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LMFBR HOT CELL REFUELING COMPONENT TESTS

FOURTH QUARTERLY REPORT
OCTOBER-DECEMBER 1972

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(04-3)189 PROJECT AGREEMENT 63

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Prepared for the
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ABSTRACT

The work performed under PA-63, LMFBF 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 detailed design of the fuel transfer container and the grapple-fuel heat simulator was completed. Design of the test setup, facility, and test support equipment for Test 1, Fuel Transfer Components Test, was continued. The experimental proposal and conceptual design for Test 2, Grapple Element Load Tests, was completed. The experimental proposals and detail designs for Test 3, Solidified Sodium Properties Tests, and Test 5, Electrical Power and Control Components Test, were completed. Work was initiated on the conceptual design for Test 6, Power Transmission Component 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 LMFBF 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, extremely high-purity argon, liquid sodium at 400°F, the argon-sodium interface, and 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

Detailed design work was completed on several portions of the tests and experimental proposals were written for Tests 1, 2, 3, and 5. Analysis was performed on the temperature control shroud for Test 1. The results of the analysis changed the scope design of the shroud from that originally planned. Design of the facility for Test 1 is progressing on schedule as planned. A detailed recommendation and justification for the use of the SEFOR Refueling Cell Mock-Up was prepared and submitted to the AEC for review.

A revised Program Development Plan — LMFBF Hot Cell Refueling Component Tests, Revision 2 dated November 1, 1972, was completed and submitted to the AEC for review. The major revision was the substitution of detailed Engineering Planning diagrams for the bar graph schedules previously issued, and the schedule was made consistent with 189a No. 13639, dated September 15, 1972.

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 practical 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 normal and accident conditions, and (3) to develop the capability to provide adequate heating of the transfer container when transferring fuel or blanket assemblies without decay heat load.

3.1.2 General

An experimental proposal was drafted for Test 1. Detail design drawings were completed for the fuel transfer container, grapple, and fuel heat simulator, and sent out for internal review. A modification to the RDT standard for core component pots was drafted.

3.1.3 Siphon Sizing Calculations

A siphon is included in the fuel transfer container design to lower the sodium inside the container to the level of the siphon inlet upon withdrawal of the container from the sodium pool (see Figure 1). As the sodium reaches that level, the siphon begins to suck argon and a gas lock forms which persists until the sodium has expanded upward to the top of the siphon. In the present design, this provides a buffer of 4 inches through which the sodium could thermally expand or slosh before spillage would occur. This is equivalent to a rise in temperature of 150°F.

The siphon is designed so that the siphoning action is completed before the outlet is exposed above the sodium level exterior to the transfer container when the withdrawal rate of the container from the surrounding tank of sodium is 20 ft/min. Two problems are solved by this requirement. First, a deflector is not needed at the siphon outlet to prevent outward streaming of the sodium and impingement on the temperature control shroud or other components. Second, submersion of the outlet eliminates the possibility of argon leakage into the siphon through the outlet.

The calculations detailed below indicate that the design requirements can be met with two sets of a "tube within a tube" type siphon as shown in Figure 1, each with the outer tube of 2-1/2 in. Schedule 40 pipe and the inner tube of 1-1/4 in. Schedule 40 pipe.

Referring to Figure 1, the differential equations describing the liquid level, h_i , in the transfer container during siphon operation are given by

$$\rho \frac{g}{g_0} (h_i - h_o) = K \frac{\rho V_s^2}{2g_0} \quad (1)$$

$$V_s = \frac{A_c}{A_s} \frac{dh_i}{dt} \quad (2)$$

$$h_o = -V_c t \quad (3)$$

Figure 1. Siphon Systematic Schematic

where,

- ρ = sodium density
- g = acceleration of gravity
- g_o = proportionality constant
- h_o = sodium height outside transfer container
- V_s = sodium velocity inside siphon
- A_c/A_s = cross-sectional area container/cross-sectional area siphon pipes
- K = siphon loss coefficient
- V_c = container withdrawal rate
- t = time

Combining equations (1), (2), and (3) yields

$$h_i + V_c t = C \left(\frac{dh_i}{dt} \right)^2 \quad (4)$$

where C is defined as:

$$C = \frac{K}{2g} \left(\frac{A_c}{A_s} \right)^2$$

Equation (4) may be integrated if it is assumed that the sodium level changes much faster on the outside than on the inside of the container, giving

$$h_i + V_c t \cong V_c t$$

Making this approximation, Equation (4) may be integrated between limits, giving

$$\int_0^{\ell_i} dh_i = - \left(\frac{V_c}{C} \right)^{1/2} \int_{t_1}^{t_2} t^{1/2} dt$$

or,

$$\ell_i = \frac{2}{3} \left(\frac{V_c}{C} \right)^{1/2} (t_2^{3/2} - t_1^{3/2}) \quad (b)$$

