201

<u>Polished</u>		<u>Rough Machined</u>		<u>Grit Blasted</u>	
<u>Temp. °F</u>	<u>ε</u>	<u>Temp. °F</u>	<u>ε</u>	<u>Temp. °F</u>	<u>ε</u>
1900	.180				
1800	.172	1800	.237	1800	.406
1650	.158	1650	.256	1650	.385
1270	.138				

- HASTELLOY X

Grit Blasted and Oxidized

<u>Temp. °F</u>	<u>ε</u>
1900	.706/.98 - Variation due to specific heat value used.
1000	.821

- ROKIDE C ON NICKEL 201 SUBSTRATE

<u>Vendor E</u>		<u>Vendor S</u>	
<u>Temp. °F</u>	<u>ε</u>	<u>Temp. °F</u>	<u>ε</u>
1650	.892	1650	.848

- CALCIUM TITANATE (CaTiO₃) ON 304SS SUBSTRATE

<u>Vendor E</u>		<u>Vendor G</u>	
<u>Temp. °F</u>	<u>ε</u>	<u>Temp. °F</u>	<u>ε</u>
1270	.800	1270	.88
1100	.840	1100	.85

- ROKIDE C ON 304SS SUBSTRATE

<u>Vendor S</u>	
<u>Temp. °F</u>	<u>ε</u>
1650	.82

*The coating spalled during the first heating cycle.

Commercially available, plasma sprayed coatings were considered, "Rokide C (Norton Company Trademark) for the nickel inner core and calcium titanate, CaTiO_3 , for the outer core. Specimens were coated by several vendors and the measurements tabulated in Table 2-6 were made. Coatings were in the range of .005 to .020 inch thick, including the substrate plasma sprayed coat of nichrome which improves adherence. One specimen of CaTiO_3 spalled during the emittance testing which subjects the specimens to much higher heating and cooling rates (on the order of several hundred degrees per minute) than is expected in service. None of the "Rokide C" specimens showed evidence of spalling. High effective emittance values were obtained for all of the plasma sprayed coatings.

To confirm the stability of the emissivity enhancing coatings and surface preparations used on core components, a set of high temperature exposure tests was performed. These tests duplicated expected conditions during ECS, both temperature and environment. The 1-1/2 inch diameter disks previously used for emissivity measurements were seal welded in a stainless steel container in an inert atmosphere welding chamber for test times of 1000 hours. The samples and test conditions are as follows:

<u>Material</u>	<u>Environment</u>	<u>Surface</u>
Rokide-C Coated 304SS	1270°F in argon	Outer Core ID
Rokide-C Coated Ni-201	1650°F in argon	Inner Core OD
Grit-blasted Ni-201	1800°F in helium	Fuel Pin Cavity

Figure 2-16 shows the test pieces following the test and also shows for comparison purposes 'as-coated' samples. No spalling or significant change in appearance was noted for the Rokide-C coated samples and the Ni sample gave no indication of change in surface roughness.

In summary, the plasma sprayed coatings provide a high emittance surface with good adherence as measured in short time tests. The greater tendency toward spalling observed for the calcium titanate resulted in "Rokide-C" being considered the preferred coating for both the inner and outer core surfaces.

Figure 2-16. Core Samples - Furnace Test

2.3.3 Component Testing

Prototype Heat Pipe Testing - This program was initiated based on the Phase II selected heat pipe operating conditions, namely for heat pipe off and full-on temperatures of 1125 and 1175°F, respectively. The initial tests included both vertical and horizontal orientations which confirmed the ability of the heat pipe to transfer the design heat load in both orientations. These tests also showed that a pool of sodium occupied a portion of the evaporator as evidenced by a 90°F ΔT along the evaporator length. This condition was corrected by addition of a sump at the bottom of the evaporator. The operational characteristics of the heat pipe with 80 in³, 40 in³ and 20 in³ neon reservoir volumes was determined and an 80 in³ reservoir volume was selected. Figure 2-17 shows the heat pipe under test in the vertical orientation; operating characteristics are shown in Figure 2-18.

Verification of the thermal response of the heat pipe was completed for both a step increase in heat load as well as the predicted ECS ramp increase. In Figure 2-19, temperatures are plotted versus time after a 1000 watt step increase in heat input. Thermocouple 5 represents the heater block temperature; the locations of the remaining thermocouples are shown in Figure 2-20. The heater block temperature rises until it is stable 40 minutes after the increase in heat input which indicates that the heat pipe is not rejecting the full 1000 watts until that time. This operating mode was more demanding in that an instantaneous heat addition was imposed on the heat pipe as compared to the expected ECS heat addition ramp over a period of one to two hours.

Life Test - Life testing of a prototype Co-60 heat pipe and a sodium migration pipe were conducted to provide information on long term reliability and operational characteristics. The prototype Co-60 heat pipe completed 717 days (6.29×10^7 seconds) of successful operation. The heat pipe was cycled 35 times from "off" to "full on", simulating emergency core cooling. The design specification called for a "switch-on" temperature of 1040°F (normal operating mode when the evaporator length constitutes the entire active length of the heat pipe) with a "switching temperature" difference of 50°F. After 90 days of operation

Figure 2-17. Heat Pipe Test - Vertical Orientation

Figure 2-18. Operating Characteristics of Prototype Heat Pipe

Figure 2-19. Temperature Distribution on Co-60 Heat Pipe Prototype
SN/1A During Emergency Conditions

Figure 2-20. Thermocouple Locations on Prototype Heat Pipe SN/1A

and approximately 20 operational cycles, the prototype heat pipe had a measured "switch on" temperature of 1031°F (200 watts input to evaporator) and a full-on temperature of 1076°F (1150 watts input to evaporator). After 717 days of operation and a total of 35 operational cycles from off to full on, the switching temperature did not exceed 50°F. On the final cycle prior to shutdown with 190 watts input to evaporator (normal operating mode) the heat block temperature was 1022°F. With 1000 watts input, the full on temperature of the heat block was 1067°F, a 45°F switching temperature difference. The operational characteristics of the prototype heat pipe thus remained essentially unchanged.

Sodium Migration Test - This heat pipe test was conducted to determine whether or not sodium would migrate across the sodium vapor/neon gas interface and freeze out in the condenser thereby depleting the sump and evaporator of sodium. The sodium migration test pipe was a straight heat pipe with a 10 inch long evaporator, i.e., in the normal operating mode, the neon gas/sodium vapor interface was 10 inches from the bottom of the pipe. The temperature of the evaporator was monitored and sodium depletion from the evaporator by migration would have resulted in an increase in the evaporator temperature. For 836 days (7.2×10^7 seconds) of operation, the temperature at the mid length of the evaporator was $682^\circ\text{C} \pm 8^\circ\text{C}$ ($1260^\circ\text{F} \pm 14^\circ\text{F}$). From the results of this test, it was concluded that the sodium does not migrate across the sodium vapor/neon gas interface.

Heat Pipe Qualification Testing - Qualification testing of the production heat pipes was completed to demonstrate heat pipe operability, switch-on temperature and heat transport capability. A statistical evaluation of the startup temperatures of the production heat pipes was completed following qualification testing. The mean startup temperatures are 1040°F and 1038°F, with standard deviations of 3.6°F and 4.8°F, for the long and short evaporator configurations, respectively. The distribution is as follows:

<u>Configuration</u>	<u>Number of Heat Pipes</u>	
	<u>1σ</u>	<u>2σ</u>
Short Evaporator	14	4
Long Evaporator	13	5

2.4 FABRICATION

Fabrication activities completed during Phase III have been segregated into the following primary areas:

- Heat Source
- Heat Source Supporting Equipment
- Fuel Pin Assemblies (including encapsulation)
- Demonstration Test Loop

The following sections summarize significant occurrences encountered during the fabrication sequence for the above.

2.4.1 Heat Source

Heat source fabrication activities included procurement of raw material (where supplied to the fabrication vendor), fabrication of the pressure vessel/core assembly, heat pipes and biological shielding.

Raw Material Procurement - To facilitate subsequent fabrication activities pre-procurement of significant raw material was completed by WANL to be provided to the fabricators.

In general this was done to minimize schedule impact associated with the detailed modification of the heat source design resulting from the change in encapsulating material and the inclusion of provisions for sealing the fuel pin cavity.

WANL pre-procurement of the following material was completed:

- Inner Core Forging (Ni-201)
- Outer Core Ring Forging (304SS)
- Upper Head Forging (Hastelloy X)
- Lower Head Forging (304SS)

- Fuel Pin Cavity Extension (Hastelloy X)
- Biological Shielding (carbon steel plate)
- Fuel Pin/Capsule Shell (Hastelloy X)

The above procurements incorporated requirements for actual chemical and property data generally to support pressure vessel code requirements. In the case of the fuel pin/capsule shell material it was further specified that all material come from the same heat. This requirement was established such that the WANL materials testing program to characterize creep strength characteristics (and the SRL oxidation program) would be applicable to the material used for component fabrication (see Section 2.3).

The only significant problem encountered was in procurement of the Ni-201 forging for the inner core. The rough machined forging, 29 inch long by 15 inch diameter, represented the largest Ni-201 forging fabricated. In addition to ultrasonic inspection, acceptability of the forging was dependent on satisfactory sections from each end of the forging.

Full cross-sectioned slices from each end of the forging were evaluated. These macroetch sections exhibited unacceptable porosity, inclusions and cold-shuts as shown in Figure 2-21. The forging was rejected on macroetch quality. Subsequent investigations identified that this forging came from the upper end of the original casting where a higher frequency of porosity and cold-shut defects would be expected. A macroetch section of the forging corresponding to the mid-portion of the original casting was found to be defect free. The adjacent lower section of the forging was found acceptable based on macroetch quality.

The impact of the original rejection of the Ni-201 forging was an approximate four month delay in the fabrication of the pressure vessel/core assembly. Material from this forging was forwarded to SRL for oxidation tests.

Pressure Vessel/Core Assembly - Fabrication of the pressure vessel/core assembly (see Figure 2-3) required a unique combination of fabrication activities, including:

Cold Shut

Scattered Porosity

Figure 2-21. Sections From Rejected Ni-201 Forging

- Deep Hole Drilling - Ni-201, 304SS and Hastelloy X
- Precision Machining
- Precision Welding
- Coded Welding
- Application of Emissivity Coating

A single shop could not be identified to accomplish pressure vessel/core assembly operations. It was therefore necessary to use a number of vendors to complete this activity. This change in fabrication plans greatly extended the fabrication time beyond that originally estimated.

Figures 2-22 through 2-24 show the inner and outer core sections as they progressed through the fabrication sequence. Figure 2-25 shows the inner core following coating of the OD with Rokide C and subsequent installation of the insulated container assembly which, in conjunction with the pressure vessel, separates the inlet and outlet gas flow in the lower plenum of the heat source. Figure 2-26 shows the inner and outer cores during the assembly sequence and prior to completion of the final weld between the inner and outer cores.

In completing fabrication of the inner core-outer core subassembly the only area of significant difficulty was that associated with completion of the Ni-201 to Hastelloy X weld between the inner core and seal ring, respectively. In completing the actual weld, cracking was experienced in the Hastelloy X (Seal Ring) material. This had not been experienced in the qualification weld program which included both flat and cylindrical samples. Additional full size samples were completed which included a better representation of the Ni-201 inner core heat sink (a full diameter slice of the inner core material) which established changes in joint gap, joint preparation and welding technique. These changes resulted in obtaining the required full penetration weld with a minimum of heat input to the Hastelloy X and eliminated the cracking previously encountered.

The final steps of the fabrication sequence were completed by the coded pressure vessel vendor. These steps included fabrication of the upper and lower pressure vessel heads and

Outer Core

Inner Core

Figure 2-22. Outer and Inner Core Following Deep Hole Drilling

View from Upper End

View from Lower End

Figure 2-23. Outer Core - Final Machined

View from Upper End

View from Lower End

Figure 2-24. Inner Core - Final Machined

Figure 2-25. Inner Core - Bottom View Showing Insulation Assembly

Figure 2-26. Inner Core/Outer Core Prior to Final Welding

and subsequent code welding. Fabrication of the upper and lower pressure vessel heads was completed without incident. Additionally, no undue difficulty was experienced in completing the welds between the fuel pin extensions and the inner core and the final welds between the upper head cup and the fuel pin extensions even though access for these welds was severely limited.

The as-fabricated pressure vessel was successfully pneumatically tested by the vessel manufacturer. A pneumatic test was specified to preclude difficulties due to water absorption by insulation within the insulated container. The Section VIII Code Certificates are shown in Figures 2-27 and 2-28.

Heat Pipes - While shielding requirements necessitated use of heat pipes of two geometries, to separate the heat pipes into two levels where they penetrate the heat source biological shielding, fabrication techniques were unchanged. The wire mesh wicks were wound on a carbon steel mandrel and the outer stainless steel casing swaged. Following removal of the mandrels by etching the heat pipes were formed into the proper geometry and the sump, inert-gas reservoir and fins installed. While some difficulty was expected in maintaining required dimensions after bending the heat pipe to its final geometry, the use of a manual process using normal tube bending techniques proved very satisfactory. This process was, of course, preceded by an extensive trial and effort program to achieve reproducibility. In this sequence it was determined that stress relieving was necessary to reproducibly control springback.

The final fabrication steps included outgassing, helium leak check, sodium loading, inert gas loading, operational check and final sealing. Sealing of the fill tube was completed following verification of proper heat pipe operation. A completed heat pipe is shown in Figure 2-29.

Biological Shielding - Fabrication of the biological shielding was generally completed without difficulty. One exception was fabrication of the conical shield section shown in Figure 2-30. As a result of machine limitations, the heat pipe penetration slots as-machined resulted

FORM U-1 MANUFACTURERS' DATA REPORT FOR UNFIRED PRESSURE VESSELS

As required by the Provisions of the ASME Code Rules and the National Board

1. Manufactured by Ionics, Incorporated, P. O. Box 99, Bridgeville, Pennsylvania 15017
(Name and address of Manufacturer)

2. Manufactured for Westinghouse Electric Corp., Astronuclear Lab., Pittsburgh, Pennsylvania
(Name and address of Purchaser)

3. Type vert. Kind Tank Vessel No. (5239) (Mfr.' Serial) (State & State No.) Nat'l Bd. No. 329 Yr. Built 1972
(Horiz. or Vert.) (Tank, Jacketed, Heat Exch.) (Fig. or P. B. & Spec. Min. T.S.)

Items 4-9 incl. to be completed for single wall vessels (such as air tanks), jackets of jacketed vessels, or shells of Heat Exchangers

4. SHELL: Material T-304 SA336 T.S. 70,000 Nominal Thickness .310 in. Corrosion Allowance .029 in. Diam. 1 ft. 4 in. Length 2 ft. 4 in.
(Kind and Spec. No.) (Fig. or P. B. & Spec. Min. T.S.)

5. SEAMS: Long seamless H.T. NO X.R. NO Sectioned NO Efficiency 100 %
(Welded, Dbl., Single, Lap, Butt) (Yes or No)
Girth none H.T. NO X.R. NO Sectioned NO No. of Courses 1
If riveted describe seams fully on reverse side of form

6. HEADS: (a) Material Hast alloy X SB-366 T.S. 95,000 (b) Material S/S T-304 SA336 T.S. 70,000
Location Thickness Crown Radius Knuckle Radius Elliptical Ratio Conical Apex angle Hemispherical Radius Flat Diameter Side to Pressure (Convex or Concave)
(Top, bottom, ends)
(a) Upper 2.75 Flat - - - - - Flat
(b) Lower 2.75 Flat - - - - - Flat
If removable, bolts used _____ Other fastening _____
(Material, Spec. No., T.S., Size, Number) (Describe or Attach Sketch)

7. STAYBOLTS: _____ If hollow _____ Attachment _____ Pitch _____ X _____ Diam. _____
(Material) (Size of Hole) (Threaded, Welded) (Horiz.) (Vert.) (Nominal)

8. JACKET CLOSURE: _____
(Describe as cover & weld, bar, etc. If bar give dimensions, if bolted, describe or sketch)

9. Constructed for max. allowable working press. 100 psi at max. temp. 1300 °F Min. temp. (when less than -20°) _____ °F Test _____ psi
(Hydrostatic, Pneumatic or Combination) (Where & How)

Items 10 and 11 to be completed for tube sections.

10. TUBE SHEETS: Stationary. Material _____ Diam. _____ in. Thickness _____ in. Attachment _____
(Kind & Spec. No.) (Subject to Pressure) (Welded, Bolted)
Floating. Material _____ Diam. _____ in. Thickness _____ in. Attachment _____
(Kind & Spec. No.)

11. TUBES: Material _____ O.D. _____ in. Thickness _____ inches Type _____
(Kind & Spec. No.) or gage. Number _____ (Straight or U)

Items 12-15 incl. to be completed for inner chambers of jacketed vessels, or channels of heat exchangers.

12. SHELL: Material _____ T.S. _____ Nominal Thickness _____ in. Corrosion Allowance _____ in. Diam. _____ ft. _____ in. Length _____ ft. _____ in.
(Kind and Spec. No.) (Fig. or P. B. & Spec. Min. T.S.)

13. SEAMS: Long _____ H.T. _____ X.R. _____ Sectioned _____ Efficiency _____ %
(Welded, Dbl., Single, Lap, Butt) (Yes or No) (Spot or Complete) (Yes or No)
Girth _____ H.T. _____ X.R. _____ Sectioned _____ No. of courses _____
If riveted describe seams fully on reverse side of form

14. Heads (a) Material _____ T.S. _____ (b) Material _____ T.S. _____ (c) Material _____ T.S. _____
Location Thickness Crown Radius Knuckle Radius Elliptical Ratio Conical Apex angle Hemispherical Radius Flat Diameter Side to Pressure (Convex or Concave)
(a) Top, bottom, ends _____
(b) Channel _____
(c) Floating _____
If removable, bolts used (a) _____ (b) _____
(Material, Spec. No., T.S., Size, Number) (Describe or Attach Sketch)
(c) _____ Other fastening _____

15. Constructed for max. allowable working press. _____ psi at max. temp. _____ °F Min. temp. (when less than -20°) _____ °F Test _____ psi
(Hydrostatic, Pneumatic or Combination) (Where & How)

Items below to be completed for all Vessels where applicable.

16. SAFETY VALVE OUTLETS: Number _____ Size _____ Location _____

17. NOZZLES: Purpose (Inlet, Outlet, Drain) Number Diam. or Size Type Material Thickness Reinforcement Material How Attached
Outlet 1 3 butt-weld T-304 sch40 nozzle neck welded
Inlet 3 1 1/4 butt-weld T-304 sch40 nozzle neck welded

18. INSPECTION OPENINGS: Manholes, No. _____ Size _____ Location _____
Handholes, No. _____ Size _____ Location _____
Threaded, No. 5 Size 3/4-14 NPT Location Top head

19. SUPPORTS: Skirt by others Legs _____ (Number) _____ Other _____ Attached welded lower head
(Yes or No) (Number) (Describe) (Where & How)

20. REMARKS: The 201 nickle inside of vessel is excluded from code stamping. Vessel to be used as a Colbit 60 heat source.
(Brief description of purpose of the vessel, as Air Tank, After Cooler, Jacketed Cooler, etc. State contents of each part.) (Over)

CPCo 10M
2 If Postweld Heat-Treated
3 List other internal or external pressures with coincident temperatures when applicable.

Figure 2-27. ASME Form U-1 (Front)

Figure 2-29. Heat Pipe Assembly

Figure 2-30. Conical Shield Section

in removal of excess material than intended. While the cross-sectional area of the resulting slots was larger than desired, no significant change in radiation levels at the boundary of the shield was projected.

2.4.2 Heat Source Supporting Equipment

No difficulties were experienced in completing fabrication of the fueling cask, alignment plate/shield assembly, or fuel pin handling tools.

2.4.3 Fuel Pin Assemblies

Completion of the fuel pin assemblies included fabrication of the capsule and pin components as well as those activities associated with encapsulation of the SRL supplied wafers.

All Hastelloy X capsule and pin components were fabricated from the same heat of material. Fabrication of these components included deep hole drilling, rough machining, surface oxidation, and final machining. Specific NDT checks included in this sequence of fabrication steps included the following:

	<u>Ultrasonic Inspection</u>	<u>Helium Leak Check</u>
Raw Material	X	
Rough Machined	X	X
Final Machined		X

Except for failure of a furnace during oxidation of the pin and capsule components, which resulted in the loss of four capsule shells, no difficulties were encountered. A total of 52 capsules and 13 pins were available for use during encapsulation. This represented 4 spare capsules and 1 spare pin sets. Figure 2-31 shows the completed fuel pin shell and closure.

The final operations associated with completion of the fuel pin assemblies were those associated with encapsulation. This effort was completed by the Gamma Industries Division of Nuclear Systems Incorporated.

Figure 2-31. Fuel Pin Shell and Closure

Detailed requirements for this effort are presented in WANL PS-597989, "Cobalt 60 Heat Source Fuel Assembly. " Significant prerequisites to this effort were the completion of detailed procedures by the encapsulator to implement the requirements of the controlling process specification, fabrication and checkout of the required in-cell equipment, and qualification of the capsule and pin weld process.

In the latter case initial capsule and pin welding parameters were established by means of a process qualification program. During the production phase of the encapsulation effort, pre- and post-production samples were evaluated including monitoring of welding parameters and physical inspection and examination of the welds, to aid in establishing the acceptability of the actual fuel pin and capsule production welds. A batch sampling technique was used in this evaluation.

Decanning of the SRL slugs was completed mechanically, (chemical means were not used) by milling which permitted removal of the end caps themselves. The outer cans were removed by milling a slot along the length of the slug which permitted removal of the D-bars. As a prerequisite to actual decanning and subsequent hot operations a series of dry-run checkouts were completed not only to verify proper equipment function and techniques, but more importantly to form a partial basis for safety approval.

