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LMFBR HOT CELL REFUELING COMPONENT TESTS

THIRD QUARTERLY REPORT
JULY-SEPTEMBER 1972

U.S. ATOMIC ENERGY COMMISSION
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**LMFBR HOT CELL REFUELING COMPONENT TESTS
THIRD QUARTERLY REPORT
JULY—SEPTEMBER 1972**

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ABSTRACT

The work performed under PA-63, LMFBR Hot Cell Refueling Component Tests Program, is directed to demonstration of acceptable performance, service life, repair, and maintenance techniques of the generic components which could be used in a hot cell refueling system. This will be accomplished through environmental development tests of specifically designed equipment, such as the fuel transfer container, and commercially available equipment, which may be modified for hot cell use.

During this report period further thermal and stress analysis of the fuel transfer container was performed and planning was begun on the testing facility. Conceptual design work was completed on Test 3, solidified sodium properties, and Test 5, electrical power and control components, and detail design work was initiated on both tests.

1. INTRODUCTION

The PA-63 Program is a component development effort to test, develop, and qualify generic components which would find use in an LMFBR hot cell refueling system. Program objectives include the demonstration by environmental tests of acceptable performance, service life, repair and maintenance techniques for these components. The environments to which these components may be subjected include ambient air conditions, extremely high purity argon, immersion in sodium pools, operation through the argon-sodium interface and in argon with sodium vapor.

An essential feature of the program is early identification and test of those items essential to the eventual design of the equipment to be employed in the hot cell refueling system.

2. SUMMARY

Based upon the Program Development Plan, issued in preliminary form as Appendix A of the Second Quarterly Report¹, work has begun on several of the tests and related support equipment. These activities include analysis of the fuel transfer container for thermal response and accompanying stresses, improvements to transfer container design, preliminary scoping of facility availability and requirements for container tests, and the design of the solidified sodium and electrical power and components tests. Definition of specific component requirements has begun and several preliminary component requirement data sheets are included in the appendix.

Detailed planning activities conducted in this period resulted in planning diagrams for each of the tests to be performed as a part of this program.

3. TECHNICAL ACCOMPLISHMENTS

3.1 TEST 1 – FUEL TRANSFER COMPONENT TESTS

3.1.1 Introduction

In an LMFBR Demonstration Plant hot cell fuel handling system, new and irradiated fuel assemblies are transferred between the fuel storage tank and the reactor vessel within an open, sodium-filled fuel transfer container. Fuel and blanket assemblies are loaded and removed from the fuel transfer container while the container is submerged in the sodium of the fuel storage tank or the reactor vessel. The container is moved between the reactor vessel and the fuel storage tank by a fuel transfer hoist. In order to confirm the fuel transfer container concept, and to identify areas of uncertainty that require additional design, it is necessary to perform a development program designed to determine the overall capability of the system.

The major objectives of the fuel transfer container development program are: (1) to demonstrate that the use of the fuel transfer container is a feasible method of transferring fuel and blanket assemblies between the vessel and the fuel storage tank, (2) to develop the capability of the fuel transfer container to dissipate the decay heat output from one irradiated fuel assembly being transferred from the reactor vessel under all probable conditions, (3) to develop the capability to provide adequate heating of the transfer container when transferring fuel or blanket assemblies without decay heat load, and (4) to develop and demonstrate a reliable means of handling the fuel transfer container.

3.1.2 Conceptual Thermal Design

As the transfer container is hoisted from the sodium bath in the reactor vessel or fuel storage tank, it will be immediately withdrawn into a section of the tube hoist containing heating and cooling devices designed to maintain temperature control.

As will be discussed in this report, the large thermal inertia of the container is adequate to prevent excessive temperature changes during the ~5 minute transfer from reactor to fuel storage tank or from fuel storage tank to reactor. The heating and cooling devices shown schematically in Figure 1 will be needed only in off-normal conditions when the time between reactor and fuel storage tank is somehow increased.

A ~10 kW radiant electrical heater is provided to maintain the transfer container close to the tank temperature of 400°F when the container is heated by a fuel assembly having insufficient decay heat. A blower maintains this temperature by forced convection cooling using the refueling cell argon when the transfer container holds a fuel assembly with high decay heat. Finally, should the blower fail, radiant heat transfer from an exposed area of the transfer container would prohibit the bundle from exceeding a maximum temperature of 1100-1200°F which would be attained ~4 hours after the loss of cooling. This latter temperature is less than the peak cladding temperature in service and thus should not harm the fuel. Thermal analyses carried out in support of the design are detailed below.

3.1.3 Lumped Transient Analysis of System

In this analysis, the transfer container is considered to be a single mass, M , at constant temperature, T . Heat is generated within the container at the rate, Q , and is removed by convection at the rate $UA (T - T_\infty)$ where UA is the conductance between the outer surface and the refueling cell and T_∞ is the refueling cell temperature. For a container heat capacity

$$(\rho CV)_{eq} = \sum_i \rho_i C_i V_i \quad (3-1)$$

the differential equation describing the container temperature is given by

$$(\rho CV)_{eq} \frac{dT}{dt} = Q - (T - T_\infty) \quad (3-2)$$

which, with the initial condition $T(0) = T_0$ gives

$$T - T_\infty = \frac{Q}{UA} + (T_0 - T_\infty - \frac{Q}{UA}) \exp \left[\frac{-UA}{(\rho CV)_{eq}} t \right] \quad (3-3)$$

The heat capacity $(\rho CV)_{eq}$ of the container, filled with 820 lb of sodium and containing a fuel bundle, is 400 Btu/°F. The heat conductance, UA , is made up of convective and radiative parts. The film coefficient for free convection off the upper exposed surface of the container at 400°F is found using the correlation for turbulent free convection²

$$Nu = 0.0210 (Gr Pr)^{0.4} \quad (3-4)$$

For an exposed container height of 6 ft, a surface temperature of 400°F, a sink temperature of 100°F and using argon properties, equation (3-3) yields $h = 0.65 \text{ Btu/h-ft}^2\text{-°F}$. For an exposed area $A_e = 17.3 \text{ ft}^2$ (the upper area not covered by the forced convection shroud)

$$(UA)_{convective} = 11.2 \text{ Btu/h-°F}$$

Figure 1. Internal Heat Transfer Model and Results

The conductance due to radiant transfer is given by

$$(UA)_{\text{rad}} = \frac{\epsilon \sigma (T^4 - T_{\infty}^4) \left(A_e + \frac{A_s}{3-\epsilon} \right)}{T - T_{\infty}} \quad (3-5)$$

where ϵ = emissivity
 σ = Stefan-Boltzmann constant
 A_e = area of full exposed surface
 A_s = area of surface shrouded by one layer of stainless steel