Equation (5) gives the time, t_2 , at which the internal sodium level is lowered to the siphon inlet level if the siphoning action commences at time t_1 . Time zero is defined as the point at which the container top breaks the exterior sodium surface. The time t_1 is defined in terms of the head of sodium necessary to prime the siphon, which initially contains a gas lock. Defining this priming head as ℓ_p it is noted that

$$t_1 = \frac{\ell_p}{V_c} \quad (6)$$

Also, the time of siphoning completion is required to be

$$t_2 = \frac{\ell_o}{V_c} \quad (7)$$

Combining (6) and (7) with (5), and solving for the siphon system size characteristics C,

$$C = \frac{4}{9} \frac{(\ell_o^{3/2} - \ell_p^{3/2})^2}{V_c^2 \ell_i^2} \quad (8)$$

The present transfer container design has $\ell_i = 1.4$ feet and the withdrawal rate, V_c is 0.33 ft/sec. The distance, ℓ_o , to the siphon outlet is chosen as 5.5 feet in order to maximize C without making the pipe excessively long for structural reasons. The major uncertainty is the priming head ℓ_p , for which sound data are not available. Informal experiments run with ~5/16 in. i.d. Tygon tubing and water indicate that in a siphon containing a substantial fraction of entrained gas bubbles in the fluid column, the liquid flow rate is very slow until the differential head is sufficient to produce a net downward movement of the large bubbles. These large bubbles span the tube bore during the initial flow phase and permit downward liquid flow only in a thin stream adjoining the tube wall. As flow increases the bubbles rise more slowly until their movement reverses and they are swept downstream and out of the siphon outlet. The siphon becomes full primed (bubble free) almost instantaneously. The experiment shows that in the small-bore Tygon tube, the priming length is less than 3 feet. For this reason ℓ_p is taken as 3 feet. It is uncertain how the small bore tube results extrapolate to larger pipe sizes without running (planned) water tests with larger pipe bores. The effect of underestimation of the priming length for design purposes would be to reduce the withdrawal rate V_c , meeting the design criterion of siphoning completion before the outlet orifice clears the sodium surface.

Inserting these values into (8), the necessary value of C is found as 127 sec²/ft. To find the necessary pipe size, the loss coefficient is calculated* as

$$\begin{aligned} K &= K_{\text{inlet}} + K_{\text{outlet}} + K_{90 \text{ degree elbow}} + K_{\text{annulus to pipe}} + f \frac{L}{D} \\ &= 0.05 + 1.0 + 0.25 + 1.0 + 0.014 \times 48 \\ &= 3.4 \end{aligned}$$

And, taking $g = 32.2 \text{ ft/sec}^2$ and $A_c = 143 \text{ in.}^2$, Equation (8) is solved for the siphon cross-sectional area, to give

$$A_s = 2.93 \text{ in.}^2$$

As the cross-sectional area of two 1-1/4-inch Schedule 40 pipes is 3.26 in.², the design criterion is met. Combined area of the two intertube annuli is 5.24 in.², well in excess of the amount needed.

3.1.4 Temperature Control Shroud Design

Detailed design of the temperature control shroud was initiated. The current design differs in several respects from the designs outlined in previous quarterly reports. In the earlier designs, "radiant heat transfer windows" or apertures in the shroud were present to enhance radiant heat transfer in the emergency condition of a blower failure. Also, a radiant heater was present at the bottom of the shroud to maintain the transfer container temperature near 400°F when it contained a fresh fuel assembly emitting no decay heat.

Design calculations have shown that unless almost all of the surface area of the transfer container is efficiently used for forced convection cooling, the blower horsepower requirements for removal of 27 kW of decay heat become excessive. Apertures in the shroud are difficult to seal against argon flow leakage. In some designs, large ducts would be required running parallel to the shroud along most of its length resulting in a bulky envelope for this part of the transfer hoist. It appears feasible to eliminate the apertures and the problems they cause by maintaining a solid shroud the full length of the transfer container. Heat transfer from the container under blower failure is then by radiant heat transfer to the shroud which in turn radiates to the cell environment. In this new design, resistance to radiant heat transfer of the shroud must be kept low by coating its inner and outer surfaces with a high emissivity material. The "black chrome" finish investigated by Atomics International¹ is a leading candidate. Tests on Type-304 stainless steel coated with the chrome finish material have a minimum emissivity of ~ 0.79 at 700 and 1000°F. This is true both before and after immersion in sodium and after post-immersion exposure to air.

The heat transferred off the outside of the transfer container per unit area is given by

$$q'' = \frac{\epsilon_c \sigma (T_c^4 - T_\infty^4)}{1 + 2 \frac{\epsilon_c}{\epsilon_s} - \epsilon_c} \quad (9)$$

where

ϵ_c = emissivity of transfer container surface

ϵ_s = emissivity of shroud, inside and outside

σ = Stefan-Boltzmann constant

T_c = temperature of transfer container surface

T_∞ = temperature of cell walls

* All coefficients except $K_{\text{annulus to pipe}}$ from L. Marks, *Mechanical Engineering Handbook*, 5th Edition, page 255.