The capsule weld qualification program was completed in November 1971 with no difficulty. Qualification specimens were evaluated to establish the quality and reproducibility of the joining process and all requirements of the process specification were met. Satisfactory weld penetration level (greater than 0.050 in.) and quality (defect free as determined from penetrant inspection) were obtained for six consecutive specimens produced in the hot cell under actual assembly conditions. Results of this program are presented in Table 2-7, which presents details of the capsule qualification weld, and Figure 2-32 which shows sections of the qualification welds.

TABLE 2-7
FUEL PIN WELD QUALIFICATION SPECIMEN RESULTS

SPECIMEN IDENTIFICATION	1	2	3	4	5	6
WELDING PARAMETERS						
AMPERAGE - AMPS	43.8	43.8	41.8	42.5	41.8	42.0
VOLTAGE - VOLTS	16.8	16.8	18.7	17.5	17.8	18.5
SPEED - %	69	69	70	69	69	69
TEMPERATURE - °F	671	671	671	675	671	675
WELD CHARACTERISTICS						
VISUAL INSPECTION	OK	OK	OK	OK	OK	OK
DYE PENETRANT	OK	OK	OK	OK	OK	OK
PENETRATION - IN.	0.057	0.059	0.059	0.057	0.056	0.056

Specimen 1 - 25X

Specimen 2 - 25X

Figure 2-32. Capsule Weld Qualification Sections - Sheet 1

Specimen 3 - 25X

Specimen 4 - 25X

Figure 2-32. Capsuel Weld Qualification Sections - Sheet 2

Specimen 5 - 25X

Specimen 6 - 25X

Figure 2-32. Capsule Weld Qualification Sections - Sheet 3

Qualification of the pin welding process was completed in April 1972 following welding of the first eight production capsules. In this case the initial set of qualification samples which was submitted was rejected when WANL identified the presence of crater cracks at the termination point of the weld. This was easily overcome by incorporating a manual weld taper at the end of the weld. The second set of pin qualification welds was acceptable. The developed welding parameters are presented in Table 2-7 while sections of these pin qualification welds are presented in Figure 2-33.

In addition to dummy weld specimens required for the weld process qualification programs for the capsules and pins, additional specimens were required for pre- and post-weld qualification specimens for the actual encapsulation production process. It is significant to note that the quantity of weld specimens actually used exceeded the original estimate by a factor of 3 and 4 for pins and capsules, respectively.

SRL completed the calorimetry on the GFE slugs and prepared detailed fuel pin loading sheets based on these calorimetry measurements. In terms of controlling the fuel pin loading, administrative controls were used to implement the SRL loading sheets and calorimetry was not performed by the encapsulator on either the fuel capsules or pins. Of the slugs received from SRL, two were rejected by the encapsulator. Upon decanning the wafers in one slug (Cluster 18 Position 4 - for use in Fuel Pin Number 3) were found to be extensively corroded. With regard to this slug visual inspection as well as water sampling incident to transportation and storage in the pool at the encapsulators facility gave no indication that the slug cladding had been breached. In the second case the slug (Cluster 14 Position 4 - for use in Fuel Pin Number 8) was found to be swollen and was rejected prior to decanning. Appropriate fuel pin loading substitutions were made and additional slugs supplied by SRL. The defective slugs were returned to SRL for disposition.

Fuel pin loading sheets and QA Certification Sheets for the fuel pin assemblies are presented in Appendix A.

Specimen 1 - 15X

Specimen 2 - 15X

Figure 2-33. Pin Weld Qualification Sections - Sheet 1

Specimen 3 - 15X

Specimen 4 - 15X

Figure 2-33. Pin Weld Qualification Sections - Sheet 2

Specimen 5 - 15X

Specimen 6 - 15X

Figure 2-33. Pin Weld Qualification Sections - Sheet 3

Shipping plans for the encapsulation effort were based on use of the SRP-LMF cask. The initial slug shipment would be made to the encapsulator and the cask returned to SRP. The subsequent sequence would provide for shipment of additional slugs (SRP to encapsulator) and the sequential shipment of completed pins to WARD, with the LMF cask returning to SRP to repeat the cycle. The LMF cask was used for all slug shipments. However, after completion of the initial fuel pin shipment to WARD (two fuel pins) it was withdrawn from use.

A commercial cask to complete the delivery of the final ten fuel pins (five shipments) from the encapsulators facility to WARD. The Neutron Products Incorporated (NPI) Mode II Shipping Cask was used for these shipments. These shipments were completed without incident once the required cask cleanliness levels were established and demonstrated.

2.4.4 Demonstration Test Loop

Fabrication of the demonstration test loop included fabrication of the control console and Data Acquisition System (Figures 2-34 and 2-35) as well as loop piping spools and associated hardware (supports, etc.). No difficulty was experienced in completing the DAS and control console. In the case of the piping spools, a total of twelve sections were defined to minimize the extent of field erection. Fabrication of the piping spools was completed in accordance with the Power Piping Code. While spot radiography was completed as a result of rejection of all spools based on the results of the initial spot radiography.

Pressure testing of the pipe spools was not included as part of the fabrication sequence. Testing was planned to be completed during the installation sequence.

Figure 2-34. Control Console

Figure 2-35. Data Acquisition System

2.5 HEAT SOURCE ASSEMBLY/DISASSEMBLY

2.5.1 Assembly Operations

Heat source assembly operations were in progress at the time of notification by the AEC that FY 74 program funding would not be available. In the interest of obtaining maximum information in view of the program investment as of that time it was proposed to the AEC and subsequently approved that heat source assembly operations were to be completed. In this manner, and as a result of checkout operations also completed (see Section 3.0), acceptability of heat source hardware and assembly procedures or apparent discrepancies, could be established.

While loop installation activities were not initiated, heat source assembly operations were completed in a manner such that subsequent loop installation and ultimately fueling could be completed should a source of follow-on funding be identified. The assembly sequence did not however include installation of the heat source secondary insulation. Figures 2-36 through 2-42 show the heat source at various stages of this assembly sequence. Heat source assembly operations were completed at WARD and generally in accordance with Assembly Route Cards 1003 and 1004 (Route Cards 1001 and 1002 covered those assembly operations completed as part of the pressure vessel/core fabrication sequence). Route Cards covering the WARD assembly operations, annotated to include modifications which reflect improvements identified during assembly, are presented in Appendix B.

The following is a listing of those significant hardware changes or procedural changes implemented during the assembly sequence (see Figure 2-43):

- 1) In insulating the adiabatic sections of the heat pipes glass tape was used in lieu of wire to fix the insulation to the heat pipes.
- 2) Use of the heat pipe assembly fixture was deleted.
- 3) Shims were added to eliminate the horizontal clearance gap at the inner surface of the stacked side shield sections (three places).

Figure 2-36. Base Structure and Shield in Position

Figure 2-37. PV Installed on Base Structure and Shields

Figure 2-38. Conical Shield with Upper Heat Pipes in Position

Figure 2-39. Conical Shield with All Heat Pipes Installed

Figure 2-40. Side Shields Partially Installed - HP Sump Level

Figure 2-41. Side Shields Complete - Heat Pipe Shields Partially Installed

Figure 2-42. Heat Source Assembly - Complete (Except for Secondary Insulation and Thermal Guard)

Figure 2-43. Heat Source Assembly

- 4) The theta orientation of two levels of side shield sections was varied to preclude a potential radiation streaming problem.
- 5) As a result of the pre-installation of heat pipe thermocouples it was necessary to modify the identification of the system thermocouples.
- 6) Due to space limitations handling of some of the side shield segments was completed using a smaller fork lift truck with crane assistance.
- 7) The final fueling shield sections were installed with the crane rather than with the fork lift truck since this was advantageous.
- 8) The upper central shield section, containing the twelve fuel pin penetrations, was modified to eliminate an interference.
- 9) Temporary shims were added to the vertical joint between side shield segments.

The planned sequence of operations following installation of the pressure vessel/core assembly on the base shielding (see Figure 2-37), included determining the proper elevation of the conical shield section, pre-positioning the upper 18 heat pipes (insulated) on the conical shield section using temporary fixturing and lowering the conical shield with 18 heat pipes in place into final position. The temporary heat pipe fixturing proved awkward and it was therefore deleted since sufficient radial clearance existed between the conical shield and the pressure vessel to permit insertion of the upper heat pipes. In establishing the elevation of the conical shield section, shims were placed between the support pads and the upper surface of the shield plate on the pressure vessel head to provide an approximate vertical clearance of .06 in. between the conical shield section and the side shields. This clearance was provided to aid in putting the final side shield segments in position (see Figure 2-44). In installing the heat pipes on the side wall of the pressure vessel it is important to insure that the heat pipe was in contact along its full length, (i.e., does not ride up on the relief at the end of the groove), and that the heat pipe is at the bottom of the slots in the conical shield. The latter insures adequate clearance to accommodate differential thermal expansion between the pressure vessel/heat pipe assembly and the radiation shielding.

Figure 2-44. Heat Pipe Installation Sequence

The theta orientation of adjacent side shield layers was varied to eliminate a potential radiation streaming path. As shown in Figure 2-45 a potential streaming path existed in the as-designed side shields. Specifically reduced shielding effectiveness resulted from the alignment of inner and outer joints of shield segments from adjacent layers. By rotating one shield layer relative to the next layer the alignment of joints in adjacent layers was precluded. The proper theta orientation was maintained for the first and last side shield layers. Figure 2-40 shows the first two layers of side shields installed prior to rotating the second layer. Figure 2-41 and subsequent figures shows the rotation of the second and third shield layers, thirty and sixty degrees, respectively. Since an uneven pattern was used for the tie rods which axially penetrate the side shields it was necessary to delete tie rods from the assembly. In order to minimize the number of tie rods to be deleted and to preclude deletion of adjacent tie rods the thinner side shield (4 in. thick), was modified in the field by the addition of a tie rod clearance hole. Modification of the thicker side shield section (16 in. thickness) could not be accomplished in the field. As a result only two tie rods were deleted from the assembly. As shown in Section 3.3, there were no areas of significant radiation streaming through the side shields following the above actions.

The central section of the upper shield was modified to eliminate an interference. Specifically, an interference resulted from an eccentricity of the centerline of the twelve fuel pin extensions relative to the centerline of the stacked shields such that the final shield section could not be installed. The point of interference occurred at $\theta = 120^\circ$ and was corrected by locally removing material (1/16 inch) from the stepped central shield section. This section is shown in Figure 2-46 following installation. In this figure the varying gap between the central shield section and the surrounding shield can be easily seen.

With regard to reassembly of the heat source it is recommended that the following changes be incorporated:

- 1) The two lower side shield layers be installed prior to installing the conical shield -- heat pipes, i. e., steps 010 through 040 of Route Card 1004 should immediately follow step 170 of Route Card 1003. In this regard use of the fork lift truck method of handling these shield sections can be eliminated in favor of use of a crane.

Figure 2-45. Side Shield Streaming Path

Figure 2-46. View of Upper Shield Section with Fuel Pin Extension Hardware Shown

- 2) Shear pins be used to maintain the relative position of the conical shield section and the shield handling fixture (948C054, H01 and H02).
- 3) The horizontal shims should be replaced between shield layers if damaged as a result of the disassembly sequence. The following summarizes the gap between layers and the shims which were installed during the initial buildup of the heat source assembly:

<u>Shield Sections</u>	<u>Measured Gap</u>	<u>Shim Thickness</u>
940J347 H05 and H06	.040	.047
940J347 H07 and H08	.030	.032
940J347 H09 and H10	.022	.032
940J450 H02 and H03		

- 4) Shims should be installed to essentially fill the vertical gap between the halves of the side shields. The following summarizes the as-measured gap between shield halves:

<u>Shield Sections</u>	<u>Gap</u>
940J347 H07 and H08	2 at 0.041 in.
940J347 H09 and H10	2 at 0.104 in.
940J450 H02 and H03	2 at 0.140 in.

2.5.2 Disassembly Operations

In essence heat source disassembly was completed as the reverse of the assembly sequence. A brief disassembly procedure was prepared and is presented in Appendix B. Disassembly was completed with future reassembly in mind and therefore suitable precautions were taken to minimize potential damage to heat source components. Additionally, disassembly was completed only to the extent necessary to insure safe shipment. Where subassemblies could be easily handled, further disassembly was not completed. Match marks were made on appropriate components to facilitate reassembly as noted in the disassembly procedure.

3.0 CHECKOUT OPERATIONS

In accordance with the program redirection and to maximize the extent of useful information to be gained, a number of checkout operations, previously planned as a part of the test phase, were completed. Included were the following:

- Heat Source Dummy Fueling
- Fueling Cask Shielding Survey
- Heat Source Shielding Survey

3.1 HEAT SOURCE DUMMY FUELING

Heat source dummy fueling operations were completed following completion of heat source assembly. The objectives of the dummy fueling operations were to provide a functional checkout of the heat source and heat source supporting equipment (handling tools, fueling cask, and alignment plate/shield assembly) and to verify associated operating procedures for cask handling and heat source fueling. This sequence of operations was completed using a dummy (unfueled) fuel pin assembly. Satisfactory operation was demonstrated for each of the twelve fuel pin positions.

Prior to the dummy fueling operations the full sequence of cask loading and unloading operations were successfully completed in the WARD Transfer Building Pool. Following these operations heat source dummy fueling was completed. Figures 3-1 through 3-3 show representative portions of this sequence. The only difficulty encountered was the need for excessive force required to manually move the slide of the alignment plate/shield assembly. This difficulty was overcome by the addition of an air cylinder to the actuating arm of the alignment plate/shield which can be seen in Figure 3-1. Since final positioning of the alignment plate/shield assembly was essentially blind the original intent was to position the lightweight alignment plate initially and then to put the shield in place. Experience however did show that two separate handling operations were not necessary and the unit could be installed as a single assembly. Operating personnel have additionally recommended two areas of change to improve the operation:

Figure 3-1. Heat Source with Alignment Plate/Shield and Fueling Cask Installed

Figure 3-2. Dummy Fueling Sequence - Uppermost Position

Figure 3-3. Dummy Fueling Sequence - Lower Position

- 1) Use of permanent type scaffolding for personnel engaged in the fueling operation.
- 2) The addition of a chamfer at the bottom of the fueling cask (fuel pin port) to facilitate entry of the fuel pin when moving from the heat source into the fueling cask.

3.2 FUELING CASK SHIELDING SURVEY

A shielding survey of the fueling cask was completed using a typical Co-60 fuel pin assembly. Radiation survey data taken during this check is summarized in Figure 3-4. Predictions are also shown on this figure. Radiation background in the immediate vicinity of the cask ranged up to 5 mr/hr; the data as presented does not reflect a correction for background. Measurements were obtained with an Eberline Model E510 survey meter.

In general the measurements confirmed the predictions and the acceptability of the fueling cask. The area of primary variance with prediction was the handling tool access hole at the top of the cask. Data applicable to this area is summarized as follows:

<u>Condition</u>	<u>Surface Dose Rate</u>	
	<u>Predicted</u>	<u>Measured</u>
Plug installed - with cover	-	60 mr/hr
Plug installed - without cover	1 mr/hr	80 mr/hr
Plug removed	45 mr/hr	10 R/hr

Data taken at one meter from the surface shows that the high measured levels are the result of a highly collimated beam. It should be noted that the condition with the central plug removed exists only for a short period of time and that this void space is filled with the handling tool during the fueling sequence of operations. It appears that radiation streaming up the annular gap between the fuel pin and the inside wall of the cask creates a diffuse volumetric source of scattered radiation at the top of the fuel pin. Thus, the small step provided at the top of the

* WITH PLUG REMOVED

DOSE RATE IN MR/HR UNLESS OTHERWISE NOTED.

BRACKETED NUMBERS ARE PREDICTIONS.

Figure 3-4. Fueling Cask Shielding Survey

annular gap is not effective in attenuating radiation escaping through the unplugged access hole. However, with appropriate procedural controls applicable to this sequence of operations, this condition is considered acceptable.

3.3 HEAT SOURCE SHIELDING SURVEY

Heat source radiation survey data is presented in Figure 3-5 for the condition of a single fuel pin installed in the outermost core position in line with the uppermost vertical joint of the sections of the side shield.

Through the sequence of operations required it is possible to assess shielding adequacy for the fueling operation as well as to project radiation levels for the fully fueled condition.

For the fueling sequence of operations the peak radiation level measured, exclusive of the access port at the top of the fueling cask, was less than predicted. Specifically, a peak value of 120 mr/hr was measured in the area of the heat source fueling shield with the active portion of the fuel pin located within the upper plenum of the pressure vessel. This represents a transient condition during fueling and is less than the predicted level of 200 mr/hr. With the fuel pin installed in the core, the alignment plate/shield in position, and with the fueling cask removed the general level over the alignment plate/shield (contact) was essentially background, approximately 1 mr/hr.

High radiation levels were experienced in two areas:

- 1) The vertical joint between the upper side shield sections (85 to 100 mr/hr).
- 2) The top surface of the heat source in the general area of the twelve fuel pin penetrations (130 to 175 mr/hr).

In the case of streaming through the joint between side shield sections, the measured level was approximately a factor of 5 higher than that measured adjacent to the joint. It should be noted that by introducing a partial shim in the joint the measured radiation level was

Figure 3-5. Heat Source Radiation Survey - Single Fuel Pin
(Dose Rates in mr/hr)

reduced from 100 mr/hr to less than 50 mr/hr. Therefore, through the use of an appropriate full shim, the radiation level can be reduced even further.

For the upper surface of the heat source in the general area of the fuel pin penetrations, a general dose field of 100 to 175 mr/hr was measured. The field is essentially flat in comparison to the single pin characteristic curve previously reported (Figure 2-23 of Reference 2) and significantly higher than predictions. The discrepancy is attributed to the existence of a high source level in the pressure vessel upper plenum due to streaming up the core coolant channels. Similar streaming then occurs up the twelve voids through the pressure vessel head/shield plate which results in a higher source just below the heat source top shield plate than predicted.

Appropriate multiplication factors have been defined for extrapolating the single pin measurements to a fully loaded condition. In the radial direction the single pin measurements should be multiplied by a factor of 4 to 5 to obtain a projection for the fully fueled condition. All heat source radial dose rates should therefore be less than 200 mr/hr at the surface. However, since radiation streaming up the coolant channels and the access holes in the pressure vessel head results in a rather flat single pin dose rate above the top shield, it is concluded that the field from a fully fueled condition will be 12 times as intense in the axial direction, i. e., where streaming predominates, than measured for a single fuel pin. Figure 3-6 shows projected dose rates for the fully fueled condition based on this evaluation. It should be noted that the high radiation levels are limited to the region directly above the top shield plate of the upper shield and not in an area normally or easily accessible to personnel. During the period when fueling operations are in process the alignment plate/shield or fueling cask is in position and radiation levels are not excessive.

Figure 3-6. Projected Heat Source Radiation Levels - 12 Fuel Pins Loaded

4.0 BIBLIOGRAPHY

Significant documentation applicable to the Phase III effort is summarized in the following sections. This documentation includes the Co-60 heat source drawing list which defines fabrication and assembly requirements, applicable process specifications prepared to cover significant fabrication activities, and route cards which provided the step-by-step sequencing of heat source assembly operations. Finally a listing of reports prepared during Phase III is presented. This listing of reports does not include monthly progress reports issued during the course of Phase III.

4.1 DRAWINGS

The following is a listing of program drawings including identification of latest revision.

<u>Title</u>	<u>Drawing No.</u>	<u>Rev.</u>
Heat Source Assembly	940J335	
Pressure Vessel-Core Assembly	940J311	A
Core-Heat Pipe Assembly	940J461 Sh. 1	
Heat Pipe	940J456	--
Core Sub-Assembly	940J345 Sh. 1 Sh. 2	F E
Support Plate	914E926	B
Shield Ring	914E846	B
Insulation Container	929F402	--
Lower Closure	914E828	A
Components	914E827	B
Lower Shield Components	940J347	F
Shield Components	940J455	E
Upper Shield Components	940J450	H

<u>Title</u>	<u>Drawing No.</u>	<u>Rev.</u>
Fuel Capsule	982D222	C
Fuel Pin	914E822	F
Miscellaneous Components	982D232	--
<u>Supporting Equipment</u>		
Fueling Cask Assembly	940J330	B
Fueling Cask Components	940J325	E
Grappler	914E824	--
Grappler Details	982D235	--
Grappler Details	914E968	--
Guide Ring Assembly	940J463	C
Shipping Container	940J349	--
Handling Fixture-Shield	982D234	--
Handling Fixture-Shield	914E945	--
Handling Fixture-Shield	914E946	--
Handling Fixture-Shield	914E947	--
Handling Fixture-Shield	914E948	--
Handling Fixture-Shield	914E955	--
<u>Demonstration Test Loop</u>		
Piping Loop Assembly	940J471	C
Piping Assemblies	982D238	A
Piping Assemblies	982D239	--
Piping Assemblies	982D241	B
Piping Assemblies	982D242	B
Loop Components	914E969	--
Console & DAS Wiring Diagram	389D180	--
Console & DAS Interconn. Diagram	389D181	--

AiResearch drawings prepared under subcontract to WANL and covering the BCD unit are as follows:

<u>Drawing No.</u>	<u>Title</u>
306736-1	Frequency to D.C. Converter
306737-1	Amplifier, Thermocouple
306738	Timer/Logic
306739-1	Two Amp Driver Assy
306753-1	Control Console Co ⁶⁰ Demonstrator
306754	Console Control Panel
306755	System Control Panel
306756	24 Volt Breaker/Distribution Box
30657-1	Relay Assembly
306759	Logic Diagram Schematic Co ⁶⁰ Control System

4.2 PROCESS SPECIFICATIONS

The following is a listing of WANL Process Specifications specifically prepared in support of the Co-60 Heat Source Demonstration Program.

<u>PS Number</u>	<u>Title</u>
PS597989	Co-60 Heat Source Fuel Assembly
PS597990	Co-60 Heat Source Assembly Components
PS597991	Co-60 Heat Pipe Assembly

4.3 ROUTE CARDS

Route cards were prepared covering both the fabrication and assembly operations. Specifically two route cards (1001 and 1002) covered assembly operations incident to fabrication of the pressure vessel/core assembly. The remaining route cards, 1003 and 1004, covered assembly of the heat source at WARD.