A conservative low emissivity of 0.4 is employed, which should be attainable without surface treatments.³ Taking as unshrouded area 2/3 of the upper 7.1 ft of surface area and as shrouded by one layer of steel the other 1/3 of the upper 7.1 ft,

$$(UA)_{\text{rad}} = 21.8 \text{ Btu/h-}^\circ\text{F}$$

and the total conductance is the sum of the radiation and convection effects

$$(UA)_{\text{Total}} = 33.0 \text{ Btu/h-}^\circ\text{F}$$

The conductance is variable with temperature but is approximately constant in the vicinity of the reference temperature, 400°F. Introducing $Q = 27.3 \text{ kW}$ and $T_o = 400^\circ\text{F}$ into Equation (3-3), a relation is derived describing behavior at or near a container temperature of 400°F with a fuel assembly emitting 27 kW of decay heat.

$$T = 2920 - 2520 \exp(-t/12.1) \quad (3-6)$$

where t is time in hours

Using equation (3-6), one can show that the temperature rise in the 5 minute period of a transfer operation is 17°F.

Were the transfer hoist to be stalled in an out-of-sodium position and were the blower to simultaneously fail to function, the transfer container would heat up to 550°F in 46 minutes as calculated by Equation (3-6). That temperature is of significance as the temperature at which visible vapor forms above a liquid sodium surface. The container temperature is asymptotic to 1100°F. As a point of reference, the time to reach 1000°F (calculated using a temperature varying UA) is 5.8 hours.

With a fresh fuel bundle, emitting no decay heat and with the radiant heater off, $Q = 0$ in Equation (3-3). In the 5 minute transfer time under these conditions, the container temperature will drop 2.1°F. Time to reduce the container temperature to the 203°F melting point of sodium with the heater inoperative would be 12.4 hours.

Table 1 presents a summary of the foregoing results. Numbers differ from those reported in the last Quarterly* due to the consideration of a larger container size in the present analysis.

Table 1
SUMMARY OF LUMPED TRANSIENT ANALYSIS FOR FUEL TRANSFER CONTAINER TEMPERATURE
INITIAL TEMPERATURE = 400°F

A. With 27 kW decay heat, blower off

Temperature rise in 5 minutes (normal transfer time)	17°F
Time to reach 550°F (visible sodium vapor temperature)	46 minutes
Time to reach 1000°F	5.8 hours
Steady-state temperature	1100°F

*loc. cit.

Table 1 (Continued)

B. With fresh fuel assembly, radiant heater off

Temperature drop in 5 minutes (normal transfer time)

Time to reach 208°F (sodium freezing point)

2.1°F

12.4 hours

3.1.4 Temperature Distribution Within Container

A computer analysis was carried out to determine ΔT between the fuel assembly center and the outer wall of the container (ignored in the lumped analysis of 3.1.3). Heat transfer was assumed to be by axial free convection and radial conduction. Figure 1 shows the model used to calculate the temperature distribution. The fuel assembly is assumed to reside at the center of the container whereas it is actually off to one side. A slug flow (constant axial sodium velocity) approximation is made and it is assumed that there is upflow in the fuel assembly and downflow in the fluid annulus surrounding it.

Referring to Figure 1, a heat balance for centerline node i (not including node 1 which is slightly different) gives

$$4 \pi k_{eq} (T_i - T_{i+1}) + \frac{\dot{m}C}{2\Delta z} (T_i - T_{i-3}) = q'_i \quad (3-7)$$

where,

$\dot{m}$	=	Sodium mass flow rate
C	=	Sodium specific heat
Δz	=	Axial distance between nodes
q'_i	=	Linear heat generation rate, node i

k_{eq} is the equivalent radial thermal conductivity of the fuel assembly. Assuming that the fuel rods conduct negligible heat compared to the sodium, a geometrical argument as illustrated in Figure 2 gives an approximate expression for the equivalent thermal conductivity which yields, for a pitch to diameter ratio of 1.24,

$$\frac{k_{eq}}{k_{Na}} = 0.212 \quad (3-8)$$

A heat balance for fuel assembly outer wall node gives

$$4 \pi k_{eq} (T_i - T_{i-1}) + \frac{2 \pi k_{Na}}{\ln(b/a)} (T_i - T_{i+1}) = 0 \quad (3-9)$$

Finally, a heat balance for the container outer wall nodes (not including node 30) gives

$$\begin{aligned} & \frac{2 \pi k_{Na}}{\ln(b/a)} (T_i - T_{i-1}) + \frac{\dot{m}C}{2\Delta z} (T_i - T_{i+3}) \\ & + h P f_i (T_i - T_{\infty}) + \sigma \epsilon P g_i (T_i^4 - T_{\infty}^4) = 0 \end{aligned} \quad (3-10)$$

where,

h	=	film coefficient for free convection off the container outer wall
P	=	outer perimeter of the container = $2\pi b$
f_i	=	fraction of outer perimeter exposed to free convection
σ	=	Stefan-Boltzmann constant
ϵ	=	emissivity of container outer surface
g_i	=	fraction of outer perimeter exposed to radiant heat transfer
T_{∞}	=	hot cell temperature
a	=	defined in Figure 1
b	=	defined in Figure 1

Estimate equivalent thermal conductivity for a hexagonal array of cylindrical holes normal to the axis of the holes.

