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LMFBR HOT CELL REFUELING COMPONENT TESTS

FIRST QUARTERLY REPORT
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LMFBR HOT CELL REFUELING COMPONENT TESTS
FIRST QUARTERLY REPORT

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ABSTRACT

The work performed under the PA-63 LMFBR Hot Cell Refueling Component Tests program is directed at demonstrating, through environmental development tests, acceptable performance, service life, repair, and maintenance techniques of components for hot cell refueling application.

Conceptual designs, including mechanical design and preliminary thermal analysis, were prepared on a fuel transfer container. Conceptual design layouts and design specifications were prepared for a fuel transfer hoist. Closure transfer crane conceptual drawings were revised and updated. Scope design and functional requirements for a refueling hoist were started.

A design specification was prepared for an environmental test facility to be used to run environmental tests on refueling equipment components. A design specification was prepared and a scope design initiated on a fuel assembly simulator to be used during various development tests.

1. INTRODUCTION

The purpose of PA-63 is to demonstrate through environmental development tests acceptable performance, service life, repair and maintenance techniques of components for hot cell refueling applications.

An LMFBR Nuclear Servicing system consists of components which function to receive new fuel, handle and transport fuel through the various steps to and from the reactor core, and finally to prepare it for shipment to the fuel reprocessing plant. The system boundaries are essentially the various containment barriers which enclose the fuel handling and reactor servicing activities occurring between the receiving and shipping docks and the reactor. The system includes all of the equipment utilized within these activity zones. The hot cell is directly above the reactor and the fuel storage tank. Figures 1 and 2 show the pertinent features of the system.

1.1 GENERAL DESCRIPTION

The nuclear servicing equipment system provides the means to safely handle fuel and reactor internals during all stages of refueling, shipping, and maintenance activities. This system also provides the necessary transfer ports and other portions of the containment barriers which are used to assure containment integrity during these operations.

New Fuel Handling — All new fuel is inspected upon receipt and later stored in a special storage tank. A new fuel transfer cask with an integral hoist, grapple, and shielding is used to withdraw the accumulated new fuel from its dry storage and move it into the reactor building for storage in the fuel storage tank.

Refueling Cell — A long rectangular steel-lined concrete vault provides biological shielding and containment over the reactor, fuel storage tank and component storage dry well. During open reactor refueling, a high purity argon environment is required for the in-cell atmosphere. However, during "at power" periods, higher levels of impurity are permissible, and a breathable atmosphere may be used for maintenance operations.

Transport traffic associated with reactor servicing is along the cell's major axis. The reactor closure is transported by a crane system operating on rails in the cell's upper region. Fuel is transferred between the core and submerged transfer containers at the reactor and between the fuel storage locations and submerged transfer container at the fuel storage tank by a refueling hoist system. The fuel transfer containers are moved between the reactor and fuel storage cavities by means of a transfer crane. Window locations adjacent to the various activity areas provide direct viewing capability for the operators stationed at their mobile control consoles. This direct viewing capability is further augmented by TV and periscopes.

During refueling outages the reactor closure is isolated from the refueling region to permit conversion to a breathable atmosphere and to provide ready access for contact servicing of control drives, instrumentation, and other reactor closure related components.

In the absence of a breathable atmosphere, personnel can still perform various in-cell activities requiring direct access by wearing face masks equipped with an air supply and exhaust system. Contamination control is facilitated by entry purge locks and attached portable clean rooms. Major outage repair efforts may warrant conversion of the refueling cell to air to permit access under more normal conditions.

Irradiated Fuel Handling — Irradiated fuel assemblies that have been placed in fuel storage tanks during a refueling outage are later removed and loaded into submerged transfer containers for transport to the service building where they are prepared for off-site shipment.

1.2 TASK SCOPE

The scope of this task is to provide a systematic, disciplined development program for the refueling system components. Specifically, the program is aimed at demonstrating the ability of the components to meet the operating requirements through (1) environmental development testing, (2) performance testing, (3) life testing, and (4) maintenance, recovery, and repair technique testing. Mechanical and electrical elements are to be selected from the refueling system components to perform service environmental qualification testing.

This work will be accomplished through identification of components requiring testing, performance of environmental qualification tests, and the preparation of equipment standards.