Route Card

Co-60 1001

Co-60 1002

Co-60 1003

Co-60 1004

Assembly Description

Core Subassembly

Core Assembly

Core/Heat Pipe Assembly

Heat Source Assembly

4.4 PROGRAM REPORTS

The following is a list of program topical reports issued to date. In addition, Phase III Monthly Progress Reports were issued covering the period December 1970 to May 1973. Asterisked Reports were issued during Phase III.

Report No.WANL-543-1
January 1970WANL-543-2
January 1970WANL-543-3
December 1969*WANL-543-4
May 1971WANL-543-5
October 1970*WANL-543-6
March 1972*WANL-543-7
February 1971*WANL-543-8
January 1971*WANL-543-9
October 1972TitleCo-60 Heat Source Demonstration Program Phase I-
Preliminary Analysis and Design Technical ReportIntegrated Test Plan, Cobalt 60 Heat Source
Demonstration UnitCo-60 Heat Source Demonstration Program, Program
Plan for Phases II through V and Cost EstimateCo-60 Heat Source Demonstration Program, Phase II
Final Report - Detail DesignCo-60 Heat Source Demonstration Program, Program
Plan for Phases III through V and Cost EstimateCo-60 Heat Source Demonstration Program,
Operations ManualCo-60 Heat Source Demonstration Program,
Component Test ProgramEngineering Analysis of Shipping Container for
Encapsulated Cobalt 60Co-60 Heat Source Demonstration Program, Safety
Evaluation Report

*WANL-543-10
June 1973

Co-60 Heat Source Demonstration Program,
Phase III - Fabrication, Final Report

In addition to monthly progress letters the following formal reports were prepared by
AiResearch covering subcontract effort on the BCD:

APS-5429-R
June 30, 1972

Performance Analysis, BCD-Co-60 Isotope Heat
Source Power Conversion Loop

APS-5430-R
June 30, 1972

Controls Design and Interface Study, BCD-Co-60
Isotope Heat Source Power Conversion Demon-
stration Program

ADS-5431-R
June 30, 1972

BCD Teardown and Inspection Report, BCD-Co-60
Isotope Heat Source Power Conversion Demonstration
Program

5.0 REFERENCES

1. WANL-543-1, "Co-60 Heat Source Demonstration Program, Phase I - Preliminary Analysis and Design Technical Report, " January 1970.
2. WANL-543-4, "Co-60 Heat Source Demonstration Program, Phase II Final Report - Detail Design, " May 1971.
3. WANL-543-9, "Co-60 Heat Source Demonstration Program, Safety Evaluation Report, " October 1972.
4. WANL-543-6, "Co-60 Heat Source Demonstration Program, Operations Manual, " March 1972.
5. DP-1279, "Savannah River Laboratory Cobalt-60 Power and Heat Sources Quarterly Progress Report, " April-June 1971.
6. DP-1293, "Savannah River Laboratory Cobalt-60 Power and Heat Sources Quarterly Progress Report, " October-December 1971.
7. "Savannah River Laboratory Cobalt-60 Power and Heat Sources Quarterly Progress Report, " April-June 1973 (to be issued).
8. Westinghouse Research Memo 71-74-TAPSC-M2, "Total Emissivities of Five Bolt Steels From 250 to 1000°F, " April 12, 1971.
9. APS-5431-R, "BCD Teardown and Inspection Report, Brayton Cycle Demonstrator - Co-60 Isotope Heat Source Power Conversion Demonstration Program, " June 1972.

APPENDICES

APPENDIX A

FUEL PIN SUPPORTING DOCUMENTATION

Loading sheets for the C0-60 Fuel Pin Assemblies were prepared by SRL and were based on calorimetry measurements of selected SRL slugs. The loading sheets applicable to the fuel pin assemblies and the QA Certification Sheets prepared by the encapsulator are presented on the following pages.

FUEL PINS 3 AND 6

FUEL PIN LOADING SCHEDULE

CAPSULE	PIN NUMBER 3				PIN NUMBER 6			
	ACTIVITY-Ci*		SLUG DESIGN		ACTIVITY - Ci*		SLUG DESIGN	
	CAPSULE	SLUG	CLUSTER	POSITION	CAPSULE	SLUG	CLUSTER	POSITION
1 (TOP)	44, 110	21, 210	18	5	44, 200	21, 650	18	8
		18, 080	14	8		17, 720	1	11
		4, 820	1	5		4, 830	15	8
2	43, 200	20, 890	1	10	42, 770	20, 870	12	9
		17, 490	14	5		17, 070	15	6
		4, 820	1	5		4, 830	15	8
3	43, 640	20, 780	12	5	43, 230	20, 750	7	4
		18, 040	15	5		17, 650	1	4
		4, 820	1	5		4, 830	15	8
4 (BOTTOM)	44, 090	21, 090	1	6	44, 600	21, 470	18	9
		18, 180	8	8		18, 300	14	6
		4, 820	1	5		4, 830	15	8
PIN ACTIVITY*-Ci	175, 040				174, 800			

* AS OF 7/19/71

GAMMA INDUSTRIES
QA CERTIFICATION
PINS NUMBER 3 AND 6

PIN NO.

3

<u>3</u>		PIN NUMBER	<u>6</u>	
Init/Date	Value/Status		Value/Status	Init/Date
WELD PARAMETER				
4/12 JLC	46.5	I-AMPS	46.5	4/15 JLC
4/12 JLC	18.2	V-VOLTS	19.5	4/15 JLC
4/12 JLC	39%	S-SPEED	39%	4/15 JLC
4/12 JLC	606	T-TEMP-°F	627 °F	4/15 JLC
WELD Q. C.				
4/12 JLC	ACCEPTABLE	VISUAL	ACCEPTABLE	4/15 JLC
4/12 JLC	NO LEAKAGE	He LEAK	NO LEAKAGE	4/15 JLC
CONTAMINATION				
4/12 JLC	0.004 Mci	INITIAL	.005 Mci	4/15 JLC
4/17 JLC	0.003 Mci	FINAL *	.001 Mci	4/17 JLC
PRE QUAL. WELD				
4/12 JLC	1-3	IDENTIFICATION		
4/12 JLC	45.0	I-AMPS		
4/12 JLC	17.5	V-VOLTS		
4/12 JLC	39%	S-SPEED		
4/12 JLC	649 °F	T-TEMP-°F		
4/12 JLC	ACCEPTABLE	VISUAL		
4/12 JLC	NO INDICATIONS	DYE PENETRANT		
4/12 JLC	0.052 "	PENETRATION		
POST QUAL. WELD				
		IDENTIFICATION	2-6	
		I-AMPS	45.5	4/15 JLC
		V-VOLTS	20	4/15 JLC
		S-SPEED	39%	4/15 JLC
		T-TEMP °F	649	4/15 JLC
		VISUAL	ACCEPTABLE	4/15 JLC
		DYE PENETRANT	NO INDICATIONS	4/15 JLC
		PENETRATION	0.058 "	4/15 JLC
4/17 JLC	ACCEPTABLE	FINAL ACCEPTANCE	ACCEPTABLE	4/17 JLC

PIN NO.

6

* See attached for certified copy of contamination checks.

CAPSULE	1		2		3		4	
	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date
LOADING:								
SPACER-TOP		REM 1/10		REM 1/9		REM 1/6		REM 1/6
SLUG ID/QUAN.	1-5	REM 1/10	1-10	REM 1/9	17-5	REM 1/6	1-6	REM 1/6
SLUG ID/QUAN.	1-5/14-8		1-5/5-14		1-5/15-5		1-5/6 F	
SPACER-BOTTOM		REM 1/10		REM 1/9		REM 1/6		REM 1/6
WELD PARAMETER								
I-AMPS	36		37		30		34	
V-VOLTS	10.5		11		12		7.5	
S-SPEED	40%		40%		52%		52%	
T-TEMP-°F	692°F	REM 1/2	671	REM 1/2	615°F	REM 1/6	628°F	REM 1/6
WELD Q. C.								
VISUAL		REM 1/2		REM 1/2		REM 1/6		REM 1/6
H ₂ LEAK		REM 1/1		1/11		REM 1/11		REM 1/11
CONTAMINATION								
INIT. - μCi	>14 μCi	JLC 3/1	>21 μCi	JLC 3/1	>15 μCi	JLC 3/1	>2.0 μCi	JLC 3/1
FINAL - μCi	0.045	JLC 3/4	0.029	JLC 3/4	0.039	JLC 3/4	0.041 μCi	JLC 3/4
PRE QUAL. WELD								
IDENTIFICATION	#7	REM 1/2			#9	REM 1/6		
I-AMPS	34	REM 1/2			33	REM 1/6		
V-VOLTS	11	REM 1/2			10.5	REM 1/6		
S-SPEED	40%	REM 1/2			52%	REM 1/6		
T-TEMP-°F	675	REM 1/2			615°F	REM 1/6		
VISUAL	OK	REM 1/2			OK	REM 1/6		
DYE PENETRANT	OK	REM 1/2			OK	REM 1/6		
PENETRATION-IN.	0.052	REM 1/2			0.051	REM 1/6		
POST QUAL. WELD								
IDENTIFICATION			#8	REM 1/3			#10	REM 1/6
I-AMPS			32	REM 1/3			32	REM 1/6
V-VOLTS			6	REM 1/3			9	REM 1/6
S-SPEED			50%	REM 1/3			52%	REM 1/6
T-TEMP-°F			628°F	REM 1/3			649°F	REM 1/6
VISUAL			OK	REM 1/3			OK	REM 1/6
DYE PENETRANT			OK	REM 1/3			OK	REM 1/6
PENETRATION-IN.			0.052	REM 1/3			0.051	REM 1/6
FINAL ACCEPTANCE								

GAMMA INDUSTRIES
QA CERTIFICATION
PIN NUMBER 6

CAPSULE	1		2		3		4	
	Value/Status	Init./Date	Value/Status	Init./Date	Value/Status	Init./Date	Value/Status	Init./Date
LOADING:								
SPACER-TOP								
SLUG ID/QUAN.	1E 1E	JCV 3/21	4-12	JCV 3/20	4-7	JCV 3/17	4-12	JCV 3/16
SLUG ID/QUAN.	2-15/1-11		2-15/6-15		2-15/1-4		2-15/14-1	
SPACER-BOTTOM		JCV 3/21		JCV 3/20		JCV 3/17		JCV 3/16
WELD PARAMETER								
I-AMPS	32.0		32.0		31.8		33.5	
V-VOLTS	18.0		20.0		18.8		16.2	
S-SPEED	56%		56%		56		56	
T-TEMP-°F	671°F	JLC 3/24	671°F	JLC 3/24	662°F	JLC 3/24	680	JLC 3/24
WELD Q. C.								
VISUAL	ACCEPT	JLC 3/25	ACCEPT	JLC 3/24	ACCEPT	JLC 3/24	ACCEPT	JLC 3/24
He LEAK	PASS	JLC 3/25	PASS	JLC 3/24	PASS	JLC 3/24	PASS	JLC 3/24
CONTAMINATION								
INIT. - µCi	>0.1 µCi	JLC 3/25	>0.2 µCi	JLC 3/24	>0.08	JLC 3/24	>0.10	JLC 3/24
FINAL - µCi	0.032	JLC 3/25	0.040	JLC 3/24	0.022	JLC 3/24	0.035	JLC 3/24
PRE QUAL. WELD								
IDENTIFICATION	No 1							
I-AMPS	33.8	JLC 3/24						
V-VOLTS	16.0	JLC 3/24						
S-SPEED	56%	JLC 3/24						
T-TEMP-°F	662°F	JLC 3/24						
VISUAL	OK	JLC 3/24						
DYE PENETRANT	OK	JLC 3/24						
PENETRATION-IN.	0.051	JLC 3/24						
POST QUAL. WELD								
IDENTIFICATION							No 2	
I-AMPS							30.0	JLC 3/25
V-VOLTS							21.2	JLC 3/25
S-SPEED							67%	JLC 3/25
T-TEMP-°F							649°F	JLC 3/25
VISUAL							OK	JLC 3/25
DYE PENETRANT							OK	JLC 3/25
PENETRATION-IN.							0.051	JLC 3/25
FINAL ACCEPTANCE								

FUEL PINS 10 AND 9

FUEL PIN LOADING SCHEDULE

CAPSULE	PIN NUMBER 10				PIN NUMBER 9			
	ACTIVITY - Ci*		SLUG DESIGN		ACTIVITY - Ci*		SLUG DESIGN	
	CAPSULE	SLUG	CLUSTER	POSITION	CAPSULE	SLUG	CLUSTER	POSITION
1 (TOP)	45, 200	18, 420	9	9	44, 020	18, 450	15	9
		20, 920	7	10		20, 560	15	5
		5, 860	19	3		5, 010	19	12
2	45, 010	18, 890	18	10	43, 670	19, 330	9	7
		20, 260	13	5		19, 330	13	12
		5, 860	19	3		5, 010	19	12
3	45, 090	18, 470	9	6	43, 560	19, 610	11	5
		20, 760	19	5		18, 940	15	7
		5, 860	19	3		5, 010	19	12
4 (BOTTOM)	45, 130	18, 830	8	7	43, 970	18, 670	18	6
		20, 440	4	2		20, 290	17	5
		5, 860	19	3		5, 010	19	12
PIN ACTIVITY* - Ci	180, 430				175, 200			

* AS OF 7/19/71

GAMMA INDUSTRIES
QA CERTIFICATION
PINS NUMBER 9 AND 10

All capsules and tungsten spacers gaged @ proper depth.

PIN NO.

9

Bow test Pass

<u>9</u>		PIN NUMBER	<u>10</u>	
Init/Date	Value/Status		Value/Status	Init/Date
		WELD PARAMETER		
8/29	43 / Accept.	I-AMPS	44.5 / good	8/29
8/29	20.5 volts.	V-VOLTS	21 volts / good	8/29
8/29	370' @ 20sec	S-SPEED	370' @ 20sec	8/29
8/29	680°F	T-TEMP-°F	669°F	8/29
		WELD Q. C.		
8/29	Accept.	VISUAL	Accept.	8/29
8/29	<0.1 x 10 ⁻⁶	He LEAK	<0.1 x 10 ⁻⁶	8/29
		CONTAMINATION		
8/29	0.0003 Rci	INITIAL	0.0003 Rci	8/29
10/3	0.0003 Rci	FINAL	0.0003 Rci	10/2
		PRE QUAL. WELD		
Specimen N ₁₁ 8/29/77		IDENTIFICATION	/	
42 Amps		I-AMPS		
23 volts		V-VOLTS		
370' @ 20sec		S-SPEED		
680°F		T-TEMP-°F		
Pass		VISUAL		
Acc.		DYE PENETRANT		
0.55" min		PENETRATION		
		POST QUAL. WELD		
/		IDENTIFICATION	Specimen N ₁₂	
		I-AMPS	43 Amps.	
		V-VOLTS	23 volts	
		S-SPEED	370' @ 20sec.	
		T-TEMP-°F	680°F	
		VISUAL	Pass	
		DYE PENETRANT	Accept.	
		PENETRATION	0.55" min.	
10/3	Acceptable	FINAL ACCEPTANCE		

All capsules and tungsten spacers gaged @ proper depth.

PIN NO.

10

Bow test Pass

GAMMA INDUSTRIES
QA CERTIFICATION
PIN NUMBER 9

CAPSULE	1		2		3		4	
	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date
LOADING:								
SPACER-TOP		RP 8/7		RP 8/7		RP 8/8		RP 8/8
SLUG ID/QUAN.	15/5-20	5/18	13/12-20	5/18	15/7-20	5/18	17/5-20	5/18
SLUG ID/QUAN.	19/12-5	JCU 5/15	19/12-5	JCU 5/15	19/12-5	JCU 5/15	19/12-5	JCU 5/15
SPACER-BOTTOM		JCU 5/15		JCU 5/15		JCU 5/15		JCU 5/15
WELD PARAMETER								
I-AMPS	32 Amps	JLC 8/7	30 Amps	JLC 8/7	32 Amps	JLC 8/8	29 Amps	JLC 8/8
V-VOLTS	18 volts	JLC 8/7	19.5 volts	JLC 8/7	17 volts	JLC 8/8	20 volts	JLC 8/8
S-SPEED	52%	JLC 8/7	52%	JLC 8/7	52%	JLC 8/8	52%	JLC 8/8
T-TEMP-°F	649°F	JLC 8/7	658°F	JLC 8/7	675°F	JLC 8/8	600°F	JLC 8/8
WELD Q. C.								
VISUAL	ACCEPT		ACCEPT		ACCEPT		ACCEPT	
He LEAK	PASS		PASS		PASS		PASS	
CONTAMINATION		Initial and Final Contamination check to be						
INIT. - µCi		performed prior to pin loading. CAPSULES ARE PRESENTLY						
FINAL - µCi		STORED IN THE POOL.						
PRE QUAL. WELD								
IDENTIFICATION	No.1	JLC 8/7						
I-AMPS	32 Amps	JLC 8/7						
V-VOLTS	19.5 volts	JLC 8/7						
S-SPEED	52%	JLC 8/7						
T-TEMP-°F	671°F	JLC 8/7						
VISUAL	Accept.	JLC 8/7						
DYE PENETRANT	Pass	JLC 8/7						
PENETRATION-IN.	0.031" min	JLC 8/7						
POST QUAL. WELD								
IDENTIFICATION							No.2	
I-AMPS							29 Amps	JLC 8/8
V-VOLTS							19.5 volts	JLC 8/8
S-SPEED							52%	JLC 8/8
T-TEMP-°F							649°F	JLC 8/8
VISUAL							ACCEPT.	JLC 8/8
DYE PENETRANT							PASS	JLC 8/8
PENETRATION-IN.							0.031" min	JLC 8/8
FINAL ACCEPTANCE	Acceptable.	JLC 8/7	Acceptable	JLC 8/7	Acceptable	JLC 8/8	Acceptable	JLC 8/8

GAMMA INDUSTRIES
QA CERTIFICATION
PIN NUMBER 1D

CAPSULE	1		2		3		4	
	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date
LOADING:								
SPACER-TOP	OK (installed)	JLC 8/22	OK (installed)	JLC 8/22	OK (installed)	JLC 8/22	OK (installed)	JLC 8/22
SLUG ID/QUAN.	9-9-20	JLC 8/21	18-10-20	JLC 8/21	9-6-20	JLC 8/18	8-7-20	JLC 8/18
SLUG ID/QUAN.	5-10-20	JLC 8/21	13-5-20	JLC 8/21	15-5-20	JLC 8/18	4-2-20	JLC 8/17
SPACER-BOTTOM	OK (installed)	JLC 8/16	OK (installed)	JLC 8/16	OK (installed)	JLC 8/16	OK (installed)	JLC 8/16
WELD PARAMETER								
I-AMPS	31 AMPS	JLC 8/22	31 AMPS	JLC 8/22	30 AMPS	JLC 8/22	31 AMPS	JLC 8/22
V-VOLTS	24.5 volts	JLC 8/22	25 volts	JLC 8/22	25 volts	JLC 8/22	25.5 volts	JLC 8/22
S-SPEED	370° @ 12 sec	JLC 8/22	370° @ 12 sec	JLC 8/22	370° @ 12 sec	JLC 8/22	370° @ 12 sec	JLC 8/22
T-TEMP-°F	680°F	JLC 8/22	662°F	JLC 8/22	680°F	JLC 8/22	680°F	JLC 8/22
WELD Q. C.	8/22/72		8/22/72		8/22		8/22	
VISUAL	No surface indications	JLC 8/22	No indications	JLC 8/22	No indications	JLC 8/22	No indications	JLC 8/22
He LEAK	<0.1 x 10 ⁻⁶	JLC 8/22	<0.1 x 10 ⁻⁶	JLC 8/22	<0.1 x 10 ⁻⁶	JLC 8/22	<0.1 x 10 ⁻⁶	JLC 8/22
CONTAMINATION	[Hold until pin loading - Data to accompany loading]							
INIT. - µCi	[and welding data on pins. JLC 8/25/72]							
FINAL - µCi								
PRE QUAL. WELD	8/21/72	JLC 8/21						
IDENTIFICATION	SPECIMEN NO	JLC 8/21						
I-AMPS	31 AMPS	JLC 8/21						
V-VOLTS	23.5 volts	JLC 8/21						
S-SPEED	370° @ 12 sec	JLC 8/21						
T-TEMP-°F	662°F	JLC 8/21						
VISUAL	Good - ACCEPT	JLC 8/21						
DYE PENETRANT	No indications	JLC 8/21						
PENETRATION-IN.	0.055"	JLC 8/21						
POST QUAL. WELD							8/22/72	JLC 8/22
IDENTIFICATION							SPECIMEN NO 2	
I-AMPS							29 AMPS	JLC 8/22
V-VOLTS							24.5 volts	JLC 8/22
S-SPEED							370° @ 12 sec	JLC 8/22
T-TEMP-°F							671°F	JLC 8/22
VISUAL							Good - Accept	JLC 8/22
DYE PENETRANT							No indications	JLC 8/22
PENETRATION-IN.							0.053"	JLC 8/22
FINAL ACCEPTANCE	PRE CAP NO. 1 ACCEPT	JLC 8/22	CAP NO. 2 ACCEPT	JLC 8/22	CAP NO. 3 ACCEPT	JLC 8/22	CAP NO. 4 ACCEPT	JLC 8/22

FUEL PINS 11 AND 12

FUEL PIN LOADING SCHEDULE

CAPSULE	PIN NUMBER 12				PIN NUMBER 11			
	ACTIVITY - Ci*		SLUG DESIGN		ACTIVITY - Ci*		SLUG DESIGN	
	CAPSULE	SLUG	CLUSTER	POSITION	CAPSULE	SLUG	CLUSTER	POSITION
1 (TOP)	44, 880	20, 220	9P	5	45, 350	22, 890	13	3
		18, 340	8	6		16, 050	15	10
		6, 320	11P	3		6, 410	13P	3
2	45, 420	21, 920	12	7	44, 780	21, 020	4P	4
		17, 180	8	9		17, 350	9	10
		6, 320	11P	3		6, 410	13P	3
3	44, 910	21, 370	16	12	44, 970	21, 000	4P	3
		17, 220	14	9		17, 560	8	5
		6, 320	11P	3		6, 410	13P	3
4 (BOTTOM)	44, 920	21, 320	10	12	45, 080	22, 610	13	11
		17, 280	7	3		16, 060	7	11
		6, 320	11P	3		6, 410	13P	3
PIN ACTIVITY* - Ci	180, 130				180, 180			

* AS OF 7/19/71

GAMMA INDUSTRIES
QA CERTIFICATION
PINS NUMBER 11 AND 12

<u>11</u>		PIN NUMBER	<u>12</u>	
Init/Date	Value/Status		Value/Status	Init/Date
		WELD PARAMETER		
JLC 10/10	38.5 Amps	I-AMPS	47.5 Amps	JLC 10/10
JLC 10/10	20 volts	V-VOLTS	18 volts	JLC 10/10
JLC 10/10	370° @ 20 sec	S-SPEED	370° @ 20 sec	JLC 10/10
JLC 10/10	671°F	T-TEMP-°F	675°F	JLC 10/10
		WELD Q. C.		
JLC 10/10	Good / Accept	VISUAL	Good / Accept	JLC 10/10
JLC 10/10	<0.1810 ⁻⁶	He LEAK	<0.1810 ⁻⁶	JLC 10/10
		CONTAMINATION		
JLC 10/10	0.0003 psi	INITIAL	0.0004 psi	JLC 10/10
JLC 10/10	0.000074 psi	FINAL	0.0003 psi	JLC 10/10
		PRE QUAL WELD		
PQS-11-01		IDENTIFICATION		
JLC 10/10	41 Amps	I-AMPS		
JLC 10/10	20 volts	V-VOLTS		
JLC 10/10	370° @ 20 sec	S-SPEED		
JLC 10/10	671°F	T-TEMP-°F		
JLC 10/10	Good	VISUAL		
JLC 10/10	Per. no ind.	DYE PENETRANT		
JLC 10/10	0.075" min	PENETRATION		
		POST QUAL. WELD		
		IDENTIFICATION	P2Q-12-01	JLC 10/10
		I-AMPS	38.5 Amps	JLC 10/10
		V-VOLTS	20.5 volts	JLC 10/10
		S-SPEED	370° @ 20 sec	JLC 10/10
		T-TEMP-°F	675°F	JLC 10/10
		VISUAL	Good	JLC 10/10
		DYE PENETRANT	Per. No Ind.	JLC 10/10
		PENETRATION	0.075" min	JLC 10/10
		FINAL ACCEPTANCE	Acceptable	JLC 10/10

PIN NO.