Approximation—assume heat path is as wide as the minimum separation as $= P - D$, as shown

$$\text{Heat Path length in unit cell} = \frac{\pi P}{3}$$

$$Q = \frac{kA\Delta T}{l} = \frac{k_{Na} (P - D) \Delta T}{\frac{\pi P}{3}} = \frac{(k_{equiv}) P \frac{\sqrt{3}}{2} \Delta T}{P}$$

or

$$\frac{k_{equiv}}{k_{Na}} = 1.10 \left(1 - \frac{D}{P}\right)$$

Figure 2. Derivation of Equivalent Thermal Conductivity Normal to the Axis of Fuel Rods

The driving force for free convection is the difference in average density between the sodium in the fuel assembly and the sodium in the surrounding annulus. This is equal to the frictional pressure loss, assumed to occur wholly within the fuel region of the fuel assembly

$$\Delta \bar{\rho} \frac{g}{g_0} L = f (Re) \frac{L_f}{D_H} \frac{\rho V^2}{2g_0} \quad (3-11)$$

where

$\Delta \bar{\rho}$	=	difference in average densities of sodium in annulus and sodium in fuel assembly
g	=	acceleration of gravity
g_0	=	proportionality constant
L	=	bundle length
f	=	smooth pipe friction factor
L_f	=	fuel column length
D_H	=	hydraulic diameter of fueled region
ρ	=	sodium density
V	=	sodium velocity through fueled region
Re	=	Reynolds number in fueled region.

Knowing the temperature distribution, one may calculate the sodium velocity in the fueled region from Equation 3-11 from which the mass flow rate can be calculated directly. Since temperatures are dependent on mass flow rate, iteration is required for solution.

In the test case run, the outer diameter of the container was taken to be 14 inches, the fuel assembly outer diameter to be 4.3 inches, and the total container length to be 14.5 ft. The 30 inch long fuel column emits 27.3 kW. The container is shrouded completely up to the top of the fuel column and is 1/3 shrouded above that point. Emissivity was taken equal to 0.4. The resulting temperature distribution is shown in Figure 1. Higher or lower temperatures can be produced by changing the area of the shrouded region. The calculated Reynolds number in the fuel region is 3700, barely into the turbulent range. In the range $2000 < Re < 4000$, the computer program used, for the friction factor

$$f = 0.032 + 0.008 \frac{(Re - 2000)}{2000} \quad (3-12)$$

The fact that the Reynolds number is in the turbulent range will allow the use of an orifice plate to duplicate the flow resistance characteristic of the fuel rods.

3.1.5 Thermal Stresses

Primary stresses in the transfer container will be very low. For instance, for a vessel with a 0.25 inch wall thickness, the maximum longitudinal stress due to the weight of sodium, fuel assembly and the container itself is 180 psi. Stresses in support plates will be higher but can be kept acceptably low by choice of the plate thickness. The only life limiting stresses generated during the life of the vessel are expected to be the thermal stresses generated when the vessel, heated to a high temperature due to simultaneous hoist inoperability and blower malfunction, is lowered into a 400°F sodium pool. At the instant of contact between the vessel outer wall and the sodium, the interface assumes a temperature intermediate between the sodium and vessel material temperature while the vessel inner wall retains its original temperature. The ΔT across the vessel wall causes thermal stresses which, if large enough, may fatigue the vessel material. The temperature instantaneously assumed at the interface is derived below.

Consider two semi-infinite solids (see Figure 3) with different densities, ρ specific heats, C , and thermal conductivities, k . Relative to the coordinate system shown, the temperatures are described by

$$\frac{\partial^2 T_1}{\partial x_1^2} = \frac{\rho_1 C_1}{k_1} \frac{\partial T_1}{\partial t} \quad (3-13)$$

$$\frac{\partial^2 T_2}{\partial x_2^2} = \frac{\rho_2 C_2}{k_2} \frac{\partial T_2}{\partial t} \quad (3-14)$$

Figure 3. Two Semi-infinite Solids with Differing Thermal Properties

Continuity of heat flux at the boundary gives,

$$k_1 \frac{\partial T_1}{\partial x_1} (0, t) + k_2 \frac{\partial T_2}{\partial x_2} (0, t) = 0 \quad (3-15)$$

An equality of temperature at the interface for times greater than zero is required

$$T_1 (0, t) = T_2 (0, t) \quad (3-16)$$

Taking, for the initial temperatures of the two bodies

$$T_1 (x_1, 0) = T_0 \quad (3-17)$$

$$T_2 (x_2, 0) = 0 \quad (3-18)$$

The equations may be solved for the interface temperatures by using Laplace transforms, giving,

$$\frac{T_1 (0, t)}{T_0} = \frac{(\rho_1 C_1 k_1)^{1/2}}{(\rho_1 C_1 k_1)^{1/2} + (\rho_2 C_2 k_2)^{1/2}} \quad (3-19)$$

Letting material 1 represent sodium and material 2 represent 18-8 stainless steel, and inserting property values evaluated at 400°F

$$\frac{T_1 (0, t)}{T_0} = 0.53 \quad (3-20)$$

Thus of a total temperature drop from the bulk stainless steel to the bulk sodium, 53% of the temperature drop takes place across the stainless steel and 47% across the sodium.

At the instant of sodium-steel contact, there is a step change in temperature at the steel component's surface. The thermal expansion of the surface is completely constrained and in the elastic regime stresses in directions parallel to the surface are given by

$$\sigma = \frac{\alpha E \Delta T}{1-\nu} \quad (3-21)$$

where

- α = thermal expansion coefficient
- E = Young's modulus
- ΔT = temperature drop across component
- ν = Poisson's ratio

Inserting values for α , E , ν , and the stainless steel yield stress of 35,000 psi, it can be seen that some yielding occurs when the temperature drop across the metal exceeds about 75°F. This corresponds to a temperature difference between the bulk sodium and the steel prior to contact of $75/0.53 = 141^\circ\text{F}$.