2. SUMMARY

Conceptual designs including mechanical design and thermal analysis were prepared on the fuel transfer container. These designs are being evaluated and additional thermal analysis is planned.

Conceptual design layouts and design specifications were prepared for the transfer hoist. The closure transfer crane conceptual drawing was revised and updated.

The refueling hoist scope design and functional requirements were initiated.

A design specification was prepared for an environmental test facility to be used to run development tests on refueling equipment.

A design specification was prepared and scope design initiated on a fuel assembly simulator (electrically heated fuel assembly) to be used during various development tests.

3. TECHNICAL ACCOMPLISHMENTS

3.1 TASK GD-4 FUEL TRANSFER CONTAINER

3.1.1 Introduction

In an LMFBR Demonstration Plant hot cell fuel handling system, new and irradiated fuel and blanket 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 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 design of the fuel transfer container concept it is necessary to perform a development program designed to determine the overall capability of the system for refueling and to identify areas of uncertainty that require additional design.

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 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 attachment between the fuel transfer container and the container grapple for movement about the refueling cell.

1. REFUELING HOIST
2. TRANSFER CRANE
3. OPERATING FLOOR
4. REACTOR CONTAINER
5. FUEL TRANSFER CONTAINER
6. FUEL ASSEMBLY
7. VIEWING WINDOW
8. FUEL STORAGE TANK

Figure 1. Refueling Cell Arrangement

Figure 2. Refueling Sequence

The design of the fuel transfer container will be required to meet the following requirements: (1) provide storage space for two fuel or blanket assemblies with sufficient clearance for assemblies with assumed distortion that will be taken from the Demo Plant core or blanket, (2) dissipate the decay heat output from one irradiated fuel assembly approximately 27 kW 2 days after shutdown under design conditions, (these conditions include loss of forced convection cooling with container suspended in refueling cell atmosphere or partially immersed in sodium), (3) provide adequate heating to prevent sodium freezing while transferring fuel or blanket assemblies without decay heat, (4) provide a reliable means of attachment to the fuel transfer container grapple, and (5) provide sufficient space for thermal expansion of sodium within the transfer container to prevent spilling of sodium during transfer between the vessel and fuel storage tank.

3.1.2 Mechanical Design

A conceptual design of the fuel transfer container which is being proposed for the development program is shown on Figures 3 and 4. The container, as shown, consists of a cylinder formed from a 1/8-inch thick plate containing axial convolutions or flutes to increase the surface area through which the decay heat from a fuel assembly can be transferred to the gas which will be forced over the outside surface of the container. The cooling gas is contained within a sheet metal shroud which surrounds the container. The fluted portion of the container shell is divided into three segments by two spacer plates to which the fluted shell is butt welded. A series of T-shaped bars fitting between the lobes of the container shell are provided for protection of the container. The cylindrical upper end of the container which incorporates the features for attaching the container to the grapple is welded to the T-shaped bars; these in turn are welded at the bottom of the container to a plate which supports the fluted container shell. In this design the container shell is free to expand thermally from the lower end without being restricted by the outer structure.

Preliminary heat transfer analysis has been done on the conceptual design (Subsection 3.1.3) and will continue as the conceptual design progresses. Detail design of the fuel transfer container prototype to be used in the development program will follow completion of the conceptual design.

3.1.3 Thermal Analysis

A fuel transfer container with longitudinal fins accommodating two fuel assemblies* was scoped. The reference fuel bundle design made up of 217 rods, 0.23-inch o.d. and 30.6 inches long, was used for determination of hydraulic parameters. A sodium temperature of 1500°F was calculated for the accident condition.

An investigation comparing the longitudinal fins with cylindrical spines (pins) was conducted. The important parameter in the comparison of spines vs longitudinal fins is the effective heat transfer coefficient. The bare surface heat transfer coefficient for spines is greater than for longitudinal fins due to the breakup of the boundary layer on each spine.

The following assumptions were used in the comparison of longitudinal fins vs spines:

1. Fin and spine height—3 inches
2. Longitudinal fin width—0.1 inch
3. Spine diameter, 0.250 and 0.375 inch
4. Thermal conductivity of stainless steel—12 Btu/h-ft-°F

* Although only one assembly at any time will be transferred, the fuel shuffling scheme within the vessels requires the two-assembly design.