11

Total Ind. in Reading

<0.001 inch

Bow Test No 11

JLC 10/10 Acceptable

PIN NO

12

Total Ind. in Reading

<0.001 inch

Bow Test No 12

JLC 10/10 Acceptable

Notes: Bow Test:

Pin 11 & 12 are required to have less tolerance in the bow test gauge than pin 1 & 12. Both passed the gauge test.

**Astronuclear
Laboratory**

GAMMA INDUSTRIES
QA CERTIFICATION

PIN NUMBER 11

* Sub of 3RL feed material
for slugs of equivalent connectivity

* * Qualification for weld repair
Ref. VR No. 11718

CAPSULE	1		2		3		4	
	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date
LOADING:								
SPACER-TOP	Load / Top Pos	JLC /	Load / Top Pos	JLC /	Load / Top Pos	JLC /	Load / Top Pos	JLC /
SLUG ID/QUAN.	12/9-20	JLC 9/12	4P/4-20	JLC 9/11	4P/3	JLC 9/8	12/11-20	JLC 9/8
SLUG ID/QUAN.	2/9-20	JLC 9/12	2/10-20	JLC 9/11	5/8-20	JLC 9/8	2/11-20	JLC 9/17
SPACER-BOTTOM	10/5-5	JLC 9/7	10/5-5	JLC 9/7	10/5-5	JLC 9/7	10/5-5	JLC 9/7
	Load / Position	JLC 9/7	Load / Position	JLC 9/7	Load / Position	JLC 9/7	Load / Position	JLC 9/7
WELD PARAMETER	FINAL WELD: 30.6 COND.							
I-AMPS	29.5	JLC 9/13	30.5	JLC 9/13	31	JLC 9/13	29	JLC 9/13
V-VOLTS	27	JLC 9/13	20	JLC 9/13	17.5	JLC 9/13	21.5	JLC 9/13
S-SPEED	370° @ 12sec	JLC 9/13	370° @ 12sec	JLC 9/13	370° @ 12sec	JLC 9/13	370° @ 12sec	JLC 9/13
T-TEMP-°F	667°F	JLC 9/13	667°F	JLC 9/13	680°F	JLC 9/13	692°F	JLC 9/13
WELD Q. C.								
VISUAL	Defect notes: 9/13	Good (No Defects)	JLC 9/13	No Defects	JLC 9/13	No Defects	JLC 9/13	No Defects
He LEAK	COILX10 ⁻⁴	JLC 9/13	COILX10 ⁻⁴	JLC 9/13	COILX10 ⁻⁴	JLC 9/13	COILX10 ⁻⁴	JLC 9/13
CONTAMINATION								
INIT. - µCi	0.00175	JLC 10/10	0.00095	JLC 10/10	0.0011	JLC 10/10	0.00068	JLC 10/10
FINAL - µCi	0.00175	JLC 10/10	0.00045	JLC 10/10	0.00011	JLC 10/10	0.00068	JLC 10/10
PRE QUAL. WELD	Review of Defective Cont. as in CRD Vol							
IDENTIFICATION	PQ-11-01-01	JLC 9/11						
I-AMPS	29.5	JLC 9/11						
V-VOLTS	26.5	JLC 9/11						
S-SPEED	370° @ 12sec	JLC 9/11						
T-TEMP-°F	667°F	JLC 9/11						
VISUAL	No Defects	JLC 9/11						
DYE PENETRANT	No Defects	JLC 9/11						
PENETRATION-IN.	0.053" min	JLC 9/11						
POST QUAL. WELD	Review of Defective Cont. as in CRD Vol							
IDENTIFICATION	PQ-11-01-02	JLC 9/13					PQ-11-04-01	JLC 9/13
I-AMPS	29.5	JLC 9/13					28.2	JLC 9/13
V-VOLTS	26.5	JLC 9/13					21.5	JLC 9/13
S-SPEED	370° @ 12sec	JLC 9/13					370° @ 12sec	JLC 9/13
T-TEMP-°F	667°F	JLC 9/13					667°F	JLC 9/13
VISUAL	Good - No Def.	JLC 9/13					Good - No Def.	JLC 9/13
DYE PENETRANT	Good - No Def.	JLC 9/13					Good - No Def.	JLC 9/13
PENETRATION-IN.	0.052" min	JLC 9/13					0.052" min	JLC 9/13
FINAL ACCEPTANCE	Acceptance Test V.W.	JLC 10/10	OT	JLC 10/10	ACCEPT	JLC 10/10	ACCEPT	JLC 10/10

VR 11718 ACCEPTS THE ABOVE D.O.U. (10/10), TQM 10/31/72

GAMMA INDUSTRIES
QA CERTIFICATION
PIN NUMBER 12

CAPSULE	1		2		3		4	
	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date
LOADING:								
SPACER-TOP	load / Top	JLC 9/23	load / Top	JLC 9/27	load / Top	JLC 9/27	load / Top	JLC 9/27
SLUG ID/QUAN.	9P/5-20	JLC 9/26	15/10-20	JLC 9/17	12/12-20	JLC 9/18	10/12-20	JLC 9/15
SLUG ID/QUAN.	11P/3-5	JLC 9/15	11P/3-5	JLC 9/15	11P/3-5	JLC 9/15	11P/3-5	JLC 9/15
SPACER-BOTTOM	load / Pos.	JLC 9/15	load / Pos.	JLC 9/15	load / Pos.	JLC 9/15	load / Pos.	JLC 9/15
WELD PARAMETER			initial weld DEFECTIVE NOTE: V.R.	JLC 9/27				
I-AMPS	29.5	JLC 9/28	32 Amps	JLC 9/27	32.0 Amps	JLC 9/27	30.0	JLC 9/27
V-VOLTS	20	JLC 9/28	18 volts	JLC 9/27	17.5 volts	JLC 9/27	18.5	JLC 9/27
S-SPEED	370°@12sec	JLC 9/28	370°@12sec	JLC 9/27	370°@12sec	JLC 9/27	370°@12sec	JLC 9/27
T-TEMP-°F	684°F	JLC 9/28	675°F	JLC 9/27	675°F	JLC 9/27	680°F	JLC 9/27
WELD Q. C.								
VISUAL	Acceptable	JLC 9/28	Acceptable	JLC 9/27	Acceptable	JLC 9/27	Acceptable	JLC 9/27
He LEAK	<0.1X10 ⁻⁶	JLC 10/2	<0.1X10 ⁻⁶	JLC 10/2	<0.1X10 ⁻⁶	JLC 10/2	<0.1X10 ⁻⁶	JLC 10/2
NTAMINATION								
INIT. - µCi	0.003 µCi	JLC 9/28	0.035 µCi	JLC 9/27	0.005 µCi	JLC 9/27	0.005 µCi	JLC 9/27
FINAL - µCi	0.002 µCi	JLC 10/10	0.011 µCi	JLC 10/10	0.0004 µCi	JLC 10/10	0.005 µCi	JLC 10/10
PRE QUAL. WELD							CAPSULE No 9	JLC 9/26
IDENTIFICATION							Pre Qual	
I-AMPS							30.0 Amps	JLC 9/26
V-VOLTS							19.5 volts	JLC 9/26
S-SPEED							370°@12sec	JLC 9/26
T-TEMP-°F							680°F	JLC 9/26
VISUAL							Accept	JLC 9/26
DYE PENETRANT							Accept	JLC 9/26
PENETRATION-IN.							>0.051" in.	JLC 9/26
POST QUAL. WELD								
IDENTIFICATION								
I-AMPS	28.0 Amps	JLC 9/29	27.0 Amps	JLC 9/27				
V-VOLTS	20 volts	JLC 9/29	23 volts	JLC 9/27				
S-SPEED	370°@12sec	JLC 9/29	370°@12sec	JLC 9/27				
T-TEMP-°F	671°F	JLC 9/29	671°F	JLC 9/27				
VISUAL	Accept	JLC 9/29	Accept	JLC 9/27				
DYE PENETRANT	OT	JLC 9/29	Accept	JLC 9/27				
PENETRATION-IN.	>0.052" in.	JLC 9/29	>0.052" in.	JLC 9/27				
FINAL ACCEPTANCE	Acceptable	JLC 10/10	CONDITIONAL ACCEPTANCE SEE NOTE	JLC 10/10	Acceptable	JLC 10/10	Acceptable	JLC 10/10

VF 11725 ACCEPTS THE ABOVE DEVIATIONS. RQM 10/31/72

FUEL PINS 1 AND 5

FUEL PIN LOADING SCHEDULE

CAPSULE	PIN NUMBER 5				PIN NUMBER 1			
	ACTIVITY - Ci*		SLUG DESIGN		ACTIVITY - Ci*		SLUG DESIGN	
	CAPSULE	SLUG	CLUSTER	POSITION	CAPSULE	SLUG	CLUSTER	POSITION
1 (TOP)	45, 832	23, 650	19	11	45, 962	23, 650	11	4
		18, 060	16	2		18, 140	10	2
		4, 122	12	4		4, 172	9	5
2	44, 742	22, 320	13	4	44, 452	22, 090	1	7
		18, 300	4	1		18, 190	14	7
		4, 172	12	4		4, 172	9	5
3	44, 242	23, 820	7	5	44, 882	23, 850	9	4
		16, 300	19	2		16, 860	18	11
		4, 122	12	4		4, 172	9	5
4 (BOTTOM)	45, 282	22, 040	18	7	45, 302	22, 050	12	8
		19, 120	12	6		19, 080	4	5
		4, 122	12	4		4, 172	9	5
PIN ACTIVITY* - Ci	180, 100				180, 600			

* AS OF 7/19/71

GAMMA INDUSTRIES
QA CERTIFICATION
PINS NUMBER 1 AND 5

<u>1</u>		PIN NUMBER	<u>5</u>	
Init/Date	Value/Status		Value/Status	Init/Date
WELD PARAMETER				
JLC 12/6	41 AMPS	I-AMPS	44.5 AMPS	JLC 12/6
JLC 12/6	20 volts	V-VOLTS	18 volts	JLC 12/6
JLC 12/6	370°@2052	S-SPEED	370°@2052	JLC 12/6
JLC 12/6	671°F	T-TEMP-°F	671°F	JLC 12/6
WELD Q. C.				
JLC 12/6	No defects	VISUAL	No defects	JLC 12/6
JLC 12/6	<0.1X10 ⁻⁶	HE LEAK	<0.1X10 ⁻⁶	JLC 12/6
CONTAMINATION				
INITIAL				
JLC 12/6	<0.0006 Mci	FINAL	<0.003 Mci	JLC 12/6
PRE QUAL. WELD				
IDENTIFICATION				
I-AMPS				
V-VOLTS				
S-SPEED				
T-TEMP-°F				
VISUAL				
DYE PENETRANT				
PENETRATION				
POST QUAL. WELD				
IDENTIFICATION		PRQ-05-01 JLC 12/6		
I-AMPS		42.5 AMPS JLC 12/6		
V-VOLTS		20.5 volts JLC 12/6		
S-SPEED		370°@2052 JLC 12/6		
T-TEMP-°F		649°F JLC 12/6		
VISUAL		Good JLC 12/6		
DYE PENETRANT		No indications JLC 12/6		
PENETRATION		min 0.000" JLC 12/6		
FINAL ACCEPTANCE				

Bow Test			
JLC 12/6	ACCEPT	JLC 12/6	ACCEPT

PIN NO.

1

PIN NO.

5

GAMMA INDUSTRIES
QA CERTIFICATION
PIN NUMBER 1

CAPSULE	1		2		3		4	
	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date
LOADING:								
SPACER-TOP	Loaded	JLC 10/19	Loaded	JLC 10/19	Loaded	JLC 10/19	Loaded	JLC 10/19
SLUG ID/QUAN.	11/4-20	JLC 10/17	11/7-20	JLC 10/17	9/9-20	JLC 10/16	12/8-20	JLC 10/13
SLUG ID/QUAN.	10/2-20	JLC 10/17	10/2-20	JLC 10/17	10/11-20	JLC 10/16	10/5-20	JLC 10/13
SPACER-BOTTOM	9/5-5	JLC 10/13	9/5-5	JLC 10/13	9/5-5	JLC 10/13	9/5-5	JLC 10/13
WELD PARAMETER								
I-AMPS	28.5	JLC 10/19	29.5	JLC 10/19	29.5	JLC 10/19	29.0	JLC 10/19
V-VOLTS	19.5	JLC 10/19	19.0	JLC 10/19	18.5	JLC 10/19	19.5	JLC 10/19
S-SPEED	370°@125cc	JLC 10/19	370°@125cc	JLC 10/19	370°@125cc	JLC 10/19	370°@125cc	JLC 10/19
T-TEMP-°F	684°F	JLC 10/19	684°F	JLC 10/19	671°F	JLC 10/19	688°F	JLC 10/19
WELD Q. C.								
VISUAL	Accept	JLC 10/19	Accept	JLC 10/19	Accept	JLC 10/19	Accept	JLC 10/19
He LEAK	<10 ⁻⁶ Accept	JLC 10/19	<10 ⁻⁶ Accept	JLC 10/19	<10 ⁻⁶ Accept	JLC 10/19	<10 ⁻⁶ Accept	JLC 10/19
CONTAMINATION								
INIT. - µCi								
FINAL - µCi	<.008 µCi	JLC 12/6/72	<.008 µCi	JLC 12/6/72	<.007 µCi	JLC 12/6/72	<.010 µCi	JLC 12/6/72
PRE QUAL. WELD								
IDENTIFICATION	PQ-01-01-01	JLC 10/18						
I-AMPS	30.5	JLC 10/18						
V-VOLTS	17.0	JLC 10/18						
S-SPEED	370°@125cc	JLC 10/18						
T-TEMP-°F	675°F	JLC 10/18						
VISUAL	Accept	JLC 10/18						
DYE PENETRANT	No indication	JLC 10/18						
PENETRATION-IN.	>0.052" min	JLC 10/18						
POST QUAL. WELD								
IDENTIFICATION							PRQ-1-004	
I-AMPS							29.0	JLC 10/19
V-VOLTS							18.5	JLC 10/19
S-SPEED							370°@125cc	JLC 10/19
T-TEMP-°F							675°F	JLC 10/19
VISUAL							Accept	JLC 10/19
DYE PENETRANT							No Indication	JLC 10/19
PENETRATION-IN.							>0.052" min	JLC 10/19
FINAL ACCEPTANCE	Accept	JLC 12/6	Accept	JLC 12/6	Accept	JLC 12/6	Accept	JLC 12/6

GAMMA INDUSTRIES
QA CERTIFICATION
PIN NUMBER 5

* 11/2 used as replacement
for reject 18/4
(14/2 originally scheduled
for Pin No 9)

CAPSULE	1		2		3		4	
	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date
LOADING:								
SPACER-TOP	Loaded / OK	11/1/72	Loaded / OK	11/1/72	Loaded OK	11/2/72	Loaded / OK	10/2/72
SLUG ID/QUAN.	19/11-20	11/1/72	13/4-20	11/1/72	7/3-20	11/2/72	18/7-20	10/31/72
SLUG ID/QUAN.	16/2-20	11/1/72	4/1-20	10/31/72	4/3-20	10/31/72	12/6-20	10/31/72
SPACER-BOTTOM	Loaded / OK	10/31/72	Loaded / OK	10/31/72	Load / OK	10/31/72	load / OK	10/31/72
WELD PARAMETER								
I-AMPS	27.5	JLC 11/7	28 AMPS	JLC 11/7	27.5	JLC 11/7	29 AMPS	JLC 11/7
V-VOLTS	18 volts	JLC 11/7	18 volts	JLC 11/7	18.5	JLC 11/7	17 volts	JLC 11/7
S-SPEED	370° @ 12 sec	JLC 11/7	370° @ 12 sec	JLC 11/7	370° @ 12 sec	JLC 11/7	370° @ 12 sec	JLC 11/7
T-TEMP-°F	680°F	JLC 11/7	680°F	JLC 11/7	680°F	JLC 11/7	675°F	JLC 11/7
WELD Q. C.								
VISUAL	Good no defects	JLC 11/7	Good No Defects	JLC 11/7	Good No Defects	JLC 11/7	Good No Defects	JLC 11/7
Mo LEAK	<0.1 x 10 ⁻⁶	JLC 11/7	<0.1 x 10 ⁻⁶	JLC 11/7	<0.1 x 10 ⁻⁶	JLC 11/7	<0.1 x 10 ⁻⁶	JLC 11/7
CONTAMINATION								
INIT. - µCi								
FINAL - µCi	<0.042 µCi	JLC 12/6	<0.008 µCi	JLC 12/6	<0.038 µCi	JLC 12/6	<0.005 µCi	JLC 12/6
PRE QUAL. WELD								
IDENTIFICATION	PR-05-01-01	JLC 11/6						
I-AMPS	27.5 Amps	JLC 11/6						
V-VOLTS	18 volts	JLC 11/6						
S-SPEED	370° @ 12 sec	JLC 11/6						
T-TEMP-°F	671°F	JLC 11/6						
VISUAL	Good	JLC 11/6						
DYE PENETRANT	No indications	JLC 11/6						
PENETRATION-IN.	>0.051"	JLC 11/6						
POST QUAL. WELD								
IDENTIFICATION							PR-05-04-01	
I-AMPS							27.5	JLC 11/7
V-VOLTS							18.5	JLC 11/7
S-SPEED							370° @ 12 sec	JLC 11/7
T-TEMP-°F							671°F	JLC 11/7
VISUAL							Good	JLC 11/7
DYE PENETRANT							No indications	JLC 11/7
PENETRATION-IN.							>0.051"	JLC 11/7
FINAL ACCEPTANCE	ACCEPT	JLC 12/6	ACCEPT	JLC 12/6	ACCEPT	JLC 12/6	ACCEPT	JLC 12/6

FUEL PINS 2 AND 7

FUEL PIN LOADING SCHEDULE

CAPSULE	PIN NUMBER 7				PIN NUMBER 2			
	ACTIVITY-Ci*		SLUG DESIGN		ACTIVITY - Ci*		SLUG DESIGN	
	CAPSULE	SLUG	CLUSTER	POSITION	CAPSULE	SLUG	CLUSTER	POSITION
1 (TOP)	46, 200	24, 110	17	4	46, 239	31, 900	5	3
		15, 110	14	10		10, 440	17	3
		6, 980	19	10		3, 899	17	6
2	45, 320	24, 440	15	4	45, 559	30, 300	2	11
		13, 900	12	12		11, 360	7	12
		6, 980	19	10		3, 899	17	6
3	45, 060	22, 300	2	12	45, 279	30, 200	5	11
		15, 780	13	2		11, 180	9	3
		6, 980	19	10		3, 899	17	6
4 (BOTTOM)	45, 590	24, 060	7	9	45, 672	32, 700	3	11
		14, 550	15	4		9, 073	19	1
		6, 980	19	10		3, 899	17	6
PIN ACTIVITY*-Ci	182, 170				182, 749			