The ASME code allows yielding due to "local" thermal stresses to take place repeatedly, but the use of the vessel may be limited to a certain number of cycles by fatigue considerations. The normal 5 minute transfer allows a temperature difference to develop between the container and the reactor or carrousel of only $\sim 17^\circ\text{F}$ and the fatigue life under these conditions is virtually infinite because thermal stresses are well below the yield stress. It is of interest to calculate the number of cycles the container is allowed under the code for the most extreme condition when the container, due to equipment malfunction, has been left out of the sodium baths for many hours with decay heat of 27 kW, with the blower inoperative. The vessel wall reaches 1100°F and when the container is submerged in the sodium bath at $\sim 400^\circ\text{F}$, the maximum temperature drop across the vessel wall is $0.53 (1100-400) = 370^\circ\text{F}$.

A Section III, Class 2 pressure vessel designed to the rules of Section VIII, Division 2 is limited to 83 cycles if it contains only integral attachments (no partial penetrations, welds, etc.) or 33 cycles if it contains non-integral attachments. However, the rules of Section VIII do not allow operation over 800°F .

Code Case 1331-7 (August 15, 1972) covers operation of a Section III Class I vessel above 800°F . This code case restricts accumulated inelastic strains averaged across the metal thickness to less than 1%. As the hot transfer container is lowered into the cooler sodium pool, it is conservative to assume that the cooler metal pulls the hotter metal inward, yielding the hotter metal but not the cooler. This being the case, the container diameter will ratchet inward every cycle by an amount $\alpha\Delta T$ (ignoring elastic strains which are relatively small in comparison to the inelastic strains). The allowable number of cycles under this rule, for a ΔT of 370°F is

$$N = 0.01/\alpha\Delta T = 2 \text{ cycles} \quad (3-22)$$

Because of tight tolerances called for in the present design of grapple engagement region of the container, it will be necessary to limit the allowable number of accident cycles (1100°F transfer container into 400°F sodium) to a low number even if the code case were not applicable.

The grapple engagement design will be further developed during detail design with the objective of relaxing tolerances where practical.

3.1.6 Possibilities for Scale Model Testing

It does not seem desirable to test a scale model of the transfer container. Conduction heat transfer scales as

$$Q \propto \ell \Delta T \quad (3-23)$$

where Q is heat generated in the container, ℓ is a characteristic length and ΔT is a characteristic temperature difference. Radiant heat transfer scales as

$$Q \propto \ell^2 T^4 \quad (3-24)$$

For scale model temperatures equal to actual temperatures, Equation (3-23) requires that heat output be proportional to ℓ while (3-24) requires heat output proportional to ℓ^2 . These requirements cannot be simultaneously met. Therefore, a major goal of the experiment to determine the maximum fuel assembly temperature under a loss of forced convection cooling, would be impossible.

A second difficulty is that for similitude of free convection in both the sodium and in the argon, the Grashof number, $\rho g \beta \Delta T \ell^3 / \mu^2$, should be the same between scale model and actual design. For ΔT the same in model and actual design, this is clearly impossible.

3.1.7 Mechanical Features of Design

Figure 4 shows a layout of the most recent design concept. In comparison to the design concept presented in the previous Quarterly*, the present design concept minimizes stress concentrations in the outer vessel through the use of generous radii, gradual thickness transitions and full penetration welds in order to increase the container's ability to withstand thermal stresses induced in the vessel under abnormal conditions (see Section 3.1.5). Since ability to survive high thermal stresses will be an important test objective, it is important that the container design tested be as close as possible to the final Demo Plant design. The present design is considered to meet this criterion. Only minor modifications to the bottom support plate have been made to allow insertion of an electrically heated fuel assembly mock-up suspended by the top grapple instead of a real fuel assembly supported by the bottom support plate.

The entire internal structure, with the exception of the siphon pipe, is designed to be removable for ease of post-test inspection in the development phase and for ease of part replacement in service should that ever prove necessary. The siphon has been designed to withstand side loads imposed by a fuel assembly being lowered into the container. The development test version of the siphon cap is removable to facilitate testing of various siphon concepts.

3.1.8 Test Arrangement Description

Preliminary plans have been developed for the transfer component testing program. At the start of the program, the transfer container will be soaked at 800°F in the sodium tank to be built into the SEFOR mock-up refueling cell. This will produce sodium wetting, expected to be the surface condition under actual LMFBR operating conditions (see Figure 5).

Then the grapple and its attached electrically heated fuel assembly mock-up will be lowered into the container at 400°F (see Figure 6). The grapple will be engaged and the container withdrawn into the temperature control system (see Figure 7). The temperature control system consisting of blower, radiant heater, and radiant heat transfer windows, will be tested in normal and abnormal operating modes. Normal operation will be tested with the fuel assembly mock-up heater on and the blower on, and with the fuel assembly heater off, but the radiant heater on (see Figures 8 and 9). Abnormal operation will be tested with both the fuel assembly heater and the radiant heater off (to test the rate of cooldown under these conditions), and with the fuel assembly heater on and the blower off (to test the rate of heatup and final steady state temperature under accident conditions), (see Figures 10 and 11). Finally, operation under the most severe transient thermal conditions will be tested when the 1100°F container is repeatedly lowered into the 400°F sodium bath (see Figure 12).

3.1.9 Test Grapple and Fuel Heat Simulator

The thermal tests proposed for the fuel transfer container call for the container to be immersed in a sodium-filled vessel, heated to ensure sodium wetting, and then removed from the vessel for the heat transfer tests. During the tests heat will be supplied to the container by an electrically heated bundle designed to simulate fuel decay heat and fuel assembly hydraulic characteristics. Section 3.1.8 describes the test arrangement. A scope drawing (Figure 13) of the test grapple and fuel heat simulator has been prepared. This figure includes the grapple, fuel heat simulator, and some of the instrumentation and the fuel transfer container (shown in phantom). The fuel transfer container shown is not the latest design described in Section 3.1.7, Figure 4, but the interface areas between the container and the grapple and heater are the same for either design. The top lift arrangement shown is one eye nut for single cable lifting. This scope design will be further reviewed and developed during the design of the test setup and facility interfacing.