The results of this comparison are:

	Bare Surface Heat Transfer Coefficient (Btu/h-ft ² °F)	Efficiency	Effective Fin Heat* Transfer Coefficient (Btu/h-ft ² °F)
Longitudinal Fins	0.82	0.87	1.5
Cylindrical Spines			
1/4-inch Diameter	3.9	0.48	5.8
3/8-inch Diameter	3.5	0.525	5.4

* Calculated by $h_{fi} = (\Omega A_f + A_o) \frac{h_f}{A_i}$ if A_i , A_o and A_f are assumed equal.

This analysis is to show relative magnitudes only (see Table 1 for nomenclature).

Table 1
SYMBOLS USED IN THERMAL ANALYSIS

A_o	Outside area with no fins or spines
A_f	Outside area with fins or spines
A_i	Inside area
Ω	Efficiency
h_f	Bare surface heat transfer coefficient
h_{fi}	Effective heat transfer coefficient
m_1, m_2, m_3	Sodium mass rate of flow
m_4	Gas mass rate of flow
Q	Fuel decay heat
q_1	Heat conduction across fuel channel
q_2	Heat conduction across shear boundary
q_3	Heat conduction across container boundary

It is concluded that gains can be made by selecting spines over longitudinal fins, although other design considerations motivated the investigation of an alternate design.

A new design being considered is a convoluted surface container as shown in Figures 3 and 4. Initial analyses of this design indicate the cooling capability during the accident condition is acceptable. Shrouding of one-third of the convoluted area for heating the container when no fuel decay heat is present proved to be inadequate. Presently, a shroud over the full convoluted area is being studied. The analytical model is shown on Figures 5, 6, and 7 for the forced convection cooling case. The model is an energy accumulation approach for each axial node. Figure 6 represents

828E732

Figure 3. Fuel Transfer Container

828E732

Figure 4. Fuel Transfer Container Details

Figure 5. Container Model

Figure 6. Heat Transfer Model During Forced Convection Cooling (Below Fuel Region)

Figure 7. Heat Transfer Model with Blower On (Fuel Section and Above)

the model below the fuel region. Figure 7 is the fuel region and above. An iterative solution is required to calculate the axial and radial temperature distribution. A computer solution model is being developed to perform the calculations. With slight modification, the accident condition of natural circulation cooling can also be analyzed.

An objective of the design concept was to utilize gas heating to heat the container and contents when no fuel decay heat is available. The estimated heat loss due to radiation and natural convection heat transfer from the shroud was 13 kW. The assumptions were:

1. Surface temperature = 400°F
2. Emissivity of container surface = 0.5
3. Environment emissivity = 0.9

The heating device requirements are in excess of the 13 kW of power. It does not appear practical to employ such a large capacity heater; therefore, other design alternates are being pursued.

Work planned for the next quarter includes the heat transfer analysis necessary to arrive at a concept which both satisfies the emergency condition of limiting fuel temperature with natural convection cooling and allows a practical solution to the container heating problem. Further work will also be done to improve the analytical techniques used so that detailed heat transfer analysis can be performed.

3.2 TASK GD-4 TRANSFER HOIST

3.2.1 Introduction

The transfer hoist is employed to move the sodium-filled fuel transfer containers between the reactor vessel and the carousel fuel storage vessel. The hoist must operate reliably with little maintenance, while providing a secure interface attachment to the transfer container, and supplying required services (heating or cooling) to the container. Scope design of this portion of the system is required, with subsequent development and environmental testing of the grapple assembly, grapple services supply, mechanical and electrical subassemblies operated in argon, and recovery procedures.

3.2.2 Status

Work accomplished on this subtask includes layout of various hoist and extension features to perform the necessary grappling functions within the cell confines. A design specification, detailing the requirements of the transfer hoist, was prepared. Layouts of hoist configurations have resulted in a preliminary fuel transfer hoist specification drawing (Figure 8), defining pertinent envelope dimensions. Preliminary design work on hoist details has begun with the emphasis on isolating those elements to procure for tests, as environmental test facilities become available.