Since the numerator of Equation (9) gives the heat flux from the transfer container in the absence of the shroud, the fraction

$$\frac{1}{1 + 2 \frac{\epsilon_c}{\epsilon_s} - \epsilon_c}$$

represents the fraction of that heat flux remaining in the presence of the shroud. Taking $\epsilon_c = 0.40$ and $\epsilon_s = 0.79$, the fractional heat flux, f , is found to be 0.62. The reduction in heat flux due to the presence of the shroud is only 38%.

The heat transfer computer code described in the previous quarterly report² was used to calculate the temperature distribution in the transfer container with the new shroud design under blower failure and a 27 kW heat load. The calculation was run with $\epsilon_s = 0.79$ and $\epsilon_c = 0.40$. The latter value is conservatively low in comparison with a value measured by Atomics International¹ of 0.59 for sodium-wetted Type-304 stainless steel at 1000°F. One sixth of the area of shroud is assumed to be insulated in the calculation to simulate the effect of the strip heaters which cover part of the shroud (as discussed below). Results are shown in Figure 2. In comparison with the previous design, the peak fuel temperature is reduced from 1170 to 1113°F. The quantity that is traded-off with the improved heat transfer under emergency conditions is the electrical heater power required to maintain temperatures near 400°F with a new fuel assembly. In the latter mode, poor heat transfer is desired. Since some margin remains between the calculated value and the desired maximum fuel temperature of 1200°F a practical design might include insulation of part of the shroud in order to reduce heating requirements with fresh fuel.

A "radiant heater" located toward the bottom of the shroud was proposed originally to maintain transfer container temperature at 400°F with new fuel. However, a locally concentrated heat source would produce difficult design problems, particularly with regard to thermal stresses in the shroud. These thermal stresses, caused by locally high shroud temperatures in the heated region, would limit the life of the structure due to fatigue damage. Furthermore, the high local temperatures would force the use of austenitic stainless steel in the shroud whose low thermal conductivity would further aggravate the thermal stress problem.

A simpler solution, though not one without possible problems, has been included in current concepts for the transfer container heating system. Several 1-1/2-inch wide, metal-clad ceramic strip heaters encircle the low carbon steel shroud spaced axially on 9-inch centers. The shroud material adjacent to the heated area acts as a fin to distribute heat axially, maintaining the shroud almost isothermal. If the shroud is maintained at 400°F, the almost fully enclosed transfer container must also be maintained at 400°F. The potential temperature differential in the heated shroud may be estimated from the formula³ for the temperature at the tip of a fin, T_T , given the temperature at the root T_R and the sink temperature T_∞ .

$$\frac{T_T - T_\infty}{T_R - T_\infty} = \frac{1}{\cosh (mL)}$$

where, for a wide rectangular fin rejecting heat from one of its two sides,

$$m = \sqrt{\frac{h}{kt}}$$

and,

h = unit surface conductance

k = thermal conductivity

t = metal thickness

L = fin length

Figure 2. Calculated Internal Temperature Distribution with New Shroud Design

taking,

$$k = 25 \text{ Btu/h-ft-}^{\circ}\text{F}$$

$$t = 0.0156 \text{ ft}$$

$$h = 3.0 \text{ Btu/h-ft}^2\text{-}^{\circ}\text{F (average over shroud surface at 400}^{\circ}\text{F)}$$

$$L = 0.375 \text{ ft.}$$

It is found that

$$T_R - T_T = 123^{\circ}\text{F.}$$

Thus, an overestimate of peak thermal stress in the structure is

$$\sigma = \alpha E \Delta T = 30,000 \text{ psi}$$

where

$$\alpha = 8.4 \times 10^{-6} \text{ }^{\circ}\text{F}^{-1}$$

$$E = 29 \times 10^6 \text{ psi}$$

$$\Delta T = 123^{\circ}\text{F}$$

This stress is well below the yield point and would present no fatigue problems.

The major drawback of the new design is the large amount of power which must be supplied to the shroud heaters to permit maintenance of the shroud and transfer container at 400°F with new fuel. If a high estimate of 0.89 is assumed for the shroud emissivity, the 58.6 ft² of shroud surface area radiates 12.1 kW at 400°F to cell environment, assumed to be at 70°F. An additional 3.9 kW are lost by free convection. However, with no external heat supply and new fuel, the high thermal inertia of the transfer container gives a rate of temperature decrease of only 25°F/h. Since the container will be transferred between sodium tanks in less than 1/4 hour the heater would be needed only during abnormal operating conditions. Possible savings in power requirements can also be made by maintaining temperatures with the shroud heaters at an intermediate temperature above the melting point of sodium, but below the 400°F container temperature. Very little or no fatigue damage results from the lowering of a 225°F transfer container into the 400°F sodium of the reactor or fuel storage tank so the penalty for maintaining the container at a lower temperature is small, for an event which will rarely occur.