The fuel heat simulator consists of 19 electrical heaters extending inside a fuel channel. The heated portion of the simulator is located at the same elevation as the core fuel portion of a nuclear fuel assembly. The fuel assembly lower nose piece will be used with the simulator to facilitate sodium flow simulation through the assembly. The orificing holes and plates shown in Figure 13 are shown in concept only. An analysis will be performed to size the orificing so that the natural convection sodium flow rate of the heat simulator is equivalent to that of a nuclear fuel assembly. The fuel heat simulator is suspended from the grapple to facilitate electrical connection placement in a region not subject to sodium or sodium vapor deposit. A cover will be in place on the soak tank during soak periods due to the sodium vapor evolving from the soak tank at soak temperature (800°F). The electrical assembly cannot be in place in the fuel transfer container during container soak periods.

*loc. cit.

Figure 4. Internal Heat Transfer Model and Results

Figure 5. Sodium Wetting of Fuel Transfer Container at 800°F

Figure 6. Grappling of Container

Figure 7. Hoisting of Container Into Temperature Control System

FUEL ASSEMBLY HEATER AND BLOWER ON

Figure 8. Temperature Control System – Normal Operation Tests

FUEL ASSEMBLY HEATER OFF; RADIANT HEATER ON

Figure 9. Temperature Control System — Normal Operation Tests

FUEL ASSEMBLY HEATER OFF, RADIANT HEATER OFF

Figure 10. Temperature Control System — Abnormal Operation Tests

FUEL ASSEMBLY HEATER ON, BLOWER OFF

Figure 11. Temperature Control System — Abnormal Operation Tests

Figure 12. Transient Heat Transfer and Thermal Stress Test

Figure 13. Test Grapple and Fuel Heat Simulator

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Test instrumentation will also be suspended from the grapple with some instrumentation being fastened to the heater bundle. The instrumentation designed to monitor container temperature during normal plant operation is also included in the test grapple. Instrumentation placement will be determined during the detailed design phase of the grapple-heater assembly.

The mechanisms to actuate the grapple are foreshortened due to the desire to keep the test apparatus as short as possible but are otherwise typical of a plant grapple system. A gear motor driven ball screw is used to actuate the ball latch mechanism. A bellows is placed between the moving actuator sleeve and the stationary body of the grapple to prevent sodium vapor from contacting the ball screw and the electrical and instrument connectors during high temperature phases of the heat transfer testing program when sodium vapor may be evolved.

3.1.10 Test Facility

The first tests planned using the environmental facility are the fuel transfer container heat transfer tests. Scheduling of the design, procurement, and construction of the facility is based on the schedule requirements for these tests and availability of funding.

Scope work began on the test cell facility design during this quarter. Major areas of investigation included: (1) general facility layout, dimensions and requirements, (2) sodium vessel dimensions, heat transfer characteristics, heating methods and structural considerations, (3) general argon system layouts, requirements and equipment such as coolers, monitors, compressors, reservoir and, (4) facility auxiliaries, such as lighting, viewing windows, man entrance chamber, and manipulators.

The environmental facility will be a gas-tight enclosure in which either assemblies or components, or both, can be tested. The facility will include a sodium system, an argon circulation and cooling system, and all required utilities. The facility will be designed to accommodate the planned development tests, and it will also be designed to accommodate modifications to the facility as development tests are changed or added due to equipment concept changes. As a result of the scope work done to date, Figure 14 represents the anticipated cell facility layout.

The cell steel wall inside dimensions are 15 ft 10 in. X 26 ft X 28 ft or approximately 8500 ft³ of enclosure with an additional 1500 ft³ (approximate) of external piping and tanks. Since present plans are to modify and reactivate the SEFOR Refueling Cell Mock-up in General Electric's Building D at San Jose, the only major modification will be replacement of the present "reactor vessel" with a 17 ft long X 32 in. diameter soak tank which will accommodate the fuel transfer container (FTC) of Test 1 while only requiring 700 gallons of sodium, that is presently in storage at the cell. The reactor vessel will have insulation (approximately 3 to 4 in.) contained within a stainless steel liner. The cell will be equipped with a man entry chamber, hoisting arrangement, lighting, and viewing aids such as mirrors, periscope, TV and windows. As previously mentioned the argon and sodium systems will be reinstalled and basically patterned after the old cell arrangement.

3.2 TEST 2—GRAPPLE ELEMENT LOAD TESTS

Work on this test is scheduled to begin in November 1972.

3.3 TEST 3—SOLIDIFIED SODIUM PROPERTIES TESTS

3.3.1 Introduction

The hot cell refueling concept utilizes mechanisms which must operate alternately under sodium (at ~400°F) and within the cell atmosphere (argon gas at ~80°F). The under sodium operation will involve mechanism entrapment of sodium which will freeze when exposed to the cell atmosphere. Mechanism design features will be used which will minimize adverse effects of this occurrence. However, since sodium entrapment and fouling cannot be totally prevented, design for hot cell operation must consider the forces necessary to break sodium bonds between moving parts and/or displace the sodium which has frozen within the mechanism. Freeze seal valve development work, performed by J. R. Folkrod and B. Misra of ANL⁴, has included shear strength determination within the range of interest for hot cell equipment design. However, data are needed for a broader range of test conditions and for other loading situations.

Figure 14. Test Cell Facility

Solidified sodium properties that relate directly to refueling and reactor servicing equipment design and operating conditions will be determined. Testing will include exploration of parameters pertinent to sodium drainage as well as physical properties determination for areas where sodium may be retained. This testing will be performed within a controlled atmosphere glove box situated over a sodium container. The sodium is supplied from a service loop which provides forced circulation, purity control, temperature control, and level control. Strength determinations will be made by "soaking" the test assembly in the sodium container at an elevated temperature to attain good coverage and "wetting" of the test surfaces, raising the assembly to drain off excess sodium and freezing the remains, and measuring the force required to move the test assembly parts.

3.3.2 Glove Box Assembly

The glove box arrangement is shown on Figures 15 and 16. It has two work stations, one primarily serving the area around the sodium vessel and the other serving the load and displacement test fixture. A gas tight seal joins the floor of the glove box to the upper region of the sodium vessel. This provides direct access to the sodium vessel while preserving the cover gas atmosphere. An evacuable chamber (Ante-Chamber), attached to the end of the glove box, enables test sample introduction or removal without contamination of the glove box atmosphere.