Work on this task is currently delayed due to budgetary adjustments. Fiscal year 1973 work will include review and issue of the specification, continued design effort, and testing of elements essential to this assembly.

3.3 TASK GD-2 CLOSURE TRANSFER CRANE

3.3.1 Introduction

The closure transfer crane transports the reactor closure between the reactor vessel and the closure maintenance cell during the refueling outage. Primary objectives of this subtask are to prepare a scope design of the transfer crane and associated guidance system, and determine those critical components which will require development testing.

3.3.2 Status

Activities during the current period included revision and updating of the layout drawing (Figure 9), which shows the crane carriage and hoisting method. The drawing now reflects current reference plant design. No further work was done due to budget reductions.

When work is resumed in fiscal year 1973, effort will be directed at those elements most essential for successful crane operation. Environmental component tests will proceed on those items common with other equipment as well as tests on equipment unique to the closure hoist.

3.4 TASK GD-3 REFUELING HOIST

3.4.1 Introduction

The objective of high plant availability requires efficient and reliable fuel handling equipment to minimize downtime during refueling outages. The refueling hoist, a key item in the refueling cell system, must be developed and proven to perform all intended functions with ease, accuracy, and reliability in support of this plant objective. A scope design will serve as a basis from which critical components can be identified for initial test and development. Development will continue through full assembly tests and integrated operating tests with other refueling cell equipment and interfacing plant components.

3.4.2 Status

Scope design and compilation of functional design requirements was started for the refueling hoist and grapple. This work is based on data from other development programs as well as information received from the SEFOR program. Current scope design efforts will identify components for early test and development.

3.5 TEST FACILITY TASK

3.5.1 Introduction

An environmental facility is required in which to conduct development tests on various fuel-handling equipment items and components. Such a facility must have a sodium system, an argon system, and auxiliary systems to purify, heat, and cool the sodium and argon.

The first tests planned using the environmental facility are the fuel transfer container heat transfer tests (Subsection 3.1). Scheduling of the design, procurement, and construction of the facility is based on the schedule requirements for these tests.

3.5.2 Environmental Facility

The environmental facility will include one or more gas-tight enclosures in which either assemblies or components, or both, can be tested. The facility will include sodium systems, gas circulation and cooling systems, and all required utilities. The facility will be designed to accommodate the planned development tests, and it will also be designed to facilitate modifications to the facility as development tests are changed or added due to equipment concept changes.

A design specification was prepared for the environmental test facility outlining the functional and dimensional requirements. This specification will be reviewed, approved, and issued in the near future so that a scope design of the facility can be initiated.

3.6 FUEL ASSEMBLY SIMULATOR

3.6.1 Introduction

Satisfactory fuel handling requires that (1) the decay heat generated by irradiated fuel be dissipated under all operating conditions, in particular during fuel transfers and preparation of fuel for inspection or shipping, (2) fuel cladding temperatures must be maintained below the damage limit in the event of an equipment malfunction, and (3) residual sodium must be removed prior to inspection or shipping. There are four major pieces of equipment involved in satisfying these requirements:

- a. Fuel transfer container
- b. Onsite irradiated fuel transfer cask

828E704

Figure 8. Fuel Transfer Hoist

816E291

Figure 9. Closure Transfer Crane

- c. Sodium removal system
- d. Fuel gas cooling system

In order to efficiently develop and adequately proof test this equipment it is necessary to provide an appropriate mockup of the irradiated fuel assembly. The major objective of this task, therefore, is to design and fabricate an electrically heated fuel assembly simulator possessing the anticipated decay heat, heat transfer, and flow characteristics of the irradiated fuel assembly projected for an LMFBR Demonstration Plant.