3.1.5 Forced Convection Cooling Calculations

The temperature control system uses argon gas blown through the annulus between the transfer container and the shroud to maintain the container at 400°F under a decay heat load of 27 kW. If radial conduction and convection are assumed negligible, heat is removed by radiation and axial forced convection. The radiant transfer, Equation (9) with $\epsilon_c = 0.4$ and $\epsilon_s = 0.9$, amounts to approximately 3 kW when $T_c = 400^{\circ}\text{F}$. Thus, 24 kW remain to be removed by forced convection. The surface area of transfer container, not including the uppermost foot of length that is above the sodium level, is 55 ft². Assuming a mean temperature difference between the transfer container and the argon annulus of 275°F, the required film coefficient is given by

$$h = \frac{Q}{A \Delta T} = 5.4 \text{ Btu/h-ft}^2\text{-}^{\circ}\text{F} \quad (10)$$

The width of the annulus is chosen as 1.5 inches. A narrower passage would permit the use of a smaller blower, but 3 inches total clearance is employed to provide adequate allowance for bowing of the container and other misalignment problems. The necessary flow rate is related to the film coefficient by the relation for turbulent flow forced convection heat transfer in a duct⁴

$$St Pr^{2/3} = 0.023 Re^{-0.2} \quad (11)$$

where

St = Stanton number

Pr = Prandtl number

Re = Reynolds number

Taking for property values of argon at the mean film temperature of 250°F

$$\mu = 0.069 \text{ lb}_m/\text{h-ft}$$

$$k = 0.0125 \text{ Btu/h-ft-}^\circ\text{F}$$

$$\rho = 0.071 \text{ lb}_m/\text{ft}^3,$$

the required flow rate is found to be 1340 cfm. At this flow rate, the bulk temperature rise in the argon due to 24-kW heat input is 113°F. Thus, the assumed mean temperature difference of 275°F is consistent with a cell gas temperature of 69°F.

Pressure drop through the system is given by

$$\Delta P = K \frac{\rho v^2}{2g_0}$$

where

K = total loss coefficient $\cong 3.3$

$\frac{\rho v^2}{2g_0}$ = dynamic pressure

and the total pressure drop is 1.7 in. water.

Significant uncertainties exist in heat transfer correlations and it is prudent to increase the flow rate above the nominal value calculated and noted above. If a 30% uncertainty in h is assumed, a required flow rate of 1860 cfm is calculated from Equation (11) to provide an h value of 7.02. The assumed 275°F mean temperature difference is here consistent with a cell gas temperature of 84°F. This flow rate will cause a pressure loss of 3.2 in. water, but the requirement can be fulfilled by a 1.5-horsepower centrifugal blower. Blower horsepower can be more than halved if the calculation without uncertainties proves correct.

3.1.6 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. The test grapple and fuel heat simulator are shown in Figure 3. This figure includes the grapple, fuel heat simulator, a portion of the instrumentation, and the fuel transfer container.

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Figure 3. Grapple and Fuel Heat Simulator with Fuel Transfer Container

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 is designed 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 tank during 800°F soak periods to prevent possible sodium vapor deposition on other components. The electrical assembly cannot be in place in the fuel transfer container during container soak periods.

Test instrumentation is also 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 was determined during the detailed design phase of the grapple-heater assembly.

The grapple is a foreshortened version of the reference design. The shorter grapple is required to maintain a full scale test within the existing cell dimensions. A gear motor-driven ball screw is used to actuate the ball latch mechanism.

Detailed design drawings for the grapple and fuel heat simulator were completed and submitted for internal review.

3.1.7 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.

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 accommodate the planned development tests and it will also, with minor modifications, accommodate changes or added development tests, should equipment concepts change.

The facility recommended for this test is the SEFOR Refueling Cell Mock-Up in General Electric's Building D at San Jose, California. This facility requires only minor modification and refurbishment and was chosen after an extensive study of Argonne National Laboratory and Liquid Metal Engineering Center facilities indicated that this facility was the only one available which did not require quite extensive remodeling. Facility features and requirements are documented in the Program Development Plan revised November 1, 1972, and discussed in the third quarterly report, GEAP-13823-3. A "Program Facility Recommendation for Test No. 1 — Fuel Transfer Component Test" was compiled and submitted to the AEC in December 1972 to outline the GE recommendations and justification for using the SEFOR Mock-Up Cell for this test program.

Scope work has continued during this quarter on the facility layout drawings. Figures 4, 5, and 6 represent the present anticipated cell layout. The cell equipment includes a cell access hatch, lighting, television system, periscope, fuel transfer container drain line and boom, viewing windows, sodium soak tank, and bridge assembly.

In addition to the sodium soak tank and the bridge assembly, scope work was begun on the sodium, argon, and electrical systems.