An atmosphere purification and pressure control system connected to the glove box provides moisture and oxygen removal capability down to 1 ppm. Sensitive pressure control provides for each of glove port operation, and, when interconnected to the sodium service loop, provides a simple means for level control in the sodium vessel.

The glove box assembly will be located near the sodium service loop at an elevation such that the sodium level in the vessel corresponds to that in the surge tank of the sodium service loop. As stated above, the sodium level is then readily controlled by connecting the surge tank cover gas region to the glove box atmosphere. The sodium service loop (an existing facility already in operation), provides forced circulation, temperature control, purification, and sodium inventory storage. The connection to the loop involves minimum modifications, i.e., surge tank cover gas line and valve, and sodium inlet and outlet lines with valves.

A small hand operated jib crane is provided to serve the sodium container end of the glove box. This device will aid in vessel cover and test sample handling.

Miscellaneous service penetrations, e.g., hydraulic lines, instrumentation leads, and 110 volt outlets, will be located at the back of the glove box assembly.

3.3.3 Load Test Fixture

The load test fixture shown on Figure 17 is designed to pull (or push) test samples apart at a constant velocity while providing a continuously recorded output of load and displacement. All parts of the load test fixture are mounted on a common base plate. A carriage assembly, guided for a 3-inch stroke on two precision ground shafts, is powered by a double acting hydraulic cylinder. One end of a test sample is attached to a load cell mounted on the carriage assembly and the other end is attached to an adjustable support which is then secured to the base plate. A potentiometer, mounted on the carriage, provides a displacement signal which, along with the load cell signal, is recorded on an x-y plotter.

3.3.4 Test Samples

Conceptual designs have been completed for a number of test samples. All are illustrated with positioning features necessary for maintaining alignment during the sodium soak and subsequent solidification process.

A double gap flat surface shear test sample is shown on Figure 18. The five bolts shown support the center coupon until the entrapped sodium has solidified. These bolts are then removed and the sample assembly is installed in the load test fixture using the threaded stud of the center coupon and the tapped hole of the external coupon assembly as attachment points. Shear strength testing for various gap widths is accomplished by using a common external coupon assembly with center coupons of differing thickness.

828E787

Figure 15. Glove Box Arrangement

828E787

Figure 16. Glove Box Arrangement

Figure 17. Load Test Fixture

159C4875

Figure 18. Sodium Test Sample

The cylindrical gap shear test assembly is shown on Figure 19. The center coupon in this assembly is held in place laterally by a centering bolt at the bottom and by a centering cap at the top. The tension strap and jack-screw, in conjunction with the centering bolt at the bottom, provide axial positioning of the center coupon within the external coupon. After sodium solidification, the sample assembly is prepared for load testing by removing all parts except the center and external coupons. With the tension strap assembly out of the way, the centering cap is removed by jack-screw action lifting the cap while bearing against the top end of the center coupon. Break-away force between the centering cap and external coupon during cap removal is transmitted through the center coupon and lower centering bolt thereby avoiding unnecessary loads on the frozen sodium bond. The last part to be removed prior to testing is the centering bolt at the bottom of the assembly. The assembly is installed in the load test fixture using the tapped holes at each end. Various gap widths are tested by using center coupons of differing diameters.

The sodium test sample shown on Figure 20 is used to determine extrusion forces required to displace frozen sodium from between two surfaces. After the sodium has frozen, the samples are removed from the holding fixture by removing the jam nuts and alignment frame while securely holding the two halves of the test assembly. The sodium gap width is established by how the jam nuts are adjusted during setup. The major area of interest for this sample is to determine the force-displacement relationship starting with large gaps and forcing the test samples together.

The ball-lock grapple mechanism is typical of the grapple concepts considered for hot cell refueling systems. The test sample shown on Figure 21 is designed to provide information on loads required to force a ball out to the "locked" position in the socket when the ball and socket assembly is loaded with frozen sodium. After the sodium has frozen, the ball-holder centering bolts and ball positioner will be removed. This operation will not unduly load the sodium region to be tested because of the minimum bond area between ball and ball positioner. Load-displacement data are then collected while a rod mounted in the load test fixture is used to push the ball into the socket. Testing with different ball and socket sizes will require separate assemblies of this concept.

The sodium grapple test shown on Figure 22 is a follow-on to the ball and socket test. This test will enable prototypic application and checkout of the shear strength and extrusion test data of the other test samples. This sample is prepared for load testing by removal of the centering bolts and installation in the load test fixture utilizing the threaded studs at each end.

The sodium test sample holder shown on Figure 23 is used as an aid in removing the various sodium test samples from the associated positioning and alignment fixtures. This sample holder will be located inside the glove box assembly as shown in Figure 16.

3.4 TEST 4—SODIUM-ARGON INTERFACE COMPONENT TESTS

Work on this test is scheduled to begin in February, 1973.

3.5 TEST 5—ELECTRICAL POWER AND CONTROL COMPONENT TESTS

3.5.1 Introduction

Test 5 will provide data on the performance characteristics, operational capability, reliability, and life of cable reels, cable tracks, cable festooning components and bus conductor-collector systems for use in a typical hot cell refueling system. Operation in an atmosphere of high purity argon with periodic exposure to and operation in breathable atmospheres will be conducted on package 1. The second package will continue the investigations begun with the first package, but will introduce sodium vapor as a contaminant to the high purity environment. The nature and extent of testing on the second package will be influenced by results of the tests on the first package, as well as findings from other tests on the overall sodium vapor activity which may be found in the refueling cell.

These tests will verify the suitability of typical commercially available components for the applications specified under PA-63. They will also determine those areas of design or manufacture of such items where modification or changes may be necessary to obtain adequate performance for hot cell application. The tests will also qualify these elements for use in LMFBR hot cell refueling systems. In addition, these tests will serve to point out areas in which existing standards or specifications for components require improvement or reinforcement.