* AS OF 7/19/71

GAMMA INDUSTRIES
QA CERTIFICATION
PINS NUMBER 2 AND 7

<u>2</u>		PIN NUMBER	<u>7</u>	
Init/Date	Value/Status		Value/Status	Init/Date
WELD PARAMETER				
JLC 2/1	43.0 amps	I-AMPS	42.0 amps	JLC 2/2
JLC 2/1	18.5 volts	V-VOLTS	19.0 volts	JLC 2/2
JLC 2/1	370°@20sec	S-SPEED	370°@20sec	JLC 2/2
JLC 2/1	684°F	T-TEMP-°F		
WELD Q. C				
JLC 2/1	Good/No defect	VISUAL	Good No defect	JLC 2/2
JLC 2/1	<0.1x10 ⁻⁸ cc	He LEAK	<0.1x10 ⁻⁸ cc	JLC 2/2
CONTAMINATION				
		INITIAL		
JLC 2/1	0.0005% cc	FINAL	0.00008% cc	JLC 2/2
PRE QUAL WELD				
		IDENTIFICATION		
JLC 2/1	43.0	I-AMPS		
JLC 2/2	16.5	V-VOLTS		
JLC 2/2	370°@20sec	S-SPEED		
JLC 2/1	692°F	T-TEMP-°F		
JLC 2/1	No defect	VISUAL		
JLC 2/1	No defect	DYE PENETRANT		
JLC 2/1	>0.060"m	PENETRATION		
POST QUAL. WELD				
		IDENTIFICATION	PRQ-07-01	
		I-AMPS	42.0 AMPS	JLC 2/2
		V-VOLTS	19.0 volts	JLC 2/2
		S-SPEED	370°@20sec	JLC 2/2
		T-TEMP°F	682°F	JLC 2/2
		VISUAL	No defects	JLC 2/2
		DYE PENETRANT	No defect	JLC 2/2
		PENETRATION	>0.060"m	JLC 2/2
Bow TEST			Bow TEST	
ACCEPT	JLC 2/2		ACCEPT	JLC 2/2
JLC 2/2	ACCEPT	FINAL ACCEPTANCE	ACCEPT	JLC 2/2

⊗ Note appropriate V.R.'s
11859
11858

⊗ G.E. [Signature]
Feb 2 1973

GAMMA INDUSTRIES
QA CERTIFICATION
PIN NUMBER 2

CAPSULE	1		2		3		4	
	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date
LOADING:								
SPACER-TOP	Loaded /OK	JLC 1/23	Loaded /OK	JLC 1/23	Loaded /OK	JLC 1/23	Loaded /OK	JLC 1/23
SLUG ID/QUAN.	5/3-20	1/24	2/11-20	1/24	5/11-20	1/23	3/11-20	1/23
SLUG ID/QUAN.	17/6-5	1/23	17/6-5	1/22	17/6-5	1/23	17/6-5	1/23
SPACER-BOTTOM	Loaded /OK	JLC 1/22	Loaded /OK	JLC 1/22	Loaded /OK	JLC 1/22	Loaded /OK	JLC 1/22
WELD PARAMETER								
I-AMPS	28.0 AMPS	JLC 1/25	28.5 AMPS	JLC 1/25	30.0 AMPS	JLC 1/25	30.0 AMPS	JLC 1/25
V-VOLTS	21.0 volts	JLC 1/25	18.0 volts	JLC 1/25	20.0 volts	JLC 1/25	18.5 volts	JLC 1/25
S-SPEED	370°@12sec	JLC 1/25	370°@12sec	JLC 1/25	370°@12sec	JLC 1/25	370°@12sec	JLC 1/25
T-TEMP-°F	680°@12sec	JLC 1/25	675°@12sec	JLC 1/25	680°@12sec	JLC 1/25	680°@12sec	JLC 1/25
WELD Q. C.								
VISUAL	No defects	JLC 1/25	No defects	JLC 1/25	No defects	JLC 1/25	No defects	JLC 1/25
He LEAK	<0.1X10 ⁻⁶	JLC 1/25	<0.1X10 ⁻⁶	JLC 1/25	<0.1X10 ⁻⁶	JLC 1/25	<0.1X10 ⁻⁶	JLC 1/25
CONTAMINATION								
INIT. - µCi								
FINAL - µCi	0.007 µCi	JLC 2/1	0.005 µCi	JLC 2/1	0.009 µCi	JLC 2/1	0.006 µCi	JLC 2/1
PRE QUAL. WELD								
IDENTIFICATION	PRQ-02-01-01	JLC 1/25						
I-AMPS	27.5 AMPS	JLC 1/25						
V-VOLTS	20.0 volts	JLC 1/25						
S-SPEED	370°@12sec	JLC 1/25						
T-TEMP-°F	675° F	JLC 1/25						
VISUAL	No defects	JLC 1/25						
DYE PENETRANT	No defects	JLC 1/23						
PENETRATION-IN.	>0.051"m	JLC 1/25						
POST QUAL. WELD								
IDENTIFICATION							PRQ-02-04-01	
I-AMPS							27.0 AMPS	JLC 1/25
V-VOLTS							23 volts	JLC 1/25
S-SPEED							370°@12sec	JLC 1/25
T-TEMP-°F							662° F	JLC 1/25
VISUAL							No defects	JLC 1/25
DYE PENETRANT							No defects	JLC 1/25
PENETRATION-IN.							>0.051"m	JLC 1/25
FINAL ACCEPTANCE	ACCEPT	JLC 2/2	ACCEPT	JLC 2/2	ACCEPT	JLC 2/2	ACCEPT	JLC 2/2

(U) G.E. Kelly 2-2-73

GAMMA INDUSTRIES
QA CERTIFICATION
PIN NUMBER 7

*₁ WELDER BREAK-DOWN AFTER
WELD NO 2. - See attached V.R.

*₂ Weld defect see weld chart,
Note weld repair chart - unsuccessful
thereby note V.R.

CAPSULE	1		2		3		4	
	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date
LOADING:								
SPACER-TOP	Loaded OK	JLC 1/30	Loaded	JLC 1/30	Loaded	JLC 1/30	Loaded	JLC 1/30
SLUG ID/QUAN.	17/4-20	JLC 1/30	15/4-20	JLC 1/29	4/12-20	JLC 1/31	7/4-20	JLC 1/29
SLUG ID/QUAN.	19/10-20	JLC 1/30	12/12-20	JLC 1/29	13/12-20	JLC 1/31	15/4-20	JLC 1/29
SPACER-BOTTOM	19/10-5	JLC 1/29	19/10-5	JLC 1/29	19/10-5	JLC 1/29	19/10-5	JLC 1/29
WELD PARAMETER								
I-AMPS	30 Amps	JLC 1/30	29.5 Amps	JLC 1/30	30.0 Amps	JLC 1/31	32.0 Amps	JLC 1/31
V-VOLTS	20 volts	JLC 1/30	19.5 volts	JLC 1/30	22.5 volts	JLC 1/31	19.5 volts	JLC 1/31
S-SPEED	370°@12sec	JLC 1/30	370°@12sec	JLC 1/30	370°@12sec	JLC 1/31	370°@12sec	JLC 1/31
T-TEMP-°F	667° F	JLC 1/30	659° F	JLC 1/30	675° F	JLC 1/31	675° F	JLC 1/31
WELD Q. C.								
VISUAL	No defects	JLC 1/30	No defects	JLC 1/30	Defect * ₂	JLC 1/31	No defects	JLC 1/31
He LEAK	<0.1x10 ⁻⁶	JLC 1/30	<0.1x10 ⁻⁶	JLC 1/30	<0.1x10 ⁻⁶	JLC 1/31	<0.1x10 ⁻⁶	JLC 1/31
CONTAMINATION								
INIT. - µCi								
FINAL - µCi	0.0037%	JLC 2/2	0.0024%	JLC 2/2	0.00039%	JLC 2/2	0.0004%	JLC 2/2
PRE QUAL. WELD								
IDENTIFICATION	PG-07-01-01				PG-07-03-01			
I-AMPS	30.0 Amps	1/30 JLC			30.0 Amps	JLC 1/31		
V-VOLTS	29.2 volts	1/30 JLC			18.0 volts	JLC 1/31		
S-SPEED	370°@12sec	1/30 JLC			370°@12sec	JLC 1/31		
T-TEMP-°F	680° F	1/30 JLC			675° F	JLC 1/31		
VISUAL	No defects	1/30 JLC			No defects	JLC 1/31		
DYE PENETRANT	No defects	1/30 JLC			No defects	JLC 1/31		
PENETRATION-IN.	>0.052 min.	1/30 JLC			>0.051 min	JLC 1/31		
POST QUAL. WELD								
IDENTIFICATION							PIRG-07-04-01	
I-AMPS							30.0 Amps	JLC 2/1
V-VOLTS							19.5 volts	JLC 2/1
S-SPEED							370°@12sec	JLC 2/1
T-TEMP-°F							675° F	JLC 2/1
VISUAL							No defects	JLC 2/1
DYE PENETRANT							No indication	JLC 2/1
PENETRATION-IN.							>0.051 min	JLC 2/1
FINAL ACCEPTANCE	Accept	JLC 2/2	Accept	JLC 2/2	Accept with V.R.	JLC 2/2	Accept	JLC 2/2

(W) J.E. Kelly Feb 3, 1973

FUEL PINS 4 AND 8

FUEL PIN LOADING SCHEDULE

CAPSULE	PIN NUMBER 8				PIN NUMBER 4			
	ACTIVITY - Ci*		SLUG DESIGN		ACTIVITY - Ci*		SLUG DESIGN	
	CAPSULE	SLUG	CLUSTER	POSITION	CAPSULE	SLUG	CLUSTER	POSITION
1 (TOP)	44,387	22,400	5	2	43,344	24,470	7	6
		16,380	12	11		13,224	17	7
		5,607	1	9		5,650	6	12
2	44,417	23,200	6	2	45,100	24,830	7	7
		15,610	11	6		14,620	11	9
		5,607	1	9		5,650	6	12
3	44,227	23,000	3	2	45,550	24,750	7	8
		15,620	11	7		15,150	11	5
		5,607	1	9		5,650	6	2
4 (BOTTOM)	44,097	22,900	2	2	48,307	23,970	1	8
		15,590	8	4		18,687	2	12
		5,607	1	9		5,650	6	12
PIN ACTIVITY* - Ci	177,128				182,301			

* AS OF 7/19/71

GAMMA INDUSTRIES
QA CERTIFICATION
PINS NUMBER 4 AND 8

<u>4</u>		PIN NUMBER	<u>8</u>	
Init/Date	Value/Status		Value/Status	Init/Date
		WELD PARAMETER		
JLC 12/5	42.0 AMPS	I-AMPS	40.0 AMPS	JLC 12/6
JLC 12/5	19 volts	V-VOLTS	21 volts	JLC 12/6
JLC 12/5	370° @ 20mm	S-SPEED	370° @ 20mm	JLC 12/6
JLC 12/5	688°F	T-TEMP-°F	680°F	JLC 12/6
		WELD Q. C.		
JLC 12/5	No defects	VISUAL	No defects	JLC 12/6
JLC 12/5	<0.1 x 10 ⁻⁶	He LEAK	<0.1 x 10 ⁻⁶	JLC 12/6
		CONTAMINATION		
		INITIAL		
JLC 12/5	0.0001 A/ci	FINAL	0.00002 A/ci	JLC 12/6
		PRE QUAL. WELD		
PD-04-01		IDENTIFICATION		
JLC 12/5	41.0 AMPS	I-AMPS		
JLC 12/5	20 volts	V-VOLTS		
JLC 12/5	370° @ 20mm	S-SPEED		
JLC 12/5	689°F	T-TEMP-°F		
JLC 12/5	No defects	VISUAL		
JLC 12/5	No indication	DYE PENETRANT		
JLC 12/5	min 0.060"	PENETRATION		
		POST QUAL. WELD		
		IDENTIFICATION	SEE POST QVAL	
		I-AMPS	WELD FOR DIMS	
		V-VOLTS	NWS 105	
		S-SPEED	PRG-05-01	
		T-TEMP-°F		
		VISUAL		
		DYE PENETRANT		
		PENETRATION		
Bow TEST			Bow TEST	
ACCEPT	JLC 12/5		ACCEPT	JLC 12/5
JLC 12/5	Accept	FINAL ACCEPTANCE	Accept	JLC 12/6

PIN NO.

4

PIN NO.

8

GAMMA INDUSTRIES
QA CERTIFICATION
PIN NUMBER 4

CAPSULE	1		2		3		4	
	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date
LOADING:								
SPACER-TOP	Loaded OK	12/1 JLC	Loaded OK	JLC 12/1	Loaded OK	JLC 12/1	Loaded OK	JLC 12/1
SLUG ID/QUAN.	7/6-20	11/29 JLC	7/7-20	11/28	7/18-20	11/28	1/8-20	11/30/72
SLUG ID/QUAN.	6/12-20	11/29 JLC	6/12-20	11/28	6/12-20	11/28	6/12-20	11/29
SPACER-BOTTOM	Loaded OK	JLC 11/27	Loaded OK	JLC 11/27	Loaded OK	11/27	Loaded OK	11/27
WELD PARAMETER								
I-AMPS	31 AMPS	12/1 JLC	32.5 AMPS	12/1/72 JLC	34 AMPS	12/1 JLC	32.5 A	12/1 JLC
V-VOLTS	19.5 VOLTS	12/1 JLC	18.5 VOLTS	12/1 JLC	19 VOLTS	12/1 JLC	18.5 V.	12/1 JLC
S-SPEED	370°@1250	12/1 JLC	370°@1250	12/1 JLC	370°@1250	12/1 JLC	370°@1250	12/1 JLC
T-TEMP-°F	658°F	12/1 JLC	662°F	12/1 JLC	662°F	12/1 JLC	675°F	12/1 JLC
WELD Q. C.								
VISUAL	Good No Def.	12/1 JLC	Good OK	12/1 JLC	Good No Def.	12/1 JLC	Good No Def.	12/1 JLC
He LEAK	<0.1X10 ⁻⁶	12/1 JLC	<0.1X10 ⁻⁶	12/1 JLC	<0.1X10 ⁻⁶	12/1 JLC	<0.1X10 ⁻⁶	12/1 JLC
CONTAMINATION								
INIT. - µCi								
FINAL - µCi	<0.005 µCi	JLC 12/1	<0.003 µCi	JLC 12/1	<0.005 µCi	JLC 12/1	<0.05 µCi	JLC 12/1
PRE QUAL. WELD								
IDENTIFICATION	PR0-09-01-01	11/31 JLC						
I-AMPS	32 A.	11/31 JLC						
V-VOLTS	19 V.	11/31 JLC						
S-SPEED	370°@125	11/31 JLC						
T-TEMP-°F	675°F	11/31 JLC						
VISUAL	No defects	OK JLC 11/31						
DYE PENETRANT	No indications	OK JLC 11/31						
PENETRATION-IN.	>0.051" min	JLC 11/31						
POST QUAL. WELD								
IDENTIFICATION							PR0-09-04-01	12/1 JLC
I-AMPS							30 A	12/1 JLC
V-VOLTS							21 V	12/1 JLC
S-SPEED							370°@1250	12/1 JLC
T-TEMP-°F							675°F	12/1 JLC
VISUAL							No defects	12/1 JLC
DYE PENETRANT							No indications	12/1 JLC
PENETRATION-IN.							>0.051" min	12/1 JLC
FINAL ACCEPTANCE	ACCEPTABLE	JLC 12/1	ACCEPT	JLC 12/1	ACCEPT	JLC 12/1	ACCEPT	JLC 12/1

GAMMA INDUSTRIES
QA CERTIFICATION
PIN NUMBER 8

CAPSULE	1		2		3		4	
	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date	Value/Status	Init/Date
LOADING:								
SPACER-TOP	Loaded 1	11/16 JLC	Loaded	11/16 JLC	Loaded	11/16 JLC	Loaded	11/16 JLC
SLUG ID/QUAN.	3/2-20	11/16	6/2-20	11/15	3/2-20	11/13	2/2-20	11/10
SLUG ID/QUAN.	1/9-5	11/10	1/9-5	11/10	1/9-5	11/10	1/9-5	11/10
SPACER-BOTTOM	Loaded	11/10 JLC	Loaded	11/10 JLC	Loaded	11/10 JLC	Loaded	11/10 JLC
WELD PARAMETER								
I-AMPS	28.0 AMPS	11/16 JLC	26.0 AMPS	11/16 JLC	29 AMPS	11/16 JLC	28 AMPS	11/16 JLC
V-VOLTS	18 volts	11/16 JLC	21 volts	11/16 JLC	19 volts	11/16 JLC	20 volts	11/16 JLC
S-SPEED	370° @ 12 sec	11/16 JLC	370° @ 12 sec	11/16 JLC	370° @ 12 sec	11/16 JLC	370° @ 12 sec	11/16 JLC
T-TEMP-°F	680°F	11/16 JLC	689°F	11/16 JLC	671°F	11/16 JLC	671°F	11/16 JLC
WELD Q. C.								
VISUAL	No defects	JLC 11/10	No defects	JLC 11/10	No defects	JLC 11/10	No defects	JLC 11/10
Mo LEAK	<0.1X10 ⁻⁶	JLC 11/16	<0.1X10 ⁻⁶	JLC 11/16	<0.1X10 ⁻⁶	JLC 11/16	<0.1X10 ⁻⁶	JLC 11/16
CONTAMINATION								
INIT. - µCi								
FINAL - µCi	0.001 µCi	12/6 JLC	0.002 µCi	12/6 JLC	0.0002 µCi	12/6 JLC	0.0002 µCi	12/6 JLC
PRE QUAL. WELD								
IDENTIFICATION	06-08-01-01	11/15 JLC						
I-AMPS	28.0	11/15 JLC						
V-VOLTS	19.0	11/15 JLC						
S-SPEED	370° @ 12 sec	11/15 JLC						
T-TEMP-°F	688°F	11/15 JLC						
VISUAL	No defects	11/15 JLC						
DYE PENETRANT	No indication	11/15 JLC						
PENETRATION-IN.	>0.051 mm	11/15 JLC						
POST QUAL. WELD								
IDENTIFICATION							020-08-04-01	
I-AMPS							29.0	11/16 JLC
V-VOLTS							20.0	11/16 JLC
S-SPEED							370° @ 12 sec	11/16 JLC
T-TEMP-°F							680°F	11/16 JLC
VISUAL							No defects	11/16 JLC
DYE PENETRANT							No indication	11/16 JLC
PENETRATION-IN.							>0.052 mm	11/16 JLC
FINAL ACCEPTANCE	ACCEPT	JLC 12/6	ACCEPT	JLC 12/6	ACCEPT	JLC 12/6	ACCEPT	JLC 12/6

APPENDIX B

HEAT SOURCE ASSEMBLY ROUTE CARDS

Heat Source Assembly Route Cards 1003 and 1004 are presented on the following pages. The route cards have been annotated to reflect changes implemented during heat source assembly. Notes applicable to assembly operations at AECL and the procedure used for heat source disassembly in preparation for shipment to AECL are presented.

THERMOELECTRIC ASSEMBLY ROUTE CARD

Assembly Description		Core/Heat Pipe Assembly		S/N	CO-60	Drawing No./Rev.		940J461A	Route Card No.		1003
Process Engineer		Date		Design Engineer		Date		Ass'y. Engineer		Date	
Op. No.	Operation Description						Ref. Doc.	Rev.	Oper. Sign-off	Date	
010	Position and shim the heat source I beam base structure on the concrete pad and establish proper top surface elevation. <i>Make sure top surface is level</i>						940J471	B	<i>[Signature]</i>	1/15/73	
020	Turn the base assembly (940J347GO1) upside down and remove the base ring assembly and insulation (It. 19).								<i>[Signature]</i>	1/12/73	
030	Install thermocouple T137 (It. 22) as shown on the assembly drawing. Groove the insulation (It. 12) as required to clear the thermocouple. <i>TC #78</i>						940J347		<i>[Signature]</i>	2/1/73 1/11/73	
040	Check the electrical resistance of ¹³⁷ T136 and record below. <i>T137 1.11.52</i>								<i>[Signature]</i>	2/1/73 1/11/73	
050	Reassemble the base assembly (940J347GO1)								<i>[Signature]</i>	1/16/73	
060	Position the base assembly (940J347GO1) on the I-beam base structure. Note: stringers are at $\theta = 180^\circ$								<i>[Signature]</i>	2/1/73	
070	Position the base plates (Its. 18 & 19) on the base assembly top up. Note: Check tie-bolt hole pattern.								<i>[Signature]</i>	2/2/73	

Drawing No./Rev.		Route Card No.			
940J461		1003			
Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
080	Install the guide pins (lt. 17) into the base plates (lts. 18 & 19) as shown on the assembly drawing. <i>Pin #1 in 940J347 H03</i> <i>" #2 " 940J347 H04</i>			<i>g/n</i>	<i>2/2/73</i>
090	Install thermocouple T136 (lt. 22) as shown on the assembly drawing. Check the electrical resistance and record below. <i>#84</i> <i>T136 #84 140Ω</i>			<i>g/n</i>	<i>2-2-73</i>
100	Determine shield segment stack height as required by <i>17 41.794</i>			<i>g/n</i>	<i>2/2/73</i>
110	Install bulk insulation (lt. 12) on base plates <i>Do after 170</i>			<i>JWS</i>	<i>2 5 73</i>
120	With the installed core assembly lifting fixture, position the core assembly over the base plates.			<i>JWS</i>	<i>2/6/73</i>
130	Using the guide pins and base plate stringers to orient the core assembly lower the core assembly onto the base plates. Shim the core assembly to establish perpendicularity of extensions. See <i>16</i>			<i>JWS</i>	<i>2/6/73</i>
140	Bolt the flange of the core assembly to the base plates using cap screws (lt. 27) and never-seez compound (lt. 30)			<i>JWS</i>	<i>2/6/73</i>
150	Torque the cap screws as shown on the assembly drawing.			<i>JWS</i>	<i>2/6/73</i>