Figures 7 and 8 of the sodium and argon systems demonstrate the emphasis which has been placed on simplicity, adequacy, and economy. The sodium system includes the soak tank, pressurized storage tanks, a sodium pump, a sodium purification loop, and surge tanks. The argon system includes a blower, recombiner-dryer purifier, heat exchanger, gaseous argon supply cylinders, and an O₂ and H₂O cell monitoring system. When practical, both systems have been designed to duplicate the former systems of the SEFOR Mock-Up. Also, every attempt has been made to utilize existing and readily available equipment, including the existing cell structure.

Figure 4. Plan View—Environmental Test Facility

Figure 5. Elevation B-B—Environmental Test Facility

Figure 6. Elevation C-C—Environmental Test Facility

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Figure 7. Sodium System for Environmental Test Facility

Figure 8. Argon System for Environmental Test Facility

3.2 TEST 2—GRAPPLE ELEMENT LOAD TESTS

3.2.1 Objectives

The grapple element load tests will determine latch element and component handle load capabilities and load-limiting parameters for the air operation case.

Load test information required for the grapple assemblies and the various elements includes:

- Load capability of various ball sizes and materials for representative mating part material, configurations and hardness
- Brinelling loads for candidate mechanism parts and configurations
- Confirmatory (or exploratory) operational testing of the grapple head assembly
- Socket retention of locking balls for representative tolerances and materials
- Drag forces and wear parameters for latch assembly parts subjected to relative motion while grappled to a load
- Configuration, deformation, and limiting load parameters for handles of components to be grappled

3.2.2 Justification

Grapple element load testing is required because design calculations are inadequate to cover the unique application and configuration of the loaded parts. The information from this test will be used to guide design, application, and maintenance of refueling and reactor servicing equipment. Such information is especially important in view of the range of operating conditions to which this equipment will be exposed. The grapple devices must operate across the sodium-argon interface. Sodium carryover resulting from this operation will subsequently be exposed to low-purity argon with various reactive elements (oxygen, moisture, carbon dioxide, etc.). Consideration of this exposure, plus the need to operate the equipment with clean but frozen sodium during an outage, leads to design features that minimize contact between moving parts within the grapple and between grapple-to-handle interfaces.

Grapple devices have been developed and proven for sodium-argon operation in other facilities. However, the requirements have been for operation in temperatures above sodium melting temperature. In this case, operation must be assured both in and out of sodium with below-freezing temperatures and degraded atmosphere when operating out of sodium. The application that comes close in this regard is SEFOR. However, in that case sodium-wetted handles were grappled and grapples did not operate under sodium. Therefore, the present application required for hot cell refueling imposes unique design and operational requirements that necessitate component development.

The ball-lock grapple device is one example for which load test data are required. This concept is a desirable choice for working through the argon-sodium interface because of the basic simplicity and, thus, limited potential for sodium entrapment and fouling problems.

3.2.3 General Description

The ball-lock, because of its inherent resistance to jamming, is the type of mechanism favored for use as an LMFBR grapple. However, because of the unique configurations and load applications, design calculations are inadequate and load testing must be performed. Each element of the ball-lock, Figures 9, 10, 11, and 12 (scope drawings), will be typically loaded to determine the damage thresholds as well as ultimate loads. Then, elements will be assembled into a representative grapple, attached to a fuel assembly handle, Figure 13, and the assembled chain loaded in a step-wise manner. After each load increment, the grapple will be unlocked and the handle disengaged. From this assembly testing in air, failure parameters will be identified in their order of importance. The parameters will be balanced and the grapple thus optimized.

192B4255

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SH NO.

Figure 9. Ball Crush Test

Figure 10. Ball Socket Test

159C4923

Figure 11. Brinell Test Fixture

159C4954

Figure 12. Edge Brinell Test

159C4955

-22-

Figure 13. Grapple Element Test Fixture

GEAP-13823-4

The "floating latch" grapple, a cousin to the ball-lock, will be tested as an assembly. Its configuration is such that element strengths can be determined by design calculations. The failure parameters for the mechanism as a whole, however, can be determined only by assembly testing.

Should it be necessary to operate the grapple while the grapple is loaded, it will be necessary to know the drag forces involved and the wear parameters. A fixture has been designed (Figure 14) which allows an adjustable load to be applied and the cam cycled in the grapple. Load and displacement will be recorded and wear phenomena will be observed.

3.2.4 Test Description

a. Ball Strength (for each ball size), Figure 9

A number of balls will be fractured between combinations of Type-304 and 17-4 stainless steel surfaces, with and without nitriding (compression loading).

b. Socket Strength (for each ball size), Figure 10

Sockets of Type-304 and 17-4 stainless steel with and without nitriding will be fabricated to the (representative high and low) tolerance limits. Stellite balls will be slowly pushed through the socket. Loads at which surface failure, yield, and ball loss occur will be recorded.

c. Brinelling Data (for each ball size), Figures 11 and 12

No Surface Treatment—The brinelling threshold will be determined for Type-304 stainless steel and various heat treatments of Type 17-4. Edge deformation threshold as a function of proximity and load will be determined.