VIEW A

Figure 19. Sodium Test Sample

153C5188

Figure 20. Sodium Test Sample

FCF-325X166

159C488Z

Figure 21. Sodium Ball Socket Test

FCF-325X166

159C4890

Figure 22. Sodium Grapple Test

188F518

Figure 23. Sodium Test Sample Holder

Data will be provided by the tests to assist in the revision of existing standards or preparation of RDT standards as may be deemed appropriate. These specifications will then permit procurement in a manner reflecting the character of the application.

3.5.2 Preliminary Component Requirements

Work was begun on the specific component requirements for elements to be tested in each component category. These requirements will describe the operational conditions which the component will see in service, and define the necessary capabilities the component must have to successfully meet the application.

Sample preliminary component requirements will be found in Appendix A.

3.5.3 Test Design Description

Conceptual design of the test mechanism and the containing envelope for the high purity argon atmosphere has been completed, Figure 24. Testing will be accomplished on two separate devices, operating independently but mounted on a common supporting structure and within the same environmental envelope. One mechanism will perform mechanical testing of two cable reel assemblies simultaneously with accompanying provision for testing of slip ring-brush assemblies on those reels so equipped. The second mechanism, a guided, linearly acting platform which can cycle in both directions along a ten-foot length, will test two cable track assemblies, up to six sets of cable festooning trolleys, and up to four conductor bar runs.

3.5.4 Cable Reel Test

The cable reel test utilizes a grooved sheave driven by a reversible gear motor which alternately draws out the full length of cable carried on each reel. The cable pulled from one reel retracts onto the second reel. Mechanically the drive can exert a pull of 100 pounds of force on each cable, which is consistent with the maximum demand of cable reels in the sizes selected for testing. Depending upon the specific reel design, provision will be made to carry 35-amp current at 200 Vac by means of slip rings and brushes. A design utilizing no slip rings may also be employed and its circuit carrying capabilities can be used to provide instrumentation circuits for thermal characteristics data of the loaded reel operating in the argon atmosphere.

Initial operations will test with weather and dust-tight slip ring housings customarily employed on stock cable reel equipment. These stock housings are less complicated and more desirable to use, therefore they will be tested first. More completely sealed and protected housings are obtainable on equipment for special application. Should experimentation reveal a need for controlled environment within the slip ring housing, but isolated from the refueling cell, such equipment will be procured, tested, and modified, if necessary for the high purity argon environment. All equipment must be verified to ensure that electrical and thermal design standards are adequate for the environment.

3.5.5 Linear Drive Test

The linear element test mechanism will be used to cycle lengths of different cable track designs, festoon trolley elements, and bus-collector assemblies over a distance of 10 ft and return. Simulation of cable track action is an easy task; full simulation of all the random effects on a festooning system may not be possible but the design may include fixed tilting cams to impose some measures of the force irregularities that the festooned cable imparts to the carriers. Standard bus bar-collector systems will mount to the fixed and moving portions of the mechanisms.

Initial tests will be run utilizing standard bar configurations with brushes of materials currently recommended for vacuum or high altitude applications. Current capabilities, arcing, and other electrical characteristics will be measured with the mechanism halted as well as running. Wear characteristics will be closely monitored. Simultaneously, other brush materials will be procured and fabricated for additional tests, including those materials currently used in inert cell applications.

Miscellaneous equipment employed within the environment for test operation, such as cam rollers, gear reducers and drive motors, bearings, and drive cable will be secondary items of test; as tests progress changes in these items may be made to further verify their individual suitability in the test environment and to individually qualify them for refueling hot cell use.

Figure 24. Test 5 Electrical Power and Control Component Tests

3.5.6 Environmental Provisions

In order to meet the stringent high purity argon requirements and maintain these conditions within the test chamber an argon purification and circulation unit will be employed. This unit will be capable of lowering the moisture and oxygen content to approximately 1.0 ppm each and will also circulate the argon through the cell to ensure a uniform environment. A transparent plastic enclosure has been designed to retain the atmosphere around the tested items; this enclosure, retaining approximately 1-in. W.G. pressure will be employed on first package tests to minimize containing envelope costs. Access to tests will be limited with such a scheme, although tests are planned to be interrupted at intervals for inspections and for exposure to ambient conditions. In the event of unplanned shutdown of a specific part, pull pins will be provided so that rapid disconnecting of one set of elements may be done with a minimum duration opening of the envelope and loss of environmental integrity.

3.6 POWER TRANSMISSION COMPONENT TESTS

3.6.1 Introduction

The scope of this test series is the components and subassemblies of the power, power transmission and control, and the position sensing subsystems which will make up LMFBR hot cell refueling equipment. Components to be included in the test program are typical of power transmission systems applicable to the hot cell refueling equipment and include bearings, couplings, clutches, brakes, electric motors, seals, gears, solenoids, connectors and remote disconnects, hoist cable, chain drives, position sensors, and drive screws.

The goal of the power transmission component test series is to qualify for LMFBR hot cell service standard commercially available components or, where necessary, components and materials which have been developed for special applications (such as the space environment).

Environmental conditions for this series of tests will simulate the hot cell atmosphere during normal reactor operations and open-reactor refueling outages. Additional testing will be performed to determine the effect of cyclic changes in cell atmosphere and of impurities in the cell inert gas during normal and possibly off-normal operation conditions.

3.6.2 Test Planning

Work on Test No. 6 started in the last month of the report period (September). This work consisted of preliminary test planning and literature review. Work has not progressed to a point where significant accomplishments can be reported.

4. ADMINISTRATIVE

4.1 GENERAL PROGRAM

During this reporting period the Program Development Plans were reviewed and approved, and forwarded to AEC-RDT for review and comment. These plans will continually be reviewed and changes recommended as new information becomes available which has bearing upon planned tests.

Based on the Program Development Plans and the preliminary schedules they contained, detailed planning diagrams of proposed activities were prepared, reviewed and approved within GE.

AEC Form 189(a) was prepared for issue in this period.

4.2 QUALITY ASSURANCE STATUS

The Program Development Plan document was reviewed and approved by the Quality Assurance organization for inclusion and adequacy of quality verification requirements. The 189 forms for FY-73 have been reviewed by the Quality Assurance organization.

Quality Assurance personnel have performed counseling activities to assist the technical project engineer in determination of documentation requirements.