Drawing No./Rev. 940J461		Route Card No. 1003			
Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
160	Remove the guide pins (lt. 17) and the core assembly lifting fixture.			JWS	2/6/73
170	Remove temporary fixturing tying lt. 6 to core assembly.			JWS	2/6/73
171	<i>Install bulk insulation on base flange</i>				
172	<i>Install insulation (940J334 H23, H34, H35, and H36) around inlet & outlet pipes as indicated</i>			JWS	2/6/73
180	Install handling fixture 948C054 HO1 and HO2 to the conical shield (lt. 5). Alternate the handling fixture components around the shield (i.e. HO1-HO2-HO1, etc)				
190	Raise the shield into position over the core assembly. The one (1) inch clearance holes in the shield must line up with the taped holes in the base assembly. Also the lower slots in the shield must line up with the vertical grooves in the outer core.			JWS	2/6/73
200	Lower the shield onto the core assembly.			JWS	2/6/73
210	Shim as required per Note 17 of the assembly drawing to establish .030 clearance between lt. 5 and the stacked shields; <i>then lower in place. Make sure shield is centered and level.</i>			JWS	2/7/73
220	Scribe a reference mark to orient shield with the core assembly. Lift the shield off of the core assembly.			JWS	2/7/73
230	<i>Install insulation on lead pipes in area shown on assembly drawing. Use high temperature glove tape instead of wire to hold insulation in place</i>			JWS	3/7/73

Drawing No./Rev.		Route Card No.			
940J461		1003			
Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
230	Suspend the shield to a height that will allow installation of the upper heat pipes and handling fixture 982D234. See note 18 of the assembly drawing.				2-8-73
240	Install the instrumented heat pipes (Its. 3) as follows: <i>upper</i> <i>them into place between the PV & the forward shield</i>				
240-1	Install insulation (Its. 21 and 29) on heat pipes in the areas shown on the assembly drawings. Secure with wire (It. 20).				
240-1	Install pads (Its. 8, 9, 10, or 11) as shown on the assembly drawing.				
240-2	Install and temporarily secure, three of the upper heat pipes (even numbers) into the shield about 120° apart.				
240-3	Install the handling fixture to the pipes just below the shield, see Note 18 of the assembly drawing.				
240-4	Install and secure the remaining upper heat pipes.				
240-5	Raise the position the shield/heat pipe assembly over the core assy.				
240-6	Align the shield with the core assembly reference mark and carefully lower the shield/heat pipe assembly into place on the core assembly.				
240-7	Remove the "U" bolt from the Number 2 heat pipe and position the adjacent lower heat pipe (odd number) in the core slots.				
240-8	Install the pair of heat pipes using the applicable pads (Its. 8, 9, 10, or 11) and cap screws (It. 25) as shown on the assy. drawing. See Notes 2, 19 and 21. Note: The heat pipes should be located at the bottom of the slots in It. 5.				
240-9	Progressively install the remaining heat pipes using special pads (Its. 9 and 11) at thermocouple locations as shown on the assembly drawings. <i>Correct</i>				

USED TAPE INSTEAD OF WIRE 1720

W2 2/8/73

W5 2/7/73

W2 - 2/8/73

Drawing No./Rev.		Route Card No.									
940J461		1003									
Op. No.	Operation Description	Ref. Doc.	Rev. Oper. Sign-off Date								
250	240-10 Torque all cap screws to the valve shown on the assembly drawing. <i>120 in - lbs</i>		<i>afz - 2/9/73</i>								
	Install the packing glands and thermocouples into the core assembly as follows:										
	250-1 Remove the packing gland nut and seals from the packing glands (It. 23).		<i>afz - 2/9/73</i>								
	250-2 Install the packing gland bodies into the designated threaded holes in the outer core.		<i>afz - 2/9/73</i>								
	250-3 Torque the packing gland bodies.		<i>afz - 2/9/73</i>								
	250-4 Reinstall the packing gland seals and nuts. Thread the nuts on finger tight. <i>T33 not done. Needs new fitting</i>										
	250-5 Identify and install a thermocouple (It. 22) into each of the packing glands. Assure that the thermocouple ends are bottomed in the hole. <i>T33 not done</i>		<i>afz/MH - 2/19/73</i>								
250-6 Torque the packing gland nuts to 78 in lbs. <i>T33 not done</i>		<i>afz/MH - 2/19/73</i>									
250-7 Check the electrical resistance of the thermocouples installed and record below:		<i>afz/MH - 2/19/73</i>									
	<table> <tr> <td>70 T30 <u>130</u></td> <td>74 T34 <u>130</u></td> </tr> <tr> <td>71 T31 <u>130</u></td> <td>75 T35 <u>130</u></td> </tr> <tr> <td>72 T32 <u>130</u></td> <td>76 T36 <u>130</u></td> </tr> <tr> <td>73 T33 <u>130</u></td> <td>77 T37 <u>130</u></td> </tr> </table>	70 T30 <u>130</u>	74 T34 <u>130</u>	71 T31 <u>130</u>	75 T35 <u>130</u>	72 T32 <u>130</u>	76 T36 <u>130</u>	73 T33 <u>130</u>	77 T37 <u>130</u>		
70 T30 <u>130</u>	74 T34 <u>130</u>										
71 T31 <u>130</u>	75 T35 <u>130</u>										
72 T32 <u>130</u>	76 T36 <u>130</u>										
73 T33 <u>130</u>	77 T37 <u>130</u>										
260	Install the three (3) spring loaded thermocouple assemblies, T51, T139 and T140 as follows:										

Drawing No./Rev.		Route Card No.			
940J461		1003			
Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
260-1	Remove the packing gland bodies from the thermocouple assemblies (It. 28).			AF-2/MH	2/13/73
260-2	Install the packing gland bodies into the designated threaded holes in the shield (It. 6).			AF-2/MH	2/14/73
260-3	Torque Torque the packing gland bodies the way to torque			AF-2/MH	2/13/73
260-4	Identify and install a thermocouple into each of the packing gland bodies.			AF-2/MH	2/13/73
260-5	Torque the packing gland nuts to 78 in. lbs. the way to torque			AF-2/MH	2/12/73
260-6	Check the electrical resistance of the thermocouples and record below: T 51 <u>37</u> T139 <u>37</u> T140 <u>37</u>			AF-2/MH	2/12/73
270	Identify and install the three thermocouples (T 52, T53 and T54) located at the extension cavities. <i>Notes: Do after installing top insulation (Route Card 1004, Op. # 170-171-172-173-174-175-176-177)</i>				
280	Check the electrical resistance of the thermocouples and record below. T52 _____ T53 _____ T54 _____				
290	Identify and install the four(4) thermocouples (T55, T56, T57 and T58) located on the lower pressure vessel head. See Table 2 of the assembly drawing.			AF-2	2/12/73
300	Check the electrical resistance of the thermocouples and record below. T 55 <u>70</u> T 56 <u>70</u> T57 <u>60</u> T 58 <u>60</u> 27.00 27.00 21.90 21.90 47° 167° 47° 167°			AF-2	2/12/73

Drawing No./Rev. 940J461		Route Card No. 1003			
Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
310	Identify and install T38 located on the base assembly. <i>complete of side shield installation. See RC #1004, Op. No. 381</i>				
320	Check the electrical resistance of the thermocouple and record below T 38 _____ <i>see RC #1004, Op. No. 382</i>				
330	Identify and install the three (3) thermocouples located on the outer core O.D. (T133, T134 and T135) see Table 2 of the assembly drawing.			<i>2/15</i>	<i>- 2/14/73</i>
340	Check the electrical resistance of the thermocouples and record below. <div style="display: flex; justify-content: space-around;"> <div>T 133 <u>40.12</u> <i>20</i> $Z = 40.12$ $E = 53^\circ$ <i>20</i></div> <div>T 134 <u>40.12</u> <i>95</i> 173° $17+18$</div> <div>T 135 <u>40.12</u> <i>20</i> 293° $294-30$</div> </div>			<i>2/15</i>	<i>- 2/14/73</i>
350	Route all thermocouple leads along the core assembly and exit through the top slots of the shield towards the $\theta = 0^\circ$ reference mark (or outlet side) of the core assembly. See note <u>20</u> of the assembly drawing.			<i>2/15</i>	<i>- 2/14/73</i>
360	Check the electrical resistance of all thermocouples installed. Record below:				

Drawing No./Rev.		Route Card No.			
940J461		1003			
Op.No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
70T30	125	52 T74	130	33 T111	130
71T31	135	47T75	135	19 T112	135
72T32	130	46T76	130	7 T113	135
73T33	130	31 T77	130	28T114	130
74T34	130	48 T78	130	4T115	135
75T35	135	35 T79	135	37T116	135
76T36	140	38T80	130	6 T117	135
77T37	140	68T81	130	22T118	130
T38		65T82	135	11 T119	130
87T48	58	54T83	135	29 T120	130
88T49	55	59T84	135	14T121	130
89T50	55	62T85	135	58T122	140
51T51	35 *	43T89	135	30 T123	130
T52	30	34T90	130	27T124	130
T53		49T91	135	2 T125	130
T54		21 T92	135	26T126	130
99T55	47 61	20 T93	130	3 T127	135
100T56	77	15 T94	130	24T128	135
98T57	65	9 T95	130	12T129	140
97T58	65	17 T96	130	96T133	55
T59		42T97	130	94T134	54
60T61	140	64T98	130	95T135	55
59T62	135	39T99	135	84T136	130
57T63	140	25T100	130	78T137	130
64T64	135	10 T101	135	T138	
61T65	140	23T102	135	139T139	33
62T66	135	8 T103	135	140T140	34
66T67	140	36T104	135	T141	
66T68	130	1 T105	130		
79T69	140	18T106	135		
67T70	135	5 T107	135		
51T71	130	16T108	130		
55T72	140	13T109	130		
40T73	130	53T110	135		

* Needs 20-gauge extension wire

* Needs 20-gauge extension hose

Assembly Description		Assembly, Co 60 Heat Source		S/N CO 60	Drawing No./Rev. 940J335-A		Route Card No. 1004	
Process Engineer		Date		Design Engineer		Date		Ass'y. Engineer
Op. No.	Operation Description					Ref. Doc.	Rev.	Oper. Sign-off Date
010	Install the shield (lt. 7) as follows:							
010- 101	Install the handling fixtures (914E945G01) as shown on the layout 914E955. Torque to 225 ft lbs 150							2/19/73
010- 11	Install an "ACME" drill bushing into each of the .875 diameter holes in the handling fixtures. Secure the bushings with the supplied No. 4 lock screws.							2/19/73
010- 103	Using the drill bushing as a guide, drill a .625" dia. hole through the bushing and into the shield 3 inches deep as measured from the outer surface of the drill bushing (depth in shield is 1 inch) Total two (2) holes. Blow out all chips. 4							2/19/73
010-4	Insert and drive in a .625 dia x 3.50 lg spirol pin into each of the 4 drilled holes.							2/19/73
010-5	Using the handling fixture (914E948) and a fork lift, place the shield into position on the base structure as shown on the heat source assy drawing. NOTE: The shield segments join at $\theta = 0^\circ$ and $\theta = 180^\circ$							2/19/73
010-6	Assure that the one (1) inch clearance holes in the shield line up with the taped holes in the base. A tie rod (lt. 13) could be used as gauge for checking hole alignment.							2/19/73

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Drawing No./Rev.		Route Card No.	
940J335 A		1004	
Op. No.	Operation Description	Ref. Doc.	Rev. Oper. Sign-off Date
	010-7 Remove the handling fixture from the shield (lt. 7). Do not remove the spirol pins. Roll pins will stay in fixture		2/MH/JS/IE - 2/19/73
	010-8 Install a setscrew (lt. 46) into each of the eight (8) taped holes in the shield as shown on the heat source assembly drawing. See note 12		2/IE - 2/19/73
020	Install the shield (lt. 8) as follows:		
	020-1 Install the handling fixtures (914E945G01) as shown on the layout 914E955. Torque to 2700 2800 in lbs. 150 ft-lbs.		2/MH/JS/IE - 2/19/73
	020-2 Install an "ACME" drill bushing into each of the two .875 dia. holes in the handling fixtures. Secure the bushings with the supplied No. 4 lock screws.		2/MH/IE - 2/13/73
	020-3 Using the drill bushing as a guide, drill a .625" dia. hole through the bushing and into the shield 3 inches deep as measured from the outer surface of the drill bushing. Total two 4 holes. Blow out all chips.		2/MH/IE - 2/13/73
	020-4 Insert and drive in a .625 dia. x 3.50 lg spirol pin into each of the drilled holes.		2/MH/JS/IE - 2/19/73
	020-5 Using the handling fixture (914E948) and a fork lift, place the shield into position on the core assembly as shown on the heat source assembly drawing.		2/MH/JS/IE - 2/19/73
	020-6 Assure that the one (1) inch clearance holes in the shield line up with the taped holes in the base. A tie rod (lt. 13) could be used as gauge for checking hole alignment.		2/MH/JS/IE - 2/19/73

Drawing No./Rev. 940J335 A		Route Card No. 1004			
Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
	020-7 Remove the handling fixture from the shield (lt. 8). Do not remove the spirol pins.			<i>EP/MH/JS/JE</i>	<i>2/19/73</i>
	020-8 Install a setscrew (lt. 46) into each of the eight (8) taped holes in the shield as shown on the heat source assembly drawing. See Note 12.			<i>EP/MH/JS/JE</i>	<i>2/19/73</i>
<i>021</i>	<i>Justified link insulation around heat pipe receiver</i>			<i>EP/MH/JS/JE</i>	<i>2/19/73</i>
030	Install the shield (lt. 9) as follows:			<i>EP/MH/JS/JE</i>	<i>2/19/73</i>
	030-1 Install the handling fixtures (914E945GO2) with the 24.25 radius (lt. 2 PAD) to the shield as shown on the layout 914E955. Torque to 225 ft lbs.			<i>EP/MH/JS/JE</i>	<i>2/19/73</i>
	030-2 Install an "ACME" drill bushing into each of the two .875 dia. holes in the handling fixtures. Secure the bushings with the supplied No. 4 lock screws.			<i>EP/MH/JS/JE</i>	<i>2/19/73</i>
	030-3 Using the drill bushing as a guide, drill a .625 dia. hole through the bushing and into the shield three inches deep as measured from the outer surface of the drill bushing. Total of two holes. Blow out all chips.			<i>EP/MH/JS/JE</i>	<i>2/19/73</i>
	030-4 Insert and Drive in a .625 dia x 3.50 lg spirol pin into each of the two drilled holes.			<i>EP/MH/JS/JE</i>	<i>2/19/73</i>
	030-5 Using the handling fixture (914E948) and a fork lift, place the shield into position on the core assembly as shown on the heat source assy drawing. NOTE: The shield segments join at $\theta = 0^\circ$ and $\theta = 180^\circ$.			<i>EP/MH/JS/JE</i>	<i>2/19/73</i>
	030-6 Assure that the one (1) inch clearance holes in the shield line up with the taped holes in the base. A tie rod (lt. 13) could be used as gauge for checking hole alignment.			<i>EP/JS/JE</i>	<i>2/19/73</i>

Drawing No./Rev.		Route Card No.		1004	
Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
	030-7 Remove the handling fixture from the shield (It. 9). Do not remove the spirol pins.			<i>JS/NE/MH</i>	<i>2/19/73</i>
	030-8 Install a setscrew (It. 46) into each of the eight (8) taped holes in the shield as shown on the heat source assembly drawing. See note 12.			<i>JS/NE</i>	<i>2/20/73</i>
040	Install the shield (It. 10) as follows:				
	040-1 Install the handling fixtures (914E945 GO2) with the 24.25 radius (It. 2 PAD) to the shield as shown on the layout 914E955.			<i>JS/NE/MH</i>	<i>2/19/73</i>
	040-2 Install an "ACME" drill bushing into each of the two .875 dia. holes in the handling fixtures. Secure the bushings with the supplied No. 4 lock screws.			<i>JS/MH/NE</i>	<i>2/19/73</i>
	040-3 Using the drill bushing as a guide, drill a .625 dia. hole through the bushing and into the shield three inches deep as measured from the outer surface of the drill bushing. Total of two holes. Blow out all chips.			<i>JS/MH/NE</i>	<i>2/19/73</i>
	040-4 Insert and drive in a .625 dia x 3.50 lg spirol pin into each of the two drilled holes.			<i>JS/MH/NE</i>	<i>2/19/73</i>
	040-5 Using the handling fixture (914E948) and a fork lift, place the shield into position on the core assembly as shown on the heat source assembly drawing.			<i>JS/MH/NE</i>	<i>2/19/73</i>
	040-6 Assure that the one inch clearance holes in the shield line up with the taped holes in the base. A tie rod (It. 13) could be used as gauge for			<i>JS/MH/NE</i>	<i>2/19/73</i>

Drawing No./Rev.		Route Card No.	
940J335 A		1004	
Op. No.	Operation Description	Ref. Doc.	Rev. Oper. Sign-off Date
	checking hole alignment.		
C40-7	Remove the handling fixture from the shield (It. 10). Do not remove the spiral pins.		WJ/JS/JE/MH - 2/14/73
040-8	Install a setscrew (It. 46) into each of the eight (8) taped holes in the shield as shown on the heat source assembly drawing. See Note 12.		WJ/JS/JE - 2/20/73
050	Install insulation (It. 44) around the heat pipe reservoirs as shown on the heat source assembly drawing.		WJ/JS/JE/MH - 2/20/73
051	Route & install thermocouples T48, T49 & T50		WJ/JS/JE/MH - 2/20/73
052	Check & record resistance. T48: 54 T49: 55 T50: 55		WJ/JS - 2/20/73
060	Instrument the shield (It. 11) as follows: #37 #46 #49		
060-1	At $\theta = 293^\circ$ scribe a line on the inside surface (i.e. the 9.50 radius) of the shield. See Table 2 of the heat source assembly drawing.		WJ/JS/JE - 2/20/73
060-2	Scribe a line at 6.50 inches from the top surface of the shield, bisecting the line at $\theta = 293^\circ$. This is the location of T132. See Table 2.		WJ/JS/JE - 2/20/73
060-3	Identify and install a thermocouple (It. 5) T132. Exit the lead towards the top of the shield. Secure the lead as required with clamps (It. 6) See note 3 of the heat source assembly drawing.		WJ/JS/MH - 2/20/73
060-4	Check the electrical resistance of T132 and record below. #90 T132 <u>63</u>		WJ/JS/MH - 2/21/73
070	Install the shield (It. 11) as follows:		

Drawing No./Rev. 940J335 A		Route Card No. 1004			
Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
070-1	Install the handling fixtures (914E945GO1) as shown on the layout 914E955. Torque to 225 ft lbs.			<i>2/26/73</i>	
070-2	Install an "ACME" drill bushing into each of the two .875 dia holes in the handling fixtures. Secure the bushings with the supplied No. 4 lock screws.			<i>2/26/73</i>	
070-3	Using the drill bushing as a guide, drill a .625 dia. hole through the bushing and into the shield three inches deep as measured from the outer surface of the drill bushing. Total of two holes. Blow out all chips.			<i>2/26/73</i>	
070-4	Insert and drive in a .625 dia x 3.50 lg spirol pin into each of the two drilled holes.			<i>2/26/73</i>	
070-5	Using the handling fixture (914E948) and a fork lift, place the shield into position on the core assembly as shown on the heat source assembly drawing. NOTE: The shield segments join at $\theta = 150^\circ$ and $\theta = 330^\circ$.			<i>2/26/73</i>	
070-6	Assure that the one inch clearance holes in the shield line up with the taped holes in the base. A tie rod (It. 13) could be used as gauge for checking hole alignment.			<i>2/26/73</i>	
070-7	Remove the handling fixture from the shield (It. 11). Do not remove the spirol pins.			<i>2/26/73</i>	
070-8	Install a setscrew (It. 46) into each of the eight (8) taped holes in the shield as shown on the heat source assembly drawing. See Note 12.			<i>2/26/73</i>	

Drawing No./Rev.		Route Card No.	
940J335 A		1004	
Op. No.	Operation Description	Ref. Doc.	Rev. Oper. Sign-off Date
080	070-9 Route the thermocouple lead up along the core assembly and out through a convenient lower heat pipe slot.		2/2/73 - 2/26/73
	Instrument the shield (It. 12) as follows:		
	080-1 Scribe a line at $\theta = 53^\circ$ and at $\theta = 173^\circ$ on the inside surface (i.e. the 9.50 radius) of the shield. See Table 2 of the heat source assembly drawing.		2/2/73 - 2/21/73
	080-2 Scribe a line at 6.50 inches from the top surface of the shield, bisecting the lines at $\theta = 53^\circ$ and $\theta = 173^\circ$. See Table 2.		2/2/73 - 2/21/73
	080-3 Identify and install thermocouples (It. 5) T130 and T131. Exit the lead towards the top of the shield. Secure the leads as required with clamps (It. 6). See NOTE 3 of the heat source assembly drawing.		2/2/73 - 2/21/73
090	080-4 Check the electrical resistance of the thermocouples and record below: T130 <u>63</u> 91 T131 <u>63</u> 92		2/2/73 - 2/21/73
	Install the shield (It. 12) as follows:		
	090-1 Install the handling fixtures (914E945GO1) as shown on the layout 914E955. Torque to 225 ft lbs.		2/2/73 - 2/27/73
	090-2 Install an "ACME" drill bushing into each of the two .875 dia. holes in the handling fixtures. Secure the bushings with the supplied No. 4 lock screws.		2/2/73 - 2/27/73

Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
090-3	Using the drill bushing as a guide, drill a .625 dia hole through the bushing and into the shield 3 inches deep as measured from the outer surface of the drill bushing. Total of two holes. Blow out all chips.			<i>2/MH/IG</i>	<i>2/13/73</i>
090-4	Insert and drive in a .625 dia x 3.50 lg spirol pin into each of the two drilled holes.			<i>2/MH/IS</i>	<i>2/27/73</i>
090-5	Using the handling fixture (914E948) and a fork lift, place the shield into position on the core assembly as shown on the heat source assy drawing.			<i>2/MH/IS</i>	<i>2/27/73</i>
090-6	Assure that the one (1) inch clearance holes in the shield line up with the taped holes in the base. A tie rod (lt. 13) could be used as gauge for checking hole alignment.			<i>2/MH/IS</i>	<i>2/27/73</i>
090-7	Remove the handling fixture from the shield (lt. 2). Do not remove the spirol pins.			<i>2/MH/IS</i>	<i>2/27/73</i>
090-8	Install a setscrew (lt. 46) into each of the eight (3) taped holes in the shield as shown on the heat source assembly drawing. See note 12.			<i>2/IS</i>	<i>2/27/73</i>
090-9	Route the thermocouple leads up along the core assembly and out through a convenient lower heat pipe slot.			<i>2/MH</i>	<i>2/26/73</i>
100	Install the shield (lt. 15) as follows:				
100-1	<i>a 3/4-10 cap bolt, washer, and nut in each</i> Install the handling fixtures (914E946 GO1 and GO2) as shown on the layout 914E955. Torque to 225 ft lbs. of four of the seven 3/4" holes in the outer perimeter. Plug the first, second, third, fourth, sixth, and seventh holes, starting from the mating surface			<i>2/MH</i>	<i>2/1/73</i>

Drawing No./Rev.		Route Card No.			
940J335 A		1004			
Op.No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
100-2	Install an "ACME" drill bushing into each of the two .875 dia. holes in the handling fixtures. Secure the bushings with the supplied No. 4 lock screws.				
100-3	Using the drill bushing as a guide, drill a .625 dia hole through the bushing and into the shield 3 inches deep as measured from the outer surface of the drill bushing. Total of two holes. Blow out all chips.				
100-4	Insert and drive in a .625 dia x 3.50 lg spiral pin into each of the two drilled holes.				
100-5	<i>usable long slings</i> Using the handling fixture (914B-48) and a fork lift, place the shield into position on the core assembly as shown on the heat source assembly drawing. <i>Make sure that the slings do not damage the heat pipe</i> The shield segments join at $\theta = 0^\circ$ and $\theta = 180^\circ$.			<i>SM/MH/JS</i>	<i>3/1/73</i>
100-6	Assure that the one (1) inch clearance holes in the shield line up with the taped holes in the base. <i>and in the top shield</i> A tie rod (lt. 13) could be used as gauge for checking hole alignment.			<i>SM/MH/JS</i>	<i>3/1/73</i>
100-7	<i>see letter</i> Remove the handling fixtures from the shield (lt. 15). Do not remove the spiral pins.			<i>SM/MH/JS</i>	<i>3/1/73</i>
100-8	Install a setscrew (lt. 46) into each of the eight (8) taped holes in the shield as shown on the heat source assembly drawing. See Note 12.			<i>SM/JS</i>	<i>3/5/73</i>
110	Install the shield (lt. 16) as follows:				

Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
110-1	Install the handling fixtures (914E946 G01 and G02) as shown on the layout 914E955. Torque to 225 ft. lbs. <i>a eyebolt is used around the perimeter, starting at the mating surface</i>			<i>Dr/MH</i>	<i>3/1/73</i>
110-2	Install and "ACME" drill bushing into each of the two .875 dia holes in the handling fixtures. Secure the bushings with the supplied No. 4 lock screws.				
110-3	Using the drill bushing as a guide, drill a .625 dia hole through the bushing and into the shield 3 inches deep as measured from the outer surface of the drill bushing. Total of four (4) holes. Blow out all chips.				
110-4	Insert and drive in a .625 dia x 3.50 lg spiral pin into each of the two drilled holes.				
110-5	Using <i>suitable long slings</i> the handling fixture (914E946) and a fork lift, place the shield into position on the core assembly as shown on the heat source assy drawing. <i>Make sure that the slings do not damage the heat pipes.</i>			<i>Dr/MH/JS</i>	<i>3/2/73</i>
110-6	Assure that the one (1) inch clearance holes in the shield line up with the taped holes in the base. A tie rod (It. 13) could be used as gauge for checking hole alignment.			<i>Dr/MH/JS</i>	<i>3/2/73</i>
110-7	<i>eyebolts</i> Remove the handling fixtures from the shield (It. 16). Do not remove the spiral pins.			<i>Dr/MH/JS</i>	<i>3/2/73</i>
110-8	Install a setscrew (It. 46) into each of the eight (8) taped holes in the shield as shown on the heat source assembly drawing. See Note 12.			<i>Dr/JS</i>	<i>3/5/73</i>

Drawing No./Rev.		Route Card No.	
940J335 A		1004	
Op. No.	Operation Description	Ref. Doc.	Rev. Oper. Sign-off Date
120	Remove the handling fixture (948C054 HO1 and HO2) from the previously installed shield (914E846HO1) see assembly drawing 940J461, Item. 5.		<i>Dr/MH - 3/2/73</i>
121	Connect all the fill lines		
130	Install the guards (Its. 22, 23, 24 and 25) as shown on the heat source assembly drawing, using socket head cap screws (It. 42) and never-seez compound (It. 49). See NOTE 7. <i>1/4-20 x 1 3/4, SS</i> <i>Do not torque</i>		<i>Dr/MH/JS - 3/5/73</i>
140	Torque the socket head cap screws per Note 10 of the heat source assembly drawing.		<i>Dr/MH - 3/5/73</i>
150	Install the six (6) segments of the ring (It. 27), using socket head cap screws (It. 41) and never-seez compound (It. 49) as shown on the heat source assembly drawing.		<i>Dr/MH/JS - 3/5/73</i>
160	Install bulk insulation (It. 30) and secure with wire (It. 32) as shown on the heat source assembly drawing.		<i>Dr/MH/JS - 3/6/73</i>
170	Install bulk insulation (It. 4) up to the top surface of the shield (914E846HO1).		<i>Dr/MH/JS - 3/6/73</i>
180	Install insulation (It. 18) as shown on the heat source assembly drawing.		<i>Dr/MH - 3/6/73</i>
190	See Note 6.		
200	Install three .75 in lifting eyes to the drum housing (It. 28).		<i>Dr/MH/JS - 3/8/73</i>
210	With appropriate slings raise and support the drum housing (wt. approx. 600 lbs) in position over the heat source assembly. Align the one (1) inch clearance holes in the drum housing with those in the shield. Lower the drum housing into position on the heat source assembly.		<i>MH/JS - 3/8/73</i>

Drawing No./Rev.

940J335 A

Route Card No.

1004

Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
220 240 250	Check all (12) of the one (1) inch clearance holes for alignment by inserting a tie rod (It. 13) into each hole and threading the tie rods into the base at least one full thread.			3/5 MH/JS	3/6/73
240 250 260	Remove lifting eyes from the drum housing. Remove the tie rods. <i>Torque SHCS on heat pipe guards to 150 in.-lbs.</i>			MH/JS	3/6/73
240 250 260	Apply Never-Seez compound (It. 49) to the tie bolt threads (It. 13) and thread the twelve (12) tie bolts into the base as shown on the heat source assembly drawing finger tight. Do not install the nuts (It. 38) at this time.			MH/JS	3/6/73
240 250	Position the cylinder assembly (It. 20) on the drum housing (It. 28) as shown on the heat source assembly drawing. The three (3) inch square cut out is at $\theta = 180^\circ$.			3/5 JS/MH	3/6/73
240 250 260	Align the .312 clearance holes in the cylinder assembly (It. 20) with the .250-20 tapped holes in the drum housing. Apply Never-Seez compound (It. 49) to the threads of 24 socket head cap screws (It. 45) and install the screws to secure the cylinder assembly to the drum housing. Torque It. 45 to 70 in. lbs. <i>1/4-20 x 1, SS</i>	<i>Altered if New off 310 & 220</i>		3/5 JS	3/6/73
270	Install the springs (It. 37), hangers (It. 26) and hex nuts (It. 43) to support the heat pipes. Tighten the hex nuts (It. 43) to obtain the spring dimension as shown on the heat source assembly drawing. <i>3/8-16</i> <i>10 1/2"</i>			3/5 JS	3/9/73
280	Install the segment assembly (It. 21) as follows: 280-1 Install the handling fixtures (914E945GO2) with the 33/25 radius PAD (It. 1 of 914E945) to one of the segments as shown in the layout 914E965. Torque to 2700-2800 in. lbs. <i>Locate with two holes, 2 1/2" dia. x 2 1/2" deep on the top of each segment. The holes should be located so that the segment can be lifted level from those points</i>			3/5 MH/JS	3/28/73

Drawing No./Rev.		940J335 A	Route Card No.		1004		
Op. No.	Operation Description			Ref. Doc.	Rev.	Oper. Sign-off	Date
280-2	Install an "ACME" drill bushing into each of the .875 dia holes in the handling fixtures. Secure the bushings with the supplied No. 4 lock screws. <i>Drill a hole $\phi 21/32$ dia $\times 3\frac{1}{2}$ deep at each location. Clean out all chips.</i>					<i>SM/MH/JS - 2/22/73</i>	
280-3	Using the drill bushing as a guide, drill a .625 dia hole through the bushing and into the segment three inches deep as measured from the outer surface of the drill bushing. Total of two holes. Blow out all chips. <i>Tap each hole $3/4 \times 10 \times 2\frac{1}{4}$, using a plug tap. Clean out all chips.</i>					<i>SM/MH/JS - 2/24/73</i>	
280-4	Insert and drive in a .625 dia $\times$ 3.56 lg spiral pin into each of the two drilled holes. <i>a $3/4 \times 10$ eye bolt & washers in each hole of eye of the segments</i>					<i>SM/MH/JS - 3/9/73</i>	
280-5	Using the handling fixture (914E948) and a fork lift, place the segment into position as shown on the heat source assembly drawing. <i>sketch of assembly</i>					<i>SM/MH/JS - 3/9/73</i>	
280-6	Assure that the taped holes in the bottom of the segment line up with the .750 clearance holes in the shield.					<i>SM/MH/JS - 3/9/73</i>	
30-7	Remove the handling fixtures from the segment. Do not remove the spiral pins. Then with $3/4 \times 10 \times 2\frac{1}{4}$ drilled head cap screws, the <i>Never-Secz compound on threads.</i> <i>eye bolts and washers</i>			<i>Could not remove (insufficient clearance).</i>		<i>SM/MH/JS - 3/9/73</i>	
280-8	Apply a coat of Never-Secz compound (lt. 49) to the threads of five (5) hex head cap screws (lt. 40). <i>$1/2 - 13 \times 1\frac{1}{2}$</i>					<i>SM/MH/JS - 3/9/73</i>	
280-9	Install a washer (lt. 39) and a hex head cap screw into each of the five taped holes in the bottom of the segment. Do not torque at this time.					<i>SM/MH/JS - 3/9/73</i>	
280-10	Install the handling fixtures (914E945 & 914E955) with the .03.25 radius RAG (lt. 1 of 914E945) to one of the segments as shown in the layout. <i>a $3/4 \times 10$ eye bolt and washers in each hole of segment</i> 914E955. Torque to 225 ft lbs.					<i>SM/MH/JS - 3/9/73</i>	

Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
280-11	Install an "ACME" drill bushing into each of the two .875 dia holes in the handling fixtures. Secure the bushings with the supplied No. 4 lock screws.				
280-12	Using the drill bushing as a guide, drill a .625 dia hole through the bushing and into the segment 3 inches deep as measured from the outer surface of the drill bushing. Total of two holes. Blow out all chips.				
280-13	Insert and drive in a .625 dia x 3.50 lg spiral pin into each of the two drilled holes.				
280-14	Using the handling fixture (914E943) and a fork lift, place the segment into position as shown on the heat source assembly drawing. <i>switch slings</i>			<i>DM/MH/JS - 3/9/73</i>	
280-15	Assure that the taped holes in the bottom of the segment line up with the .750 clearance holes in the shield.			<i>DM/MH/JS - 3/9/73</i>	
280-16	Remove the handling fixtures from the segment. Do not remove the spiral pins. <i>Remove the eye bolts and replace them with 3/4-10" slotted head screws. Use Never-Seez compound on threads</i>			<i>Insufficient clearance</i>	
280-17	Apply a coat of Never-Seez compound (lt. 49) to the threads of five (5) hex head cap screws (lt. 40).			<i>DM/MH/JS - 3/9/73</i>	
280-18	Install a washer (lt. 39) and a hex head cap screw into each of the five taped holes in the bottom of the segment. Do not torque at this time.			<i>DM/MH/JS - 3/9/73</i>	
280-19	Install the handling fixtures (914E945G02) with the .23.25 radius PADS (lt. 1 of 914E945) to the remaining segment as shown on the layout 914E955. Torque to 225 ft. lbs. <i>a 3/4-10 eye bolt and washer in each hole of</i>			<i>DM/MH/JS - 3/9/73</i>	

Drawing No./Rev.		Route Card No.	
940J335 A		1004	
Op. No.	Operation Description	Ref. Doc.	Rev. Oper. Sign-off Date
280-20	Install an "ACME" drill bushing into each of the two .875 dia. holes in the handling fixtures. Secure the bushings with the supplied No. 4 lock screws.		
280-21	Using the drill bushing as a guide, drill a .625 dia. hole through the bushing and into the segment 3 inches deep as measured from the outer surface of the drill bushing. Total of two holes. Blow out all chips.		
280-22	Insert and drive in a .625 dia x 3.50 lg spirol pin into each of the two drilled holes.		
280-23	<i>switch slings</i> Using the handling fixture (914E948) and a fork lift, place the segment into position as shown on the heat source assembly drawing.		<i>SMH/JS - 3/9/73</i>
280-24	Assure that the taped holes in the bottom of the segment line up with the .750 clearance holes in the shield.		<i>SMH/JS - 3/9/73</i>
280-25	<i>replace</i> Remove the handling fixtures from the segment, <i>and replace</i> do not remove the spirol pins. <i>them with 3/4-16 x 2 1/4 socket head set screws. Use Flares - Seez compound on threads</i>		<i>insufficient clearance</i>
280-26	Apply a coat of Never-Seez compound (It. 49) to the threads of the remaining five (5) Hex head cap screws (It. 40).		<i>SMH/JS - 3/9/73</i>
280-27	Install a washer (It. 39) and a hex head cap screw into each of the five taped holes in the bottom of the segment.		<i>SMH/JS - 3/9/73</i>
280-28	Torque all fifteen (15) hex head cap screws to 45 ft lbs.		<i>SMH/JS - 3/9/73</i>

B-25

Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
280-29	Drive the spiral pins into each of the three segments until they bottom.				
280-30	Install a set screw (lt. 46) into each of the 24 taped holes in the segment assembly as shown on the heat source assembly. See Note 12.				
290	Install a nut (lt. 38) on each of the twelve (12) tie rods as shown on the heat source assembly drawing. Torque nuts to 225 ¹⁵⁰ ft lbs.			<i>2/14/73</i>	<i>3/9/73</i>
300	Install bulk insulation (lt. 4) to flush with insulation (lt. 18). As shown on the heat source assembly drawing.			<i>2/14/73</i>	<i>3/9/73</i>
310	Instrument and install the top plug (lt. 29) as follows:				
310-1	Install the .75 inch lifting eyes to the top plug (lt. 29) weight approx. 300 lbs.			<i>2/14/73</i>	<i>3/14/73</i>
310-2	With appropriate slings raise the top plug to allow installation of thermocouple T46.				
310-3	Identify and install a thermocouple (lt. 5) to the bottom center of the plug as shown on the heat source assembly drawing. See Table 2. Secure the thermocouple with clamp (lt. 6) per Note 3.				
310-4	Check the electrical resistance of the thermocouple and record below T 46				
310-5	insure that protective covers are on extension threads. <i>Delete per JS. No covers available. Will not get</i> Raise the top plug into position over the heat source assembly approximately two inches above the extensions.			<i>2/14/73</i>	<i>3/14/73</i>

No way to get T46 outside Delete per J. Hedges

Drawing No./Rev.		Route Card No.	
940J335 A		1004	
Op. No.	Operation/Description	Ref. Doc.	Rev. Oper. Sign-off Date
310-6	<i>After re-machining</i> Align the top plug with the heat source assembly. The three holes in line on the top outer surface of the plug are at $\theta = 0^\circ$ (i.e. the .250 clearance hole) .438 clearance hole and the .750 taped hole.		<i>Dr/MH/JS - 3/14/73</i>
310-7	Slowly lower the top plug into position on the heat source assembly. Assure that the .438 clearance holes are aligned with the .375-16 taped holes in the drum housing. <i>Do not line up</i>		<i>Dr/MH/JS - 3/14/73</i>
310-8	Align the top plug to maximize the clearance gap between extensions and top plug at outermost radial position of the twelve (12) extensions of Item (1). See Note 8.		<i>Dr/MH/JS - 3/14/73</i>
310-9	Apply Never-Seez compound (It. 49) to the threads of the six (6) socket head cap screws (It. 44) and install the screws as shown on the heat source assembly drawing. Torque cap screws (It. 44) to 250 in. lbs. <i>Do not line up.</i>		
310-10	Drill, ream the top plug and drum housing for the four (4) dowel pins (It. 19) per Note 8 of the heat source assembly drawing. <i>Do not line up</i>	<i>Debt per J. Skelley</i>	
310-11	Install the four (4) dowel pins as shown on the heat source assy drawing.		
320	Install the remaining thermocouples as follows:		
320-1	Identify and install the thermocouple (It. 5) T47 located on the O.D. of the segment assembly (It. 21). See Table 2 for actual location. Secure the lead as required per note 3.		
320-2	Check the electrical resistance of T47 and record below. T 47 _____		

Drawing No./Rev.		Route Card No.	
940J335 A		1004	
Op. No.	Operation Description	Ref. Doc	Rev. Oper. Sign-off Date
320-3	Identify and install the thermocouples (It. 5) T39, T40, T41, T42, and T43 located at various points around the O.D. of the shield segments. See Table 2 for actual locations. Secure the leads as required per Note 3.		
320-4	Check the electrical resistance of T39 - T43 and record below T 39 _____ T 40 _____ T 41 _____ T 42 _____ T 43 _____		
330	Install the twelve top sleeves (940J345 #07) into the fuel pin cavity extensions as shown on 940J345.		<i>W/MH/JS - 3/19/13</i>
340	Install the twelve (12) sleeves (It. 33) onto the extensions as shown on the heat source assembly drawing. Apply a coat of Never-Seez to threads.		<i>W/MH/JS 3/19/13</i>
350	Install dummy fuel pin successively into each of the fuel pin cavities to verify proper fit.		<i>W/MH - 3/19/13</i>
360	Install the twelve (12) sleeve plugs (It. 3) into the extension cavities as shown on the heat source assembly drawing.		<i>W/MH/JS - 3/20/13</i>
370	Install the twelve (12) covers (It. 34) into the extensions as shown on the heat source assembly drawing.		
380	Install an adaptor (It. 35) into each of the extension sleeves as shown on the heat source assembly drawing.		
381 384	<i>Identify & install T38 on heat assembly</i> <i>Check electrical resistance & record T38 _____</i>		

Drawing No./Rev. 940J335 A		Route Card No. 1004			
Op. No.	Operation Description	Ref. Doc.	Rev.	Oper. Sign-off	Date
390	Route all instrumentation leads down and out towards and along the outlet pipe. Do not shorten T/C leads.				
400	Install the insulation (It. 31) and secure with wire (It. 32) as shown on the heat source assembly drawing.				
410	Install the cover (It. 17) as shown on the heat source assembly drawing.				
420	Raise and support the thermal guard (It. 19) over the heat source assembly. Align the three (3) inch cutout per Note 11. Lower the thermal guard into position on the heat source assembly and secure with six (6) socket head cap screws (It. 45), as shown on the heat source assembly drawing.				
	NOTE: Installation of "V-Seals" (It. 36) will be completed during the fueling sequence.				

Co-60 Heat Source Demonstration Program Notes
on Heat Source Assembly

Route Card No. 1003:

<u>Oper. No.</u>	<u>Remarks</u>
010	Make sure I-beam structure is level. Grinding may be necessary.
020 through 050	Tl37 already in place. Delete 020, 030, and 050, unless 040 reveals Tl37 has failed.
060	Make sure base assembly is level. Shim if necessary. Use precision level, transit, or cathetometer to check.
090	Tl36 already in place. Delete unless Tl36 has failed.
100	Height of top surface of core assembly shield: 50 1/64"
171	Make sure inlet and outlet pipes are adequately insulated at bottom of pressure vessel.
172	Inlet and outlet pipe insulation is extremely fragile. Handle with Care.
180	Handling fixtures are numbered.
200	Make sure conical shield is level and centered. IMPORTANT: Make sure 0° index mark is aligned with 0° mark on base. Use plumb line, and confirm location of 0° line on drawing (914ES46).
230	Insulation already installed on heat pipes. Check and repair insulation as required.

<u>Oper. No.</u>	<u>Remarks</u>
240	All heat pipe pads identified and proper location marked.
250	T30-T37, inclusive, already installed. Delete 250 unless any thermocouples have failed.
260	T51, T139 and T140 already installed. Delete 260 unless any thermocouples have failed.
270	Defer. See Route Card No. 1004, Oper. No. 171-172.
290	T55-T58, inclusive, already installed. Delete 290 unless any thermocouples have failed.
300 and 310	Defer. See Route Card No. 1004, Oper. No. 3810 and 382
370 and 380	Defer. See Route Card No. 1004, Oper. No. 141 and 142.
390	Install 940J461H13 only. Defer installation of 940J461H14 and H15. See Route Card No. 1004, Oper. No. 041. Outer piece of 940J461H13 made too short. Fill in with felt. Make joints of inner and outer pieces 180° apart. Use glass tape and wire to secure insulation.

Route Card No. 1004

<u>Oper. No.</u>	<u>Remarks</u>
010	Delete 010-2 through 010-4. Holes already drilled. Roll pins in handling fixtures. Use Flat Head Cap Screws. Torque to 150 ft-lbs. Use Torx 11mm.