Nitrided Surfaces—The brinelling threshold and surface deterioration loads will be determined. A dye checking inspection will be used to define the surface breakdown point.

d. Assembly Strength, Figure 13

A grapple assembly and prototypic handle will be used to determine the order and magnitude of the system's weaknesses. The grapple-to-handle joint will be stepwise loaded by increasingly higher separation forces. After each step, the joint will be unloaded and the grapple assembly checked for smooth and proper action and signs of damage.

e. Loaded Latch Drag, Figure 14

For the loaded latch element wear and drag force test, an internal handle will be spring loaded against a grapple. The load force will be set at several values. An external cam will lock the grapple and be subjected to cyclic linear motion relative to the grapple. The static and dynamic force required to achieve this motion will be monitored and recorded. Scoring and other symptoms of surface breakdown will be noted as a function of time.

3.2.5 Progress

Work on Test 2 was started in October 1972, and both the experimental proposal and the conceptual design work have been completed. Review of both packages is currently in progress.

A patent disclosure for a floating latch grapple was submitted. The grapple, essentially a hybrid of the ball-lock and collet finger, was designed especially for use in sodium environments. A layout, Figure 15, and detail design of this mechanism are currently underway.

159C4949

Figure 14. Drag Force Test Fixture

TITLE
FLOATING LATCH TEST FIXTURE

FIRST MADE FOR PA-63

QTY	PART NO.	NAME	DESCRIPTION, DWG. NO., MATL.
1	1	HOUSING	159C4962 GI
1	2	CAM	128D4318 PI
4	3	LATCH	159C4961 PI
1	4	ROD	192B4266 PI
1	5	HANDLE	159C4963 GI
2	6	SWING "C" WASHER	CAT# CL-2-SCW CARR LANE *

* OR ENGR. APPD. EQUIV.

3 REF.

SECTION A-A

(GI)

4 REF.

(5)

Figure 15. Floating Latch Test Fixture

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 $\sim 400^{\circ}\text{F}$) and within the cell atmosphere (argon gas at $\sim 80^{\circ}\text{F}$). 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 either break sodium bonds between moving parts or displace the sodium which has frozen within the mechanism, or both. Freeze seal valve development work, performed by J. R. Folkrod and B. Misra of ANL⁵, 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.

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 elevated temperature to attain good coverage and "wetting" of the test surfaces, raising the assembly to drain off excess sodium and freeze that remaining, and measuring the force required to move the test assembly parts.

3.3.2 Equipment Design

Scope drawings were completed and approved. Detail design drawings for the various test samples, sample holder, and load test fixture were completed and submitted for internal review.

An experimental proposal was prepared and circulated for internal review. The series of tests planned with various test samples is identified in Table 1.

Table 1
SOLIDIFIED SODIUM PROPERTIES TESTS

Test Title	Applicable Figure	Test Variations
Single-Shear Test	16	Gap Widths of 0.060, 0.030, 0.015, 0.005, 0.001 and 0.000 in.
Double-Shear Test	17	Gap Widths of 0.060, 0.030, 0.015, 0.005, 0.001 and 0.000 in.
Cylindrical Shear Test	18	Gap Widths of 0.060, 0.030, 0.015, 0.005, 0.001 and 0.000 in.
Compression-Extrusion Test	19	Initial Gap Widths of 0.125 and 0.060 in.
Tension Test	19	Initial Gap Widths of 0.125, 0.060, 0.030, 0.015, 0.005, 0.001 and 0.000 in.
Scraper Test	20, 21, 22	Four Scraper Configurations Shown
Ball-Socket Test	23	Force Ball into Socket and Force Ball out of Socket
Ball Lock Test	24	Force Ball into Socket and Force Ball out of Socket

159C4906

Figure 16. Single-Shear Test
-27-

Figure 17. Double-Shear Test

159C4876
CONT ON SHEET 34 RD

Figure 18. Cylindrical Shear Test

153C5188

FCF-325X166

Figure 19. Compression-Extrusion and Tension Test

Figure 20. Scraper Test (View 1)

- 1 MAT'L: ASTM A-276 304 SST
NITRIDE PER G.E. SPEC. 231909
TO A MINIMUM CASE DEPTH OF .0015-.0030
AND HARDNESS OF 90 ROCKWELL 15-N.