4.3 TRIPS

No trips were made during the report period.

4.4 VISITS

No visits were made during the report period.

4.5 CONTRIBUTORS

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APPENDIX A
PA-63 SPECIFIC COMPONENT REQUIREMENTS—I (Preliminary)
TEST 5

A. Component: Cable Track Elements**B. Typical Product and Manufacturers**

1. "Powertrac", Gleason Division, Maysteel Products
2. "Aerotrac", Aeromotive Mfg. Co.
3. "Gortrac", Gortite, A & A Mfg. Co.

C. Description

This element is a multiple cable carrier fixed at one end, with the other end attached to a moving carriage to which services are to be supplied. The carrier provides controlled action of the cables in a horizontal loop and provides protection from possible damage. Pull on the cables and requirements for cable strength are minimized because pull and push forces are transmitted through carrier links. The cable is also held clamped in position on the track at close intervals by spacer bars.

D. Specific Application Data

Cable track elements may be used in several specific applications to carry several cables for main power, control and instrumentation for the:

1. Closure transfer crane and auxiliary hoist, main bridge
2. Refueling hoist, bridge and trolley
3. Transfer hoist, bridge
4. Manipulator-TV transporter, bridge

E. Functional Requirements

1. Supply cables for bridges travelling 120 ft maximum.
2. Accommodate bridge speeds to 20 ft/min. maximum.
3. Carry 3 cables of 1.5-in. diameter and weighting 2-lb/ft each.
4. Be capable of 30-ft maximum unsupported length when carrying maximum load.
5. Intermediate support elements may be used for unsupported lengths greater than 30 feet.

F. Life Requirements

1. Capable of operating in high purity argon gas
 - a. Water vapor
 - b. Oxygen
 - c. N₂
 combined '2 ppm
- d. Potential exposure to sodium vapor TBD
- e. Normal ambient pressure — +1.0 to -2.0-in. water column
- f. Normal ambient temperature — 100°F ± 20°F
- g. Subject to 10 psi maximum high purity argon during cell leak check procedures
- h. Maximum temperature, 140°F
- j. Exposure to high purity argon will be alternated with exposure to air or breathable gas mixtures existing in Refueling Hot Cell between refueling outages.

PA-63 SPECIFIC COMPONENT REQUIREMENTS—I (Continued)

2. Capable of operating at TBD cycles per refueling cycle
3. Estimated refueling interval TBD
4. Durable for a design lifetime of 30 years

G. Service Maintenance and Repair Requirements

1. In-service inspection to follow each refueling cycle
2. Equipment to be replaced as an entity in the event of failure
3. Remote repair will not be required
4. Track to be permanently lubricated; no in-service maintenance to be performed

H. Materials Requirements

1. Materials, permanent lubricants, etc., to be radiation resistant
2. Compatibility with sodium vapor and sodium oxide or hydroxide will be a necessity.

J. Miscellaneous Requirements

PA-63 SPECIFIC COMPONENT REQUIREMENTS—II (Preliminary)

TEST 5

A. Component: Bus bar-collectors**B. Typical Product and Manufacturer**

1. "Insul-8", Insul-8 Corp., San Carlos, California
2. "Duct-O-Bar", Duct O Wire Corp., Long Beach, California
3. "Saf-T-Bar", Hawell Corp., Stratford, Connecticut
4. "Kant-Shok",
5. "Power Bar", Gleason Div., Maysteel Products

C. Description

This component is an electrical current carrying system designed to transfer control current between elements of the refueling cell equipment. The current transfer may be effected by either a sliding or rolling contact. Various bus conductor configurations are available, such as T-bar or Figure 8; the bars may be installed bare or in insulated coverings which expose only the surface upon which the collector rides.

Collectors may be supplied in single or double configurations depending upon system design, current requirements or reliability.

D. Specific Application Data

Bus conductor-collector systems may be applicable to all power and control circuits for crane and hoist bridge and trolley systems. In the GE Hot Cell Refueling System design these include services to:

1. Closure transfer crane, bridge
2. Closure transfer crane auxiliary hoist, trolley
3. Refueling hoist, bridge and trolley
4. Fuel transfer hoist, bridge
5. Manipulator-TV transporter, bridge

E. Functional Requirements

1. Linear travel of moving element-120 ft
2. Moving element speed, 20-ft/sec maximum
3. Provide full current carrying capability from standstill to 20-ft/sec
4. Current capability TBD amps per conductor
5. Voltage TBD Vac, TBD hz
TBD Vac, TBD hz
TBD Vdc
6. Voltage drop across system TBD % at maximum current
7. Bar spacing TBD inches maximum
8. Adapt to horizontal or vertical mountings
9. Capable of sustained operation in high purity argon
10. Collectors operate smoothly across track joints

PA-63 SPECIFIC COMPONENT REQUIREMENTS—II (Continued)**F. Environmental Requirements**

1. Ambient atmosphere: argon
 - a. Water vapor
 - b. Oxygen
 - c. Nitrogen
 } combine <2 ppm
5% maximum
2. Potential exposure to sodium vapor TBD
3. Ambient pressure — +1.0 to -2.0-in. water column
4. Ambient temperature — $100^{\circ}\text{F} \pm 20^{\circ}\text{F}$
5. Subject to 10 psi maximum high purity argon during cell leak check procedures
6. Maximum temperature, 140°F
7. Exposure to high purity argon will be alternated with exposure to air or breathable gas mixtures which may exist in the Refueling Hot Cell between refueling outages.

G. Life Requirements

1. Capable of operating at TBD cycles per refueling outage
2. Estimated refueling interval months TBD
3. Durable for a design lifetime on non-wearing parts for 30 years

H. Service, Maintenance and Repair Requirements

1. In-service inspections to follow each refueling cycle
2. Equipment to be operable after single brush failure 1 each circuit
3. Brush replacement is only allowable routine service operation
4. Remote repair or replacement will not be required

J. Materials Requirements

1. All materials of construction to be radiation resistant
2. Sliding or rolling contact elements TBD
3. Compatibility with sodium vapor and sodium oxide or hydroxide is required

K. Miscellaneous Requirements

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