3.6.2 Description and Status

A design specification has been prepared for the fuel assembly simulator and is being reviewed. Design was initiated on the simulator. The current approach is to provide two fuel assembly simulators. One relatively inexpensive simulator would consist of stock item cartridge heaters capable of producing the decay heat load, and it would be used for those tests not requiring a high degree of similitude. The second simulator would model as closely as practicable the internal geometry and surface conditions of the fuel assembly, as well as provide the correct spatial distribution of the decay heat load. This two-simulator approach has the following advantages:

- a. Reduces risk of damage to the costly high-fidelity simulator by using it only where required
- b. Provides greater flexibility in scheduling and running tests
- c. Allows more time to seek the best design for the high-fidelity simulator

The peak decay heat load of the 217-rod irradiated fuel assembly is expected to be about 27 kW. The corresponding rating of each rod is a relatively small 125 watts. Thus the heat load can be provided easily. The ideal way of constructing the simulator would be to take the prototype fuel assembly, essentially remove the nuclear fuel from each rod, and replace it with an electrical heater having lead wires that do not interfere with the flow passages. Immediately evident is a major design question: how to get power to the 217 heaters without seriously compromising the flow characteristics?

As an aid in solving this problem, a closer look was given to how the simulator would be used in developing each of the four major pieces of equipment involved in decay heat removal. From heat transfer analyses it was shown that both the fuel transfer container and the onsite transfer cask are not dependent upon the detailed fuel assembly configuration for adequate heat rejection rates. Thus for these items the simulator can be relatively simple—possibly consisting of a number of stock item heaters producing the appropriate decay heat load. On the other hand, the sodium removal system and the fuel gas cooling system do require a high degree of similitude from the simulator in order that their performance can be assessed. Additionally, for the sodium removal system and fuel gas cooling system tests, the simulator operates in air or argon and it does not appear necessary to use the heaters while the simulator is fully submerged in liquid sodium. Thus it appears possible to distinguish between those tests that require the simulator to produce heat while submerged in sodium and those tests that require a high-fidelity simulator. The high-fidelity simulator must be submerged in sodium but the heaters need not be operated under sodium.

A rod design that seeks to take advantage of the above distinction is shown in Figure 10. It consists of an electrically grounded heater, 30 inches in length (corresponding to core height). The heater sheath is centerless ground to facilitate insertion into the cladding and to minimize the temperature difference between the heater and the cladding. The single lead exists through an insulating plug and attaches to the hold-down grid which in turn is insulated from the channel walls. The grid geometry would be modified but the same through-flow area would be maintained. A single lead to the hold-down grid provides the power to the heaters. The heaters must be capable of being submerged in liquid sodium without subsequently impairing their function. Thus the heater plugs must not only insulate but must be compatible with and seal against liquid sodium. Boron nitride is a good insulator and is compatible with sodium; however, at this time it is not known how to effectively seal against sodium intrusion into the heater rod.

The only effective way of sealing against sodium is to use an all-welded construction. Such a rod design, illustrated in Figure 11, consists of a stainless steel-sheathed coaxial cable welded to a plug which in turn is welded to the cladding. Each cable exits through the fuel assembly handle. This approach produces flow area obstructions which are particularly undesirable for the sodium removal tests. The all-welded design must be examined carefully to determine whether these obstructions can be tolerated. Consideration was given to bringing the heater leads out through the lower end of the assembly but this approach would also produce substantial flow restrictions and would make assembly and disassembly of the simulator difficult.

Figure 10. Heater Rod

Figure 11. Heater Rod, All-Welded Construction

Efforts will continue toward finding some means of sealing the simulated fuel rods against sodium. Layout work is in progress to minimize the flow-area perturbations caused by the all-welded heater rod leads.

3.7 PLANNING TASK

3.7.1 Initial Planning

Detailed planning and scheduling of the LMFBR Hot Cell Refueling Component Test program activities were performed during the quarter. The overall program has been studied for purposes of eliminating duplication in testing, combining of similar tests, and assuring the planned tests will produce the required information. Scheduling emphasis has been placed on obtaining test data on critical component tests as soon as possible within budget constraints. The most significant component test is the fuel transfer container heat transfer tests described in Subsection 3.1.

The plans and schedules required revision several times due to the changes which were made to the PA-63 budget and scope for fiscal years 1972 and 1973.

3.7.2 Planned Work

Detailed development plans will be prepared for those tasks which are scheduled for early testing. As these plans develop and the test equipment design progresses, the schedules for the tasks will be revised and expanded in detail.

4. ADMINISTRATIVE

4.1 TRIPS

No trips were taken during the report period.

4.2 VISITS

No visits were made during the report period.

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