EXPLANATION OF SYMBOLS

THIS FEATURE SHALL BE SQUARE TO DATUM(S) A (POINT, LINE, PLANE, CYLINDER) WITHIN .XXX

MODIFIER

FEATURE CONTROL SYMBOL

DATUM IDENT SYMBOL

TRUE POS LOCATING DIM'S ARE BASIC
(NO TOLERANCE - THEORETICALLY EXACT)

MODIFIERS

- ① MAXIMUM MATERIAL CONDITION
- ② REGARDLESS OF FEATURE SIZE

GEOMETRIC CHARACTERISTICS & SYMBOLS

○ ROUNDNESS	∥ PARALLELISM	⌒ PROFILE - SURFACE
— STRAIGHTNESS	⊥ SQUARENESS	⊕ TRUE POSITION
⌒ FLATNESS	∠ ANGULARITY	◎ CONCENTRICITY
⊘ CYLINDRICITY	↗ RUNOUT	⊞ SYMMETRY

INTERPRETED PER ASME Y14.5-1994

Figure 21. Scraper Test (View 2)

192B4234

- 1 MAT'L: ASTM A-276 304 SST
 NOTE: NITRIDE PER G.E. SPEC. 231909
 TO A MINIMUM CASE DEPTH OF
 .0015-.0030 & HARDNESS OF
 90 ROCKWELL 15-N.

EXPLANATION OF SYMBOLS		
THIS FEATURE SHALL BE SQUARE TO DATUM(S) A (POINT, LINE, PLANE, CYLINDER) WITHIN .XXX		
$\perp$	FEATURE CONTROL SYMBOL	A DATUM IDENT SYMBOL
XXX	MODIFIER	
TRUE POS LOCATING DIM'S ARE BASIC (NO TOLERANCE - THEORETICALLY EXACT)		
MODIFIERS		
M	MAXIMUM MATERIAL CONDITION	
S	REGARDLESS OF FEATURE SIZE	
GEOMETRIC CHARACTERISTICS & SYMBOLS		
$\bigcirc$ ROUNDNESS	$\parallel$ PARALLELISM	P PROFILE - SURFACE
$-$ STRAIGHTNESS	$\triangle$ SQUARENESS	P TRUE POSITION
F FLATNESS	$\angle$ ANGULARITY	C CONCENTRICITY
C CYLINDRICITY	R RUNOUT	S SYMMETRY
INTERPRETED PER USAS Y14.5-1966		

Figure 22. Scraper Test (View 3)

159C 4832

Figure 23. Ball-Socket Test

159C 4890

Figure 24. Ball Lock Test

Design was begun on the sodium service loop tie-in for this test. This effort includes that equipment (sodium container, valves, piping, trace heating, etc.) to be added to a sodium test loop already in operation at San Jose, California.

3.4 TEST 4—SODIUM-ARGON INTERFACE COMPONENTS TEST

Engineering effort for Test 4 began during December 1972. Drafting effort on the conceptual design is scheduled to begin in January 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 in Phase 1. The second phase will continue the investigations begun in the first phase, but may introduce sodium vapor as a contaminant to the high-purity environment. The nature and extent of testing in the second phase will be influenced by results of the tests in the first phase, 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. In addition, these tests will serve to point out areas in which existing standards or specifications for components require improvement or reinforcement.

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 Experimental Proposal

The experimental proposal for Test 5 was prepared during this report period. This proposal documents the initial test phase requirements and justification, and supplements completed assembly and detail drawings.

3.5.3 Test Design Description

Assembly and detail drawings for the first phase of Test 5 were completed in November 1972 and are included as Figures 25 and 26 of this report. The segments of the test are essentially as described in the previous quarterly report.²

The atmosphere-containing envelope and test support table are shown on Figures 27 and 28. Since purging and purification of this configuration prior to each environmental run will be required, piping has been included for diffusing incoming gas at the base level, and removing the air being purged at the upper levels of the envelope. The low-velocity entrance and minimum mixing of air and purge gas, and the greater density of argon relative to air, will be utilized to minimize argon usage.

3.5.5 Test Operations and Test Cycle

A test period for Test 5 will initially include operation in air for 7 days, purging and cleanup of the contained gas after the cover is placed over the test assembly, and operation of the components in the high-purity argon atmosphere for 28 days. During this time period, under high-purity argon conditions, the linear travel mechanisms will operate approximately 20,160 cycles and travel 400,000 feet. The cable reel assemblies will operate approximately 6720 cycles per period for a travel of the cable of 672,000 feet. This may be compared to potential refueling hot cell component travel of approximately 26,000 feet of travel per refueling outage. Use of an approximate refueling outage period should permit changes to components as would be seen in the refueling cell. The large number of component operations possible during this simulated outage period of 28 days will provide an accelerated life test capability.

Figure 25. Cable Reel Test

Figure 26a. Hot Cell Refueling Component
Test 5, Sheet 1

Figure 26b. Hot Cell Refueling Component Test 5, Sheet 2

Figure 27. Test Support Table Cover

Figure 28. Table

3.6 TEST 6—POWER TRANSMISSION COMPONENT TESTS

3.6.1 Introduction

Transfer equipment appropriate to the operations to be performed in an LMFBR refueling hot cell includes:

- Reactor Closure (Shield Plug) and Reactor Internals Handling
- New and Spent Fuel Assembly Handling
- Manipulator Bridge or Wall Mounted Carriage
- Remote Television Camera Carriage
- Polar or Bridge Crane

This transfer equipment will be made up of electro-mechanical components mounted on a structural framework. In general, these components will be stock commercial components or stock components modified for service in the LMFBR hot cell environments.