Route Card No. 1004 (Continued)

<u>Oper. No.</u>	<u>Remarks</u>
020	See remarks for 010.
021	Install bulk insulation. Pack tightly.
030	See remarks for 010.
040	See remarks for 010.
041	Install insulation 940J461H14 and H15. Set joint between heat pipes 4 and 5 to permit passage of thermocouples. Use glass tape and wire to secure insulation.
050	Install bulk insulation. Pack tightly.
060	T132 will be at $0 = 83^\circ$, instead of 293° , if side shields 940J335H11 and H12 are rotated 150° clockwise.
070	See remarks for 010.
080	T130 and T131 will be at $0 = 203^\circ$ and 323° , instead of 53° and 173° , respectively, if side shields 940J335H11 and H12 are rotated 150° clockwise.
090	See remarks for 010.
100	Handling fixtures not required. Use long slings. Use match lines.
110	See remarks for 100.
120	Make sure conical shield does not shift when lowered onto stack. Lower evenly.

Oper. No.
Remarks

141
and
142

Install connectors and tubing. Tubing marked with cavity number, per 940J311.

Route along upper heat pipes as follows:

<u>Cavity No.</u>	<u>Heat Pipe No.</u>
1	34
2	2
3	30
4	36
5	6
6	26
7	24
8	12
9	10
10	22
11	18
12	14

160

Only one piece of insulation 940J335H30 available.
Fill with bulk insulation.

200
and
210

Delete. Cylinder assembly already attached to housing drum. Handle as unit. Lift with eyebolts on drum. Do not lift on cylinder.

250

Torque socket head cap screws on heat pipe guards to 150 in.-lbs.

280

Delete 280-1 through 280-3. Holes already drilled and tapped.
Delete 280-7, -13, and -19. Eyebolts cannot be removed, due to insufficient clearance.

310

Top plug (940J335H29) has been remachined. Check fit and alignment carefully. Dowel pins not necessary. Remove sleeves (940J335H33) from cavity extensions before installing top plug.

Oper. No.

Remarks

330	Delete. Top sleeves (940J345H07) already installed.
360	Attach slides (940J455H04) to sleeve plugs before installing sleeve plugs in cavity extensions.

PROCEDURE FOR DISASSEMBLY OF CO-60 HEAT SOURCE

1. Remove sleeves (940J335H33) from fuel pin cavity extensions and place them aside.
2. Insert three 3/4-10 eyebolts into tapped holes in top plug (940J335H29).
3. Using proper slings, carefully remove top plug.
4. Coat top plug with Rust-Ban, label, and place in Box #4. Be sure to brace plug securely.
5. Remove bulk insulation from around core assembly and discard.
6. Remove thermocouples T52, T53, and T54 from fuel pin cavity extensions and package for shipment.
7. Scribe index mark at 0° on top insulation (940J335H18, 2 pieces). Carefully remove insulation, label, and package for shipment.
8. Remove sleeve plugs (940J335H03) from fuel pin cavity extensions, label, and package for shipment.
9. Using a hook tool, carefully remove top sleeves (940J345H07) from fuel pin cavities, label, and package for shipment. NOTE: Do Not Force. If sleeves can't be removed, leave in place.
10. Replace sleeves (940J335H33) on fuel pin cavity extensions. Be sure threads are engaged properly.
11. Cover fuel pin cavities with double plastic bag and tape securely.
12. Remove 3/4-10 nuts (940J335H38) from tie rods (940J335H13) and place aside. Do not package for shipment.

13. Using a scribe, mark match lines on segment assembly (940J335H13) and uppermost side shields (940J336H15 and H16) at $\theta = 90^\circ$, 180° , and 270° . Be sure to identify each match line as to item, matching item, and location; e.g., 21-15ML90.
14. Remove 1/2-13 x 1 1/2 hex head cap screws and washers (940J335H40 and H39) from segment shield extending from $\theta = 120^\circ$, to 240° .
15. Using proper slings, remove first segment shield (120° to 240°) from stack. Make sure slings do not damage heat pipes.
16. Coat segment shield with Rust-Ban, label, place in Box #5, and secure for shipment.
17. Remove cap screws and washers from second segment shield (240° to 360°).
18. Using proper slings, remove second segment shield from stack. Make sure slings do not damage heat pipes.
19. Coat segment shield with Rust-Ban, label, place in Box #6, and secure for shipment.
20. Remove cap screws and washers from third segment shield (0° to 120°).
21. Using proper slings, remove second segment shield from stack. Make sure slings do not damage heat pipes.
22. Coat segment shield with Rust-Ban, label, place in Box #7, and secure for shipment.
23. Label cap screws and washers removed from segment shields and package for shipment.
24. Disconnect springs, hangers, and 3/8-16 hex nuts (940J335H37, H26, and H43, respectively) from cylinder assembly (940J335H20), but leave attached to heat pipes.

25. Remove tie rods (940J335H13) from heat source.
26. Replace 3/4-10 nuts (940J335H35) on tie rods and cover all threaded ends with tape.
27. Label tie rods and nuts and package for shipment.
28. Loosen 1/4-20 x 2 3/4 socket head cap screws (940J335H42) attaching guards (940J335H22, H23, H24, and H25) to conical shield.
29. Scribe index line on housing drum (940J335H28) at $\theta = 0^\circ$.
30. Install three 3/4-inch eyebolts in tapped holes in housing drum.
31. Using proper slings, carefully lift housing drum and cylinder assembly (940J335H20) as a unit and remove from stack.
32. Coat housing drum and cylinder assembly with Rust-Ban, label, place in Box #8, and secure for shipment. Mark box DO NOT STACK.
33. Remove any bulk insulation remaining around top of core assembly and discard.
34. Scribe match lines on heat pipe guards (940J335H22, H23, H24, and H25) and all six ring segments (940J335H27). Scribe at least three match lines on each ring segment. Identify each match line by heat pipe number and engrave accordingly. e.g., HP26.
35. Remove 1/4-20 x 1 3/4 socket head cap screws (940J335H41) holding one of six ring segments (940J335H27) in place. Then remove ring segment.
36. In a like manner, remove remaining ring segments.
37. Coat ring segments with Rust-Ban, place in Box #9, and secure for shipment.
38. Label cap screws and package for shipment.

39. Remove 1/4 - 20 x 2 3/4 socket head cap screws (940J335H42) holding heat pipe guards (940J335H22, H23, H24, and H25) in place. Label and package cap screws for shipment.
40. Remove heat pipe guards.
41. Coat guards with Rust-Ban, place in Boxes #10 and 11, and secure for shipment.
42. Disconnect He fill lines (940J461H24) from fuel pin cavity extensions. Remove fittings (940J461H07) and attach to tubing. Label and package tubing and fittings for shipment, being sure to identify cavity number for each section of tubing.
43. Remove insulation (940J335H30) from core assembly shield, label, and package for shipment.
44. Measure and record distance between core assembly shield (940J461H06) and conical shield (940J461H05). Measure at six places, adjacent to handling fixture locations.
45. Measure and record axial distance between top surface of core assembly shield and top inside edge of conical shield. Measure in six places, as above.
46. Attach handling fixtures (948C054H01 and H02) to conical shield. Be sure to install such that lifting eyes will be in alternate fixtures.
47. Using proper sling, carefully raise conical shield about 3/16".
48. Place shims on core assembly shield under all six handling fixtures. Then carefully lower conical shield so that handling fixtures bear on shims. Shim thickness should be sufficient to raise conical shield ~ 1/8".
49. Scribe match lines at $\theta = \sim 45^\circ$ on first and second side shields (940J335H15 and H11). Mark match lines 15-11 and 11-15, respectively.

50. Scribe match lines at $\theta = \sim 315^\circ$ on opposite side shields (940J335H16 and H12). Mark match lines 16-12 and 12-16, respectively.
51. Measure and record horizontal gap between the side shields. Measure at $\theta = 0^\circ$ and 180° .
52. Insert 3/4-10 eyebolts and nuts into first, second, sixth and seventh holes around perimeter of top side shield (940J335H15). Tighten nuts securely.
53. Using two long (15-20 ft.) nylon slings of adequate capacity, make a basket hitch through each pair of eyebolts. Attach ends of nylon slings to hooks of heavy-duty 4-part chain sling.
54. Carefully raise shield until weight is supported by crane. Then slide shield off stack.
55. Place shield in Box #12, remove eyebolts and nuts, and secure box for shipment.
56. Insert 3/4-10 eyebolts and nuts into first, third, sixth and eighth holes around perimeter of remaining top side shield (940J335H16).
57. Using slings as above, remove shield from stack.
58. Place shield in Box #13, remove eyebolts and nuts, and secure box for shipment.
59. Remove shims from next pair of side shields (940J335H11 and H12) by breaking welds. Discard shims.
60. Measure horizontal gaps between next pair of side shields (940J335H11 and H12), using feeler gages. Measure inside and outside gaps at places where shields meet ($\theta = 150^\circ$ and 330°).

61. Scribe match lines at $\theta = \sim 45^\circ$ on next two side shields (940J335H11 and H10). Mark match lines 11-10 and 10-11, respectively.
62. Scribe match lines at $\theta = \sim 315^\circ$ on opposite side shields (940J335H12 and H09). Mark match lines 12-9 and 9-12, respectively.
63. Attach handling fixtures (914E945G01) to top remaining shield (940J335H12), as shown on layout 914E55.
64. Attach handling fixture (914E948G01) to fork truck.
65. Cut tape holding thermocouples T130 and T131 to conical shield.
66. Using fork truck, raise shield slightly and slide partially off stack.
67. With corners of shield supported on stack, wrap nylon gling around center of shield, using choker hitch, and attach to crane.
68. Using crane and fork truck in combination, slide shield off stack and place on floor.
69. Carefully remove thermocouples T130 and T131 from shield and package for shipment.
70. Turn shield to vertical position and remove handling fixtures.
71. Place shield in Box #15 and secure for shipment.
72. Measure vertical gap between shields 940J335H11 and H09/H10 at $\theta = 150^\circ$ and 330° .
73. Attach handling fixtures to shield 940J335H11.
74. Cut tape holding thermocouple T132 to conical shield.

75. Using crane and fork truck in combination as above, carefully remove shield from stack and place on floor.
76. Carefully remove thermocouple T132 from shield and package for shipment.
77. Turn shield to vertical position and remove handling fixtures.
78. Place shield in Box #14 and secure for shipment.
79. Remove shims from next pair of side shields (940J335H09 and H10) and discard.
80. Measure horizontal gap between shields at $\theta = 30^\circ$ and 210° .
81. Scribe match lines at $\sim 45^\circ$ on next two side shields (940J335H10 and H08). Mark match lines 10-8 and 8-10, respectively.
82. Scribe match lines at $\sim 315^\circ$ on opposite side shields (940J335H09 and H07). Mark match lines 9-7 and 7-9 respectively.
83. Attach handling fixtures (914E945G02) to shield 940J335H10, as shown on layout 914E955, and to fork truck.
84. Using fork truck, carefully remove shield from stack and place on floor.
85. Turn shield to vertical position and remove handling fixtures.
86. Measure and record vertical gap between opposite shield (940J335H09) and bottom pair of side shields (940J235H07 and H08) at $\theta = 30^\circ$ and 210° .
87. Attach handling fixtures to shield 940J335H09 and to fork truck.
88. Using fork truck, carefully remove shield from stack and place on floor.

89. Turn shield to vertical position , adjacent to shield 940J335H10, and remove handling fixtures.
90. Carefully pick up shields 940J335H09 and H10 together, place in Box #16, and secure for shipment.
91. Remove bulk insulation from around heat pipe sumps and discard.
92. Scribe a line on core assembly at bottom of heat pipe sumps. Mark at four places, $\sim 90^\circ$ apart, for upper and lower heat pipes.
93. Remove pads (940J461H10/H11) holding one of lower heat pipes (940J461H04) to side of core assembly. Be sure to support heat pipe as pads are removed. Also note position of each pad, label and package for shipment.
94. Carefully remove heat pipe from core assembly and conical shield.
95. Repeat steps 93 and 94 for remaining lower heat pipes (odd numbers)
96. Place all lower heat pipes in Box #17 and secure for shipment. Be sure to use adequate saddles, braces, cushioning, etc.
97. Remove and discard all bulk insulation between core assembly and conical shield.
98. Carefully remove thermocouples T133, T134, and T135 from core assembly and package for shipment.
99. Remove pads (940J461H08/H09) holding one of upper heat pipes (940J461H03) to core assembly. Note position of pads, label, and package for shipment.
100. Carefully raise heat pipe and turn so that heat pipe sump passes between core assembly and conical shield. Then remove heat pipe.
101. Repeat steps 99 and 100 for remaining upper heat pipes, using special care to avoid damage to thermocouples.

102. Place all upper heat pipes in Box #18 and secure for shipment. Be sure to use adequate saddles, braces, cushioning, etc.
103. Label 1/4-20x1/2 socket head cap screws (940J461H25) removed from the pads, and package for shipment.
104. Scribe match lines at $\theta = \sim 45^\circ$ on bottom side shield (940J335H08) and base plate (940J461H19). Mark match lines 8-19 and 19-8, respectively.
105. Scribe match lines at $\theta = \sim 315^\circ$ on opposite side shield (940J335H07) and base plate (940J471H18). Mark match lines 7-18 and 18-7 respectively.
106. Remove all bulk insulation from grooves in conical shield.
107. Carefully remove thermocouples T48, T49, and T50 from core assembly.
108. Carefully identify and bundle all thermocouples coming from core assembly in order to prevent damage during removal of conical shield.
109. Attach suitable 3-part sling to lifting fixtures on conical shield.
110. Carefully remove conical shield from core assembly. Be sure to protect core assembly and all thermocouples from damage.
111. Place conical shield in Box #19, remove eyebolts, and secure for shipment. Handling fixtures may be left attached to shield.
112. Remove shims from bottom pair of side shields (940J335H07 and H08) and discard.
113. Attach handling fixtures (914E945G01) to shield 940J335H08).
114. Using fork truck and crane in combination, as above, carefully remove shield from stack.
115. Turn shield to vertical position and remove handling fixtures.

116. Place shield in Box #20 and secure for shipment.
117. Attach handling fixtures to opposite side shield (940J335H07).
118. Using fork truck and crane in combination, as above, carefully remove shield from stack.
119. Turn shield to vertical position and remove handling fixtures.
120. Place shield in Box #21 and secure for shipment.
121. Remove bulk insulation from around core assembly and discard.
122. Remove insulation (940J461H13) from around core assembly, label, and package for shipment.
123. Measure and record distance between base plates (940J471H18 and H19) and top surface of coreassembly shield (940J461H06). Measure at three places, $\sim 120^\circ$ apart.
124. Attach retaining bars tying core assembly shield to core assembly (940J461H01).
125. Attach special lifting fixture to core assembly.
126. Install guide pins (940J461H17) in base plates.
127. Secure all thermocouples to core assembly for shipment. Be sure to allow adequate space around side of core assembly for saddles, braces, etc.
128. Remove 3/8-16 hex head cap screws (940J461H27) from base of core assembly, label, and package for shipment.
129. Using crane and suitable sling, carefully lift core assembly off base plates.

130. Place core assembly in Box #22 and secure shipment. Be sure to use adequate saddles, braces, cushioning, etc.
131. Remove guide pins from base plates, label, and package for shipment.
132. Insert three 3/4-10 eyebolts in tapped holes in base plate 940J461H18.
133. Using 3-part sling, remove base plate from base assembly (940J471H02).
134. Place base plate in Box #23, remove eyebolts and secure for shipment.
135. Repeat steps 132 and 133 for remaining base plate (940J461H19).
136. Place base plate in Box #24, remove eyebolts, and secure for shipment.
137. Insert three 3/4-10 eyebolts into tapped holes in base assembly (940J461H02).
138. Carefully coil thermocouples T136 and T137 and secure them to base assembly.
139. Using suitable sling, remove base assembly from I-beam base structure.
140. Place base assembly in Box #25, remove eyebolts, and secure for shipment.
141. Remove I-beam base structure from concrete pad and secure for shipment.
142. Place alignment plate/fueling shield assembly (940J463G01/G02) into Box #26 and secure for shipment.
143. Place shield handling fixtures (914E945G01 and G02; 914E948G01) in Box #27, and secure for shipment.

144. Place all miscellaneous small parts, fittings, hardware, insulation, etc., in Box #28, 29 and 30 and secure for shipment. Make sure all parts are properly identified and labeled.
145. Place gas manifold (940J471H06) in Box #1 and secure for shipment.
146. Place allelectrical switchgear in Box #2 and secure for shipment.
147. Place short handling tool in Box #3 and secure for shipment.

APPENDIX C

BCD CONTROLS

AiResearch Report APS-5430-R documents the controls design completed for the BCD-Co 60 Heat Source. The following pages present a brief summary of the contents of this report.

The controls for the Co-60 Brayton Power System (BPS) provide the following features:

- Automatic start-up
- Automatic temperature control
- Automatic load (speed) control
- Automatic voltage control
- Automatic system protection
- Signal conditioning (0 to 5 vcd) parametric signals
- Critical parameter readouts
- Operator controls
- Critical parameter alarms
- Automatic shutdown

Much of the controls design for this application was based on prior work accomplished under NASA Contract NAS 3-10943 (Brayton Control System) and other related programs.

System Description

Figure C-1 shows system piping and instrumentation. During system operation the compressor circulates an inert gas (argon) through the loop, absorbing thermal energy from the heat source. The heated compressed gas is expanded through the turbine which drives the compressor and the alternator, producing electrical power.

The recuperator recovers waste heat from the turbine discharge gas and transfers the heat to the gas entering the isotope heat source, thus improving efficiency. The heat sink heat exchanger removes additional thermal energy to limit the compressor inlet temperature as required.

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Figure C-1. C₀ 60/BPS PIPING & INSTRUMENTATION DIAGRAM

Very little control of the system is required after start-up as the input energy from the Co-60 heat source is essentially constant. The controls function to maintain the desired loop temperatures and speed. Temperature is controlled by varying the flow in the loop (by controlling inventory). Speed is controlled by applying electrical load to the alternator.

The control system has been subdivided into units and subassemblies for purposes of identification as shown in Figure C-2. The major units of the control system and miscellaneous accessories are as listed below:

(a)	Engine Control Console	Unit 1
(b)	Starter Generator Set	Unit 2
(c)	Parasitic Load Bank	Unit 3
(d)	Valve Bank	Unit 4
(e)	Primary input Power Cable Assembly	W1
(f)	Starter Control Cable Assembly	W2
(g)	Load Bank Cable Assembly	W3
(h)	Valve Bank Control Cable Assembly	W4
(i)	Engine Sensor Cable Assembly	W5
(j)	Engine Harness Assembly	W6
(k)	Facility Power Cable	W7

System Operation

The automatic control functions are summarized in Table C-1. Signals, used for control logic, available for system performance evaluation, and displayed on the control panel are listed in Table C-2. Figure C-3 is a line diagram of the logic.

The control logic uses zero to 5 volt analogs of the system parameters to provide operating logic and alarms. The logic is provided by standard comparator and comparator-with-alarm printed circuit boards, and with a special circuit board to provide the control logic unique to the Co-60/BPS system.

Figure C-2. Co⁶⁰ BPS CONTROL SYSTEM

TABLE C-1
Co-60/BPS OPERATION

OBJECTIVE	REQUIRED ACTION	ACTUATOR
A. BPS STARTUP (FROM FACILITY COOLANT SYSTEM (FCS))		
1. Establish Coolant Flow	Open V21 & V23	Operator
2. Parallel BPS	Open V3 & V4	Operator
3. Initiate BPS Operation	Depress Start Switch	Operator
4. Bypass FCS	Close V1 & V2ST	Operator
5. Apply Start Power to Alt.	Energize Motor-Alt.	Auto
a. Hi Start Torque	Excite M-A for 2.5 P.U. Current	Auto
b. Motor	Excite M-A to Maintain ~33% spd	Auto
6. Remove Start Power Above Self Sust. Speed	De-Energize and Disconnect M-A At 40% Speed	Auto
B. BPS STARTUP (FROM EMERGENCY COOLING SYSTEM)		
1. Establish Coolant Flow	Open V21 & V23	Operator
2. Parallel BPS	Open V3 & V4	Operator
3. Initiate BPS Operation	Depress Start Switch	Operator
4. Inhibit ECS Pres. Reg	Inhibit SV2	(Form C, Relay Contact)
5. Inhibit Undertemp Bleed	Inhibit SV4	Auto
6. Limit Turbine Inlet Temp to 1450°F	Open SV7 as Required	Auto
7. Apply Start Power to Alt.	Energize Motor Alt	Auto
a. Hi Start Torque	Excite M-A for 2.5 P.U. Current	
b. Motor	Excite M-A to Maintain 33% Speed	
8. Remove Start Power Above Self-Sust. Speed	De-energize and Disconnect M-A At 40% Speed	Auto
C. <u>NORMAL BPS OPERATION</u>		
1. Control Turbine Inlet Temp, T6.5	T6. >1450, Open SV7 T6. >1375, Open SV3 T6. <1325, Open SV4	Auto Auto Auto
2. Control Alternator Voltage	Control Field Excitation	Auto
3. Control Speed	Control Parasitic Load Open Small By-Pass Valve (SV5) If Output Exceeds Alt. Rating	Auto Auto
D. <u>SHUTDOWN</u>		
1. Open Turbine By-Pass (SV6)	Depress Stop Switch	Operator
2. Signal Main System	Provide Signal	Form C Relay Contact
3. Turn Off Coolant Flow		Operator
4. Close V3 & V4		Operator
E. <u>EMERGENCY SHUTDOWN</u>		
Shutdown for Following Abnormalities:		
High Compressor Inlet Temp	By-Pass Turbine (Open SV6)	Auto
High Turbine Inlet Temp	Inhibit SV4	
High Journal Brg. Temp	Inhibit Alt. Excitation	
High Thrust Brg. Temp		
High Alternator Temp	Signal Main System	Form C Relay Conts.
Overspeed

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The driver circuitry provides the interface to convert the low level logic signals to 24 VCD driver signals for the control relays which in turn control the lights, valve solenoids and fields.

The signal conditioning converts the miscellaneous engine parameters from millivolts, ac voltages, ac currents and frequency to 0 to 5 volt analogs. These signals are used as input for the control logic and meters and are buffered to provide signals to the customers data acquisition system (DAS) for use in system performance evaluation.