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 the 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 or the food processing industry. RDT standards will be written to define the requirements for this equipment after the testing program has been completed; where it is determined that existing industrial standards are suitable, recommendations will be made for any necessary revisions to such standards.

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 operating conditions.

3.6.2 Test Description

The first phase of testing for Test 6 will be performed on a power transmission component package consisting of two drums powered by a single gear motor unit. The system will wind a loaded wire rope from one drum to the other and automatically reverse direction at the end of the wire rope when limit switches or proximity switches are tripped. Loading of the wire rope is accomplished with a pair of sheaves. The sheaves are in a common plane which is tangent to the surfaces of the drums. Both sheaves rotate freely with one sheave fixed in position and the other movable by powered ball screw jacks to load the wire rope and also the system components—bearings, gear motor, couplings, clutches, brakes, etc.

Instrumentation for the test will consist of atmosphere monitoring sensors and recorders, bearing temperature and bearing sound detection and recording, tension loading in the wire rope, number of cycles of operation, gear motor speed and lubricant temperature, etc. Instrumentation leads will be brought outside the test enclosure to the data recording equipment located on the test building floor. Controls for motor speed and for loading the wire rope will be located at a console outside the test enclosure.

Variable parameters in the first test phase of power transmission components include the environment atmosphere, wire rope tension, sheave diameter, and wire rope size. The general objectives of the first tests include:

- Determine the effects of the dry, inert gas-air cycle environment on unlubricated wire rope and on wire rope lubricated with non-standard lubricants such as solid-lubricants, plastic coating, and with radiation resistant oils.
- Determine leakage of gear reducer and bearing seals.
- Determine effect of dry, inert gas-air cycle on bearing and gear lubricants.

The second phase of testing will be the performance of similar tests but with the potential of exposure to sodium and its vapor. This test will be further defined when the needs and requirements are better defined.

3.6.3 Test Arrangement

The environmental box for Test 6 will be similar to the environmental box planned for Test 5. The box will consist of a steel frame base supporting a transparent plastic enclosure approximately 4 by 6 by 10 feet over the test package to control the test atmosphere. The enclosure will consist of two compartments: a test compartment plus an air lock. Entry into the test compartment is required to allow adjustment and modification of the components on the test package. The air lock will serve to minimize the effect of atmosphere contamination on the test compartment atmosphere. Sealable zipper closures will serve as doorways between the compartments and between the air-lock compartment and the outside air. Entry into the test enclosure will normally be made during or between test runs or during test runs when the test compartment has been purged with air and the atmosphere is breathable. Provisions may be made for air-pack entry into the inert atmosphere if found desirable during the test program.

Glove box glove ports will be positioned appropriately to facilitate making minor adjustments when material pass-through is not required.

4. ADMINISTRATIVE

4.1 GENERAL PROGRAM

During this reporting period, the Program Development Plan — LMFBR Hot Cell Refueling Component Tests, Revision 2, dated November 1, 1972, was prepared and submitted to the AEC for review. The major revision made at this time was the substitution of the detailed Engineering Planning diagrams for the previously published bar graph schedules.

4.2 QUALITY ASSURANCE STATUS

A PA-63 Program status review meeting with appropriate GE-BRD personnel was held at which overall program status was discussed and details of each of the six tests were presented.

The Engineering Planning diagrams are being reviewed for inclusion of the required interface information showing QA review, approvals, and inputs for the PA-63 Program.

A meeting of the Functional Classification Committee was held for the purpose of classifying the tests of PA-63. Each of the six tests was reviewed and classified to establish the level of QA required for test planning.

4.3 TRIPS

A trip to National Reactor Testing Station, Idaho Falls, Idaho, was made on October 12 and 13, 1972, by G. V. Brynsvold, K. R. Johnson, L. J. Nemeth, and L. F. Peterson.

The facilities visited in the course of this trip were the TAN Hot Shop, EBR-II, HFEF(S) and HFEF(N). These facilities all have some aspect of operation which is similar to operations required in an LMFBR refueling hot cell. During the trip, information was sought on equipment employed in the hot cells, contamination and cleanup experiences, preferences in materials used in the various hot cell systems, and operational and maintenance problems which have been found. Of particular interest was the new HFEF(N) facility, now in the final installation and checkout phase. Here all operations including all cell maintenance will be done remotely, in an argon atmosphere. Information was obtained on specific usages of materials and products, as well as the design and operational philosophies upon which the facility was based.

4.4 VISITS

No visits were made during the report period.

4.5 CONTRIBUTORS

A. L. Bashford
G. V. Brynsvold
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S. T. Oldberg
L. F. Peterson

G. R. Phipps
C. A. Smioldo
L. J. Nemeth
C. L. Larson

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